United States Environmental Protection Agency
Region 10, Air & Radiation Division
1200 Sixth Avenue, Suite 155, 15-H13
Seattle, Washington 98101-3188

Permit Number: R10PSD00103
Issued: DRAFT
Effective: DRAFT
AFS Plant I.D. Number: 16-009-00001

FACT SHEET

Prevention of Significant Deterioration
Permit to Construct
Permit Revision No. 3

Permit Writer: Dan Meyer

PotlatchDeltic Land and Lumber, LLC – St. Maries Complex

Coeur d'Alene Reservation
St. Maries, Idaho

Purpose of Permit and Fact Sheet

New major stationary sources of air pollution and major modifications to major stationary sources are required by the Clean Air Act to obtain an air pollution permit before commencing construction. The process is called new source review and is required whether the major source or modification is planned for an area where the national ambient air quality standards (NAAQS) are exceeded or an area where air quality is acceptable. Permits for sources in attainment areas are referred to as prevention of significant air quality deterioration (PSD) permits, and Title 40 of the Code of Federal Regulations (CFR), 52.21, establishes the federal PSD program that applies in Indian Country.

40 CFR Part 124 establishes the EPA procedures for issuing PSD permits. This document, the Fact Sheet, fulfills the requirements of 40 CFR 124.8 by setting forth the principal facts and the significant factual, legal, methodological and policy questions considered in preparing the draft permit. Unlike the PSD permit, this Fact Sheet is not legally enforceable. The Permittee is obligated to comply with the terms of the permit. Any errors or omissions in the summaries provided here do not excuse the Permittee from the requirements of the permit.

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Appendix A – EPA Region 10 HAP and VOC Emission Factors for Lumber Drying, November 2019

1. Introduction and Project Summary

On March 11, 2020, EPA Region 10 received an application from PotlatchDeltic Land and Lumber, LLC (PotlatchDeltic or Permittee) requesting revisions to PSD permit R10PSD00102 and tribal minor NSR permit R10TNSR01801 authorizing construction of lumber dry kiln LK-6. Region 10 is simultaneously processing the requested changes to both permits, but this Fact Sheet only addresses the changes related to the PSD permit. Table 1-1 lists in chronological order permit actions related to LK-6 along with construction and startup milestones. After receiving additional information from PotlatchDeltic upon request, Region 10 notified PotlatchDeltic that the application was complete on April 10, 2020.

Table 1-1 – LK-6 Permitting Chronology and Startup Milestones

Date	Action
06/21/19	Region 10 issues PSD permit R10PSD00100 and minor NSR permit R10TNSR01800 authorizing construction and operation of LK-6
07/22/19	PotlatchDeltic commences construction of LK-6
10/10/19	Region 10 issues R10PSD00101 and minor NSR permit R10TNSR01801 revising original permits
10/16/19	PotlatchDeltic starts operating LK-6
10/21/19	Region 10 issues R10PSD00102, revising the PSD permit a second time
03/11/20	PotlatchDeltic submits application to revise PSD and minor NSR permits
04/08/20	Region 10 indicates to PotlatchDeltic that 03/11/20 application is incomplete
04/09/20	PotlatchDeltic submits update to application to revise PSD and minor NSR permits
04/10/20	Region 10 determines application, together with update, is complete
06/09/20	PotlatchDeltic submits update to minor NSR portion of application

PotlatchDeltic is proposing the following three changes (Requests) to both the PSD and tribal minor NSR permits:

1. Revise Kiln 6 operating temperature limits to use average temperature values measured across all kiln zones as bases;
2. Incorporate EPA's updated lumber dry kiln VOC emission factors; and
3. Revise the ten-day written deviation notification requirement to apply to limited mNSR and PSD permit conditions.

Through the PSD and tribal minor NSR permitting actions, Region 10 is addressing these three requests. Requests 1 and 3 are common to both the PSD and tribal minor NSR permits. Request 2 is unique to the PSD permit. PotlatchDeltic also requested other changes to the minor NSR permit that they have since withdrawn. In addition to the revisions to address the requested permit changes, Region 10 is correcting the plant/process description in the permit as it relates to LK-6 and adding a "Permit History" section at the beginning of the permit to foster clarity.

2. Analysis of Permit Revision Requests

This is an application to revise the permit to address misunderstandings about source operation during the original permitting process. The kiln is still considered a new emission unit as provided in 40 CFR 52.21(b)(7), and there are no physical changes or changes in the method of operation being requested in the permit application. The LK-6 project was originally and remains a major modification for VOC and a minor modification for CO, NO_X, PM, PM10, and PM2.5. See Appendix B to the June 21, 2019 Fact Sheet for the Permittee's calculations for the emissions increase for the LK-6 project.

Request 1 – Revise Kiln 6 operating temperature limits to use average temperature values measured across all kiln zones as bases

Condition 3.2 of the minor NSR permit and Condition 3.3 of the PSD permit limit the temperature of the air exiting a load of lumber within a zone of the kiln to no more than 245°F. Because (a) higher drying temperatures result in higher VOC emissions, and (b) PotlatchDeltic stated in its application that the maximum temperature of air exiting the lumber would be no more than 245°F, Region 10 established the load-specific, zone-specific 245°F BACT limit. The application did not qualify its 245°F as a kiln-wide average value and the applicant did not request the permit to be changed during the public comment period to address the discrepancy. Shortly after LK-6 startup, PotlatchDeltic applied too much heat to a load in at least one zone of the kiln to remain in compliance with both permits' 245°F BACT/minor NSR control technology review limits. In identifying the root cause and corrective action, the Permittee stated in its February 28, 2020 annual report, "The monitoring condition does not match kiln management system. PotlatchDeltic discussed changes to permit term to match kiln management system."

PotlatchDeltic is requesting Region 10 to replace LK-6 245°F load-specific, zone-specific limit on the maximum temperature of the air exiting a load of lumber with a 245°F kiln-wide average limit. Region 10 is granting this request to more accurately reflect actual operation of the kiln management system. The 245°F value is established based upon the maximum set point temperature associated with the drying schedules PotlatchDeltic is proposing to implement at LK-6. To assure compliance with the 245°F limit, it is appropriate for the permit to restrict PotlatchDeltic to using drying schedules with maximum set point temperatures less than or equal to 245°F. The associated changes to Conditions 3.4 (formerly 3.3) and 4.1.5.1 (formerly 4.1.4) and creation of new Conditions 3.2 and 4.1.3 addressing the Permittee's request are explained in more detail in Section 5 of this Fact Sheet.

Because Region 10 is now limiting the kiln-wide average temperature (and not the load-specific, zone-specific temperature), it logically flows to quantify emissions using a kiln-wide average temperature in the EF equation. In the compliance demonstration for the 50-ton annual VOC emission limit applicable to LK-6, specifically in the methodology for calculating a batch's VOC EF, Region 10 is replacing the use of a batch's maximum load-specific, zone-specific air temperature entering a load of lumber with the use of a kiln-wide average entering air temperature in the wood-species specific best-fit-curve equation. The temperature monitoring during lab-scale testing upon which the temperature-dependent EF equations were derived more than likely was conducted to generate a value representative of the average temperature of the air entering the stack of lumber in the lab-scale kiln. Using a kiln-wide average temperature rather than a load-specific, zone-specific value in the EF equations will be less restrictive, but will generate an EF that is representative of a batch's emissions. In reality, the hotter, higher emitting, zones of the kiln will be balanced with cooler, lower emitting zones, so using the average temperature across all zones fits the theory that the relationship between emissions and temperature is linear. The changes to Conditions 3.3.2 (formerly 3.2.2), 3.3.3 (formerly 3.2.3) and 4.1.4 (formerly 4.1.3) addressing the Permittee's request are presented in detail in Section 5 of this Fact Sheet.

In changing to a kiln-wide average temperature limit, it will still be necessary for PotlatchDeltic to continue to address high temperatures in individual zones in order to identify system malfunctions and avoid over-drying their lumber. The computerized kiln management system achieves this as described below.

> *The temperature data from individual kiln zones are used only to calculate the kiln-wide average temperatures, except for a high-temperature alarm used to alert the kiln operator of a kiln zone temperature that is greater than 20 degrees above the drying schedule set point.*[1] *This alarm is intended to identify a malfunctioning steam valve stuck in the open position or, in the worst-case scenario, a fire in the kiln. After receiving a high-temperature alarm, the kiln operator will check the steam valves associated with the indicated kiln zone and manually close the malfunctioning steam value. After the batch of lumber is dried, the malfunctioning steam valve is checked and, if necessary, replaced… The Wellons kiln management software produces a record of high-temperature alarm conditions, and PotlatchDeltic maintains an operation and maintenance manual (O&M) manual for Kiln 6 with procedures for responding to a high-temperature alarm... PotlatchDeltic has incorporated the procedures to be followed by kiln operators during a high-temperature alarm scenario into the O&M manual for Kiln 6.*

[1] The standard high temperature alarm was set by Wellons at 20 degrees temperature differential (actual compared to drying schedule).

To assure that PotlatchDeltic is identifying and responding to high-temperature alarms in a manner that minimizes emissions, Region 10 is revising the permit to establish a new BACT work practice requirement. Specifically, the permit will require the computerized kiln management system to be used to identify "hot spots" and alert the operator of their occurrence, and the operator will be required to take corrective action when the actual temperature is more than 20°F above the drying schedule setpoint. At the beginning of the drying schedule, the temperature inside the kiln may be greater than the drying schedule's initial set point due to the ambient (outside) temperature. In those instances, an exceedance of the set point temperature by any amount does not indicate that the kiln is malfunctioning or over-drying lumber. The permit, therefore, does not require corrective action be taken in those instances. The creation of new Conditions 3.5, 4.1.5.2 and 5.3.1 addressing the Permittee's request are presented in detail in Section 5 of this Fact Sheet.

Request 2 – Incorporate EPA's updated lumber dry kiln VOC emission factors

PotlatchDeltic is requesting Region 10 to revise LK-6 VOC EF equations to reflect new emission estimation techniques Region 10 has developed since the June 21, 2019 permit issuance. See Appendix A to this Fact Sheet for Region 10's November 2019 HAP and VOC Emission Factors for Lumber Drying. The equations have changed since June 21, 2019 because Region 10 has changed two aspects of how the underlying test results are used to derive EF. First, all test results generated by Oregon State University (OSU) have been adjusted to account for the high bias resulting from use of its lab-scale kiln. The high bias is documented in the National Council for Air and Stream Improvement's (NCASI's) May 2002 Technical Bulletin entitled, "A Comparative Study of VOC Emissions from Small-Scale and Full-Scale Lumber Kilns Drying Southern Pine." Second, all individual test results have been plotted rather than plotting one average value for multiple tests conducted at the same drying temperature.

Region 10 is revising the permit to reflect the updated VOC EF for drying the species of wood the Permittee is authorized to dry: Grand Fir, Western Hemlock and White Fir. Both Grand Fir and White Fir are considered Western True Firs and thus share the same EF. The changes to Conditions 3.3.2 (formerly 3.2.2) and 3.3.3 (formerly 3.2.3) addressing the Permittee's request are presented in detail in Section 5 of this Fact Sheet.

Request 3 – Revise the ten-day written deviation notification requirement to apply to limited minor NSR and PSD permit conditions

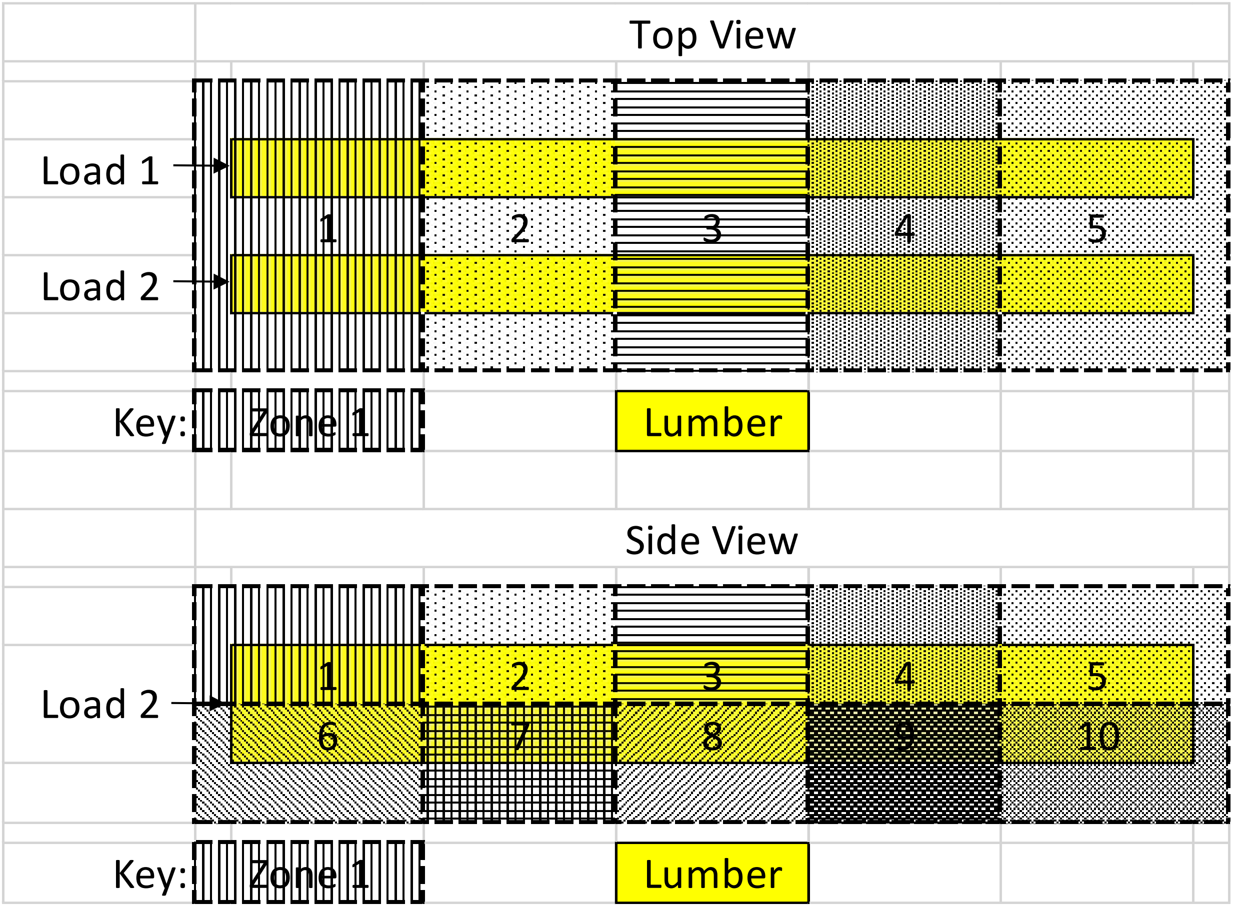
PotlatchDeltic is requesting Region 10 to narrow the applicability of the 10-day written notice deviation reporting requirement to deviations with excess emissions that continue for more than two hours. Condition 5.2 of the permit requires that a written notice be submitted within ten working days of the occurrence of all deviations. In contrast, 40 CFR 71.6(a)(3)(iii)(B)(4) only requires a ten-day written notice of deviations associated with excess emissions continuing beyond a defined duration. At this time, Region 10 can identify no compelling reason to have the PSD permit depart from Part 71 program default deviation reporting requirements. Region 10, however, is clarifying that exceedances of LK-6 temperature and lumber moisture content limits can result in emissions in excess of permit requirements (excess emissions). The changes to Condition 5.2 and creation of new Conditions 5.2.2.2 and 5.2.3 addressing the Permittee's request are presented in detail in Section 5 of this Fact Sheet.

3. Revising Permit for Cause

Condition 2.7 of the permit states that Region 10 may revise the permit for cause. Region 10 is using this authority to correct and clarify certain aspects of the existing PSD permit. Section 1 of the permit currently states, "The kiln is designed with ten heating zones arranged along the length of the kiln from the entrance to the exit wherein the drying process can be separately controlled." The Fact Sheet accompanying the June 21, 2019 permit presented an incorrect illustration of the kiln and its drying zones. Since issuance of the June 21, 2019 permit and the subsequent two revisions in October 2019, Region 10 has come to understand through communication with PotlatchDeltic and independent analysis that both the description in the permit and the illustration in the Fact Sheet are incorrect.

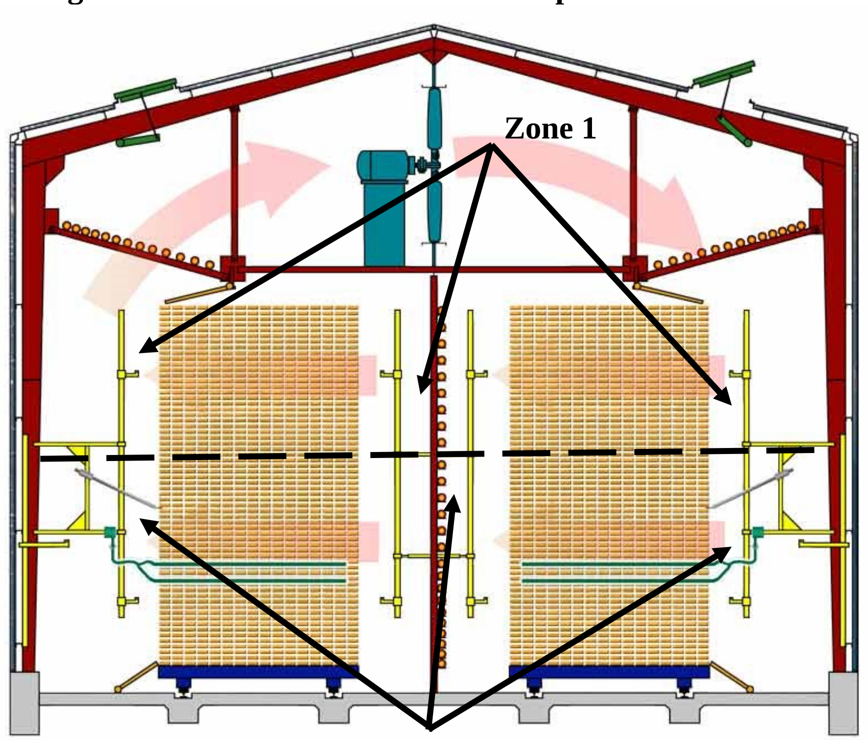
The following illustration of the top and side view of LK-6 correctly present the ten zones within the lumber dry kiln:

Figure 3-1 – LK-6 Zones



The following illustration of the end view of LK-6 presents Zones 1 and 6 separated in the illustration by a horizontal dashed line. Each zone is depicted as employing four thermocouples; one on either side of the two loads.

Figure 3-2 – Placement of Thermocouples in LK-6 Zones[1]



End View

The changes to the text in Section 1 of the permit explaining the layout of the zones and placement of thermocouples are presented in detail in Section 5 of this Fact Sheet.

Region 10 is inserting the term “batch” into the first paragraph of Section 1 of the permit to more clearly describe LK-6.

Lastly, the physical capacity of LK-6 listed in the permit is being increased by approximately 1% to 282,426 bf because PotlatchDeltic reported on multiple occasions batches of that volume in its February 28, 2020 annual report to Region 10.

4. Additional Analyses

EPA Trust Responsibility. As part of the EPA Region 10’s direct federal implementation and oversight responsibilities in Indian Country, Region 10 has a trust responsibility to each of the 271 federally recognized Indian tribes within the Pacific Northwest and Alaska. The trust responsibility stems from various legal authorities including the U.S. Constitution, Treaties, statutes, executive orders, historical relations with Indian tribes and, in this case, the 1873 Executive Order and subsequent series of treaty agreements. In general terms, the EPA is charged with considering the interest of tribes in planning and decision-making processes. Each

[1] http://www.wellons.com/trackkilns.html

office within the EPA is mandated to establish procedures for regular and meaningful consultation and collaboration with Indian tribal governments in the development of EPA decisions that have tribal implications. Region 10's Air and Radiation Division has contacted the Tribe to invite consultation on the revisions to this PSD permit and has maintained ongoing communications with Tribal environmental staff throughout the permitting process.

Statutory and Policy Requirements. Given the limited scope of this application, Region 10's findings related to the Endangered Species Act, National Historic Preservation Act and Environmental Justice Policy remain unchanged from those reached in support of issuance of June 21, 2019 PSD Permit No. R10PSD00100 authorizing construction of LK-6.

5. Permit Changes

The changes to the permit are explained below in the order that the permit is organized:

Permit Section: Permit History
Permit Section 1: Source Information and Project Description
Permit Section 2: General Requirements
Permit Section 3: Emission Limitations and Work Practice Requirements
Permit Section 4: Monitoring and Recordkeeping Requirements
Permit Section 5: Reporting Requirements

All changes are transcribed below. New text appears in underlined font, deleted text appears in ~~strikeout~~ font. To the extent necessary, permit conditions have been renumbered to accommodate proposed revisions to the permit.

Permit Section – Permit History

To provide clarification, Region 10 is creating a new section of the permit as follows:

Permit Action Date	*Permit Number*	*Permit Action Description*
06/21/2019	*R10PSD00100*	*Original PSD permit for LK-6*
10/10/2019	*R10PSD00101*	*Revision No. 1 – revised LK-6 lumber moisture monitoring*
10/21/2019	*R10PSD00102*	*Revision No. 2 – corrected a typographical error*
draft	*R10PSD00103*	*Revision No. 3 – revised LK-6 temperature limit, LK-6 temperature and moisture monitoring, deviation reporting and source description*

Permit Section 1 – Source Information and Project Description

As discussed in Section 3, Region 10 is inserting the term "batch" into the first paragraph of Section 1 of the permit as follows:

> *This permit authorizes construction of a new indirect steam-heated batch lumber dry kiln and the emission increases resulting from operation of the kiln and associated existing emission-generating activities at the St. Maries Complex.*

As discussed in Section 3, Region 10 is changing the second paragraph of Section 1 of the permit as follows:

> *The kiln is designed with ten heating zones ~~arranged along the length of the kiln from the entrance to the exit~~ wherein the drying process can be separately controlled. The length of the kiln is segmented into five cross-sectional areas. The*

top of each cross-sectional area is one heating zone, and the bottom another. Four thermocouples are employed per zone, and at any one time two thermocouples are measuring the temperature of the air entering the loads (one thermocouple per load) and the other two are measuring the temperature of the air exiting the loads (one thermocouple per load).

To make the format of Table 1-1 consistent with the format typically used in other Region 10 permits, Region 10 is changing the title and third column of Table 1-1 of the permit as follows:

Table 1-1 – Emission Units and Control Devices

EU ID	***Emission Unit Description***	***VOC Control Device~~/Work Practices~~****
New (Proposed) Emission Generating Activities		
LK-6	*Lumber Dry Kiln No. 6. Dual-track, ~~280,000~~282,426 board foot per batch, indirect steam-heated lumber dry kiln*	*None~~Wood species restriction, air temperature ≤ 245°F, final lumber moisture content ≥ 13% (dry basis), operation and maintenance requirements~~*
PCWR-PM-SH	*Exhaust from cyclone (receiving planer shavings) is~~Planer Shavings~~ pneumatically conveyed to baghouse BH-2.*	*None*

* ~~Use of the listed control devices and work practices is required by this permit.~~

In the second column of Table 1-1, Region 10 is changing the listing for the physical capacity of LK-6 to 282,426 bf. In the second column of Table 1-1 for PCWR-PM-SH, Region 10 is changing the emission unit description to reflect that PotlatchDeltic recently installed a cyclone upstream of BH-2.

