UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION 10
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OFFICE OF
AIR, WASTE, AND TOXICS

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MEMORANDUM

SUBJECT: Non-HAP Potential to Emit Emission Factors for Biomass Boilers Located in Pacific Northwest Indian Country

FROM: Dan Meyer, Environmental Engineer
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TO: Permit File

EPA Region 10 has compiled the attached list of non-hazardous air pollutant ("non-HAP") emission factors ("EFs") for use in determining the potential emissions, more commonly referred to as potential to emit ("PTE"), for biomass boilers located in Pacific Northwest Indian Country. The EFs are presented in units of pounds of pollutant per million British thermal units heat input or "lb/MMBtu." PTE generally represents the maximum capacity of a source to emit a pollutant under its physical and operational design taking into consideration restrictions that are federally enforceable. Non-HAP PTE is used to determine applicability of the Title V operating permit program and the Prevention of Significant Deterioration construction permit program.

For each of the 11 pollutants addressed in the attachment, a list of EFs is presented from which one will ultimately be selecting on a case-by-case basis to determine PTE for a particular boiler. From the list, it is generally the one that is (a) derived from an underlying applicable enforceable limit, and (b) the least numerical value among the group that is selected. The Federal Air Rules for Reservations ("FARR"), the New Source Performance Standards ("NSPS") and the National Emission Standards for Hazardous Air Pollutants ("NESHAP")[1] are all federal regulations that restrict certain non-HAP emissions from biomass boilers. For each pollutant-specific limit, a corresponding EF has been derived. Similarly, greenhouse gas EFs have been derived from those appearing in the Mandatory Greenhouse Gas Reporting Rule. In addition to these regulatory-derived EFs, the attachment presents EFs appearing in Section 1.6 of EPA's AP-42 (September 2003); a compilation of average emission factors.[2] In general, it is appropriate to employ an AP-42 EF to determine PTE for a particular pollutant only when (a) no federal regulation or permit is limiting, and (b) a more representative emission factor is not available.

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[1] Biomass boiler emissions of particulate matter may consist partially of trace metal HAPs, and those particulate matter emissions are limited in both the major and area source boiler NESHAPs. The major source boiler NESHAP also limits carbon monoxide as a surrogate for organic HAP.

[2] "Average" in this context means arithmetic average for a set of values upon which the EF is based. It is not meant to be descriptive of the relative quality of the EF.

EPA Region 10 Non-HAP Potential to Emit Emission Factors for Biomass Boilers Located in Pacific Northwest Indian Country, May 2014

Criteria Pollutant	EF Reference
Carbon Monoxide (CO)	1
Lead (Pb)	2
Nitrogen Oxides (NO_X)	3
Particulate (PM)	4
Respirable Particulate (PM_{10})	5
Fine Particulate ($PM_{2.5}$)	6
Sulfur Dioxide (SO_2)	7
Volatile Organic Compounds (VOC)	8

Greenhouse Gas Pollutant	EF Reference
Carbon Dioxide (CO_2)[1]	9
Methane (CH_4)	10
Nitrous Oxide (N_2O)	11

[1] The DC Circuit Court of Appeals on July 12, 2013 vacated EPA regulations that delayed until July 21, 2014 consideration of CO_2 emissions resulting from biomass combustion in determining PSD and Title V applicability pursuant to 40 CFR 52.21(b)(49)(ii)(a) and 40 CFR 71.2 definition of "subject to regulation." See explanation for exemption provided by EPA at 76 FR 43490. See DC Circuit Court of Appeals July 12, 2013 ruling vacating the exemption at http://www.cadc.uscourts.gov/internet/opinions.nsf/F523FF1F29C06ECA85257BA6005397B5/$file/11-1101-1446222.pdf

EF Reference	Description
1	(see below)

Option 1: 0.6 lb/MMBtu

Basis: AP-42, September 2003. Table 1.6-2.

Option 2: 0.243 - 2.281 lb/MMBtu (EPA Reference Method 10, 10A or 10B)

Basis: Major Source Boiler MACT ("NESHAP DDDDD")

In order to create an EF in units of "lb/MMBtu heat input" based upon NESHAP DDDDD CO emission limits expressed in units of "ppm @3%O_2," the following equation must be employed:

EF (lb/MMBtu) = NESHAP DDDDD CO Limit (ppmvd@3%O_2) X $CF_{3\rightarrow 0\%O2}$ X $CF_{ppm\rightarrow lb/dscfCO}$ X F_d (dscf/MMBtu)

• NESHAP DDDDD specifies a range of different CO emission limits based upon (a) the date the boiler commenced construction or reconstruction, (b) the design of the boiler and (c) type of fuel combusted. For the purpose of this PTE EF exercise, only the emission limits in units of "ppm" will be employed here. The alternative "lb/MMBtu steam output" or "lb/MWh electric generation output" emission limits could be employed if the efficiency of the boiler is known.