Permit Section 2 – Generally Applicable Requirements

No revisions.

Permit Section 3 – Emission Limitations and Work Practice Requirements

Region 10 is revising Section 3 of the permit in response to the Permittee's Requests 1 and 2 as follows:

Permit Condition 3.3.2 (formerly 3.2.2):

> *For batches of lumber consisting of any amount of Grand Fir or White Fir, each batch's emission factor (lb/mbf) shall be calculated by multiplying the highest 60-minute kiln-wide average dry bulb temperature of the heated air that enters a load of lumber ~~in any zone of the kiln~~(°F) measured, calculated and recorded pursuant to Condition ~~4.1.3~~4.1.4 by ~~0.00660~~0.00817 and subtracting ~~0.58181~~1.02133 from the product.*

Permit Condition 3.3.3 (formerly 3.2.3):

> *For batches of lumber consisting exclusively of Western Hemlock, each batch's emission factor (lb/mbf) shall be calculated by multiplying the highest 60-minute*

kiln-wide average dry bulb temperature of the heated air that enters a load of lumber ~~in any zone of the kiln~~(°F) measured, calculated and recorded pursuant to Condition ~~4.1.3~~4.1.4 by ~~0.00370~~0.00369 and subtracting ~~0.30850~~0.39197 from the product.

Region 10 is revising Section 3 of the permit in response to Permittee's Request 1.

The heading introducing Permit Conditions 3.1 and 3.2 is being revised as follows:

LK-6 Restrictions on Wood Species and Drying Schedules

Permit Condition 3.2:

The Permittee shall not dry any lumber using a drying schedule with a maximum set point temperature of heated air that exits a load of lumber exceeding 245°F.

Permit Condition 3.4 (formerly 3.3):

The highest 60-minute kiln-wide average dry bulb temperature of heated air that exits~~exiting~~ ~~each~~a load of lumber ~~in each zone of the kiln~~as measured, calculated and recorded pursuant to Condition ~~4.1.4~~4.1.5.1 shall not exceed 245°F.

Permit Condition 3.5:

The Permittee shall take corrective action to return the actual temperature to the set point temperature if the instantaneous dry bulb temperature of heated air that exits any load of lumber in any zone of the kiln as measured pursuant to Condition 4.1.5.2 exceeds the set point temperature in the drying schedule by more than 20°F. This condition applies only when the drying schedule's set point temperature is greater than the ambient (outside) temperature.

To provide clarification, Region 10 is revising Permit Condition 3.6 as follows:

Permit Condition 3.6 (formerly 3.4):

The lowest, average, kiln-wide moisture content for each batch of lumber dried, as measured, calculated and recorded pursuant to Condition 4.1.6~~4.1.5~~, shall not be less than 13%, dry basis.

Permit Section 4 – Testing, Monitoring and Recordkeeping Requirements

Region 10 is revising Section 4 of the permit in response to Permittee's Request 1 as follows.

Permit Condition 4.1.3:

The maximum set point temperature (°F) specified in the drying schedule;

Permit Condition 4.1.4 (formerly 4.1.3):

…For each load of lumber in each zone of the kiln, calculate and record an average temperature every 60 minutes using the temperature data collected by the computerized kiln management system required by Condition ~~3.5~~3.7 over the 60-minute period. Calculate and record a corresponding 60-minute kiln-wide average temperature. Use the highest 60-minute kiln-wide average temperature measured during each batch to calculate the batch's VOC emission factor pursuant to Conditions ~~3.2.2~~3.3.2 and ~~3.2.3~~3.3.3;

Permit Condition 4.1.5.1 (formerly 4.1.4):

> *For each load of lumber in each zone of the kiln, calculate and record the~~an~~ average temperature every 60 minutes using the temperature data collected by the computerized kiln management system required by Condition ~~3.5~~3.7 over the 60-minute period. Calculate and record the 60-minute kiln-wide average temperature using all load-specific, zone-specific 60-minute averages. Use the highest 60-minute kiln-wide average temperature measured during each batch to demonstrate compliance with Condition~~s~~ ~~3.3~~3.4;*

Permit Condition 4.1.5.2:

> *For each load of lumber in each zone of the kiln, calculate the instantaneous temperature differential by subtracting the set point temperature in the drying schedule from the dry bulb temperature of the heated air that exits the load of lumber. Record each temperature differential that exceeds 20°F and the corrective action taken to resolve the exceedance. This condition applies only when the drying schedule's set point temperature is greater than the ambient (outside) temperature.*

To provide clarification, Region 10 is revising Section 4 of the permit as follows.

Permit Condition 4.1:

> *For LK-6, the Permittee shall install, calibrate, operate, and maintain, in accordance with manufacturer specifications, equipment and procedures necessary to measure, calculate and record (including the date and time of measurements or records and, if applicable, the company or entity that performed the analyses and the analytical techniques or methods used) the following for each batch of lumber dried:*

Permit Condition 4.1.4 (formerly 4.1.3):

~~Continuously measure t~~The dry bulb temperature of the heated air that enters each load of lumber in each zone of the kiln (°F), continuously measured…

Permit Condition 4.1.5 (formerly 4.1.4):

> *~~Continuously measure t~~The dry bulb temperature of the heated air that exits each load of lumber in each zone of the kiln (°F), continuously measured…*

Permit Condition 4.1.6 (formerly 4.1.5):

> *Beginning the thirteenth hour of each batch's drying cycle~~, continuously measure~~ the moisture content (%, dry basis) of a representative sample of boards (minimum of two courses[2]) in each load of lumber at a minimum of four equally-spaced locations (per load) along the length of the load using a capacitance-based in-kiln moisture measurement system, continuously measured…*

Permit Section 5 – Reporting Requirements

Region 10 is revising Section 5 of the permit in response to Permittee's Request 1 as follows.

Permit Condition 5.3.1:

> *The summary of monitoring performed to satisfy Condition 4.1.5.2 shall include*

the time and location of the occurrence of each temperature differential that exceeds 20°F and the corrective action taken to resolve the exceedance.

Region 10 is revising Section 5 of the permit in response to Permittee's Request 3 as follows.

Permit Condition 5.2:

> *The Permittee shall promptly report to Region 10 by telephone (206-553-1331) deviations from permit conditions, including those attributable to upset conditions as defined in this permit, the probable cause of such deviations, and any corrective actions or preventive measures taken. Reports shall also include the company name, permit number, and permit condition number.~~ A written notice shall be submitted within 10 working days of the occurrence.~~*

Permit Condition 5.2.2.2:

> *For deviations of Conditions 3.2, 3.4, 3.5 and 3.6 that continue for more than two hours, the report must be made within 48 hours of the occurrence; or*

Permit Condition 5.2.3:

> *Within ten working days of the occurrence of a deviation as provided in Condition 5.2.2.1 and 5.2.2.2, the Permittee shall also submit a written notice, which shall include a narrative description of the deviation and updated information as listed in Condition 5.2, to EPA.*

6. Public Participation

Public Notice and Comment

The EPA's procedures for issuing PSD permits are in 40 CFR Part 124, and include an opportunity for public comment and a hearing. As required in 40 CFR 124.10(b), all draft PSD permits must be publicly noticed and made available for public comment for 30 days. For this draft permit, the public comment period begins on January 23, 2021 and ends on February 22, 2021. EPA will hold a public hearing on the draft permit as further explained below, if EPA determines that there is a significant degree of public interest in the draft permits.

40 CFR 124.10(c)(2)(iii)(C) requires reviewing authority to post the administrative record on an identified public Web site if the record is not available for public inspection at a physical location. For this draft permit, access to the record is available through the EPA's website at https://www.epa.gov/publicnotices/notices-search/location/Idaho. The public can request a copy of the administrative record or of individual documents in the record by contacting EPA as follows: by email to meyer.dan@epa.gov or by phone to Dan Meyer at (206) 553-4150. Pursuant to 40 CFR 124.9(b), the record consists of the application and any supporting data furnished by the applicant, the draft permit, the Fact Sheet, all documents cited in the Fact Sheet, and other documents contained in the supporting file for the draft permit. In accordance with 40 CFR 124.9(c), material readily available at Region 10 or published material that is generally available, and that is included in the record need not be posted with the rest of the record as long as it is specifically referred to in the Fact Sheet.

40 CFR 124.10(a)(1) requires the reviewing authority to give public notice that a draft permit has been prepared. The public notice must provide an opportunity for public comment and notice of a public hearing, if any, on the draft permit. For this draft permit, the notice is posted on the

EPA's website at https://www.epa.gov/publicnotices/notices-search/location/Idaho.

40 CFR 124.11 explains how to submit comments and request a public hearing and 40 CFR 124.12 explains the requirements for holding a public hearing.

Any interested person may submit written comments on the draft permit by e-mail. If you believe that any condition of the draft permit is inappropriate, you must raise all reasonably ascertainable issues with all reasonably available supporting arguments by submitting your written comments on or before the end of the comment period or providing oral comments at the public hearing if one is held. Any documents supporting your comments must be included in full and may not be incorporated by reference, unless they are already part of the administrative record for the draft permit or consist of tribal, state or federal statutes or regulations or other generally available referenced materials.

All written comments must be received by EPA on or before February 22, 2021 at r10_air_permits@epa.gov. Include "PotlatchDeltic" in the subject line of the email. If you are unable to submit comments via email, please call Dan Meyer at (206) 553-4150.

EPA will hold a public hearing on the draft permit pursuant to 40 CFR 124.12 if EPA determines, on the basis of requests, that there is a significant degree of public interest in the draft permit. Requests for a public hearing on the draft permit must be in writing and received by EPA by February 22, 2021. Requests must be sent by email to r10_air_permits@epa.gov. Include "PotlatchDeltic" in the subject line of the email. If you are unable to submit your request via email, please call Dan Meyer at (206) 553-4150. In your request, you must indicate the nature of the issues you wish to raise through oral testimony during the hearing. If a public hearing is held, EPA will provide 30-days advance notice of the date, time, and place of the public hearing, and the public comment period will be extended to the close of the public hearing.

Response to Public Comments and Permit Issuance

After the public comment period closes, the EPA will consider all comments in making a final permit decision. As required in 40 CFR 124.15, the EPA will notify the applicant and each person who has submitted written comments or requested notice of the final permit decision. The final permit decision becomes effective 30 days after service of notice of the decision, unless (1) a later effective date is specified in the permit decision; (2) review of the final permit is requested under 40 CFR 124.19; or (3) no comments requested a change in the draft permit, in which case the permit shall become effective immediately upon issuance.

7. Abbreviations, Acronyms and Symbols

bf	Board feet
BACT	Best Available Control Technology
CAA	Clean Air Act [42 U.S.C. section 7401 et seq.]
CBI	Confidential business information
CFR	Code of Federal Regulations
EPA	United States Environmental Protection Agency (also U.S. EPA)
hr	Hour
lb	Pound (lbs = pounds)
m	Thousand
mm	Million
NCASI	National Council for Air and Stream Improvement

NSR	New Source Review
PSD	Prevention of significant deterioration
Region 10	U.S. EPA, Region 10
sf	Square feet
SIC	Standard Industrial Code
tpy	Tons per year
VOC	Volatile organic compound

EPA Region 10 HAP and VOC Emission Factors for Lumber Drying, November 2019

This spreadsheet calculates and compiles hazardous air pollutant (HAP) and volatile organic compound (VOC) 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 indirect steam-heated batch lumber drying kilns. The EFs are based on actual lab-scale emission test data when available. When no suitable HAP or VOC test data is available for a species of wood (e.g western red cedar, engelmann spruce, larch and western white pine), 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. When test data is available for some individual HAP (methanol, formaldehyde, acetaldehyde, propionaldehyde and acrolein) or VOC compounds (ethanol and acetic acid) but not others, data substitution for that species of wood is not performed so as to maintain the integrity of the WPP1 VOC EF calculation. Only douglas fir and ponderosa pine EF are supported by full suite of test data for all seven aforementioned compounds.

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. The methanol, formaldehyde and VOC EF are temperature dependent best-fit linear equations. The temperature variable reflects the maximum temperature of the heated air entering the lumber. Because acetaldehyde, propionaldehyde and acrolein emissions across different species are not consistently dependent upon maximum drying temperature, EF are calculated by averaging test results. Whereas HAP EF are derived in the HAP sheets, EF for individual VOC ethanol and acetic acid are derived in the VOC sheets for douglas fir and ponderosa pine (only wood species undergoing testing for these two VOC compounds).

Species	WPP1 VOC[1,2] (lb/mbf)	Methanol[2] (lb/mbf)	Formaldehyde[2] (lb/mbf)	Acetaldehyde (lb/mbf)	Propionaldehyde (lb/mbf)	Acrolein (lb/mbf)
Non-Resinous Softwood Species						
Western True Firs[3]	0.00817x - 1.02133	0.00465x - 0.73360	0.00016x - 0.02764	0.0550	no data	no data
Western Hemlock	0.00369x - 0.39197	0.00249x - 0.39750	0.000046x - 0.007622	0.0677	0.0004	0.0012
Western Red Cedar	0.00817x - 1.02133	0.00465x - 0.73360	0.00016x - 0.02764	0.0677	0.0004	0.0012
Resinous Softwood Species (Non-Pine Family)						
Douglas Fir	0.01460x - 1.77130	0.00114x - 0.16090	0.000028x - 0.003800	0.0275	0.0003	0.0005
Engelmann Spruce	0.1769	0.00088x - 0.13526	0.000042x - 0.006529	0.0201	0.0002	0.0005
Larch	0.01460x - 1.77130	0.00114x - 0.16090	0.000028x - 0.003800	0.0275	0.0003	0.0005
Resinous Softwood Species (Pine Family)						
Lodgepole Pine	1.1352	0.0550	0.0030	no data	no data	no data
Ponderosa Pine	0.02083x - 1.30029	0.00137x - 0.18979	0.000074x - 0.010457	0.0340	0.0010	0.0026
Western White Pine	0.02083x - 1.30029	0.00137x - 0.18979	0.000074x - 0.010457	0.0340	0.0010	0.0026

[1] VOC emissions approximated consistent with EPA's Interim VOC Measurement Protocol for the Wood Products Industry - July 2007 (WPP1 VOC). 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. Contribution of ethanol and acetic acid to VOC emissions has been quantified here when emissions testing data is available.

[2] Because WPP1 VOC, methanol and formaldehyde emissions are dependent upon maximum drying temperature, a best-fit linear equation with dependent variable maximum temperature of heated air entering the lumber has been generated to model emissions, with a couple of exceptions. For engelmann spruce and lodgepole pine, a single VOC EF (based upon high-temperature drying) has been generated due to lack of sufficient test data to build a best-fit linear equation.

[3] Western true firs consist of the following seven species classified in the same Abies genus: bristlecone fir, California red fir, grand fir, noble fir, pacific silver fir, subalpine fir and white fir.

Hazardous Air Pollutant Emission Factors for Drying Western True Fir Lumber

This sheet presents lab-scale HAP test data and calculations used to create HAP EF for drying western true fir lumber in an indirect steam-heated batch kiln. Western true fir consists of the following seven species classified in the same Abies genus: bristlecone fir, California red fir, grand fir, noble fir, pacific silver fir, subalpine fir and white fir. The methanol and formaldehyde EF are temperature dependent best-fit linear equations. The temperature variable reflects the maximum temperature of the heated air entering the lumber. The acetaldehyde EF reflects the results of a single test. No EF are presented for either propionaldehyde or acrolein as EPA Region 10 is not aware of any test data for those HAP.

Test data generated through the use of the smaller of the two small-scale kilns at Oregon State University (OSU) has been adjusted to account for bias documented in NCASI's May 2002 Technical Bulletin No. 845 entitled, "A Comparative Study of VOC Emissions from Small-Scale and Full-Scale Lumber Kilns Drying Southern Pine." See last spreadsheet of this workbook for Stimson Lumber Company's October 18, 2019 letter to EPA Region 10 highlighting the bias.

Step One: Compile Western True 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] Green highlight denotes data generated by testing conducted on the small-scale kiln at the University of Idaho. All other data was generated by testing conducted on the smaller of the two small-scale kilns at OSU.

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

Step Two: Adjust Western True Fir HAP Emission Test Data to Account for Bias in Underlying Small-Scale Kiln to Represent Full-Scale Kiln Emissions[1]

Maximum Dry Bulb Temperature (°F)	Methanol (lb/mbf)	Formaldehyde (lb/mbf)	Acetaldehyde (lb/mbf)	Propionaldehyde (lb/mbf)	Acrolein (lb/mbf)
180	0.0875	0.0016	no data	no data	no data
180	0.1348	0.0025	no data	no data	no data
225	no data	no data	0.0550	no data	no data
240	0.3827	0.0115	no data	no data	no data
240	0.3818	0.0120	no data	no data	no data

[1] Green highlighted results from the test conducted at the University of Idaho have not been adjusted because the kiln was not calibrated to a full-scale kiln.

Adjusted OSU emission test data $value_i$ = (OSU reported emission test data $value_i$) X (NCASI TB No. 845 study full-scale kiln $value_i$/NCASI TB No. 845 study OSU small-scale kiln $value_i$)

where: OSU reported emission test data $value_i$ is the emission rate "lb/mbf" for compound "i" documented in Step One (not highlighted in green)

NCASI study full-scale kiln $value_i$ is the average emission rate "lb/mbf" for compound "i" measured while drying southern yellow pine lumber in a full-scale indirect steam-heated batch lumber dry kiln

NCASI study OSU small-scale kiln $value_i$ is the average emission rate "lb/mbf" for compound "i" measured while drying southern yellow pine lumber in OSU's small-scale indirect steam-heated batch lumber dry kiln

The lumber dried in the OSU kiln was (a) extracted from the pool of lumber dried in the full-scale kiln and (b) dried according the schedule employed by the full-scale kiln.

NCASI TB No. 845 - Emission Rate (lb/mbf)

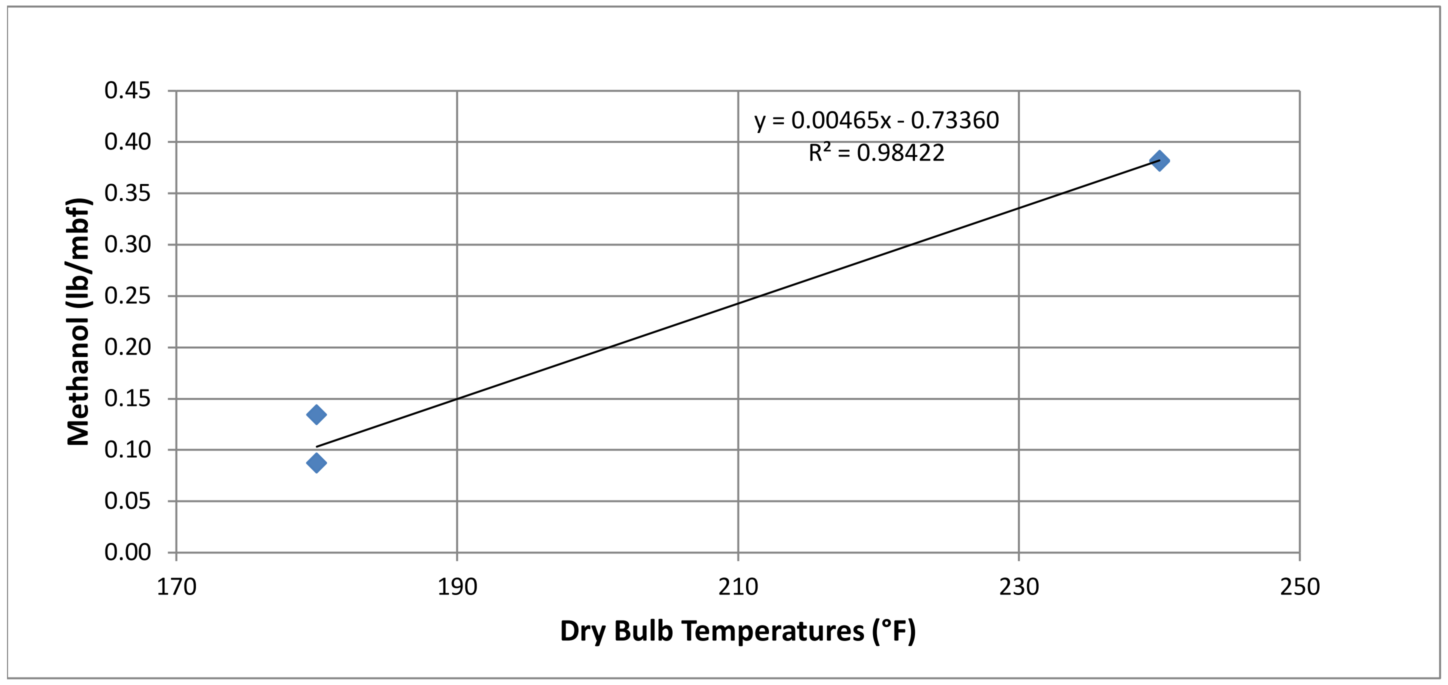
	Methanol	Formaldehyde	Acetaldehyde	Propionaldehyde	Acrolein
Full-Scale Kiln	0.205	0.0155	0.039	0.001	0.006
OSU Kiln	0.225	0.0210	0.065	0.003	0.009

Step Three: Calculate Western True Fir HAP Emission Factors

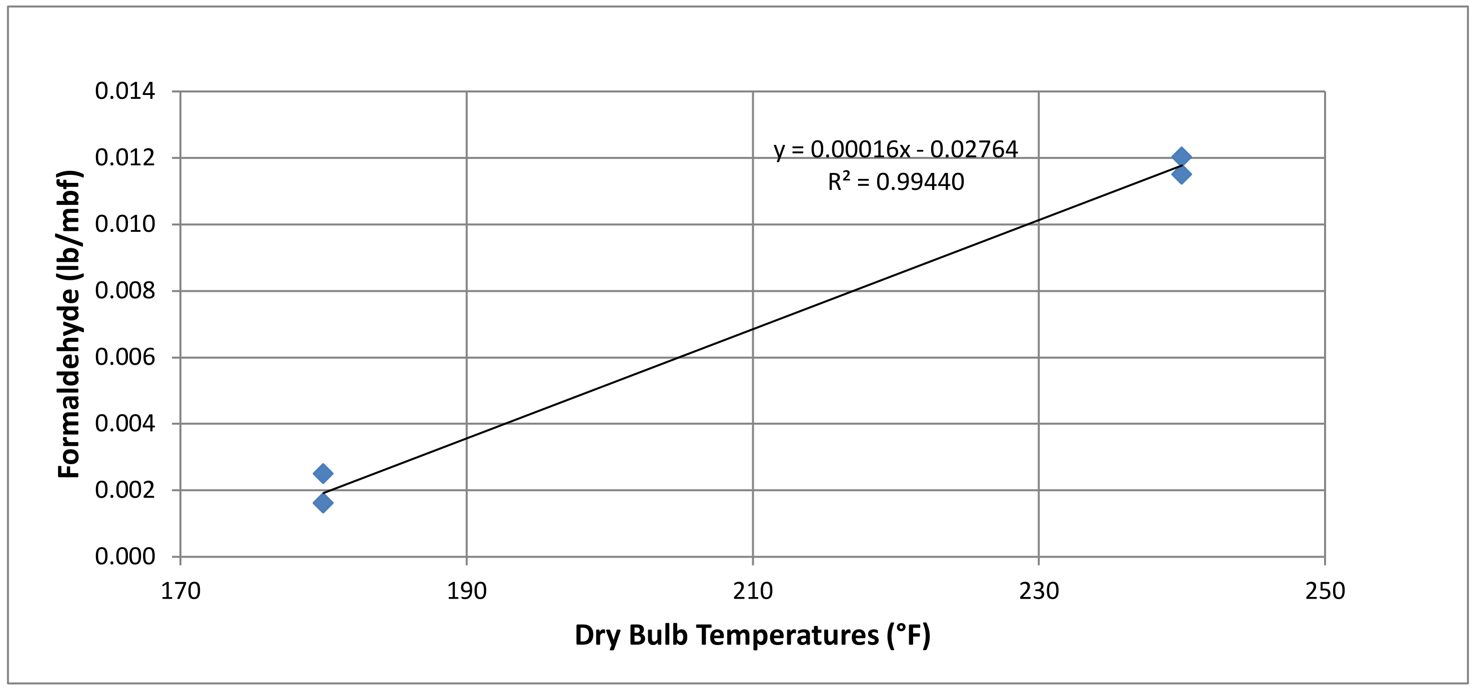
Methanol[1] (lb/mbf)	Formaldehyde[1] (lb/mbf)	Acetaldehyde[2] (lb/mbf)	Propionaldehyde (lb/mbf)	Acrolein (lb/mbf)
0.00465x - 0.73360	0.00016x - 0.02764	0.0550	no data	no data

[1] Because methanol and formaldehyde emissions are dependent upon drying temperature, best-fit linear equations model emissions with dependent variable "x" equal to the maximum drying temperature of heated air entering the lumber.

[2] The acetaldehyde EF reflects the results of a single test.



y = 0.00465x - 0.73360
R² = 0.98422
Methanol (lb/mbf)
Dry Bulb Temperatures (°F)



y = 0.00016x - 0.02764
R² = 0.99440
Formaldehyde (lb/mbf)
Dry Bulb Temperatures (°F)

Volatile Organic Compound Emission Factors for Drying Western True Fir Lumber

This sheet presents lab-scale EPA Reference Method 25A (RM25A) and speciated VOC test data and calculations used to create VOC EF for drying western true fir lumber in an indirect steam-heated batch kiln. Western true fir consists of the following seven species classified in the same Abies genus: bristlecone fir, California red fir, grand fir, noble fir, pacific silver fir, subalpine fir and white fir. RM25A has some limitations in that it misses some pollutant compounds (or portions thereof) 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 pollutant compounds (some HAP and some non-HAP) are accounted for through separate testing. RM25A test data is adjusted to fully account for three known pollutant compounds that are VOC using separate 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 RM25A results are adjusted to account for not only methanol and formaldehyde but also for acetaldehyde in this case.

More specifically, ten separate drying-temperature-specific VOC emission rates (upon which a best-fit linear equation will be established) are calculated based upon underlying RM25A and speciated VOC test data as indicated above. Temperature-specific methanol and formaldehyde emission rates are calculated for each temperature at which RM25A testing was performed using temperature-dependent best-fit linear equations. The temperature variable reflects the maximum temperature of the heated air entering the lumber. The temperature-independent acetaldehyde emission rate reflects the result of a single test. EPA Region 10 is not aware of any further speciated VOC test data. That portion of the (speciated) VOC compounds that are measured by the RM25A test method (based on known flame ionization detector response factors) is subtracted from the RM25A measured emission rate. The remaining "unspeciated" RM25A emission rate is adjusted to represent propane rather than carbon and then added to the speciated VOC emission rate to provide the "total" temperature-specific VOC emission rate. The resultant VOC EF is a 10-point best-fit linear equation with dependent variable "x" equal to the maximum drying temperature of heated air entering the lumber.

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. Based upon the mass-to-carbon ratios and response factors noted above, 1 lb/mbf ethanol is reported as 0.4194 lb/mbf propane and 1 lb/mbf acetic acid is reported as 0.2806 lb/mbf propane through the use of EPA Reference Method 25A unless compound-specific sampling and analysis is performed. The contribution of ethanol and acetic acid has been quantified through sampling and analysis for douglas fir and ponderosa pine. For douglas fir, ethanol's contribution over three tests was measured to be 0, 1.4 and 5.4 percent of WPP1 VOC, and acetic acid's contribution over the same three tests was measured to be 37, 20 and 13 percent of WPP1 VOC. For ponderosa pine, ethanol's contribution over one test was measured to be 32 percent of WPP1 VOC, and acetic acid's contribution over the same test was measured to be 6.4 percent. Without western true fir lumber drying test data for ethanol and acetic acid, EPA assumes propane adequately represents the mix of unspeciated VOC.

Test data generated through the use of the smaller of the two small-scale kilns at Oregon State University (OSU) has been adjusted to account for bias documented in NCASI's May 2002 Technical Bulletin No. 845 entitled, "A Comparative Study of VOC Emissions from Small-Scale and Full-Scale Lumber Kilns Drying Southern Pine." See last spreadsheet of this workbook for Stimson Lumber Company's October 18, 2019 letter to EPA Region 10 highlighting the bias.

Step One: Compile Western True Fir RM25A 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	0.26	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] Green highlight denotes data generated by testing conducted on the small-scale kiln at the University of Idaho. All other data was generated by testing conducted on the smaller of the two small-scale kilns at OSU.

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

Step Two: Adjust Western True Fir VOC Emission Test Data to Account for Bias in Underlying Small-Scale Kiln to Represent Full-Scale Kiln Emissions[1]

Maximum Dry Bulb Temperature (°F)	Method 25A VOC as Carbon (lb/mbf)
180	0.22
180	0.22
180	0.18
180	0.21
190	0.52
190	0.42
200	0.44
225	0.39
240	0.52
240	0.50

[1] Green highlighted results from the test conducted at the University of Idaho have not been adjusted because the kiln was not calibrated to a full-scale kiln.

Adjusted OSU emission test data value = (OSU reported emission test data value) X (NCASI TB No. 845 study full-scale kiln value/NCASI TB No. 845 study OSU small-scale kiln value)

where: OSU reported emission test data value is the RM25A VOC as carbon emission rate "lb/mbf" documented in Step One (not highlighted in green)

NCASI study full-scale kiln value is the average RM25A VOC as carbon emission rate "lb/mbf" measured while drying southern yellow pine lumber in a full-scale indirect steam-heated batch lumber dry kiln

NCASI study OSU small-scale kiln value is the average RM25A VOC as carbon emission rate "lb/mbf" measured while drying southern yellow pine lumber in OSU's small-scale indirect steam-heated batch lumber dry kiln

The lumber dried in the OSU kiln was (a) extracted from the pool of lumber dried in the full-scale kiln and (b) dried according the schedule employed by the full-scale kiln.

	NCASI TB No. 845 - Emission Rate (lb/mbf) RM25A VOC as carbon
Full-Scale Kiln	3.53333
OSU Kiln	4.25000

Step Three: Calculate/Compile Western True Fir Speciated HAP Emission Factors at Maximum Drying Temperatures Observed during RM25A VOC Testing[1]

Maximum Dry Bulb Temperature (°F)	Methanol[2] (lb/mbf)	Formaldehyde[3] (lb/mbf)	Acetaldehyde (lb/mbf)	Propionaldehyde (lb/mbf)	Acrolein (lb/mbf)
180	0.1034	0.0012	0.0550	no data	no data
190	0.1499	0.0028			
200	0.1964	0.0044			
225	0.3127	0.0084			
240	0.3824	0.0108			

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

[2] Methanol EF = 0.00465x - 0.73360; where dependent variable "x" equal to the maximum drying temperature of heated air entering the lumber.

[3] Formaldehyde EF = 0.00016x - 0.02764; where dependent variable "x" equal to the maximum drying temperature of heated air entering the lumber.

Step Four: Compile True Fir Speciated Non-HAP Emission Factors at Maximum Drying Temperatures Observed during RM25A VOC Testing

Maximum Dry Bulb Temperature (°F)	Ethanol (lb/mbf)	Acetic Acid (lb/mbf)
180	no data	no data
190		
200		
225		
240		

Step Five: Convert Western True Fir Speciated HAP and Non-HAP Emission Factors to "as Carbon" and Total

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

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)	Ethanol as Carbon (lb/mbf)	Acetic Acid as Carbon (lb/mbf)	SUM	Speciated Compounds as Carbon (lb/mbf)
180	0.0279	0	0.0150	no data	no data	no data	no data		0.0429
190	0.0405	0							0.0555
200	0.0530	0							0.0680
225	0.0844	0							0.0994
240	0.1032	0							0.1182

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
Ethanol	0.66	46.0688	C_2H_6O	2	6	1	1
Acetic Acid	0.575	60.0524	$C_2H_4O_2$	2	4	2	1
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 Six: Subtract Speciated HAP and Non-HAP Compounds from Western True Fir RM25A VOC Emission Factors and Convert Result to "as Propane"

Maximum Dry Bulb Temperature (°F)	FROM STEP TWO Method 25A VOC as Carbon (lb/mbf)		FROM STEP FIVE Speciated Compounds as Carbon (lb/mbf)		Method 25A VOC as Carbon without Speciated Compounds (lb/mbf)	Propane Mass Conversion Factor	Method 25A VOC as Propane without Speciated Compounds (lb/mbf)
180	0.22		0.0429		0.1733		0.2120
180	0.22		0.0429		0.1816		0.2222
180	0.18		0.0429		0.1400		0.1713
180	0.21		0.0429		0.1649		0.2018
190	0.52		0.0555		0.4683		0.5731
190	0.42		0.0555		0.3602		0.4408
200	0.44		0.0680		0.3726		0.4560
225	0.39		0.0994		0.2906		0.3557
240	0.52	MINUS	0.1182	EQUALS	0.3972		0.4861
240	0.50		0.1182		0.3806	X 1.2238 =	0.4658

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

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."

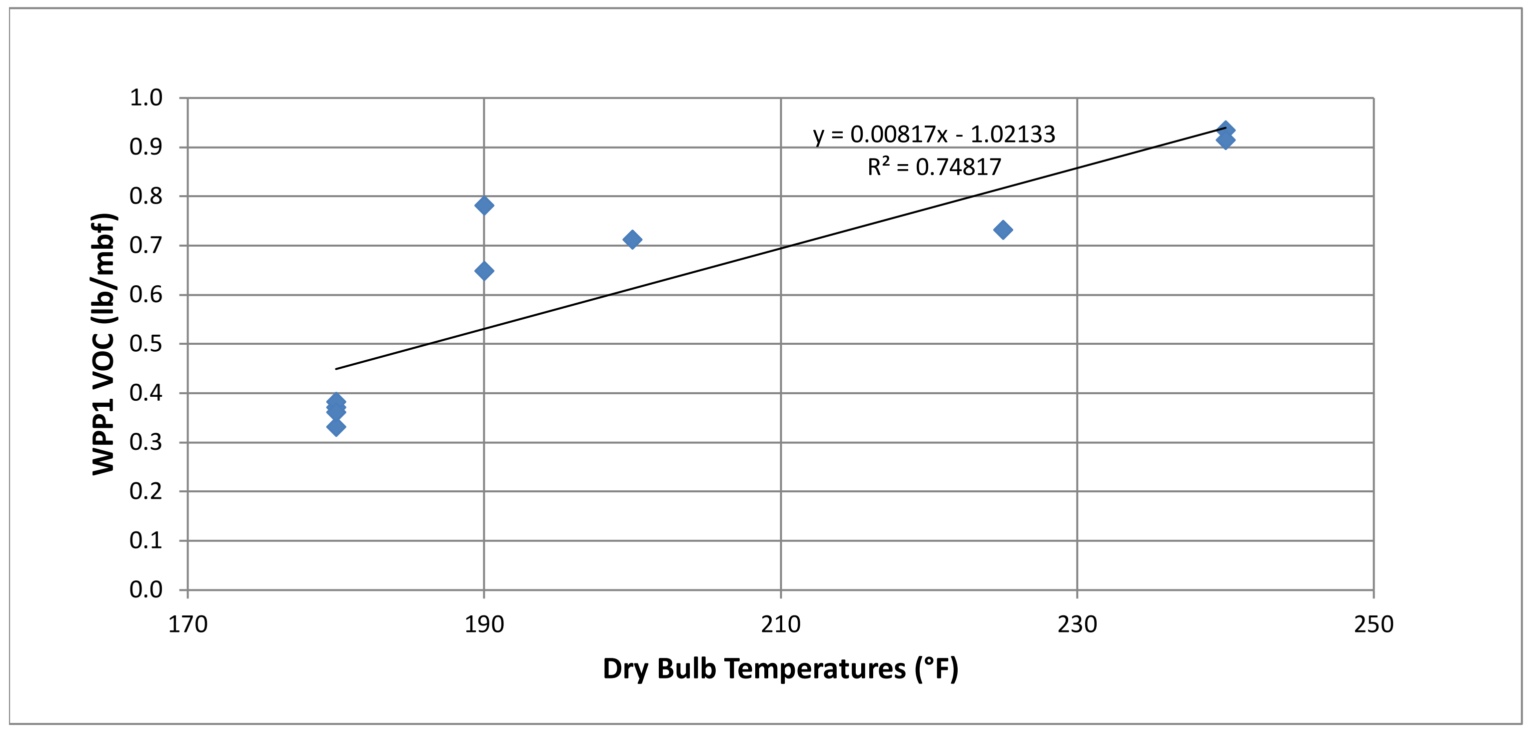
Step Seven: Calculate WPP1 VOC by Adding Speciated HAP and Non-HAP Compounds to Western True Fir RM25A VOC Emission Factors "as Propane"

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

	FROM STEP SIX		FROM STEP THREE						FROM STEP FOUR			
Maximum Dry Bulb Temperature (°F)	Method 25A VOC as Propane without Speciated Compounds (lb/mbf)		Methanol (lb/mbf)	Formaldehyde (lb/mbf)	Acetaldehyde (lb/mbf)	Propionaldehyde (lb/mbf)	Acrolein (lb/mbf)		Ethanol (lb/mbf)	Acetic Acid (lb/mbf)		WPP1 VOC (lb/mbf)
180	0.2120		0.1034	0.0012	0.0550	no data	no data		no data	no data		0.3716
180	0.2222		0.1034	0.0012								0.3818
180	0.1713		0.1034	0.0012								0.3309
180	0.2018		0.1034	0.0012								0.3614
190	0.5731		0.1499	0.0028								0.7808
190	0.4408		0.1499	0.0028								0.6485
200	0.4560		0.1964	0.0044								0.7118
225	0.3557		0.3127	0.0084								0.7317
240	0.4861	PLUS	0.3824	0.0108				PLUS			EQUALS	0.9343
240	0.4658		0.3824	0.0108								0.9140

Step Eight: Generate Western True Fir Best-Fit Linear Equation with Dependent Variable Maximum Drying Temperature of Heated Air Entering the Lumber to Model WPP1 VOC Emissions

WPP1 VOC (lb/mbf): 0.00817x - 1.02133 ; where dependent variable "x" equal to the maximum drying temperature of heated air entering the lumber



Hazardous Air Pollutant Emission Factors for Drying Western Hemlock Lumber

This sheet presents lab-scale test data and calculations used to create HAP EF for drying western hemlock lumber in an indirect steam-heated batch kiln. The methanol and formaldehyde EF are temperature dependent best-fit linear equations. The temperature variable reflects the maximum temperature of the heated air entering the lumber. The acetaldehyde, propionaldehyde and acrolein EF are calculated by averaging test results.

Test data generated through the use of the smaller of the two small-scale kilns at Oregon State University (OSU) has been adjusted to account for bias documented in NCASI's May 2002 Technical Bulletin No. 845 entitled, "A Comparative Study of VOC Emissions from Small-Scale and Full-Scale Lumber Kilns Drying Southern Pine." See last spreadsheet of this workbook for Stimson Lumber Company's October 18, 2019 letter to EPA Region 10 highlighting the bias.

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	8, 11, 14
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	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] All data was generated by testing conducted on the smaller of the two small-scale kilns at OSU.

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

Step Two: Adjust Western Hemlcock HAP Emission Test Data to Account for Bias in Underlying Small-Scale Kiln to Represent Full-Scale Kiln Emissions

Maximum Dry Bulb Temperature (°F)	Methanol (lb/mbf)	Formaldehyde (lb/mbf)	Acetaldehyde (lb/mbf)	Propionaldehyde (lb/mbf)	Acrolein (lb/mbf)
180	0.0756	0.0010	no data	no data	no data
180	0.0683	0.0010	0.0468	0.0007	0.0008
180	0.0856	0.0011	0.0846	0.0003	0.0008
180	0.0474	0.0005	no data	no data	no data
180	0.0284	0.0006	no data	no data	no data
180	0.0277	0.0006	no data	no data	no data
200	0.0893	0.0011	no data	no data	no data
200	0.1594	0.0012	no data	no data	no data
200	0.1403	0.0013	no data	no data	no data
200	0.0401	0.0006	0.0798	0.0003	0.0016
200	0.0702	0.0010	0.0768	0.0003	0.0007
200	0.0519	0.0010	no data	no data	no data
215	0.1257	0.0032	no data	no data	0.0018
225	0.1722	0.0026	no data	no data	no data
225	0.1522	0.0025	no data	no data	no data
225	0.2187	0.0030	no data	no data	no data
235	0.1704	0.0033	0.0504	0.0005	0.0013

Adjusted OSU emission test data value$_i$ = (OSU reported emission test data value$_i$) X (NCASI TB No. 845 study full-scale kiln value$_i$/NCASI TB No. 845 study OSU small-scale kiln value$_i$)

where: OSU reported emission test data value$_i$ is the emission rate "lb/mbf" for compound "i" documented in Step One (not highlighted in green)

NCASI study full-scale kiln value$_i$ is the average emission rate "lb/mbf" for compound "i" measured while drying southern yellow pine lumber in a full-scale indirect steam-heated batch lumber dry kiln

NCASI study OSU small-scale kiln value$_i$ is the average emission rate "lb/mbf" for compound "i" measured while drying southern yellow pine lumber in OSU's small-scale indirect steam-heated batch lumber dry kiln

The lumber dried in the OSU kiln was (a) extracted from the pool of lumber dried in the full-scale kiln and (b) dried according the schedule employed by the full-scale kiln.

NCASI TB No. 845 - Emission Rate (lb/mbf)

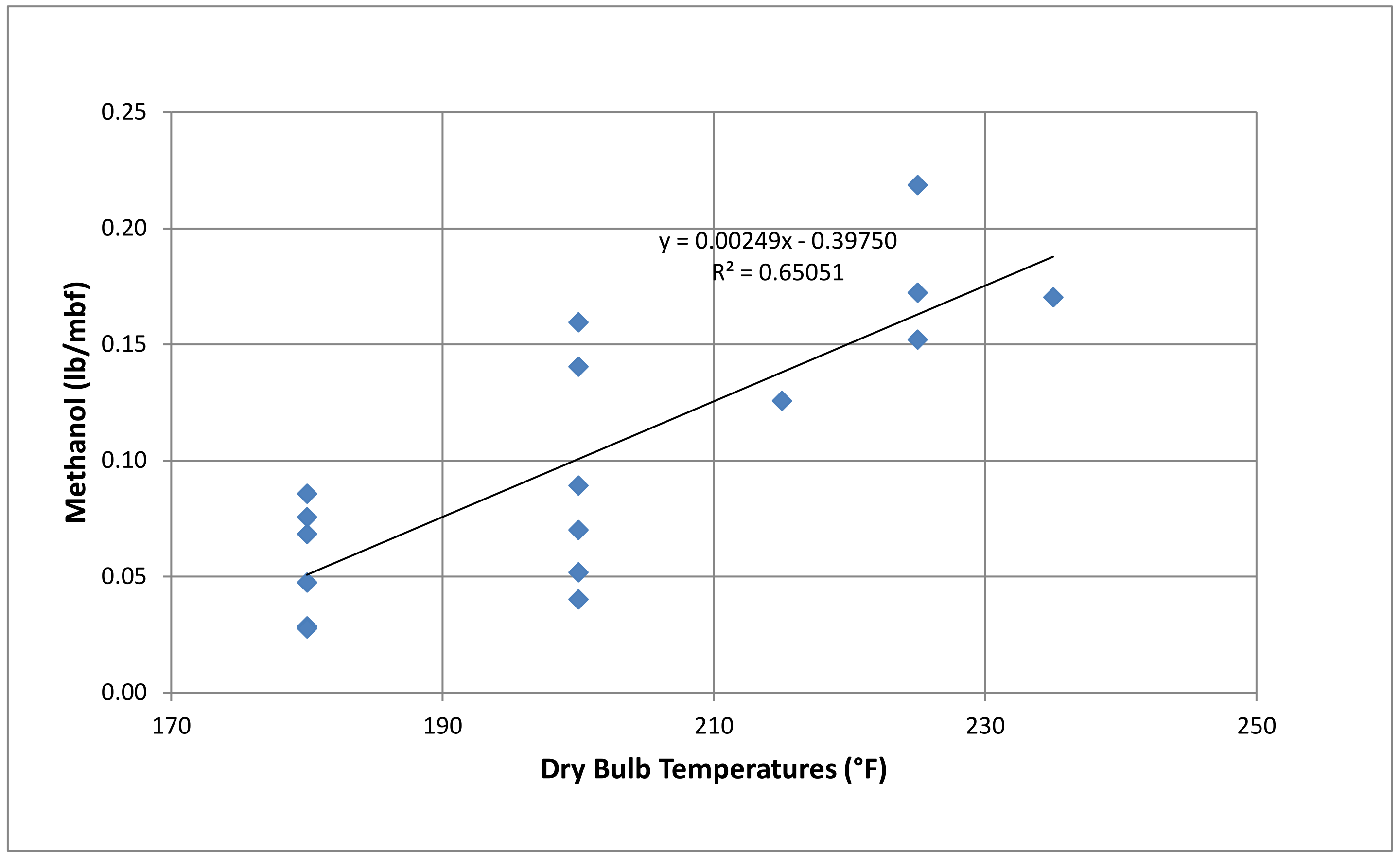
	Methanol	Formaldehyde	Acetaldehyde	Propionaldehyde	Acrolein
Full-Scale Kiln	0.205	0.0155	0.039	0.001	0.006
OSU Kiln	0.225	0.0210	0.065	0.003	0.009