Maximum Design Heat Input Capacity, X (MMBtu/hr)	Date Construction or Reconstruction Commenced, Y	Boiler Design	NESHAP DDDDD CO Emission Limit (ppmvd@3%O_2)	Regulatory Citation 40 CFR 63.7500(a)(1) and NESHAP DDDDD…
10 ≤ X	Y ≤ 06/04/10	Stokers/sloped grate/others designed to burn wet biomass fuel	1,500 (3-run avg) 720 (30-day rolling avg)	Table 2, Row 7
		Stokers/sloped grate/others designed to burn kiln-dried biomass fuel	460 (3-run avg)	Table 2, Row 8
		Fluidized bed units designed to burn biomass/bio-based solid	470 (3-run avg) 310 (30-day rolling avg)	Table 2, Row 9
		Suspension burners designed to burn biomass/bio-based solid	2,400 (3-run avg) 2,000 (10-day rolling avg)	Table 2, Row 10
		Dutch ovens/pile burners designed to burn biomass/bio-based solid	770 (3-run avg) 520 (10-day rolling avg)	Table 2, Row 11
		Fuel cell units designed to burn biomass/bio-based solid	1,100 (3-run avg)	Table 2, Row 12
		Hybrid suspension grate boiler designed to burn biomass/bio-based solid	2,800 (3-run avg) 900 (30-day rolling avg)	Table 2, Row 13
	06/04/10 < Y	Stokers/sloped grate/others designed to burn wet biomass fuel	620 (3-run avg) 390 (30-day rolling avg)	Table 1, Row 7
		Stokers/sloped grate/others designed to burn kiln-dried biomass fuel	460 (3-run avg)	Table 1, Row 8
		Fluidized bed units designed to burn biomass/bio-based solid	230 (3-run avg) 310 (30-day rolling avg)	Table 1, Row 9
		Suspension burners designed to burn biomass/bio-based solid	2,400 (3-run avg) 2,000 (10-day rolling avg)	Table 1, Row 10
		Dutch ovens/pile burners designed to burn biomass/bio-based solid	330 (3-run avg) 520 (10-day rolling avg)	Table 1, Row 11
		Fuel cell units designed to burn biomass/bio-based solid	910 (3-run avg)	Table 1, Row 12
		Hybrid suspension grate boiler designed to burn biomass/bio-based solid	1,100 (3-run avg) 900 (30-day rolling avg)	Table 1, Row 13

• $CF_{3\rightarrow 0\%O2}$ (unitless) = (20.9 - X_{O2Fd}) / (20.9 - $X_{O2NESHAP5D}$). To create a conversion factor that adjusts the basis of the NESHAP DDDDD CO emission limit from 3% O_2 to 0% O_2 (the basis for F_d), X_{O2Fd} = 0 and $X_{O2NESHAP5D}$ = 3. The value 20.9 is the percent by volume of the ambient air that is O_2. Decreasing the O_2 from the NESHAP DDDDD CO baseline increases the pollutant concentration. See Equation 19-1 of EPA Method 19 at Appendix A-7 to 40 CFR Part 60.

• $CF_{ppm\rightarrow lb/dscfCO}$ (lb CO/dscf / ppm CO) = [CO Concentration (ppm)] X [$CF_{ppm\rightarrow unitless}$ (1/ppm)] X [MW CO (g/mol)] X [Ideal Gas Constant @ EPA Standard Conditions (L/mol)]$^{-1}$ X [$CF_{L\rightarrow ft3}$ (L/ft^3)] X [$CF_{g\rightarrow lb}$ (g/lb)]$^{-1}$. This factor converts CO concentration from units "ppm" to "lb/dscf." To create the conversion factor, start by assuming CO concentration of 1 ppm and dividing by 1,000,000 to create a volumetric ratio of CO to exhaust gas. The molecular weight of CO is 28.010 g/mol. EPA standard conditions for reference method testing are a temperature of 20°C and a pressure of 1 atm. See Footnote 1 of Table 19-2 of EPA Method 19. The ideal gas constant is 0.08205746 L-atm/°K-mol. At EPA standard conditions, the value for ideal gas constant becomes 24.05514 L/mol through the following calculation: (0.08205746 L-atm/°K-mol) X (1 atm)$^{-1}$ X (293.15°K). Note that °K = [°C] + 273.15. There are around 28.32 liters (L) in a cubic foot (ft^3) and around 453.6 grams (g) in a pound (lb).