Step Three: Calculate Western Hemlock HAP Emission Factors

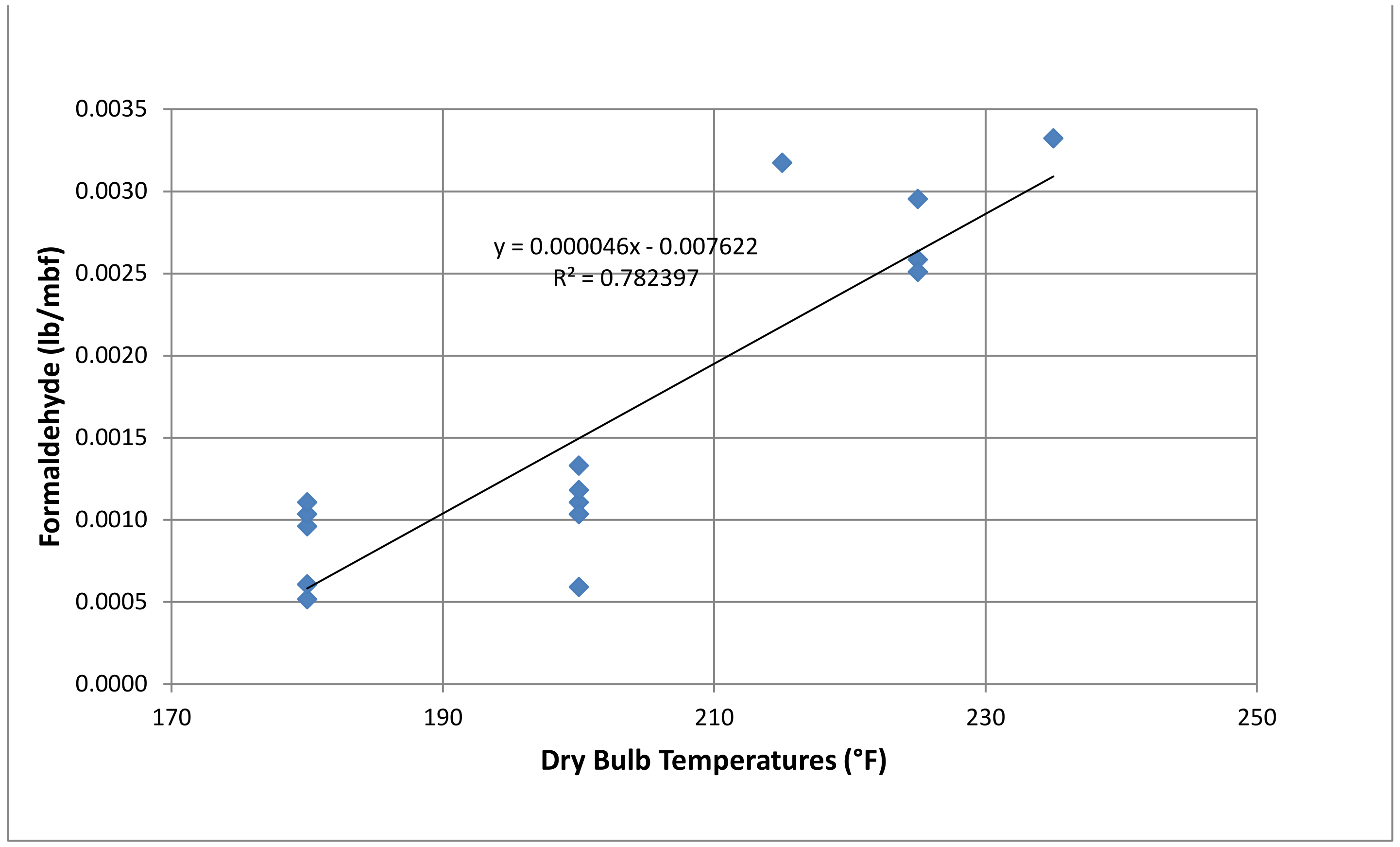
Methanol[1] (lb/mbf)	Formaldehyde[1] (lb/mbf)	Acetaldehyde[2] (lb/mbf)	Propionaldehyde[2] (lb/mbf)	Acrolein[2] (lb/mbf)
0.00249x - 0.39750	0.000046x - 0.007622	0.0677	0.0004	0.0012

[1] Because methanol and formaldehyde emissions are dependent upon maximum drying temperature, best-fit linear equations model emissions with dependent variable "x" equal to the maximum drying temperature of heated air entering the lumber

[2] Because acetaldehyde, propionaldehyde and acrolein emissions across different species are not consistently dependent upon maximum drying temperature, EF are calculated by averaging test results.



y = 0.00249x - 0.39750
R² = 0.65051
Methanol (lb/mbf)
Dry Bulb Temperatures (°F)
0.25
0.20
0.15
0.10
0.05
0.00
170
190
210
230
250



y = 0.000046x - 0.007622
R² = 0.782397
Formaldehyde (lb/mbf)
Dry Bulb Temperatures (°F)
0.0035
0.0030
0.0025
0.0020
0.0015
0.0010
0.0005
0.0000
170
190
210
230
250

Volatile Organic Compound Emission Factors for Drying Western Hemlock Lumber

This sheet presents lab-scale EPA Reference Method 25A (RM25A) and speciated VOC test data and calculations used to create VOC EF for drying western hemlock lumber in an indirect steam-heated batch kiln. RM25A has some limitations in that it misses some pollutant compounds (or portions thereof) 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 pollutant compounds (some HAP and some non-HAP) are accounted for through separate testing. RM25A test data is adjusted to fully account for five known pollutant compounds that are VOC using separate 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 RM25A results are adjusted to account for not only methanol and formaldehyde but also for acetaldehyde, propionaldehyde and acrolein in this case.

More specifically, twenty-three separate drying-temperature-specific VOC emission rates (upon which a best-fit linear equation will be established) are calculated based upon underlying RM25A and speciated VOC test data as indicated above. Temperature-specific methanol and formaldehyde emission rates are calculated for each temperature at which RM25A testing was performed using temperature-dependent best-fit linear equations. The temperature variable reflects the maximum temperature of the heated air entering the lumber. The temperature-independent acetaldehyde, propionaldehyde and acrolein emission rates reflect the average of all test results independent of the temperature of heated air entering the lumber. EPA Region 10 is not aware of any further speciated VOC test data. That portion of the (speciated) VOC compounds that are measured by the RM25A test method (based on known flame ionization detector response factors) is subtracted from the RM25A measured emission rate. The remaining "unspeciated" RM25A emission rate is adjusted to represent propane rather than carbon and then added to the speciated VOC emission rate to provide the "total" temperature-specific VOC emission rate. The resultant VOC EF is a 23-point best-fit linear equation with dependent variable "x" equal to the maximum drying temperature of heated air entering the lumber.

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. Based upon the mass-to-carbon ratios and response factors noted above, 1 lb/mbf ethanol is reported as 0.4194 lb/mbf propane and 1 lb/mbf acetic acid is reported as 0.2806 lb/mbf propane through the use of EPA Reference Method 25A unless compound-specific sampling and analysis is performed. The contribution of ethanol and acetic acid has been quantified through sampling and analysis for douglas fir and ponderosa pine. For douglas fir, ethanol's contribution over three tests was measured to be 0, 1.4 and 5.4 percent of WPP1 VOC, and acetic acid's contribution over the same three tests was measured to be 37, 20 and 13 percent of WPP1 VOC. For ponderosa pine, ethanol's contribution over one test was measured to be 32 percent of WPP1 VOC, and acetic acid's contribution over the same test was measured to be 6.4 percent. Without western hemlock lumber drying test data for ethanol and acetic acid, EPA assumes propane adequately represents the mix of unspeciated VOC.

Test data generated through the use of the smaller of the two small-scale kilns at Oregon State University (OSU) has been adjusted to account for bias documented in NCASI's May 2002 Technical Bulletin No. 845 entitled, "A Comparative Study of VOC Emissions from Small-Scale and Full-Scale Lumber Kilns Drying Southern Pine." See last spreadsheet of this workbook for Stimson Lumber Company's October 18, 2019 letter to EPA Region 10 highlighting the bias.

Step One: Compile Western Hemlock RM25A VOC Emission Test Data by Drying Temperature[1,2]

Maximum Dry Bulb Temperature (°F)	Method 25A VOC as Carbon (lb/mbf)	Lumber Dimensions	Moisture Content[3] (%) (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	JUM 3-200	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] Green highlight denotes data generated by testing conducted on the small-scale kiln at the University of Idaho. All other data was generated by testing conducted on the smaller of the two small-scale kilns at OSU.

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

Step Two: Adjust Western Hemlock VOC Emission Test Data to Account for Bias in Underlying Small-Scale Kiln to Represent Full-Scale Kiln Emissions[1]

Maximum Dry Bulb Temperature (°F)	Method 25A VOC as Carbon (lb/mbf)
180	0.141
180	0.058
180	0.100
180	0.333
180	0.196
180	0.118
180	0.150
180	0.165
180	0.101
200	0.24
200	0.166
200	0.125
200	0.249
200	0.170
200	0.178
200	0.199
215	0.283
215	0.283
225	0.233
225	0.224
225	0.258
235	0.205
235	0.188

[1] Green highlighted results from the test conducted at the University of Idaho have not been adjusted because the kiln was not calibrated to a full-scale kiln.

Adjusted OSU emission test data value = (OSU reported emission test data value) X (NCASI TB No. 845 study full-scale kiln value/NCASI TB No. 845 study OSU small-scale kiln value)

where: OSU reported emission test data value is the RM25A VOC as carbon emission rate "lb/mbf" documented in Step One (not highlighted in green)

NCASI study full-scale kiln value is the average RM25A VOC as carbon emission rate "lb/mbf" measured while drying southern yellow pine lumber in a full-scale indirect steam-heated batch lumber dry kiln

NCASI study OSU small-scale kiln value is the average RM25A VOC as carbon emission rate "lb/mbf" measured while drying southern yellow pine lumber in OSU's small-scale indirect steam-heated batch lumber dry kiln

The lumber dried in the OSU kiln was (a) extracted from the pool of lumber dried in the full-scale kiln and (b) dried according the schedule employed by the full-scale kiln.

	NCASI TB No. 845 - Emission Rate (lb/mbf) RM25A VOC as carbon
Full-Scale Kiln	3.53333
OSU Kiln	4.25000

Step Three: Calculate/Compile Western Hemlock Speciated HAP Emission Factors at Maximum Drying Temperatures Observed during RM25A VOC Testing1[1]

Maximum Dry Bulb Temperature (°F)	Methanol[2] (lb/mbf)	Formaldehyde[3] (lb/mbf)	Acetaldehyde (lb/mbf)	Propionaldehyde (lb/mbf)	Acrolein (lb/mbf)
180	0.0507	0.0007			
200	0.1005	0.0016			
215	0.1379	0.0023	0.0677	0.0004	0.0012
225	0.1628	0.0027			
235	0.1877	0.0032			

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

[2] Methanol EF = 0.00249x - 0.39750; where dependent variable "x" equal to the maximum drying temperature of heated air entering the lumber.

[3] Formaldehyde EF = 0.000046x - 0.007622; where dependent variable "x" equal to the maximum drying temperature of heated air entering the lumber.

Step Four: Compile Western Hemlock Speciated Non-HAP Emission Factors at Maximum Drying Temperatures Observed during RM25A VOC Testing

Maximum Dry Bulb Temperature (°F)	Ethanol (lb/mbf)	Acetic Acid (lb/mbf)
180		
200		
215	no data	no data
225		
235		

Step Five: Convert Western Hemlock Speciated HAP and Non-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)	Ethanol as Carbon (lb/mbf)	Acetic Acid as Carbon (lb/mbf)
180	0.0137	0					
200	0.0271	0					
215	0.0372	0	0.0185	0.0002	0.0005	no data	no data
225	0.0439	0					
235	0.0506	0					

SUM ⇨

Speciated Compounds as Carbon (lb/mbf)
0.0328
0.0462
0.0563
0.0630
0.0698

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
Ethanol	0.66	46.0688	C_2H_6O	2	6	1	1
Acetic Acid	0.575	60.0524	$C_2H_4O_2$	2	4	2	1
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 Six: Subtract Speciated HAP and Non-HAP Compounds from Western Hemlock RM25A VOC Emission Factors and Convert Result to "as Propane"

Maximum Dry Bulb Temperature (°F)	FROM STEP TWO Method 25A VOC as Carbon (lb/mbf)		FROM STEP FIVE Speciated Compounds as Carbon (lb/mbf)		Method 25A VOC as Carbon without Speciated Compounds (lb/mbf)		Method 25A VOC as Propane without Speciated Compounds (lb/mbf)
180	0.1413		0.0328		0.1085		0.1328
180	0.0582		0.0328		0.0254		0.0311
180	0.0998		0.0328		0.0670		0.0820
180	0.3325		0.0328		0.2998		0.3668
180	0.1962		0.0328		0.1634		0.2000
180	0.118		0.0328		0.0853		0.1043
180	0.150		0.0328		0.1169		0.1430
180	0.165		0.0328		0.1318		0.1613
180	0.101		0.0328		0.0686		0.0840
200	0.240		0.0462		0.1938		0.2371
200	0.166		0.0462		0.1200		0.1469
200	0.125		0.0462		0.0785		0.0960
200	0.249		0.0462		0.2032		0.2486
200	0.170		0.0462		0.1234		0.1510
200	0.178		0.0462		0.1317		0.1611
200	0.199		0.0462		0.1525		0.1866
215	0.283		0.0563		0.2264		0.2770
215	0.283		0.0563		0.2264	Propane Mass Conversion Factor	0.2770
225	0.233		0.0630		0.1697		0.2077
225	0.224		0.0630		0.1614		0.1976
225	0.258		0.0630		0.1947		0.2383
235	0.205	MINUS	0.0698	EQUALS	0.1356		0.1659
235	0.188	⇨	0.0698	⇨	0.1181	X 1.2238 =	0.1446

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

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, $(1/RF_{C3H8}) \times [(MW_{C3H8}) / (MW_C)] \times [(\#C_C) / (\#C_{C3H8})]$, equals 1.2238 and can be referred to as the "propane mass conversion factor."

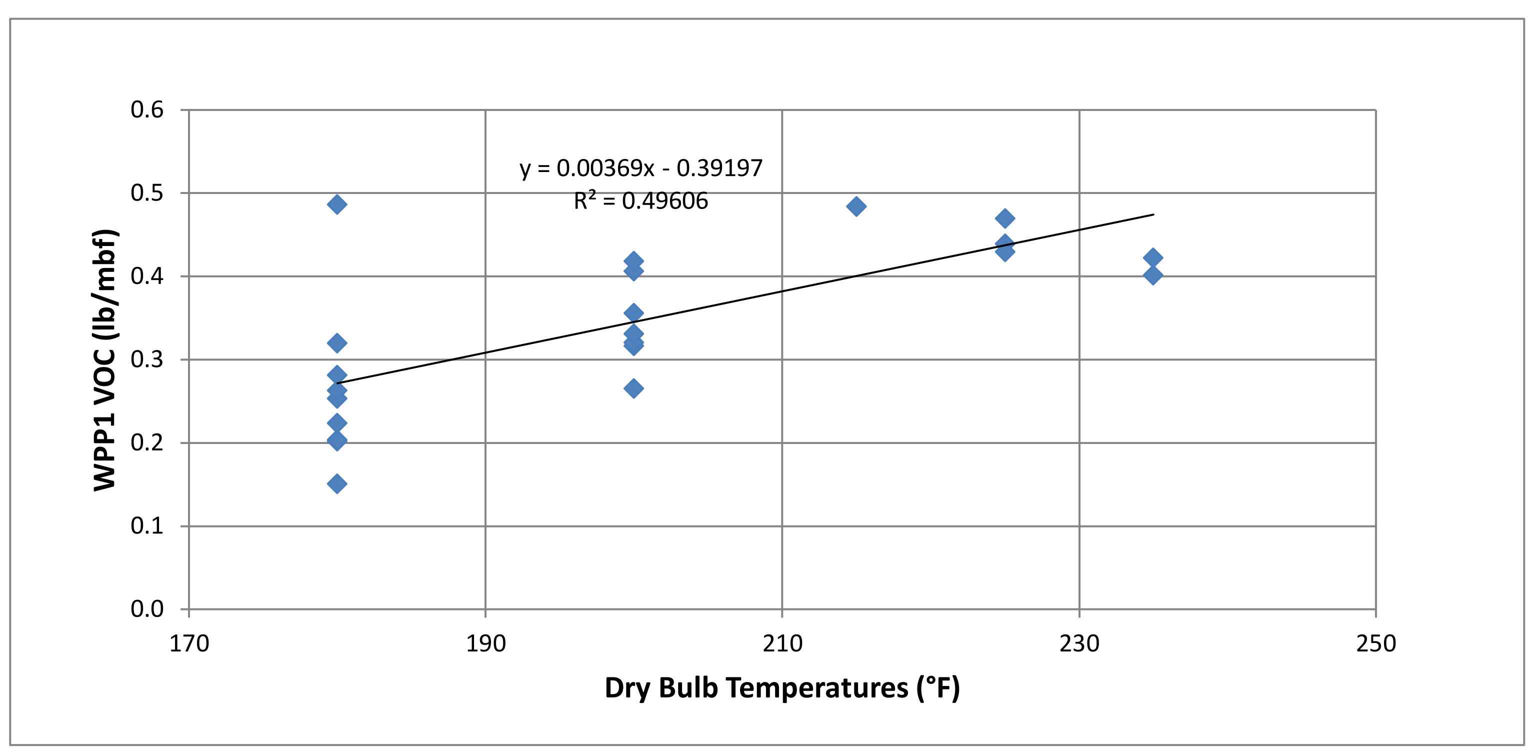
Step Seven: Calculate WPP1 VOC by Adding Speciated HAP and Non-HAP Compounds to Western Hemlock RM25A VOC Emission Factors "as Propane"

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

	FROM STEP SIX		FROM STEP THREE						FROM STEP FOUR			
Maximum Dry Bulb Temperature (°F)	Method 25A VOC as Propane without Speciated Compounds (lb/mbf)		Methanol (lb/mbf)	Formaldehyde (lb/mbf)	Acetaldehyde (lb/mbf)	Propionaldehyde (lb/mbf)	Acrolein (lb/mbf)		Ethanol (lb/mbf)	Acetic Acid (lb/mbf)		WPP1 VOC (lb/mbf)
180	0.1328		0.0507	0.0007								0.2534
180	0.0311		0.0507	0.0007								0.1505
180	0.0820		0.0507	0.0007								0.2014
180	0.3668		0.0507	0.0007								0.4863
180	0.2000		0.0507	0.0007								0.3194
180	0.1043		0.0507	0.0007								0.2238
180	0.1430		0.0507	0.0007								0.2624
180	0.1613		0.0507	0.0007								0.2808
180	0.0840		0.0507	0.0007								0.2034
200	0.2371		0.1005	0.0016								0.4064
200	0.1469		0.1005	0.0016								0.3161
200	0.0960		0.1005	0.0016	0.0677	0.0004	0.0012		no data	no data		0.2653
200	0.2486		0.1005	0.0016								0.4179
200	0.1510		0.1005	0.0016								0.3202
200	0.1611		0.1005	0.0016								0.3304
200	0.1866		0.1005	0.0016								0.3558
215	0.2770		0.1379	0.0023								0.4836
215	0.2770		0.1379	0.0023								0.4836
225	0.2077		0.1628	0.0027								0.4392
225	0.1976		0.1628	0.0027								0.4290
225	0.2383		0.1628	0.0027								0.4697
235	0.1659	PLUS	0.1877	0.0032				PLUS			EQUALS	0.4223
235	0.1446	⇨	0.1877	0.0032				⇨			⇨	0.4010

Step Seven: Generate Western Hemlock Best-Fit Linear Equation with Dependent Variable Maximum Drying Temperature of Heated Air Entering the Lumber to Model WPP1 VOC Emissions

WPP1 VOC (lb/mbf): 0.00369x - 0.39197 ; where dependent variable "x" equal to the maximum drying temperature of heated air entering the lumber



Hazardous Air Pollutant Emission Factors for Drying Western Red Cedar Lumber

This sheet presents the HAP EF for drying western red cedar lumber. EPA Region 10 is not aware of any HAP emission testing of western red cedar. When no test data is available for any HAP, 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.

In the absence of western red cedar test data, western true fir test data has been substituted for methanol and formaldehyde and western hemlock test data has been substituted for acetaldehyde, propionaldehyde and acrolein. Western red cedar is similar to western true firs and western hemlock in that all species are non-resinous softwood species in the scientific classification order Pinales. For methanol and formaldehyde, western true fir EF are greater. For acetaldehyde, western hemlock EF is greater. EPA Region 10 is not aware of any western true fir test data for either propionaldehye or acrolein. See the western true fir and western hemlock HAP sheets for lab-scale test data and calculations.

Western Red Cedar (Western True Firs and Western Hemlock Substitution) HAP Emission Factors

Methanol (lb/mbf)	Formaldehyde (lb/mbf)	Acetaldehyde (lb/mbf)	Propionaldehyde (lb/mbf)	Acrolein (lb/mbf)
0.00465x - 0.73360	0.00016x - 0.02764	0.0677	0.0004	0.0012

Volatile Organic Compound Emission Factors for Drying Western Red Cedar Lumber

This sheet presents the VOC EF for drying western red cedar lumber. EPA Region 10 is aware of two tests being conducted while drying western red cedar lumber, and both were conducted at 160°F. Because VOC emissions increase with maximum drying temperature, employing an EF based upon testing at 160°F would underreport emissions when drying at maximum drying temperatures greater than 160°F. A temperature of 160°F is not a particularly high drying temperature. When little or no test data is 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.

Given the limited western red cedar test data, western true fir test data has been substituted. Western red cedar is similar to western true firs and western hemlock in that all species are non-resinous softwood species in the scientific classification order Pinales. Western true fir VOC emissions are greater than western hemlock VOC emissions. See the western true fir and western hemlock VOC sheets for lab-scale test data and calculations.

<u>Western Red Cedar (Western True Firs Substitution) WPP1 VOC Emission Factor</u>

WPP1 VOC (lb/mbf): 0.00817x - 1.02133 ; where dependent variable "x" equal to the maximum drying temperature of heated air entering the lumb

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 in an indirect steam-heated batch kiln. The methanol and formaldehyde EF are temperature dependent best-fit linear equations. The temperature variable reflects the maximum temperature of the heated air entering the lumber. The acetaldehyde, propionaldehyde and acrolein EF are calculated by averaging test results.

Test data generated through the use of the smaller of the two small-scale kilns at Oregon State University (OSU) has been adjusted to account for bias documented in NCASI's May 2002 Technical Bulletin No. 845 entitled, "A Comparative Study of VOC Emissions from Small-Scale and Full-Scale Lumber Kilns Drying Southern Pine." See last spreadsheet of this workbook for Stimson Lumber Company's October 18, 2019 letter to EPA Region 10 highlighting the bias.

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
145	0.013	0.001	0.057	0.005	0.000	2x4	49.6 / 15	39.7	NCASI ISS/FP-A105.01	Link to June 8, 2012 Exterior Wood Test Report
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	13
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
175	0.019	0.001	0.006	0.0001	0.0004	2x4	32.5 / 15	17.8	NCASI ISS/FP-A105.01	Link to May 23, 2013 Sierra Pacific Industries - Centralia Test Report
175	0.084	0.0016	0.042	0.0002	0.0008	4x5	39.5 / 15	150	NCASI ISS/FP-A105.01	Link to March 24, 2015 Columbia Vista Test Report
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		
200	0.080	0.003	0.037	0.0006	0.0017	2x4	69.3 / 15	20.8	NCASI ISS/FP-A105.01	Link to February 10, 2012 Hampton Lumber - Morton Test Report
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	0.0012	2x4 or 2x6	47.7 / 15	19	NCASI Method 105	18, 21

[1] Green highlight denotes data generated by testing conducted on the small-scale kiln at the University of Idaho. All other data was generated by testing conducted on the smaller of the two small-scale kilns at OSU.

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

Step Two: Adjust Douglas Fir HAP Emission Test Data to Account for Bias in Underlying Small-Scale Kiln to Represent Full-Scale Kiln Emissions[1]

Maximum Dry Bulb Temperature (°F)	Methanol (lb/mbf)	Formaldehyde (lb/mbf)	Acetaldehyde (lb/mbf)	Propionaldehyde (lb/mbf)	Acrolein (lb/mbf)
145	0.012	0.0007	0.034	0.0017	0.0000
160	0.023	0.0006	no data	no data	no data
160	0.021	0.0006	no data	no data	no data
160	0.024	0.0013	no data	no data	no data
160	0.016	0.0008	no data	no data	no data
170	0.014	0.0004	no data	no data	no data
170	0.024	0.0006	no data	no data	no data
170	0.022	0.0006	0.018	0.0001	0.0003
175	0.017	0.0007	0.004	0.0000	0.0003
175	0.077	0.0012	0.025	0.0001	0.0005
180	0.046	0.0017	0.030	0.0002	0.0006
180	0.077	0.0014	0.037	0.0001	0.0005
200	0.062	0.0013	0.026	0.0002	0.0006
200	0.063	0.0014	0.043	0.0002	0.0003
200	0.073	0.0022	0.022	0.0002	0.0011
220	no data	no data	0.030	no data	no data
220	no data	no data	0.022	no data	no data
235	0.107	0.0032	0.040	0.0003	0.0008

[1] Green highlighted results from the test conducted at the University of Idaho have not been adjusted because the kiln was not calibrated to a full-scale kiln.

Adjusted OSU emission test data value$_i$ = (OSU reported emission test data value$_i$) X (NCASI TB No. 845 study full-scale kiln value$_i$/NCASI TB No. 845 study OSU small-scale kiln value$_i$)

where: OSU reported emission test data value$_i$ is the emission rate "lb/mbf" for compound "i" documented in Step One (not highlighted in green)

NCASI study full-scale kiln value$_i$ is the average emission rate "lb/mbf" for compound "i" measured while drying southern yellow pine lumber in a full-scale indirect steam-heated batch lumber dry kiln

NCASI study OSU small-scale kiln value$_i$ is the average emission rate "lb/mbf" for compound "i" measured while drying southern yellow pine lumber in OSU's small-scale indirect steam-heated batch lumber dry kiln

The lumber dried in the OSU kiln was (a) extracted from the pool of lumber dried in the full-scale kiln and (b) dried according the schedule employed by the full-scale kiln.

NCASI TB No. 845 - Emission Rate (lb/mbf)

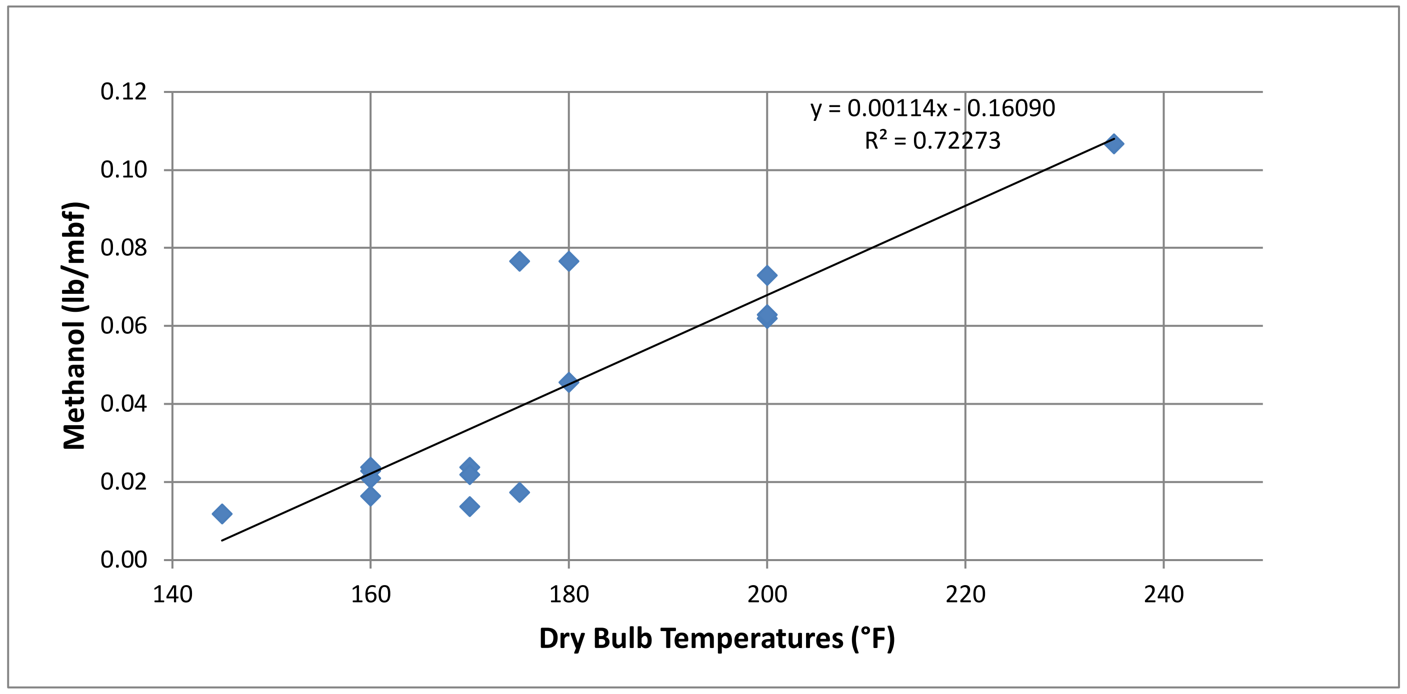
	Methanol	Formaldehyde	Acetaldehyde	Propionaldehyde	Acrolein
Full-Scale Kiln	0.205	0.0155	0.039	0.001	0.006
OSU Kiln	0.225	0.0210	0.065	0.003	0.009

Step Three: Calculate Douglas Fir HAP Emission Factors

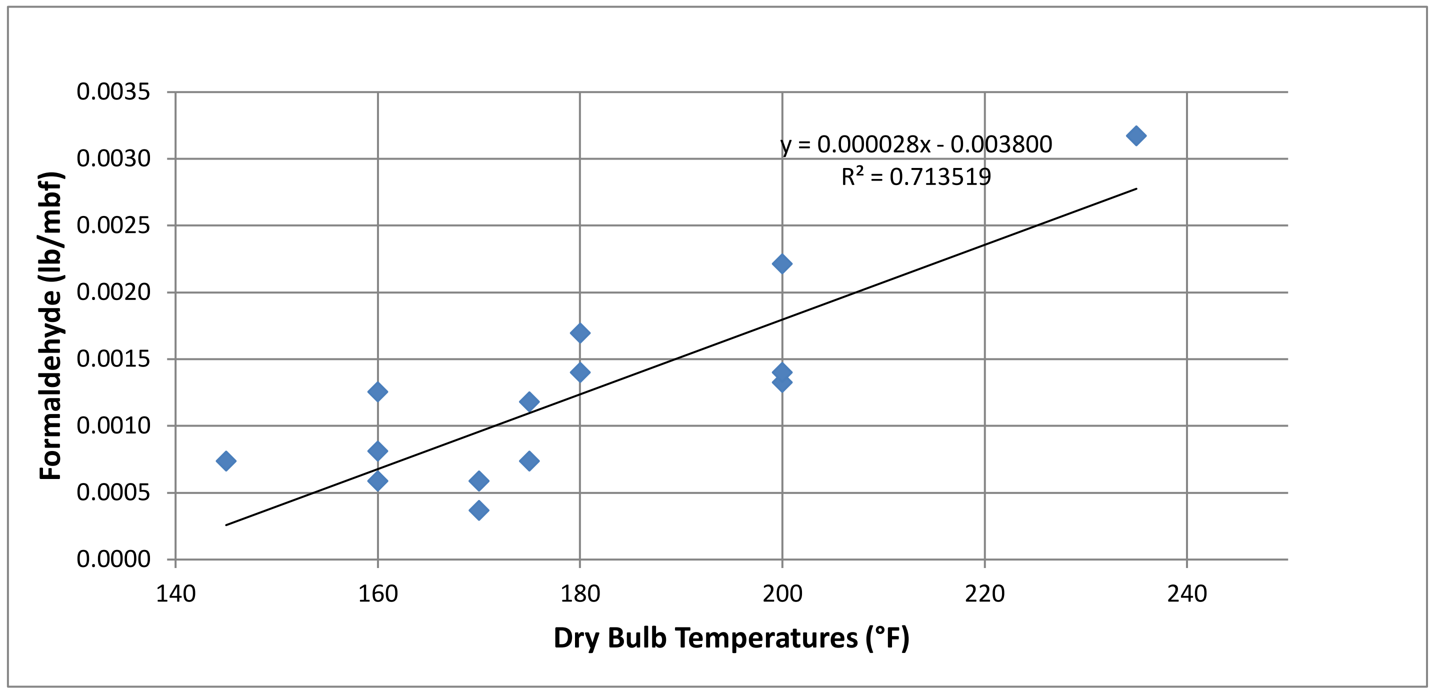
Methanol[1] (lb/mbf)	Formaldehyde[1] (lb/mbf)	Acetaldehyde[2] (lb/mbf)	Propionaldehyde[2] (lb/mbf)	Acrolein[2] (lb/mbf)
0.00114x - 0.16090	0.000028x - 0.003800	0.0275	0.0003	0.0005

[1] Because methanol and formaldehyde emissions are dependent upon drying temperature, best-fit linear equations model emissions with dependent variable "x" equal to the maximum drying temperature of heated air entering the lumber.

[2] Because acetaldehyde, propionaldehyde and acrolein emissions across different species are not consistently dependent upon maximum drying temperature, EF are calculated by averaging test results.



y = 0.00114x - 0.16090
R² = 0.72273
Methanol (lb/mbf)
Dry Bulb Temperatures (°F)



y = 0.000028x - 0.003800
R² = 0.713519
Formaldehyde (lb/mbf)
Dry Bulb Temperatures (°F)

Volatile Organic Compound Emission Factors for Drying Douglas Fir Lumber

This sheet presents lab-scale EPA Reference Method 25A (RM25A) and speciated VOC test data and calculations used to create VOC EF for drying douglas fir lumber in an indirect steam-heated batch kiln. RM25A has some limitations in that it misses some pollutant compounds (or portions thereof) 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 pollutant compounds (some HAP and some non-HAP) are accounted for through separate testing. RM25A test data is adjusted to fully account for seven known pollutant compounds that are VOC using separate 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 RM25A results are adjusted to account for not only methanol and formaldehyde but also for acetaldehyde, propionaldehyde, acrolein, ethanol and acetic acid in this case.

More specifically, twenty-one separate drying-temperature-specific VOC emission rates (upon which a best-fit linear equation will be established) are calculated based upon underlying RM25A and speciated VOC test data as indicated above. Temperature-specific methanol, formaldehyde and ethanol emission rates are calculated for each temperature at which RM25A testing was performed using temperature-dependent best-fit linear equations. The temperature variable reflects the maximum temperature of the heated air entering the lumber. The temperature-independent acetaldehyde, propionaldehyde, acrolein and acetic acid emission rates reflect the average of all test results independent of the temperature of heated air entering the lumber. EPA Region 10 is not aware of any further speciated VOC test data. That portion of the (speciated) VOC compounds that are measured by the RM25A test method (based on known flame ionization detector response factors) is subtracted from the RM25A measured emission rate. The remaining "unspeciated" RM25A emission rate is adjusted to represent propane rather than carbon and then added to the speciated VOC emission rate to provide the "total" temperature-specific VOC emission rate. The resultant VOC EF is a 21-point best-fit linear equation with dependent variable "x" equal to the maximum drying temperature of heated air entering the lumber.

Test data generated through the use of the smaller of the two small-scale kilns at Oregon State University (OSU) has been adjusted to account for bias documented in NCASI's May 2002 Technical Bulletin No. 845 entitled, "A Comparative Study of VOC Emissions from Small-Scale and Full-Scale Lumber Kilns Drying Southern Pine." See last spreadsheet of this workbook for Stimson Lumber Company's October 18, 2019 letter to EPA Region 10 highlighting the bias.

Step One: Compile Douglas Fir RM25A 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
145	0.24	2x4	49.6 / 15	39.7	JUM VE-7	Link to June 8, 2012 Exterior Wood Test Report
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
175	0.185	2x4	32.5 / 15	17.8	JUM VE-7	Link to May 23, 2013 Sierra Pacific Industries - Centralia Test Report
175	0.86	4x5	39.5 / 15	150	JUM VE-7	Link to March 24, 2015 Columbia Vista Test Report
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	JUM VE-7	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		
200	0.66	2x4	69.3 / 15	20.8	JUM VE-7	Link to February 10, 2012 Hampton Lumber - Morton Test Report
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] Green highlight denotes data generated by testing conducted on the small-scale kiln at the University of Idaho. All other data was generated by testing conducted on the smaller of the two small-scale kilns at OSU.

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

Step Two: Adjust Douglas Fir VOC Emission Test Data to Account for Bias in Underlying Small-Scale Kiln to Represent Full-Scale Kiln Emissions[1]

Maximum Dry Bulb Temperature (°F)	Method 25A VOC as Carbon (lb/mbf)
145	0.200
160	0.424
160	0.457
160	0.374
160	0.382
170	0.540
170	0.200
175	0.154
175	0.715
180	0.942
180	0.669
180	0.21
180	0.478
180	0.324
180	0.703
200	0.588
200	0.731
200	0.549
220	1.2
220	1.3
235	1.003

[1] Green highlighted results from the test conducted at the University of Idaho have not been adjusted because the kiln was not calibrated to a full-scale kiln.

Adjusted OSU emission test data value = (OSU reported emission test data value) X (NCASI TB No. 845 study full-scale kiln value/NCASI TB No. 845 study OSU small-scale kiln value)

where: OSU reported emission test data value is the RM25A VOC as carbon emission rate "lb/mbf" documented in Step One (not highlighted in green)

NCASI study full-scale kiln value is the average RM25A VOC as carbon emission rate "lb/mbf" measured while drying southern yellow pine lumber in a full-scale indirect steam-heated batch lumber dry kiln

NCASI study OSU small-scale kiln value is the average RM25A VOC as carbon emission rate "lb/mbf" measured while drying southern yellow pine lumber in OSU's small-scale indirect steam-heated batch lumber dry kiln

The lumber dried in the OSU kiln was (a) extracted from the pool of lumber dried in the full-scale kiln and (b) dried according the schedule employed by the full-scale kiln.

	NCASI TB No. 845 - Emission Rate (lb/mbf) RM25A VOC as carbon
Full-Scale Kiln	3.53333
OSU Kiln	4.25000

Step Three: Calculate/Compile Douglas Fir Speciated HAP Emission Factors at Maximum Drying Temperatures Observed during RM25A VOC Testing[1]

Maximum Dry Bulb Temperature (°F)	Methanol[2] (lb/mbf)	Formaldehyde[3] (lb/mbf)	Acetaldehyde (lb/mbf)	Propionaldehyde (lb/mbf)	Acrolein (lb/mbf)
145	0.0044	0.0003	0.0275	0.0003	0.0005
160	0.0215	0.0007			
170	0.0329	0.0010			
175	0.0386	0.0011			
180	0.0443	0.0012			
200	0.0671	0.0018			
220	0.0899	0.0024			
235	0.1070	0.0028			

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

[2] Methanol EF = 0.00114x - 0.16090; where dependent variable "x" equal to the maximum drying temperature of heated air entering the lumber.

[3] Formaldehyde EF = 0.000028x - 0.003800; where dependent variable "x" equal to the maximum drying temperature of heated air entering the lumber.

Step Four: Compile Douglas Fir Speciated Non-HAP Emission Test Data by Drying Temperature

Maximum Dry Bulb Temperature (°F)	Ethanol (lb/mbf)	Acetic Acid (lb/mbf)	Lumber Dimensions	Moisture Content[1] (%) (Initial / Final)	Time to Final Moisture Content (hours)	VOC Sample Collection Technique	Reference
145	0.0000	0.166	2x4	49.6 / 15	39.7	NCASI ISS/FP-A105.01	Link to June 8, 2012 Exterior Wood Test Report
175	0.0010	0.094	2x4	32.5 / 15	17.8	NCASI ISS/FP-A105.01	Link to May 23, 2013 Sierra Pacific Industries - Centralia Test Report
175	0.0230	0.242	4x6	39.5 / 15	150	NCASI ISS/FP-A105.01	Link to March 24, 2015 Columbia Vista Test Report
200	0.0610	0.142	2x4	69.3 / 15	20.8	NCASI ISS/FP-A105.01	Link to February 10, 2012 Hampton Lumber - Morton Test Report

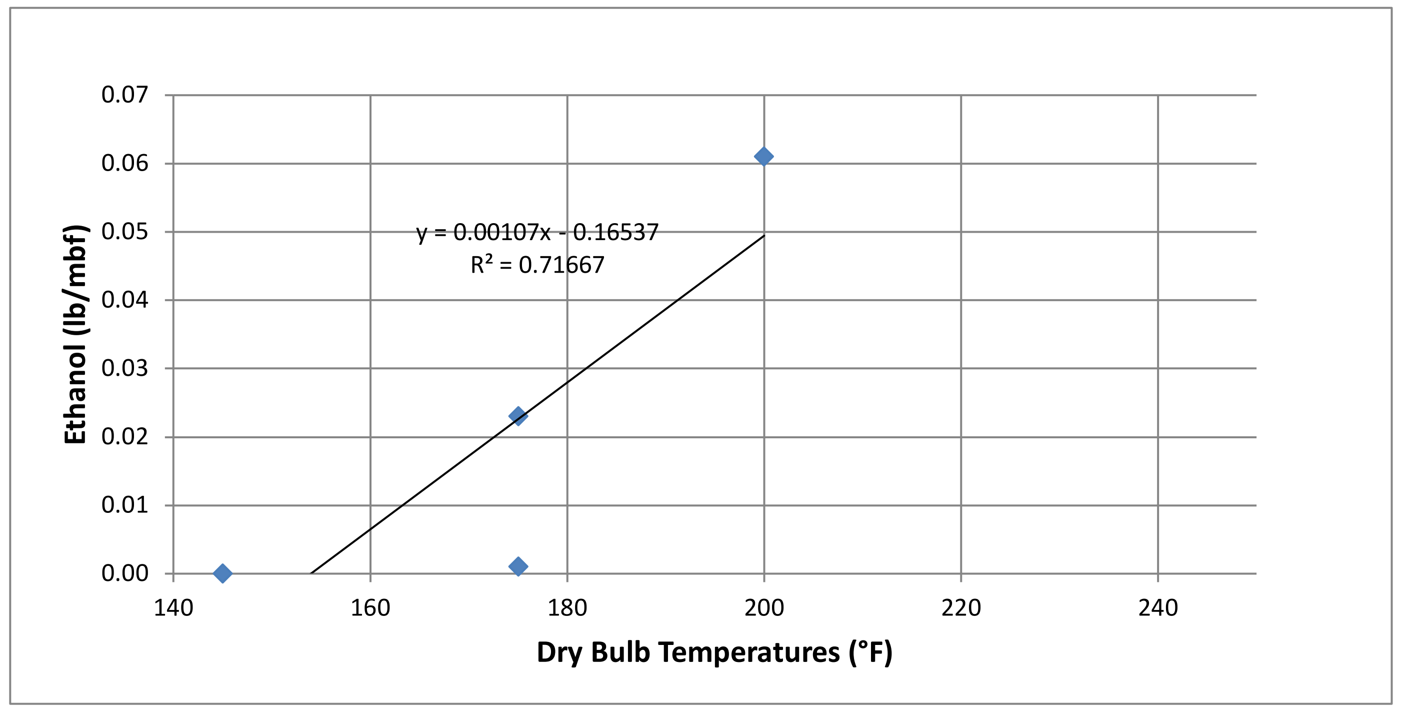
[1] Dry basis. Moisture content = (weight of water / weight wood) x 100

Step Five: Calculate Douglas Fir Speciated Non-HAP Emission Factors

Ethanol[1] (lb/mbf)	Acetic Acid[2] (lb/mbf)
0.00107x - 0.16537	0.1610

[1] Because ethanol emissions are dependent upon drying temperature, a best-fit linear equation models emissions with dependent variable "x" equal to the maximum drying temperature of heated air entering the lumber.

[2] Because acetic acid emissions are independent of drying temperature, EF is calculated by averaging test results.



Step Six: Calculate/Compile Douglas Fir Speciated Non-HAP Emission Factors at Maximum Drying Temperatures Observed during RM25A VOC Testing

Maximum Dry Bulb Temperature (°F)	Ethanol[1] (lb/mbf)	Acetic Acid (lb/mbf)
145	0	0.1610
160	0.00583	
170	0.01653	
175	0.02188	
180	0.02723	
200	0.04863	
220	0.07003	
235	0.08608	

[1] Ethanol EF = 0.00107x - 0.16537; where dependent variable "x" equal to the maximum drying temperature of heated air entering the lumber.

Step Seven: Convert Douglas Fir Speciated HAP and Non-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)	Ethanol as Carbon (lb/mbf)	Acetic Acid as Carbon (lb/mbf)		Speciated Compounds as Carbon (lb/mbf)
145	0.0012	0	0.0075	0.0001	0.0002	0	0.0370		0.0461
160	0.0058	0				0.0020			0.0527
170	0.0089	0				0.0057			0.0594
175	0.0104	0				0.0075			0.0628
180	0.0120	0				0.0094			0.0662
200	0.0181	0				0.0167			0.0797
220	0.0243	0				0.0241		SUM	0.0932
235	0.0289	0				0.0296		⇨	0.1034

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
Ethanol	0.66	46.0688	C_2H_6O	2	6	1	1
Acetic Acid	0.575	60.0524	$C_2H_4O_2$	2	4	2	1
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 Eight: Subtract Speciated HAP and Non-HAP Compounds from Douglas Fir VOC Emission Factors and Convert Result to "as Propane"

Maximum Dry Bulb Temperature (°F)	FROM STEP TWO Method 25A VOC as Carbon (lb/mbf)	MINUS	FROM STEP SIX Speciated Compounds as Carbon (lb/mbf)	EQUALS	Method 25A VOC as Carbon without Speciated Compounds (lb/mbf)	X 1.2238 = (Propane Mass Conversion Factor)	Method 25A VOC as Propane without Speciated Compounds (lb/mbf)
145	0.1995		0.0461		0.1535		0.1878
160	0.4240		0.0527		0.3713		0.4544
160	0.4573		0.0527		0.4046		0.4951
160	0.3741		0.0527		0.3214		0.3934
160	0.3824		0.0527		0.3298		0.4035
170	0.5404		0.0594		0.4810		0.5886
170	0.1995		0.0594		0.1401		0.1714
175	0.1538		0.0628		0.0910		0.1114
175	0.7150		0.0628		0.6522		0.7981
180	0.9420		0.0662		0.8758		1.0718
180	0.6690		0.0662		0.6028		0.7377
180	0.2100		0.0662		0.1438		0.1760
180	0.4780		0.0662		0.4118		0.5040
180	0.3242		0.0662		0.2580		0.3158
180	0.7025		0.0662		0.6363		0.7787
200	0.5878		0.0797		0.5081		0.6218
200	0.7308		0.0797		0.6511		0.7968
200	0.5487		0.0797		0.4690		0.5739
220	1.2000		0.0932		1.1068		1.3544
220	1.3000		0.0932		1.2068		1.4768
235	1.0026		0.1034		0.8993		1.1005

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."