The calculation to determine $CF_{COvolume}$ is presented in the following table:

$CF_{ppm \rightarrow lb/dscfCO}$	CO Concentration (ppm)	$CF_{ppm \rightarrow unitless}$ (1/ppm)	CO Molecular Weight (g/mol)	Ideal Gas Constant (L/mol)	$CF_{L \rightarrow ft3}$ (L/ft^3)	$CF_{g \rightarrow lb}$ (g/lb)
7.27E-08	1	1.E-06	28.010	24.05514	28.3168466	453.59237

• F_d = 9,240 dscf/MMBtu for combustion of "wood" or 9,600 dscf/MMBtu for combustion of "wood bark." See Table 19-2 of EPA Method 19 at Appendix A-7 to 40 CFR Part 60.

Returning to the equation, EF (lb/MMBtu) = NESHAP DDDDD CO Limit (ppmvd@3%O_2) X $CF_{3 \rightarrow 0\%O2}$ X $CF_{ppm \rightarrow lb/dscfCO}$ X F_d (dscf/MMBtu), the wood residue-fired boiler NESHAP DDDDD EF can now be calculated assuming combustion of two different types of solid biomass as illustrated in the following two tables:

For "Existing" Units (Commencing Construction or Reconstruction <u>on or before</u> June 4, 2010)

Boiler Design	Fuel	NESHAP DDDDD CO Calculated EF (lb/MMBtu)	NESHAP DDDDD CO Emission Limit[1] (ppmvd@3%O_2)	$CF_{3 \rightarrow 0\%O2}$ (unitless)	$CF_{ppm \rightarrow lb/dscfCO}$ (lb/dscf / ppm)	F_d (dscf/MMBtu)
Stokers/sloped grate/others designed to burn wet biomass fuel	Wood	1.176	1500	1.168	7.27E-08	9240
	Bark	1.222	1500			9600
Stokers/sloped grate/others designed to burn kiln-dried biomass fuel	Wood	0.361	460			9240
	Bark	0.375	460			9600
Fluidized bed units designed to burn biomass/bio-based solids	Wood	0.369	470			9240
	Bark	0.383	470			9600
Suspension burners designed to burn biomass/bio-based solids	Wood	1.882	2400			9240
	Bark	1.956	2400			9600
Dutch ovens/pile burners designed to burn biomass/bio-based solids	Wood	0.604	770			9240
	Bark	0.627	770			9600
Fuel cell units designed to burn biomass/bio-based solids	Wood	0.863	1100			9240
	Bark	0.896	1100			9600
Hybrid suspension grate boiler designed to burn biomass/bio-based solids	Wood	2.196	2800			9240
	Bark	2.281	2800			9600

[1] Least stringent emission limit selected to calculate EF when NESHAP DDDDD allows source to choose from among more than one.

For "New" Units (Commencing Construction or Reconstruction <u>after</u> June 4, 2010)

Boiler Design	Fuel	NESHAP DDDDD CO Calculated EF (lb/MMBtu)	NESHAP DDDDD CO Emission Limit[1] (ppmvd@3%O_2)	$CF_{3 \rightarrow 0\%O2}$ (no units)	$CF_{ppm \rightarrow lb/dscfCO}$ (lb/dscf / ppm)	F_d (dscf/MMBtu)
Stokers/sloped grate/others designed to burn wet biomass fuel	Wood	0.486	620	1.168	7.27E-08	9240
	Bark	0.505	620			9600
Stokers/sloped grate/others designed to burn kiln-dried biomass fuel	Wood	0.361	460			9240
	Bark	0.375	460			9600
Fluidized bed units designed to burn biomass/bio-based solids	Wood	0.243	310			9240
	Bark	0.253	310			9600
Suspension burners designed to burn biomass/bio-based solids	Wood	1.882	2400			9240
	Bark	1.956	2400			9600
Dutch ovens/pile burners designed to burn biomass/bio-based solids	Wood	0.408	520			9240
	Bark	0.424	520			9600
Fuel cell units designed to burn biomass/bio-based solids	Wood	0.714	910			9240
	Bark	0.741	910			9600
Hybrid suspension grate boiler designed to burn biomass/bio-based solids	Wood	0.863	1100			9240
	Bark	0.896	1100			9600

[1] Least stringent emission limit selected to calculate EF when NESHAP DDDDD allows source to choose from among more than one.

2 <u>Option 1</u>: 4.8×10^{-5} lb/MMBtu

Basis: AP-42, September 2003. Table 1.6-4.

3 <u>Option 1</u>: 0.22 lb/MMBtu

Basis: AP-42, September 2003. Table 1.6-2 for wet wood-fired boiler

<u>Option 2</u>: 0.49 lb/MMBtu

Basis: AP-42, September 2003. Table 1.6-2 for dry wood-fired boiler

<u>Option 1</u>: 0.030 - 0.20 lb/MMBtu (EPA Reference Method 5)

Basis: NSPS Subpart Db as follows:

Maximum Design Heat Input Capacity, X (MMBtu/hr)	Action*	Date Action Commenced, Y	ACF	NSPS Db PM Emission Limit (lb/MMBtu)	NSPS Db PM Emission Limit (% removal)	Regulatory Citation
100 < X	C, R, M	06/19/84 < Y ≤ 02/28/05	30% < Z	0.10	N/A	60.43b(c)(1)
100 < X ≤ 250	C, R, M	06/19/84 < Y ≤ 02/28/05	30% ≥ Z	0.20	N/A	60.43b(c)(2)
100 < X	C, R, M	02/28/05 < Y	N/A	0.030	N/A	60.43b(h)(1)
100 < X	M	02/28/05 < Y	N/A	0.051	99.8	60.43b(h)(2)
100 < X ≤ 250	M	02/28/05 < Y	30% < Z	0.10	N/A	60.43b(h)(3)
250 < X	M	02/28/05 < Y	30% < Z	0.085	N/A	60.43b(h)(4)

* C - construction, R - reconstruction and M - modification

<u>Option 2</u>: 0.030 - 0.30 lb/MMBtu (EPA Reference Method 5)

Basis: NSPS Subpart Dc as follows:

Maximum Design Heat Input Capacity, X (MMBtu/hr)	Action*	Date Action Commenced, Y	ACF	NSPS Dc PM Emission Limit (lb/MMBtu)	NSPS Dc PM Emission Limit (% removal)	Regulatory Citation
30 ≤ X ≤ 100	C, R, M	06/09/89 < Y ≤ 02/28/05	30% < Z	0.10	N/A	60.43c(b)(1)
	C, R, M	06/09/89 < Y ≤ 02/28/05	30% ≥ Z	0.30	N/A	60.43c(b)(2)
	C, R, M	02/28/05 < Y	N/A	0.030	N/A	60.43c(e)(1)
	M	02/28/05 < Y	N/A	0.051	99.8	60.43c(e)(2)
	M	02/28/05 < Y	30% < Z	0.10	N/A	60.43c(e)(3)

* C - construction, R - reconstruction and M - modification

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Option 3: 0.03 - 0.07 lb/MMBtu (EPA Reference Method 5)

Basis: Area Source Boiler MACT ("NESHAP JJJJJJ") as follows:

Maximum Design Heat Input Capacity, X (MMBtu/hr)	Date Construction or Reconstruction Commenced, Y	NESHAP JJJJJJ PM Emission Limit (lb/MMBtu)	Regulatory Citation 40 CFR 63.11201(a) and NESHAP 5D…
30 ≤ X	06/04/10 < Y	0.03	Table 1, Row 3
10 ≤ X < 30	06/04/10 < Y	0.07	Table 1, Row 4

Option 4: 0.0032 - 0.44 lb/MMBtu (EPA Reference Method 5)

Basis: NESHAP DDDDD as follows:

• NESHAP DDDDD specifies a range of different PM emission limits based upon (a) the date the boiler commenced construction or reconstruction, (b) the design of the boiler and (c) type of fuel combusted. For the purpose of this PTE EF exercise, only the emission limits in units of "lb/MMBtu heat input" will be employed here. The source may choose to comply with an alternative "lb/MMBtu heat input" emission limit for total selected metals (TSM). Because TSM constitutes only a fraction of total PM, TSM emission limits will not be considered in determining PM PTE EF. TSM is limited to arsenic, beryllium, cadmium, chromium, lead, manganese, nickel and selenium.