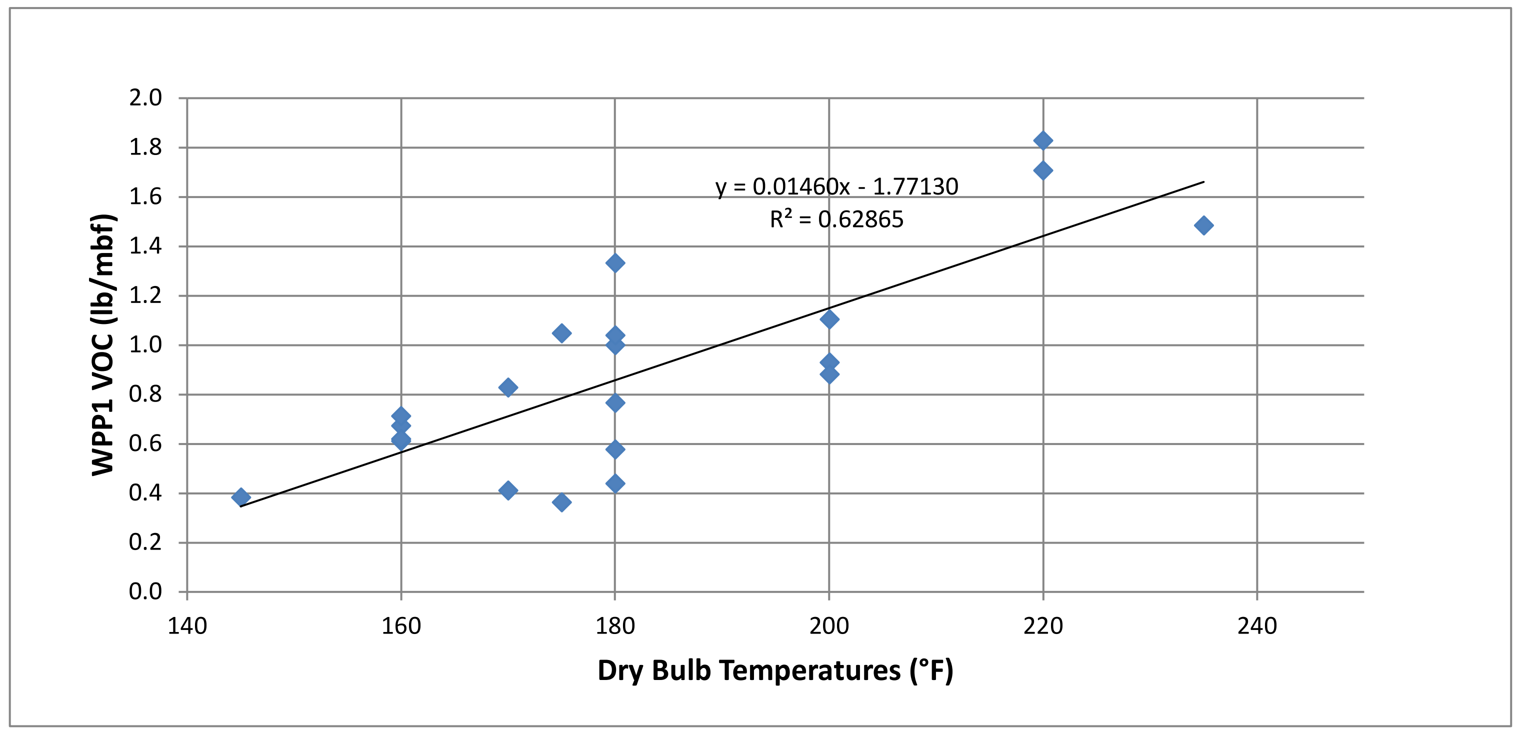
Step Nine: Calculate WPP1 VOC by Adding Speciated HAP and Non-HAP Compounds to Douglas Fir VOC Emission Factors "as Propane"

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

	FROM STEP EIGHT		FROM STEP THREE						FROM STEP SIX			
Maximum Dry Bulb Temperature (°F)	Method 25A VOC as Propane without Speciated Compounds (lb/mbf)		Methanol (lb/mbf)	Formaldehyde (lb/mbf)	Acetaldehyde (lb/mbf)	Propionaldehyde (lb/mbf)	Acrolein (lb/mbf)		Ethanol (lb/mbf)	Acetic Acid (lb/mbf)		WPP1 VOC (lb/mbf)
145	0.1878		0.0044	0.0003					0			0.3818
160	0.4544		0.0215	0.0007					0.0058			0.6717
160	0.4951		0.0215	0.0007					0.0058			0.7124
160	0.3934		0.0215	0.0007					0.0058			0.6107
160	0.4035		0.0215	0.0007					0.0058			0.6209
170	0.5886		0.0329	0.0010					0.0165			0.8283
170	0.1714		0.0329	0.0010					0.0165			0.4111
175	0.1114		0.0386	0.0011					0.0219			0.3622
175	0.7981		0.0386	0.0011					0.0219			1.0490
180	1.0718		0.0443	0.0012					0.0272			1.3339
180	0.7377		0.0443	0.0012	0.0275	0.0003	0.0005		0.0272	0.1610		0.9998
180	0.1760		0.0443	0.0012					0.0272			0.4381
180	0.5040		0.0443	0.0012					0.0272			0.7661
180	0.3158		0.0443	0.0012					0.0272			0.5779
180	0.7787		0.0443	0.0012					0.0272			1.0408
200	0.6218		0.0671	0.0018					0.0486			0.9286
200	0.7968		0.0671	0.0018					0.0486			1.1036
200	0.5739		0.0671	0.0018					0.0486			0.8808
220	1.3544		0.0899	0.0024					0.0700			1.7060
220	1.4768	PLUS	0.0899	0.0024				PLUS	0.0700		EQUALS	1.8284
235	1.1005	⇨	0.1070	0.0028				⇨	0.0861		⇨	1.4857

Step Ten: Generate Douglas Fir Best-Fit Linear Equation with Dependent Variable Maximum Drying Temperature to Model WPP1 VOC Emissions

WPP1 VOC (lb/mbf): 0.01460x - 1.77130 ; where dependent variable "x" equal to the maximum drying temperature of heated air entering the lumber



Hazardous Air Pollutant Emission Factors for Drying Engelmann Spruce Lumber

This sheet presents lab-scale test data and calculations used to create HAP EF for engelmann spruce lumber in an indirect steam-heated batch kiln. EPA Region 10 is not aware of any HAP emission testing of englemann spruce. 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. 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.

The methanol and formaldehyde EF are temperature dependent best-fit linear equations. The temperature variable reflects the maximum temperature of the heated air entering the lumber. The acetaldehyde, propionaldehyde and acrolein EF are calculated by averaging test results.

Test data generated through the use of the smaller of the two small-scale kilns at Oregon State University (OSU) has been adjusted to account for bias documented in NCASI's May 2002 Technical Bulletin No. 845 entitled, "A Comparative Study of VOC Emissions from Small-Scale and Full-Scale Lumber Kilns Drying Southern Pine." See last spreadsheet of this workbook for Stimson Lumber Company's October 18, 2019 letter to EPA Region 10 highlighting the bias.

Step One: Compile Engelmann Spruce (White Spruce Substitution) HAP Emission Test Data by Drying Temperature

Maximum Dry Bulb Temperature (°F)	Methanol (lb/mbf)	Formaldehyde (lb/mbf)	Acetaldehyde (lb/mbf)	Propionaldehyde (lb/mbf)	Acrolein (lb/mbf)	Lumber Dimensions	Moisture Content[1] (%) (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] Dry basis. Moisture content = (weight of water / weight wood) x 100

Step Two: Adjust Engelmann Spruce (White Spruce Substitution) HAP Emission Test Data to Account for Bias in Underlying Small-Scale Kiln to Represent Full-Scale Kiln Emissions

Maximum Dry Bulb Temperature (°F)	Methanol (lb/mbf)	Formaldehyde (lb/mbf)	Acetaldehyde (lb/mbf)	Propionaldehyde (lb/mbf)	Acrolein (lb/mbf)
180	0.023	0.0010	0.022	0.0001	0.0003
235	0.071	0.0032	0.019	0.0002	0.0007

Adjusted OSU emission test data value$_i$ = (OSU reported emission test data value$_i$) X (NCASI TB No. 845 study full-scale kiln value$_i$/NCASI TB No. 845 study OSU small-scale kiln value$_i$)

where: OSU reported emission test data value$_i$ is the emission rate "lb/mbf" for compound "i" documented in Step One (not highlighted in green)

NCASI study full-scale kiln value$_i$ is the average emission rate "lb/mbf" for compound "i" measured while drying southern yellow pine lumber in a full-scale indirect steam-heated batch lumber dry kiln

NCASI study OSU small-scale kiln value$_i$ is the average emission rate "lb/mbf" for compound "i" measured while drying southern yellow pine lumber in OSU's small-scale indirect steam-heated batch lumber dry kiln

The lumber dried in the OSU kiln was (a) extracted from the pool of lumber dried in the full-scale kiln and (b) dried according the schedule employed by the full-scale kiln.

NCASI TB No. 845 - Emission Rate (lb/mbf)

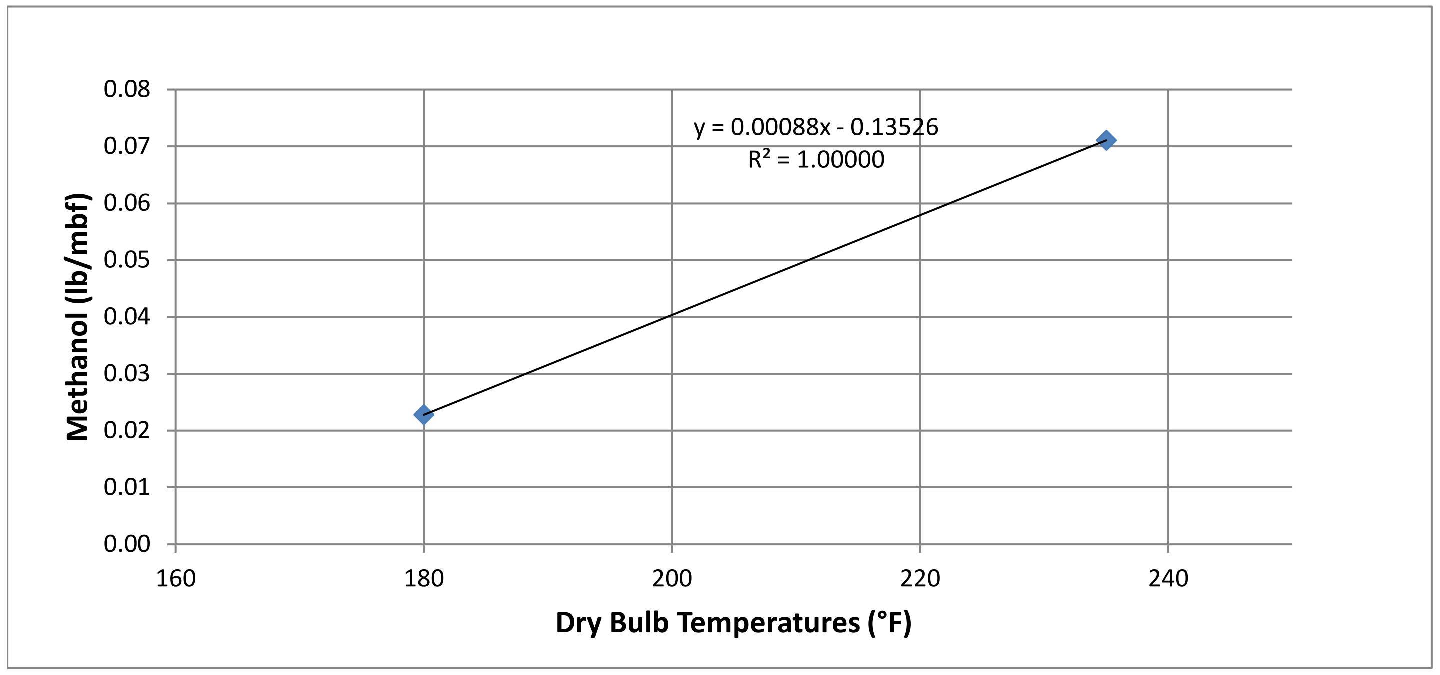
	Methanol	Formaldehyde	Acetaldehyde	Propionaldehyde	Acrolein
Full-Scale Kiln	0.205	0.0155	0.039	0.001	0.006
OSU Kiln	0.225	0.0210	0.065	0.003	0.009

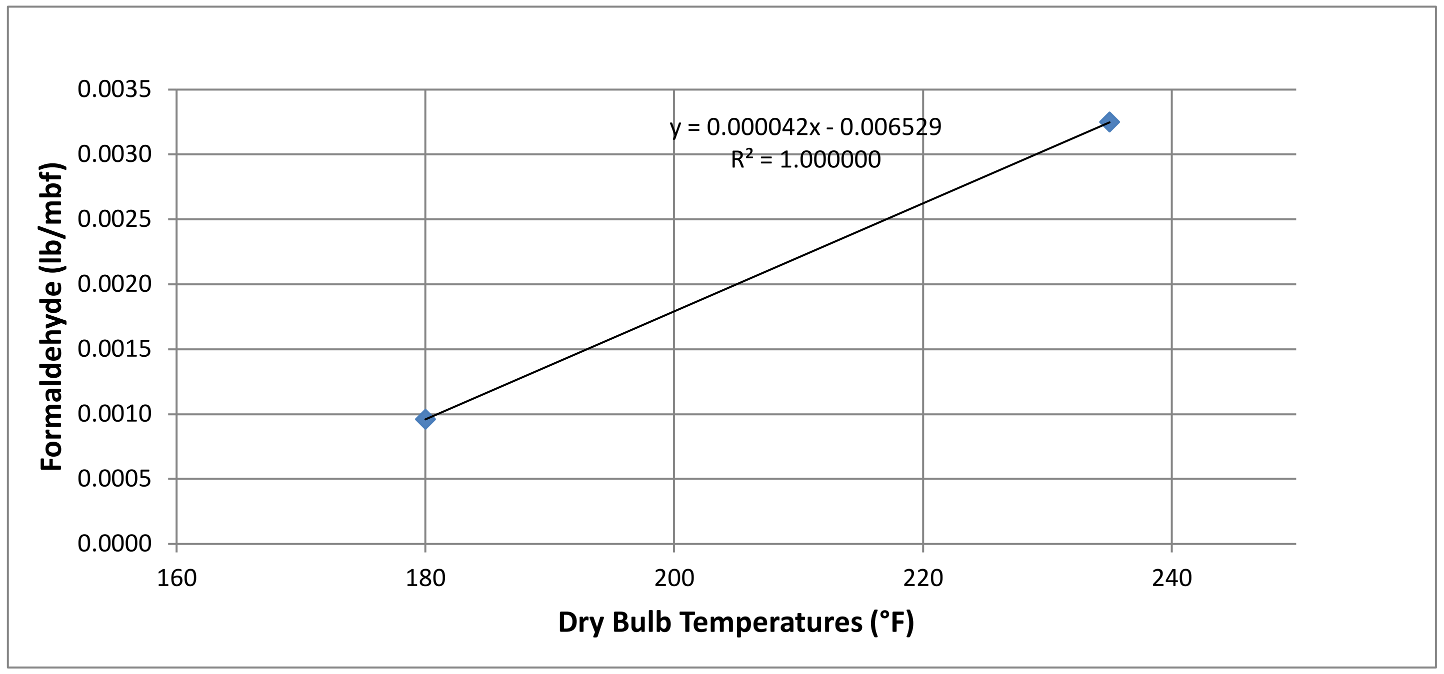
Step Three: Calculate Engelmann Spruce (White Spruce Substitution) HAP Emission Factors

Methanol[1] (lb/mbf)	Formaldehyde[1] (lb/mbf)	Acetaldehyde[2] (lb/mbf)	Propionaldehyde[2] (lb/mbf)	Acrolein[2] (lb/mbf)
0.00088x - 0.13526	0.000042x - 0.006529	0.0201	0.0002	0.0005

[1] Because methanol and formaldehyde emissions are dependent upon drying temperature, best-fit linear equations model emissions with dependent variable "x" equal to the maximum drying temperature of heated air entering the lumber.

[2] Because acetaldehyde, propionaldehyde and acrolein emissions across different species are not consistently dependent upon maximum drying temperature, EF are calculated by averaging test results.


y = 0.00088x - 0.13526
R² = 1.00000
Methanol (lb/mbf)
Dry Bulb Temperatures (°F)
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
160
180
200
220
240


y = 0.000042x - 0.006529
R² = 1.000000
Formaldehyde (lb/mbf)
Dry Bulb Temperatures (°F)
0.0035
0.0030
0.0025
0.0020
0.0015
0.0010
0.0005
0.0000
160
180
200
220
240

Volatile Organic Compound Emission Factors for Drying Engelmann Spruce Lumber

This sheet presents lab-scale EPA Reference Method 25A (RM25A) and speciated VOC test data and calculations used to create VOC EF for drying white spruce lumber in an indirect steam-heated batch kiln. EPA Region 10 is not aware of any HAP or VOC emission testing of englemann spruce. 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. 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. Although only one RM25A VOC test was performed while drying white spruce, it was performed while drying lumber at a relatively high maximum temperature of 235°F. Because emissions increase with maximum drying temperature, employing an EF based upon testing at 235°F would overreport emissions when drying at maximum drying temperatures less than than 235°F.

RM25A has some limitations in that it misses some pollutant compounds (or portions thereof) 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 pollutant compounds (some HAP and some non-HAP) are accounted for through separate testing. RM25A test data is adjusted to fully account for five known pollutant compounds that are VOC using separate 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 RM25A results are adjusted to account for not only methanol and formaldehyde but also for acetaldehyde, propionaldehyde and acrolein in this case.

More specifically, one VOC emission rate is calculated based upon underlying RM25A and speciated VOC test data as indicated above. Temperature-specific methanol and formaldehyde emission rates are calculated for each temperature at which RM25A testing was performed using temperature-dependent best-fit linear equations. The temperature variable reflects the maximum temperature of the heated air entering the lumber. The temperature-independent acetaldehyde, propionaldehyde and acrolein emission rates reflect the average of all test results independent of the temperature of heated air entering the lumber. EPA Region 10 is not aware of any further speciated VOC test data. That portion of the (speciated) VOC compounds that are measured by the RM25A test method (based on known flame ionization detector response factors) is subtracted from the RM25A measured emission rate. The remaining “unspeciated” RM25A emission rate is adjusted to represent propane rather than carbon and then added to the speciated VOC emission rate to provide the “total” temperature-specific VOC emission rate.

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. Based upon the mass-to-carbon ratios and response factors noted above, 1 lb/mbf ethanol is reported as 0.4194 lb/mbf propane and 1 lb/mbf acetic acid is reported as 0.2806 lb/mbf propane through the use of EPA Reference Method 25A unless compound-specific sampling and analysis is performed. The contribution of ethanol and acetic acid has been quantified through sampling and analysis for douglas fir and ponderosa pine. For douglas fir, ethanol's contribution over three tests was measured to be 0, 1.4 and 5.4 percent of WPP1 VOC, and acetic acid's contribution over the same three tests was measured to be 37, 20 and 13 percent of WPP1 VOC. For ponderosa pine, ethanol's contribution over one test was measured to be 32 percent of WPP1 VOC, and acetic acid's contribution over the same test was measured to be 6.4 percent. Without white spruce lumber drying test data for ethanol and acetic acid, EPA assumes propane adequately represents the mix of unspeciated VOC.

Test data generated through the use of the smaller of the two small-scale kilns at Oregon State University (OSU) has been adjusted to account for bias documented in NCASI's May 2002 Technical Bulletin No. 845 entitled, "A Comparative Study of VOC Emissions from Small-Scale and Full-Scale Lumber Kilns Drying Southern Pine." See last spreadsheet of this workbook for Stimson Lumber Company's October 18, 2019 letter to EPA Region 10 highlighting the bias.

Step One: Compile Engelmann Spruce (White Spruce Substitution) RM25A 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
235	0.11	2x4 or 2x6	32.7 / 15	no data	JUM VE-7	18

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

Step Two: Adjust Engelmann Spruce (White Spruce Substitution) VOC Emission Test Data to Account for Bias in Underlying Small-Scale Kiln to Represent Full-Scale Kiln Emissions

Maximum Dry Bulb Temperature (°F)	Method 25A VOC as Carbon (lb/mbf)
235	0.09

Adjusted OSU emission test data value = (OSU reported emission test data value) X (NCASI TB No. 845 study full-scale kiln value/NCASI TB No. 845 study OSU small-scale kiln value)

where: OSU reported emission test data value is the RM25A VOC as carbon emission rate "lb/mbf" documented in Step One (not highlighted in green)

NCASI study full-scale kiln value is the average RM25A VOC as carbon emission rate "lb/mbf" measured while drying southern yellow pine lumber in a full-scale indirect steam-heated batch lumber dry kiln

NCASI study OSU small-scale kiln value is the average RM25A VOC as carbon emission rate "lb/mbf" measured while drying southern yellow pine lumber in OSU's small-scale indirect steam-heated batch lumber dry kiln

The lumber dried in the OSU kiln was (a) extracted from the pool of lumber dried in the full-scale kiln and (b) dried according the schedule employed by the full-scale kiln.

	NCASI TB No. 845 - Emission Rate (lb/mbf) RM25A VOC as carbon
Full-Scale Kiln	3.53333
OSU Kiln	4.25000

Step Three: Calculate/Compile Engelmann Spruce (White Spruce Substitution) Speciated HAP Emission Factors at Maximum Drying Temperatures Observed during RM25A VOC Testing[1]

Maximum Dry Bulb Temperature (°F)	Methanol (lb/mbf)	Formaldehyde (lb/mbf)	Acetaldehyde (lb/mbf)	Propionaldehyde (lb/mbf)	Acrolein (lb/mbf)
235	0.0715	0.0033	0.0201	0.0002	0.0005

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

[2] Methanol EF = 0.00088x - 0.13526; where dependent variable "x" equal to the maximum drying temperature of heated air entering the lumber.

[3] Formaldehyde EF = 0.000042x - 0.006529; where dependent variable "x" equal to the maximum drying temperature of heated air entering the lumber.