Maximum Design Heat Input Capacity, X (MMBtu/hr)	Date Construction or Reconstruction Commenced, Y	Boiler Design	NESHAP DDDDD PM Emission Limit (lb/MMBtu; 3-run avg)	Regulatory Citation 40 CFR 63.7500(a)(1) and NESHAP 5D…
10 ≤ X	Y ≤ 06/04/10	Stokers/sloped grate/others designed to burn wet biomass fuel	0.037	Table 2, Row 7
		Stokers/sloped grate/others designed to burn kiln-dried biomass fuel	0.32	Table 2, Row 8
		Fluidized bed units designed to burn biomass/bio-based solid	0.11	Table 2, Row 9
		Suspension burners designed to burn biomass/bio-based solid	0.051	Table 2, Row 10
		Dutch ovens/pile burners designed to burn biomass/bio-based solid	0.28	Table 2, Row 11
		Fuel cell units designed to burn biomass/bio-based solid	0.02	Table 2, Row 12
		Hybrid suspension grate boiler designed to burn biomass/bio-based solid	0.44	Table 2, Row 13
	06/04/10 < Y	Stokers/sloped grate/others designed to burn wet biomass fuel	0.03	Table 1, Row 7
		Stokers/sloped grate/others designed to burn kiln-dried biomass fuel	0.03	Table 1, Row 8
		Fluidized bed units designed to burn biomass/bio-based solid	0.0098	Table 1, Row 9
		Suspension burners designed to burn biomass/bio-based solid	0.03	Table 1, Row 10
		Dutch ovens/pile burners designed to burn biomass/bio-based solid	0.0032	Table 1, Row 11
		Fuel cell units designed to burn biomass/bio-based solid	0.02	Table 1, Row 12
		Hybrid suspension grate boiler designed to burn biomass/bio-based solid	0.026	Table 1, Row 13

Option 5: 0.397 lb/MMBtu for wood and 0.412 lb/MMBtu for bark (EPA Reference Method 5)

Basis: FARR wood-fired boiler stack PM emission limit of 0.2 gr/dscf corrected to 7% O_2 at 40 CFR 49.125(d)(2)

EF (lb/MMBtu) = FARR PM Limit (gr/dscf@7%O_2) X $CF_{7\rightarrow0\%O2}$ X F_d (dscf/MMBtu) / $CF_{gr\rightarrow lb}$

• $CF_{7\rightarrow0\%O2}$ = (20.9 - X_{O2Fd}) / (20.9 - X_{O2FARR}). To create a correction factor that adjusts the basis of the FARR emission limit from 7% O_2 to 0% O_2 (the basis for F_d), X_{O2Fd} = 0 and X_{O2FARR} = 7. The value 20.9 is the percent by volume of the ambient air that is O_2. Decreasing the O_2 from the FARR baseline increases the pollutant concentration. See Equation 19-1 of EPA Method 19 at Appendix A-7 to 40 CFR Part 60.

• F_d = 9,240 dscf/MMBtu for combustion of "wood" or 9,600 dscf/MMBtu for combustion of "wood bark." See Table 19-2 of EPA Method 19 at Appendix A-7 to 40 CFR Part 60.

Fuel	FARR PM Calculated EF (lb/MMBtu)	FARR PM Emission Limit (gr/dscf @7%O_2)	$CF_{7\rightarrow0\%O2}$ (unitless)	F_d (dscf/MMBtu)	$CF_{gr\rightarrow lb}$ (gr/lb)
Wood	0.397	0.2	1.504	9240	7000
Bark	0.412	0.2	1.504	9600	7000

Option 6: 0.35 lb/MMBtu (EPA Reference Method 5)

Basis: (a) AP-42, September 2003. Table 1.6-1. (b) Fuel blending and installation of mechanical collectors to comply with FARR PM limit.

According to AP-42 Table 1.6-1, combustion of dry and wet wood in the absence of control equipment results in PM emissions of 0.40 and 0.33 lb/MMBtu, respectively. Combustion of bark and wet wood together without controls results in PM emissions of 0.56 lb/MMBtu. While combustion of wood alone may result in exceedances of the FARR PM emission limit (40 CFR 49.152(d)(2)) if controls are not installed (0.40 and 0.33 ~ 0.397), combustion of bark and wet wood together will likely result in exceedances (0.56 > 0.412). Installing mechanical collectors and blending bark with wood results in PM emissions less than or equal to 0.35 lb/MMBtu.