Step Four: Compile Engelmann Spruce (White Spruce Substitution) Speciated Non-HAP Emission Factors at Maximum Drying Temperatures Observed during RM25A VOC Testing

Maximum Dry Bulb Temperature (°F)	Ethanol (lb/mbf)	Acetic Acid (lb/mbf)
235	no data	no data

Step Five: Convert Engelmann Spruce (White Spruce Substitution) 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)	Ethanol as Carbon (lb/mbf)	Acetic Acid as Carbon (lb/mbf)	SUM	Speciated Compounds as Carbon (lb/mbf)
235	0.0193	0	0.0055	0.0001	0.0002	no data	no data	⇨	0.0251

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
Ethanol	0.66	46.0688	C_2H_6O	2	6	1	1
Acetic Acid	0.575	60.0524	$C_2H_4O_2$	2	4	2	1
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 Six: Subtract Speciated HAP and Non-HAP Compounds from Engelmann Spruce (White Spruce Substitution) VOC Emission Factors and Convert Result to "as Propane"

	FROM STEP TWO		FROM STEP FIVE			Propane Mass Conversion	
Maximum Dry Bulb Temperature (°F)	Method 25A VOC as Carbon (lb/mbf)	MINUS	Speciated Compounds as Carbon (lb/mbf)	EQUALS	Method 25A VOC as Carbon without Speciated Compounds (lb/mbf)		Method 25A VOC as Propane without Speciated Compounds (lb/mbf)
235	0.0915	⇨	0.0251	⇨	0.0664	X 1.2238 =	0.0812

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 Seven: Calculate WPP1 VOC by Adding Speciated HAP and Non-HAP Compounds to Engelmann Spruce (White Spruce Substitution) 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 SIX		FROM STEP THREE						FROM STEP FOUR			
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)	PLUS	Ethanol (lb/mbf)	Acetic Acid (lb/mbf)	EQUALS	WPP1 VOC (lb/mbf)
235	0.0812	⇨	0.0715	0.0033	0.0201	0.0002	0.0005	⇨	no data	no data	⇨	0.1769

Hazardous Air Pollutant Emission Factors for Drying Larch Lumber

This sheet presents the HAP EF for drying larch lumber. 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.

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 http://www.faculty.sfasu.edu/mcbroommatth/lectures/wood_science/lab_2_resin_canal_species.pdf. While the white spruce EF for formaldehyde is greater than that of douglas fir at high drying temperatures, the opposite is true at low drying temperatures. The douglas fir EF equation for formaldehyde is based upon seven tests while the white spurce EF equation is based upon two. All other HAP EF are greater for douglas fir at all drying temperatures. Under the circumstances, EPA Region 10 has decided to substitue the douglas fir formaldehyde EF equation. See the white spruce (appearing under engelmann spruce tab) and douglas fir HAP sheets for lab-scale test data and calculations.

Larch (Douglas Fir Substitution) HAP Emission Factors

Methanol (lb/mbf)	Formaldehyde (lb/mbf)	Acetaldehyde (lb/mbf)	Propionaldehyde (lb/mbf)	Acrolein (lb/mbf)
0.00114x - 0.16090	0.000028x - 0.003800	0.0275	0.0003	0.0005

Volatile Organic Compound Emission Factors for Drying Larch Lumber

This sheet presents the VOC EF for drying larch lumber. EPA Region 10 is not aware of any VOC emission testing of larch. 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.

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 http://www.faculty.sfasu.edu/mcbroommatth/lectures/wood_science/lab_2_resin_canal_species.pdf. Because the douglas fir EF is greater than that of white spruce (and EPA Region 10 is not aware of any VOC test data for engelmann spruce), the douglas fir EF has been substituted. See the douglas fir VOC sheet for lab-scale test data and calculations.

Larch (Douglas Fir Substitution) WPP1 VOC Emission Factor

WPP1 VOC (lb/mbf): 0.01460x - 1.77130 ; where x is maximum drying temperature in °F

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 in an indirect steam-heated batch kiln. The EF are calculated by averaging test results. Lodgepole pine testing was performed while drying lumber at a relatively high maximum temperature of around 237°F. Because emissions increase with maximum drying temperature, employing an EF based upon testing at 237°F would overreport emissions when drying at maximum drying temperatures less than than 237°F.

Test data generated through the use of the smaller of the two small-scale kilns at Oregon State University (OSU) has been adjusted to account for bias documented in NCASI's May 2002 Technical Bulletin No. 845 entitled, "A Comparative Study of VOC Emissions from Small-Scale and Full-Scale Lumber Kilns Drying Southern Pine." See last spreadsheet of this workbook for Stimson Lumber Company's October 18, 2019 letter to EPA Region 10 highlighting the bias.

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: Adjust Lodgepole Pine VOC Emission Test Data to Account for Bias in Underlying Small-Scale Kiln to Represent Full-Scale Kiln Emissions[1]

Maximum Dry Bulb Temperature (°F)	Methanol (lb/mbf)	Formaldehyde (lb/mbf)	Acetaldehyde (lb/mbf)	Propionaldehyde (lb/mbf)	Acrolein (lb/mbf)
236	0.057	0.0030	no data	no data	no data
237	0.056	0.0030	no data	no data	no data
238	0.051	0.0029	no data	no data	no data

Adjusted OSU emission test data value$_i$ = (OSU reported emission test data value$_i$) X (NCASI TB No. 845 study full-scale kiln value$_i$/NCASI TB No. 845 study OSU small-scale kiln value$_i$)

where: OSU reported emission test data value$_i$ is the emission rate "lb/mbf" for compound "i" documented in Step One (not highlighted in green)

NCASI study full-scale kiln value$_i$ is the average emission rate "lb/mbf" for compound "i" measured while drying southern yellow pine lumber in a full-scale indirect steam-heated batch lumber dry kiln

NCASI study OSU small-scale kiln value$_i$ is the average emission rate "lb/mbf" for compound "i" measured while drying southern yellow pine lumber in OSU's small-scale indirect steam-heated batch lumber dry kiln

The lumber dried in the OSU kiln was (a) extracted from the pool of lumber dried in the full-scale kiln and (b) dried according the schedule employed by the full-scale kiln.

NCASI TB No. 845 - Emission Rate (lb/mbf)

	Methanol	Formaldehyde	Acetaldehyde	Propionaldehyde	Acrolein
Full-Scale Kiln	0.205	0.0155	0.039	0.001	0.006
OSU Kiln	0.225	0.0210	0.065	0.003	0.009

Step Three: Calculate Lodgepole Pine HAP Emission Factors

Methanol (lb/mbf)	Formaldehyde (lb/mbf)	Acetaldehyde (lb/mbf)	Propionaldehyde (lb/mbf)	Acrolein (lb/mbf)
0.0550	0.0030	no data	no data	no data

Volatile Organic Compound Emission Factors for Drying Lodgepole Pine Lumber

This sheet presents lab-scale EPA Reference Method 25A (RM25A) and speciated VOC test data and calculations used to create VOC EF for drying lodgepole pine lumber in an indirect steam-heated batch kiln. Although three RM25A VOC tests were performed while drying lodgepole pine, they were performed while drying lumber at a relatively high maximum temperature of around 238°F. Because emissions increase with maximum drying temperature, employing an EF based upon testing at 238°F would overreport emissions when drying at maximum drying temperatures less than than 238°F.

RM25A has some limitations in that it misses some pollutant compounds (or portions thereof) 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 pollutant compounds (some HAP and some non-HAP) are accounted for through separate testing. RM25A test data is adjusted to fully account for two known pollutant compounds that are VOC using separate 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).

More specifically, one VOC emission rate is calculated based upon underlying RM25A and speciated VOC test data as indicated above. Temperature-specific methanol and formaldehyde emission rates are calculated for each temperature at which RM25A testing was performed using temperature-dependent best-fit linear equations. The temperature variable reflects the maximum temperature of the heated air entering the lumber. EPA Region 10 is not aware of any further speciated VOC test data. That portion of the (speciated) VOC compounds that are measured by the RM25A test method (based on known flame ionization detector response factors) is subtracted from the RM25A measured emission rate. The remaining “unspeciated” RM25A emission rate is adjusted to represent propane rather than carbon and then added to the speciated VOC emission rate to provide the “total” temperature-specific VOC emission rate.

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. Based upon the mass-to-carbon ratios and response factors noted above, 1 lb/mbf ethanol is reported as 0.4194 lb/mbf propane and 1 lb/mbf acetic acid is reported as 0.2806 lb/mbf propane through the use of EPA Reference Method 25A unless compound-specific sampling and analysis is performed. The contribution of ethanol and acetic acid has been quantified through sampling and analysis for douglas fir and ponderosa pine. For douglas fir, ethanol's contribution over three tests was measured to be 0, 1.4 and 5.4 percent of WPP1 VOC, and acetic acid's contribution over the same three tests was measured to be 37, 20 and 13 percent of WPP1 VOC. For ponderosa pine, ethanol's contribution over one test was measured to be 32 percent of WPP1 VOC, and acetic acid's contribution over the same test was measured to be 6.4 percent. Without reliable lodgepole pine lumber drying test data for ethanol and acetic acid, EPA assumes propane adequately represents the mix of unspeciated VOC.

Test data generated through the use of the smaller of the two small-scale kilns at Oregon State University (OSU) has been adjusted to account for bias documented in NCASI's May 2002 Technical Bulletin No. 845 entitled, "A Comparative Study of VOC Emissions from Small-Scale and Full-Scale Lumber Kilns Drying Southern Pine." See last spreadsheet of this workbook for Stimson Lumber Company's October 18, 2019 letter to EPA Region 10 highlighting the bias.

Step One: Compile Lodgepole Pine RM25A 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
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 Factor[1]

Maximum Dry Bulb Temperature (°F)	Method 25A VOC as Carbon (lb/mbf)
238	1.0767

[1] Three-run average.

Step Three: Adjust Ponderosa Pine VOC Emission Test Data to Account for Bias in Underlying Small-Scale Kiln to Represent Full-Scale Kiln Emissions[1]

Maximum Dry Bulb Temperature (°F)	Method 25A VOC as Carbon (lb/mbf)
238	0.8951

Adjusted OSU emission test data value = (OSU reported emission test data value) X (NCASI TB No. 845 study full-scale kiln value/NCASI TB No. 845 study OSU small-scale kiln value)

where: OSU reported emission test data value is the RM25A VOC as carbon emission rate "lb/mbf" documented in Step One (not highlighted in green)

NCASI study full-scale kiln value is the average RM25A VOC as carbon emission rate "lb/mbf" measured while drying southern yellow pine lumber in a full-scale indirect steam-heated batch lumber dry kiln

NCASI study OSU small-scale kiln value is the average RM25A VOC as carbon emission rate "lb/mbf" measured while drying southern yellow pine lumber in OSU's small-scale indirect steam-heated batch lumber dry kiln

The lumber dried in the OSU kiln was (a) extracted from the pool of lumber dried in the full-scale kiln and (b) dried according the schedule employed by the full-scale kiln.

	NCASI TB No. 845 - Emission Rate (lb/mbf) RM25A VOC as carbon
Full-Scale Kiln	3.53333
OSU Kiln	4.25000

Step Four: Compile Lodgepole Pine Speciated HAP Emission Factors at Maximum Drying Temperatures Observed during RM25A VOC Testing[1]

Maximum Dry Bulb Temperature (°F)	Methanol (lb/mbf)	Formaldehyde (lb/mbf)	Acetaldehyde (lb/mbf)	Propionaldehyde (lb/mbf)	Acrolein (lb/mbf)
238	0.0550	0.0030	no data	no data	no data

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

Step Five: Compile Lodgepole Pine Speciated Non-HAP Emission Factors at Maximum Drying Temperatures Observed during RM25A VOC Testing

Maximum Dry Bulb Temperature (°F)	Ethanol (lb/mbf)	Acetic Acid (lb/mbf)
238	no data	no data

Step Six: 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	Methanol as Carbon	Formaldehyde as Carbon	Acetaldehyde as Carbon	Propionaldehyde as Carbon	Acrolein as Carbon	Ethanol as Carbon	Acetic Acid as Carbon		Speciated Compounds as Carbon

(°F)	(lb/mbf)	(lb/mbf)	(lb/mbf)	(lb/mbf)	(lb/mbf)	(lb/mbf)	(lb/mbf)	SUM	(lb/mbf)
238	0.0148	0	no data	no data	no data	no data	no data	⟹	0.0148

Element and Compound Information

Element / Compound	FID RF[1]	Molecular Weight (lb/lb-mol)	Formula	Number of Carbon Atoms	Number of Hydrogen Atoms	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
Ethanol	0.66	46.0688	C_2H_6O	2	6	1	1
Acetic Acid	0.575	60.0524	$C_2H_4O_2$	2	4	2	1
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 Seven: Subtract Speciated HAP and Non-HAP Compounds from Lodgepole Pine VOC Emission Factors and Convert Result to "as Propane"

	FROM STEP THREE		FROM STEP SIX			Propane Mass Conversion Factor	
Maximum Dry Bulb Temperature (°F)	Method 25A VOC as Carbon (lb/mbf)	MINUS	Speciated Compounds as Carbon (lb/mbf)	EQUALS	Method 25A VOC as Carbon without Speciated Compounds (lb/mbf)	X 1.2238 =	Method 25A VOC as Propane without Speciated Compounds (lb/mbf)
238	0.8951	⟹	0.0148	⟹	0.8803		1.0773

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

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, $(1/RF_{C3H8}) \times [(MW_{C3H8}) / (MW_C)] \times [(\#C_C) / (\#C_{C3H8})]$, equals 1.2238 and can be referred to as the "propane mass conversion factor."

Step Eight: Calculate WPP1 VOC by Adding Speciated HAP and Non-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 SEVEN		FROM STEP FOUR						FROM STEP FIVE			
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)	PLUS	Ethanol (lb/mbf)	Acetic Acid (lb/mbf)	EQUALS	WPP1 VOC (lb/mbf)
238	1.0773	⟹	0.0550	0.0030	no data	no data	no data	⟹	no data	no data	⟹	1.1352

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 in an indirect steam-heated batch kiln. The methanol and formaldehyde EF are temperature dependent best-fit linear equations. The temperature variable reflects the maximum temperature of the heated air entering the lumber. The acetaldehyde, propionaldehyde and acrolein EF are calculated by averaging test results.

Test data generated through the use of the smaller of the two small-scale kilns at Oregon State University (OSU) has been adjusted to account for bias documented in NCASI's May 2002 Technical Bulletin No. 845 entitled, "A Comparative Study of VOC Emissions from Small-Scale and Full-Scale Lumber Kilns Drying Southern Pine." See last spreadsheet of this workbook for Stimson Lumber Company's October 18, 2019 letter to EPA Region 10 highlighting the bias.

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

Maximum Dry Bulb Temperature (°F)	Methanol (lb/mbf)	Formaldehyde (lb/mbf)	Acetaldehyde (lb/mbf)	Propionaldehyde (lb/mbf)	Acrolein (lb/mbf)	Lumber Dimensions	Moisture Content[1] (%) (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		
180	0.058	0.005	0.100	0.0035	0.0055	2x4	103.9 / 15	39.4	NCASI Method 105	Link to March 7, 2013 Hampton Affiliates - Randle Test Report
235	0.144	0.0092	0.028	0.0032	0.0045	2x4 or 2x6	89.1 / 15	19	NCASI Method 105	18, 21

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

Step Two: Adjust Ponderosa Pine HAP Emission Test Data to Account for Bias in Underlying Small-Scale Kiln to Represent Full-Scale Kiln Emissions

Maximum Dry Bulb Temperature (°F)	Methanol (lb/mbf)	Formaldehyde (lb/mbf)	Acetaldehyde (lb/mbf)	Propionaldehyde (lb/mbf)	Acrolein (lb/mbf)
170	0.032	0.0020	0.025	0.0006	0.0011
176	0.046	0.0016	no data	no data	no data
176	0.073	0.0027	no data	no data	no data
180	0.053	0.0037	0.060	0.0012	0.0037
235	0.131	0.0068	0.017	0.0011	0.0030

Adjusted OSU emission test data value$_i$ = (OSU reported emission test data value$_i$) X (NCASI TB No. 845 study full-scale kiln value$_i$/NCASI TB No. 845 study OSU small-scale kiln value$_i$)

where: OSU reported emission test data value$_i$ is the emission rate "lb/mbf" for compound "i" documented in Step One (not highlighted in green)

NCASI study full-scale kiln value$_i$ is the average emission rate "lb/mbf" for compound "i" measured while drying southern yellow pine lumber in a full-scale indirect steam-heated batch lumber dry kiln

NCASI study OSU small-scale kiln value$_i$ is the average emission rate "lb/mbf" for compound "i" measured while drying southern yellow pine lumber in OSU's small-scale indirect steam-heated batch lumber dry kiln

The lumber dried in the OSU kiln was (a) extracted from the pool of lumber dried in the full-scale kiln and (b) dried according the schedule employed by the full-scale kiln.

NCASI TB No. 845 - Emission Rate (lb/mbf)

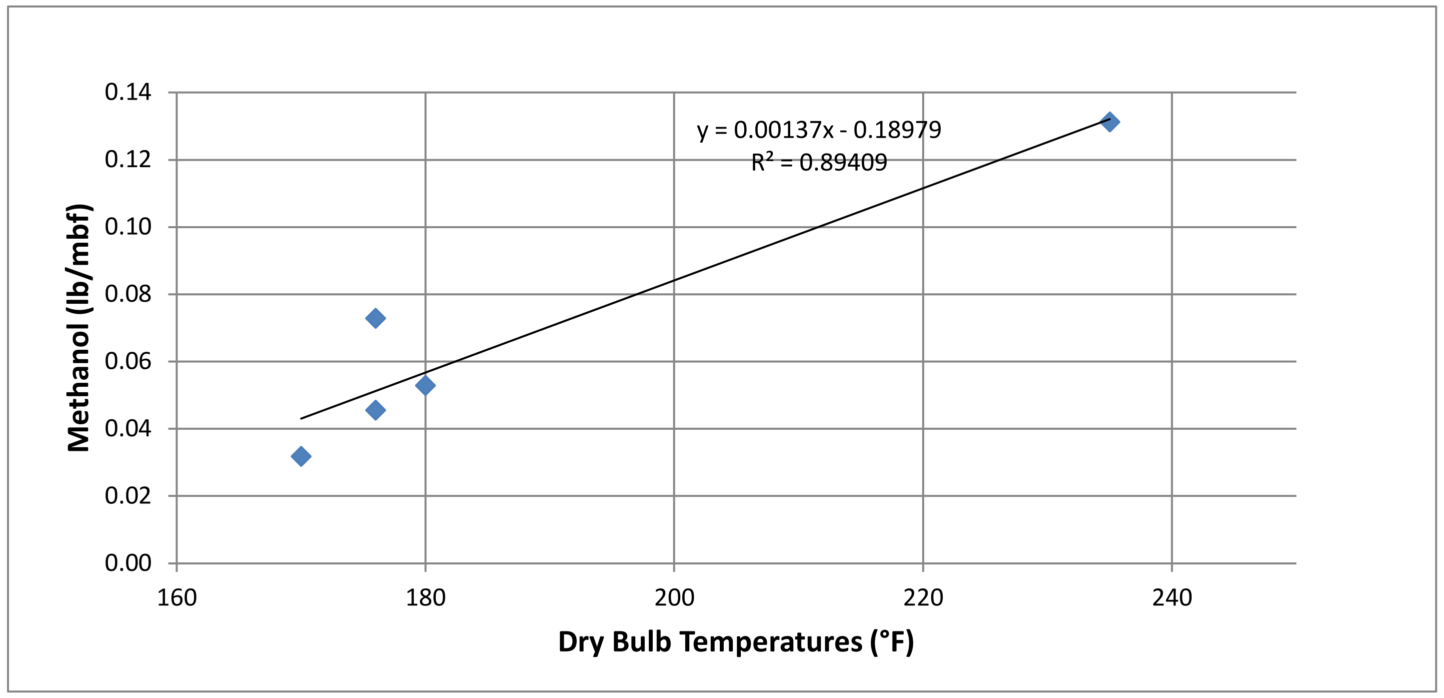
	Methanol	Formaldehyde	Acetaldehyde	Propionaldehyde	Acrolein
Full-Scale Kiln	0.205	0.0155	0.039	0.001	0.006
OSU Kiln	0.225	0.0210	0.065	0.003	0.009

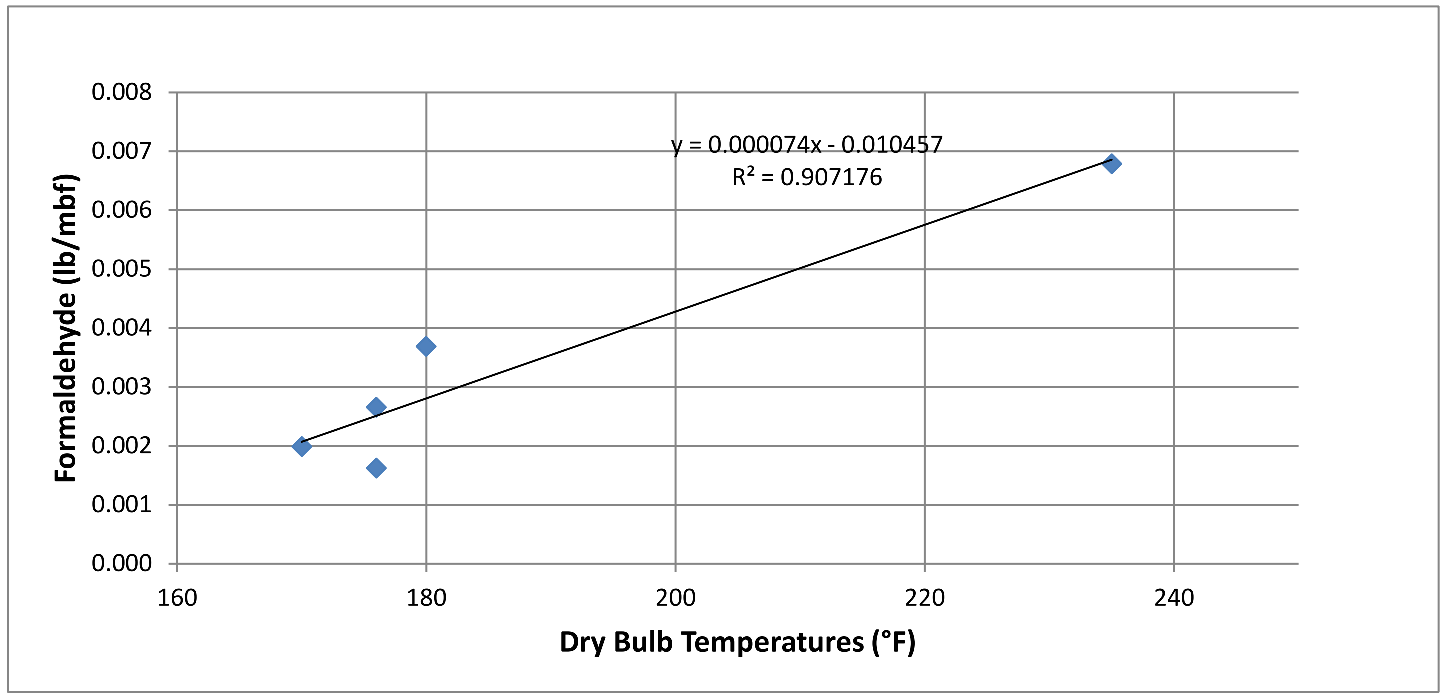
Step Three: Calculate Ponderosa Pine HAP Emission Factors

Methanol[1] (lb/mbf)	Formaldehyde[1] (lb/mbf)	Acetaldehyde[2] (lb/mbf)	Propionaldehyde[2] (lb/mbf)	Acrolein[2] (lb/mbf)
0.00137x - 0.18979	0.000074x - 0.010457	0.0340	0.0010	0.0026

[1] Best-fit linear equations with dependent variable maximum drying temperature entering the lumber

[2] Because acetaldehyde, propionaldehyde and acrolein emissions across different species are not consistently dependent upon maximum drying temperature, EF are calculated by averaging test results.


y = 0.00137x - 0.18979
R² = 0.89409
Methanol (lb/mbf)
Dry Bulb Temperatures (°F)


y = 0.000074x - 0.010457
R² = 0.907176
Formaldehyde (lb/mbf)
Dry Bulb Temperatures (°F)

Volatile Organic Compound Emission Factors for Drying Ponderosa Pine Lumber

This sheet presents lab-scale EPA Reference Method 25A (RM25A) and speciated VOC test data and calculations used to create VOC EF for drying ponderosa pine lumber in an indirect steam-heated batch kiln. RM25A has some limitations in that it misses some pollutant compounds (or portions thereof) 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 pollutant compounds (some HAP and some non-HAP) are accounted for through separate testing. RM25A test data is adjusted to fully account for seven known pollutant compounds that are VOC using separate 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 RM25A results are adjusted to account for not only methanol and formaldehyde but also for acetaldehyde, propionaldehyde, acrolein, ethanol and acetic acid in this case.