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Option 1: 0.047 - 0.217 lb/MMBtu

Basis: NSPS Subpart Db (0.03 - 0.20 lb/MMBtu) as noted above for PM plus 0.017 lb/MMBtu condensible portion as noted in AP-42.

Option 2: 0.047 - 0.317 lb/MMBtu

Basis: NSPS Subpart Dc (0.03 - 0.30 lb/MMBtu) as noted above for PM plus 0.017 lb/MMBtu condensible portion as noted in AP-42.

Option 3: 0.047 - 0.087 lb/MMBtu

Basis: NESHAP JJJJJJ (0.03 - 0.07 lb/MMbtu) as noted above for PM plus 0.017 lb/MMBtu condensible portion as noted in AP-42.

Option 4: 0.0202 - 0.457 lb/MMBtu

Basis: NESHAP DDDDD (0.0032 - 0.44 lb/MMBtu) as noted above for PM plus 0.017 lb/MMBtu condensible portion as noted in AP-42.

Option 5: 0.429 lb/MMBtu

Basis: FARR wood-fired boiler stack PM emission limit of 0.2 gr/dscf corrected to 7% O_2 at 40 CFR 49.125(d)(2) for filterable portion and AP-42 for condensible portion.

As stated previously in analysis of PM EF, an EF of 0.412 is calculated assuming compliance with FARR PM limit and combustion of bark. EPA Reference Method 5 is the test method employed to determine compliance with the limit. EPA Reference Method 5 measures only filterable PM, but PM_{10} consists of both a filterable and condensible portion. AP-42 estimates the condensible contribution to be 0.017 lb/MMBtu. Adding the two together, 0.412 + 0.017 = 0.429 lb/MMBtu.

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Option 1: 0.047 - 0.217 lb/MMBtu

Basis: NSPS Subpart Db (0.03 - 0.20 lb/MMBtu) as noted above for PM plus 0.017 lb/MMBtu condensible portion as noted in AP-42.

Option 2: 0.047 - 0.317 lb/MMBtu

Basis: NSPS Subpart Dc (0.03 - 0.30 lb/MMBtu) as noted above for PM plus 0.017 lb/MMBtu condensible portion as noted in AP-42.

Option 3: 0.047 - 0.087 lb/MMBtu

Basis: NESHAP JJJJJJ (0.03 - 0.07 lb/MMbtu) as noted above for PM plus 0.017 lb/MMBtu condensible portion as noted in AP-42.

Option 4: 0.0202 - 0.457 lb/MMBtu

Basis: NESHAP DDDDD (0.0032 - 0.44 lb/MMBtu) as noted above for PM plus 0.017 lb/MMBtu condensible portion as noted in AP-42.

Option 5: 0.429 lb/MMBtu

Basis: FARR wood-fired boiler stack PM emission limit of 0.2 gr/dscf corrected to 7% O_2 at 40 CFR 49.125(d)(2) for filterable portion and AP-42 for condensible portion.

As stated previously in analysis of PM EF, an EF of 0.412 is calculated assuming compliance with FARR PM limit and combustion of bark. EPA Reference Method 5 is the test method employed to determine compliance with the limit. EPA Reference Method 5 measures only filterable PM, but $PM_{2.5}$ consists of both a filterable and condensible portion. AP-42 estimates the condensible contribution to be 0.017 lb/MMBtu. Adding the two together, 0.412 + 0.017 = 0.429 lb/MMBtu.

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Option 1: 1.153 lb/MMBtu for wood and 1.198 lb/MMBtu for bark

Basis: FARR combustion source stack SO_2 emission limit of 500 parts per million by volume dry basis (ppmvd) corrected to 7% O_2 at 40 CFR 49.129(d)(1)

EF (lb/MMBtu) = FARR SO_2 Limit (ppmvd@7%O_2) X $CF_{7\rightarrow 0\%O2}$ X $CF_{ppm\rightarrow lb/dscfSO2}$ X F_d (dscf/MMBtu)

• $CF_{7\rightarrow 0\%O2}$ = (20.9 - X_{O2Fd}) / (20.9 - X_{O2FARR}). To create a correction factor that adjusts the basis of the FARR emission limit from 7% O_2 to 0% O_2 (the basis for F_d), X_{O2Fd} = 0 and X_{O2FARR} = 7. The value 20.9 is the percent by volume of the ambient air that is O_2. Decreasing the O_2 from the FARR baseline increases the pollutant concentration. See Equation 19-1 of EPA Method 19 at Appendix A-7 to 40 CFR Part 60.

• $CF_{ppm\rightarrow lb/dscfSO2}$ = 1.660 X 10^{-7} lb SO_2/dscf / ppm SO_2. See Table 19-1 of EPA Method 19 at Appendix A-7 to 40 CFR Part 60.

• F_d = 9,240 dscf/MMBtu for combustion of "wood" or 9,600 dscf/MMBtu for combustion of "wood bark." See Table 19-2 of EPA Method 19 at Appendix A-7 to 40 CFR Part 60.

Fuel	FARR 500 ppm Calculate SO_2 EF (lb/MMBtu)	FARR SO_2 Emission Limit (ppmvd@7%O_2)	$CF_{7\rightarrow 0\%O2}$ (unitless)	$CF_{ppm\rightarrow lb/dscfSO2}$ (lb/dscf / ppm)	F_d (dscf/MMBtu)
Wood	1.153	500	1.504	1.66E-07	9240
Bark	1.198	500	1.504	1.66E-07	9600

Option 2: 4.615 lb/MMBtu for wood and 4.444 lb/MMBtu for bark

Basis: FARR solid fuel sulfur limit of 2% by weight (dry) at 40 CFR 49.130(d)(7)

EF (lb/MMBtu) = {[FARR Fuel S Limit (%S) / 100] X $CF_{S\rightarrow SO2}$ / HV_{fuel} (Btu/lb)} X $CF_{Btu\rightarrow MMBtu}$ (Btu/MMBtu)

• $CF_{S\rightarrow SO2}$ = 2 lb SO_2/lb S. S + O_2 → SO_2. For every 1 mol S (16 lb/lb-mol) reactant, there is 1 mol SO_2 (32 lb/lb-mol) product. 32 / 16 = 2.

• HV (heating value) wood (dry) = 8,667 Btu/lb. (5200/(1-0.4)). HV bark (dry) = 9,000 Btu/lb. (4500/(1-0.5)). See page A-5 of Appendix A to AP-42, September 1985.

Fuel	FARR Fuel S Calculate SO_2 EF (lb/MMBtu)	FARR Fuel Sulfur Limit (% by weight)	$CF_{S\rightarrow SO2}$ (lb SO_2/lb S)	HV_{fuel} (Btu/lb)	$CF_{Btu\rightarrow MMBtu}$ (Btu/MMBtu)
Wood	4.615	2	2	8667	1.0E+06
Bark	4.444	2	2	9000	1.0E+06

Option 3: 0.462 lb/MMBtu for wood and 0.444 lb/MMBtu for bark

Basis: Bark upper bound sulfur estimate of 0.2% by weight (dry). See H. S. Oglesby & R. O. Blosser (1980) Information on the Sulfur Content of Bark and its Contribution to SO_2 Emissions when Burned as a Fuel, Journal of the Air Pollution Control Association, 30:7, 769-772, DOI:10.1080/00022470.1980.10465107

Despite evidence to the contrary from Oglesby and Blosser, conservatively assume all sulfur introduced to boiler is exhausted as SO_2.

EF (lb/MMBtu) = {[Upper bound S Content (%S) / 100] X $CF_{S\rightarrow SO2}$ / HV_{fuel} (Btu/lb)} X $CF_{Btu\rightarrow MMBtu}$ (Btu/MMBtu)

• $CF_{S\rightarrow SO2}$ = 2 lb SO_2/lb S. S + O_2 → SO_2. For every 1 mol S (16 lb/lb-mol) reactant, there is 1 mol SO_2 (32 lb/lb-mol) product. 32 / 16 = 2.

• HV (heating value) wood (dry) = 8,667 Btu/lb. (5200/(1-0.4)). HV bark (dry) = 9,000 Btu/lb. (4500/(1-0.5)). See page A-5 of Appendix A to AP-42, September 1985.