More specifically, ten separate drying-temperature-specific VOC emission rates (upon which a best-fit linear equation will be established) are calculated based upon underlying RM25A and speciated VOC test data as indicated above. Temperature-specific methanol and formaldehyde emission rates are calculated for each temperature at which RM25A testing was performed using temperature-dependent best-fit linear equations. The temperature variable reflects the maximum temperature of the heated air entering the lumber. The temperature-independent acetaldehyde, propionaldehyde and acrolein emission rates reflect the average of all test results independent of the temperature of heated air entering the lumber. The ethanol and acetic acid emission rates reflect the results of a single test. EPA Region 10 is not aware of any further speciated VOC test data. That portion of the (speciated) VOC compounds that are measured by the RM25A test method (based on known flame ionization detector response factors) is subtracted from the RM25A measured emission rate. The remaining "unspeciated" RM25A emission rate is adjusted to represent propane rather than carbon and then added to the speciated VOC emission rate to provide the "total" temperature-specific VOC emission rate. The resultant VOC EF is a 10-point best-fit linear equation with dependent variable "x" equal to the maximum drying temperature of heated air entering the lumber.

Test data generated through the use of the smaller of the two small-scale kilns at Oregon State University (OSU) has been adjusted to account for bias documented in NCASI's May 2002 Technical Bulletin No. 845 entitled, "A Comparative Study of VOC Emissions from Small-Scale and Full-Scale Lumber Kilns Drying Southern Pine." See last spreadsheet of this workbook for Stimson Lumber Company's October 18, 2019 letter to EPA Region 10 highlighting the bias.

Step One: Compile Ponderosa Pine RM25A 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
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		
180	1.48	2x4	103.9 / 15	39.4	JUM VE-7	Link to March 7, 2013 Hampton Affiliates - Randle Test Report
180	1.72	2x4	122.0 / 15	43.6		
235	3.00	2x4 or 2x6	89.1 / 15	19	JUM VE-7	18, 21

[1] Green highlight denotes data generated by testing conducted on the small-scale kiln at the University of Idaho. All other data was generated by testing conducted on the smaller of the two small-scale kilns at OSU.

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

Step Two: Adjust Ponderosa Pine VOC Emission Test Data to Account for Bias in Underlying Small-Scale Kiln to Represent Full-Scale Kiln Emissions

Maximum Dry Bulb Temperature (°F)	Method 25A VOC as Carbon (lb/mbf)
170	1.32
170	1.795
170	1.925
176	1.07
176	1.28
176	1.16
176	1.08
180	1.23
180	1.43
235	2.49

[1] Green highlighted results from the test conducted at the University of Idaho have not been adjusted because the kiln was not calibrated to a full-scale kiln.

Adjusted OSU emission test data value = (OSU reported emission test data value) X (NCASI TB No. 845 study full-scale kiln value/NCASI TB No. 845 study OSU small-scale kiln value)

where: OSU reported emission test data value is the RM25A VOC as carbon emission rate "lb/mbf" documented in Step One (not highlighted in green)

NCASI study full-scale kiln value is the average RM25A VOC as carbon emission rate "lb/mbf" measured while drying southern yellow pine lumber in a full-scale indirect steam-heated batch lumber dry kiln

NCASI study OSU small-scale kiln value is the average RM25A VOC as carbon emission rate "lb/mbf" measured while drying southern yellow pine lumber in OSU's small-scale indirect steam-heated batch lumber dry kiln

The lumber dried in the OSU kiln was (a) extracted from the pool of lumber dried in the full-scale kiln and (b) dried according the schedule employed by the full-scale kiln.

	NCASI TB No. 845 - Emission Rate (lb/mbf) RM25A VOC as carbon
Full-Scale Kiln	3.53333
OSU Kiln	4.25000

Step Three: Calculate/Compile Ponderosa Pine Speciated HAP Emission Factors at Maximum Drying Temperatures Observed during RM25A VOC Testing[1]

Maximum Dry Bulb Temperature (°F)	Methanol[2] (lb/mbf)	Formaldehyde[3] (lb/mbf)	Acetaldehyde (lb/mbf)	Propionaldehyde (lb/mbf)	Acrolein (lb/mbf)
170	0.0431	0.0021	0.0340	0.0010	0.0026
176	0.0513	0.0026			
180	0.0568	0.0029			
235	0.1322	0.0069			

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

[2] Methanol EF = 0.00137x - 0.18979; where dependent variable "x" equal to the maximum drying temperature of heated air entering the lumber.

[3] Formaldehyde EF = 0.000074x - 0.010457; where dependent variable "x" equal to the maximum drying temperature of heated air entering the lumber.

Step Four: Compile Ponderosa Pine Speciated Non-HAP Emission Test Data by Drying Temperature

Maximum Dry Bulb Temperature (°F)	Ethanol (lb/mbf)	Acetic Acid (lb/mbf)	Lumber Dimensions	Moisture Content[1] (%) (Initial / Final)	Time to Final Moisture Content (hours)	VOC Sample Collection Technique	Reference
180	0.826	0.162	2x4	103.9 / 15	39.4	NCASI Method 105	Link to March 7, 2013 Hampton Affiliates - Randle Test Report

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

Step Five: Calculate Ponderosa Pine Speciated Non-HAP Emission Factors

Ethanol (lb/mbf)	Acetic Acid (lb/mbf)
0.826	0.162

Step Six: Calculate/Compile Ponderosa Pine Speciated Non-HAP Emission Factors at Maximum Drying Temperatures Observed during RM25A Testing

Maximum Dry Bulb Temperature (°F)	Ethanol (lb/mbf)	Acetic Acid (lb/mbf)
170	0.826	0.162
176		
180		
235		

Step Seven: Convert Ponderosa Pine Speciated HAP and Non-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)	Ethanol as Carbon (lb/mbf)	Acetic Acid as Carbon (lb/mbf)	SUM ⇨	Speciated Compounds as Carbon (lb/mbf)
170	0.0116	0	0.0093	0.0004	0.0011	0.2843	0.0373		0.3461
176	0.0139	0							0.3487
180	0.0153	0							0.3505
235	0.0357	0							0.3749

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
Ethanol	0.66	46.0688	C_2H_6O	2	6	1	1
Acetic Acid	0.575	60.0524	$C_2H_4O_2$	2	4	2	1
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 Eight: Subtract Speciated HAP and Non-HAP Compounds from Ponderosa Pine VOC Emission Factors and Convert Result to "as Propane"

Maximum Dry Bulb Temperature (°F)	FROM STEP TWO Method 25A VOC as Carbon (lb/mbf)	MINUS	FROM STEP SEVEN Speciated Compounds as Carbon (lb/mbf)	EQUALS	Method 25A VOC as Carbon without Speciated Compounds (lb/mbf)	X 1.2238 = (Propane Mass Conversion Factor)	Method 25A VOC as Propane without Speciated Compounds (lb/mbf)
170	1.3219		0.3461		0.9758		1.1942
170	1.7950		0.3461		1.4489		1.7732
170	1.9250		0.3461		1.5789		1.9323
176	1.0725		0.3487		0.7238		0.8857
176	1.2803		0.3487		0.9316		1.1401
176	1.1639		0.3487		0.8152		0.9976
176	1.0808		0.3487		0.7321		0.8959
180	1.2304		0.3505		0.8799		1.0769
180	1.4300		0.3505		1.0795		1.3210
235	2.4941		0.3749		2.1192		2.5934

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

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, $(1/RF_{C3H8}) \times [(MW_{C3H8}) / (MW_C)] \times [(\#C_C) / (\#C_{C3H8})]$, equals 1.2238 and can be referred to as the "propane mass conversion factor."

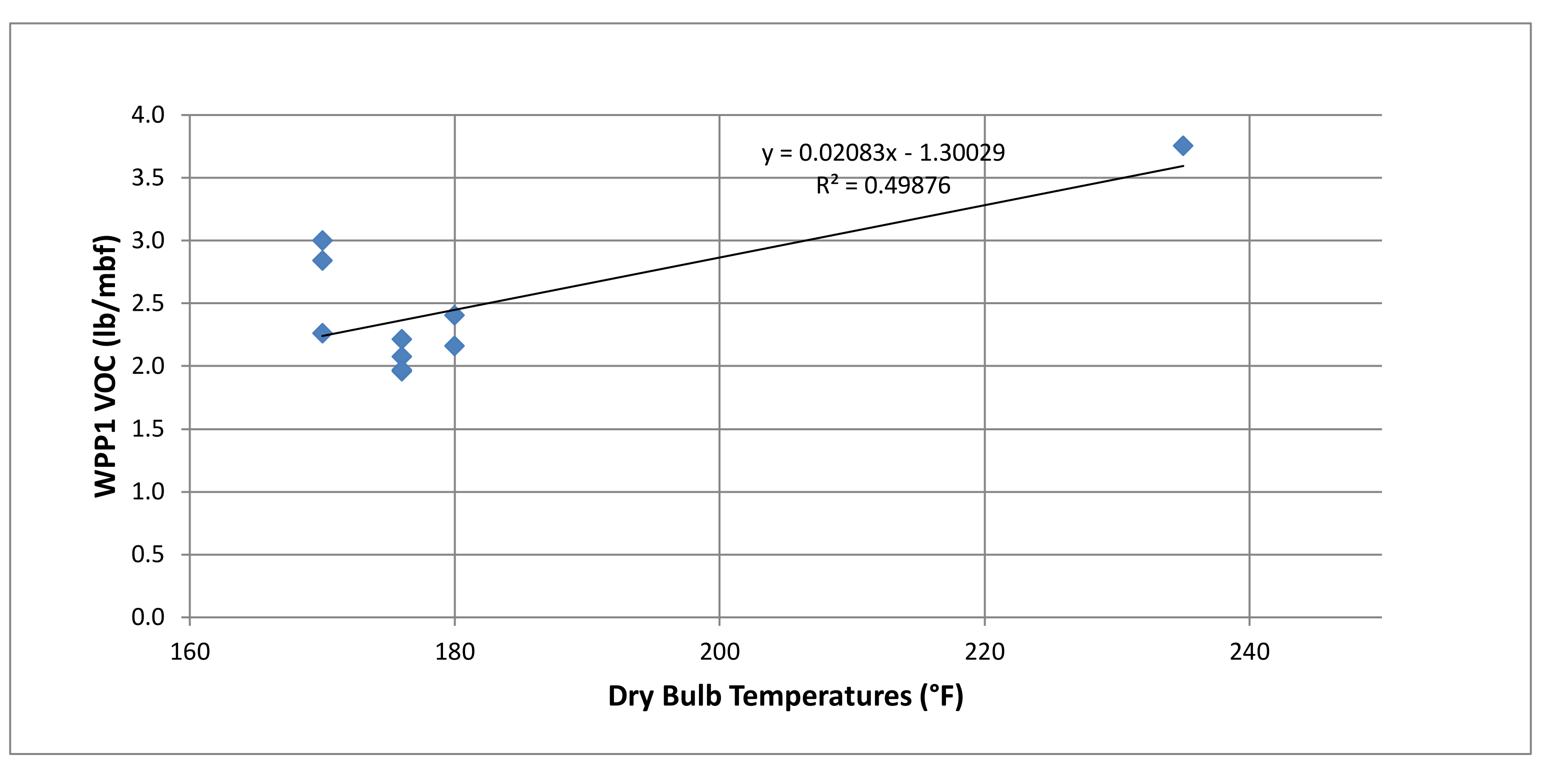
Step Nine: Calculate WPP1 VOC by Adding Speciated HAP and Non-HAP Compounds to Ponderosa Pine VOC Emission Factors "as Propane"

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

Maximum Dry Bulb Temperature (°F)	FROM STEP EIGHT Method 25A VOC as Propane without Speciated Compounds (lb/mbf)	PLUS	FROM STEP THREE Methanol (lb/mbf)	Formaldehyde (lb/mbf)	Acetaldehyde (lb/mbf)	Propionaldehyde (lb/mbf)	Acrolein (lb/mbf)	PLUS	FROM STEP SIX Ethanol (lb/mbf)	Acetic Acid (lb/mbf)	EQUALS	WPP1 VOC (lb/mbf)
170	1.1942		0.0431	0.0021	0.0340	0.0010	0.0026		0.826	0.162		2.2650
170	1.7732		0.0431	0.0021								2.8440
170	1.9323		0.0431	0.0021								3.0031
176	0.8857		0.0513	0.0026								1.9652
176	1.1401		0.0513	0.0026								2.2195
176	0.9976		0.0513	0.0026								2.0771
176	0.8959		0.0513	0.0026								1.9753
180	1.0769		0.0568	0.0029								2.1621
180	1.3210		0.0568	0.0029								2.4063
235	2.5934		0.1322	0.0069								3.7581

Step Ten: Generate Ponderosa Pine Best-Fit Linear Equation with Dependent Variable Maximum Drying Temperature to Model WPP1 VOC Emissions

WPP1 VOC (lb/mbf): 0.02083x - 1.30029 ; where dependent variable "x" equal to the maximum drying temperature of heated air entering the lumber



Hazardous Air Pollutant Emission Factors for Drying Western White Pine Lumber

This sheet presents the HAP EF for drying western white pine lumber. EPA Region 10 is not aware of any HAP emission testing of western white pine. 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.

Given the limited western white pine test data, ponderosa pine test data has been substituted. 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. EPA Region 10 is aware of three Lodgepole Pine test runs for methanol and formaldehyde and none for acetaldehyde, propionaldehyde and acrolein. Five ponderosa pine test runs were conducted for methanol and formaldehyde and three for acetaldehyde, propionaldehyde and acrolein. While the lodgepole pine runs were conducted at about the same maximum drying temperature, the ponderosa pine runs were distributed across a wide maximum drying temperature range. Based upon the available test data, ponderosa pine is higher-emitting than lodgepole pine for methanol and formaldehyde. See the ponderosa pine and lodgepole pine HAP sheets for lab-scale test data and calculations.

Western White Pine (Ponderosa Pine Substitution) HAP Emission Factors

Methanol (lb/mbf)	Formaldehyde (lb/mbf)	Acetaldehyde (lb/mbf)	Propionaldehyde (lb/mbf)	Acrolein (lb/mbf)
0.00137x - 0.18979	0.000074x - 0.010457	0.0340	0.0010	0.0026

Volatile Organic Compound Emission Factors for Drying Western White Pine Lumber

This sheet presents the VOC EF for drying western white pine lumber. EPA Region 10 is aware of one test being conducted while drying western white pine lumber, and it was conducted at 170°F. Because VOC emissions increase with maximum drying temperature, employing an EF based upon testing at 170°F would underreport emissions when drying at maximum drying temperatures greater than 170°F. A temperature of 170°F is not a particularly high drying temperature. When little or no actual test data is 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.

Given the limited western white pine test data, ponderosa pine test data has been substituted. 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. EPA Region 10 is aware of three lodgepole pine test runs and eight ponderosa pine test runs. While the lodgepole pine runs were conducted at about the same maximum drying temperature, the ponderosa pine runs were distributed across a wide maximum drying temperature range. Based upon the available test data, ponderosa pine is higher-emitting than lodgepole pine. See the ponderosa pine and lodgepole pine HAP and VOC sheets for lab-scale test data and calculations.

Western White Pine (Ponderosa Pine Substitution) WPP1 VOC Emission Factor

WPP1 VOC (lb/mbf): 0.02083x - 1.30029 ; where dependent variable "x" equal to the maximum drying temperature of heated air entering the lumb

Index to References Appearing in
EPA Region 10 HAP and VOC Emission Factors for Lumber Drying, June 2018

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^{9}g) 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^{9}g) 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^{9}g) 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.

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Environmental Affairs
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18 October 2019

Mr. Doug Hardesty
U.S. EPA
1435 N Orchard
Boise, Idaho 83706

RE: Proposed Kiln Emissions Factors for Stimson, Plummer Title V Renewal

Dear Mr. Hardesty:

Stimson wishes to thank EPA for the time and effort that has gone into the technical analysis needed for renewal of the Plummer facility's Title V permit. We are appreciative of the opportunity to review the proposed emissions factors for the permit analysis.

We have looked over the proposed kiln emission factors, as well as the work done by the Washington Southwest Clean Air Agency (SWCAA) and have the following comments. In general, we agree that the approach is an improvement over previous efforts and, in particularly, the use of a regression equation for the formaldehyde and methanol emissions is superior to having a single cut point.

The issue of concern is the reliance upon small lab-scale kilns to derive the emissions factors. For a number of reasons, these kilns are not representative of operations at full-scale production kilns. Based upon work that we present below, this seems to be particularly true of the OSU kiln used by Dr. Milota, which serves as the primary source of HAP emission factors for western species. The unfortunate fact is that there is very little data comparing the emissions from a small lab kiln to those of a production kiln - in fact, we are only aware of NCASI Technical Bulletin 845 from 2002. However, based upon that study, we find the following differential in measured emissions:

From NCASI Technical Bulletin 845:

Pollutant	FSK	OSU	OSU:FSK
VOC	3.5	4.3	1.23
Formaldehyde	0.016	0.021	1.31
Methanol	0.21	0.23	1.10
Acetaldehyde	0.039	0.065	1.67
Acrolein	0.006	0.009	1.50
Proprionaldehyde	0.001	0.003	3.00

FSK = Full Scale Kiln
OSU = Oregon State University lab scale kiln

We note that the OSU kiln yields a consistently higher bias in the emissions – by an average of 64%. Neither the Mississippi State nor the Horizon Engineering kilns demonstrated this consistent high bias so we do not believe it is simply a matter of the difficulty in fully characterizing the production kiln. In the technical bulletin NCASI staff come to the conclusion that "…VOC emissions measured at a small-scale kiln can reasonably approximate those from a full-scale kiln…" However, this conclusion is based upon the full sample set from multiple small scale kilns. Indeed, if we include the Phase II MSU kiln results in the analysis the average results are much closer. Unfortunately, virtually all of the western species data is from the OSU kiln, so there is a high bias. What significant differences in the operation of the OSU kiln can account for this consistently higher bias?

Unidirectional flow: Unlike full scale production kilns, the OSU kiln features unidirectional airflow. Production kilns have reversible fans that allow bidirectional air flow. The OSU design results in uneven drying that would be unacceptable in a commercial environment.

Hotter wood: The smaller charge size in the OSU kiln results in less volume of wood to absorb the thermal energy of the surrounding air. This is further compounded by the shorter linear distance the air has to travel over in the lab kiln. The result is anticipated to be hotter wood than equivalent kiln temperatures would yield in a full scale production kiln. Thus, we would expect the dry bulb temperature to be less indicative of the actual wood temperature in a full scale kiln than in the lab kilns. This is borne out by the faster drying time in the OSU kiln.

Increased airflow: Table 8.3 of NCASI Technical Bulletin 845 illustrates the dramatically enhanced airflow through the lab kiln relative to a full scale production kiln:

Table 8.3. Phase II Total Volume of Kiln Exhaust Gas per MBF

Test Charge	FSK	MSU	OSU
	wacf x 10^4 per MBF		
	Direct Fired Drying Schedule		
DF1	18.80	8.36	9.49
DF2	18.10	8.72	9.04
DF3	17.30	8.74	9.11
DF4	18.10	7.67	6.61
DF5	17.50	7.73	9.75
DF6	17.00	8.90	9.85
Average	17.80	8.35	8.97
	Steam-Heated Drying Schedule		
INDF1	2.69	8.62	8.99
INDF2	3.98	9.96	7.32
INDF3	3.75	9.95	8.50
INDF5	3.44	10.90	7.25
INDF6	3.38	6.68	7.56
INDF7	3.71	7.29	8.48
Average	3.49	8.90	8.07

Note that for steam heated kilns the airflow of the OSU kiln averages over 200% greater on a per unit of lumber basis. This is likely to increase emissions by enhancing pollutant removal.

Of course, the best case scenario would be to have comprehensive production kiln test results, but this would be very expensive and difficult to acquire. And, in any event, it is not currently available. Thus, the straight-forward approach to adapting the lab kiln results is to simply adjust the lab emissions by a correction factor. Absent additional data, the NCASI Technical Bulletin is what we have available to do this. Applying such a correction factor yields the factors attached.

Thus, Stimson proposes revised emission factors for the facility. We note, however, that this accepts that temperature is a valid parameter for correlation with emissions. At this time, Stimson has not looked closely at whether moisture contents might be a useful in this regard. Less data is likely to be available for a moisture approach and it would likely suffer the same issues with scaling of lab kiln results. Further, we have largely accepted EPA's sample selection and analysis due to time constraints. Stimson may look at this in more detail as discussions continue.

We will be providing an analysis of boiler emission factors shortly.

Sincerely,

STEVEN PETRIN
Environmental Manager

NCASI Technical Bulletin No. 845

Pollutant	Emission Rate (lb/mbf)*		# of Runs	Run ID	Location of Data within Technical Bulletin
	Full Scale Kiln	Oregon State Universtity Kiln			
VOC as carbon	3.533333	4.25	6	1 – 3 & 5 – 7	Table 8.2
Formaldehyde	0.0155	0.021	2	1 & 3	Table 9.5**
Methanol	0.205	0.225	2	1 & 3	Table 9.6**
Acetaldehyde	0.039	0.065	1	3	Appendix BB1
Acrolein	0.006	0.009	1	3	
Propionaldehyde	0.001	0.003	1	3	

* Value reflects arithmetic mean in those instances when more than one run was performed

** Run 3 data also in Appendix BB1