Fuel	Calculate SO_2 EF (lb/MMBtu)	Reasonable Upper Bound Fuel Sulfur Content (% by weight)	100% Conversion $CF_{S\rightarrow SO2}$ (lb SO_2/lb S)	HV_{fuel} (Btu/lb)	$CF_{Btu\rightarrow MMBtu}$ (Btu/MMBtu)
Wood	0.462	0.2	2	8667	1.0E+06
Bark	0.444	0.2	2	9000	1.0E+06

Option 4: 0.046 lb/MMBtu for wood and 0.044 lb/MMBtu for bark

Basis: Bark upper bound sulfur estimate of 0.2% by weight (dry) and 10% conversion to SO_2. See H. S. Oglesby & R. O. Blosser (1980) Information on the Sulfur Content of Bark and its Contribution to SO_2 Emissions when Burned as a Fuel, Journal of the Air Pollution Control Association, 30:7, 769-772, DOI:10.1080/00022470.1980.10465107

Consistent with Oglesby and Blosser, assume that only 10% of sulfur introduced to boiler is exhausted as SO_2.

EF (lb/MMBtu) = {[Upper bound S Content (%S) / 100] X $CF_{S\rightarrow SO2}$ / HV_{fuel} (Btu/lb)} X $CF_{Btu\rightarrow MMBtu}$ (Btu/MMBtu)

• $CF_{S\rightarrow SO2}$ = 2 lb SO_2/lb S. S + O_2 → SO_2. For every 1 mol S (16 lb/lb-mol) reactant, there is 1 mol SO_2 (32 lb/lb-mol) product. 32 / 16 = 2. But empiral data suggests that only 10% of sulfur is exhausted to atmosphere as SO_2. The balance precipitates out as sulfates in the ash. Multiplying by 0.1, resultant $CF_{S\rightarrow SO2}$ = 0.2 lb SO_2/lb S.

• HV (heating value) wood (dry) = 8,667 Btu/lb. (5200/(1-0.4)). HV bark (dry) = 9,000 Btu/lb. (4500/(1-0.5)). See page A-5 of Appendix A to AP-42, September 1985.

	Calculate SO_2 EF (lb/MMBtu)	Reasonable Upper Bound Fuel Sulfur Content (% by weight)	10% Conversion $CF_{S\rightarrow SO2}$ (lb SO_2/lb S)	HV_{fuel} (Btu/lb)	$CF_{Btu\rightarrow MMBtu}$ (Btu/MMBtu)
Wood	0.046	0.2	0.2	8667	1.0E+06
Bark	0.044	0.2	0.2	9000	1.0E+06

Option 5: 0.069 lb/MMBtu for wood and 0.067 lb/MMBtu for bark

Basis: Bark upper bound sulfur estimate of 0.2% by weight (dry) and 15% conversion to SO_2. See H. S. Oglesby & R. O. Blosser (1980) Information on the Sulfur Content of Bark and its Contribution to SO_2 Emissions when Burned as a Fuel, Journal of the Air Pollution Control Association, 30:7, 769-772, DOI:10.1080/00022470.1980.10465107

Assuming that 15 percent of sulfur introduced to boiler is exhausted as SO_2 strikes a balance between Option 3's 100% and Option 4's 10% sulfur-to-SO_2 conversion factors. A 15% conversion factor is a reasonable upper bound estimate given that Option 4's 10% conversion factor is based upon a limited amount of data from a handful of species evaluated by Oglesby and Blosser.

EF (lb/MMBtu) = {[Upper bound S Content (%S) / 100] X $CF_{S\rightarrow SO2}$ / HV_{fuel} (Btu/lb)} X $CF_{Btu\rightarrow MMBtu}$ (Btu/MMBtu)

• $CF_{S\rightarrow SO2}$ = 2 lb SO_2/lb S. S + O_2 → SO_2. For every 1 mol S (16 lb/lb-mol) reactant, there is 1 mol SO_2 (32 lb/lb-mol) product. 32 / 16 = 2. Assume that only 15% of sulfur is exhausted to atmosphere as SO_2. The balance precipitates out as sulfates in the ash. Multiplying by 0.15, resultant $CF_{S\rightarrow SO2}$ = 0.3 lb SO_2/lb S.

• HV (heating value) wood (dry) = 8,667 Btu/lb. (5200/(1-0.4)). HV bark (dry) = 9,000 Btu/lb. (4500/(1-0.5)). See page A-5 of Appendix A to AP-42, September 1985.

	Calculate SO_2 EF (lb/MMBtu)	Reasonable Upper Bound Fuel Sulfur Content (% by weight)	15% Conversion $CF_{S\rightarrow SO2}$ (lb SO_2/lb S)	HV_{fuel} (Btu/lb)	$CF_{Btu\rightarrow MMBtu}$ (Btu/MMBtu)
Wood	0.069	0.2	0.3	8667	1.0E+06
Bark	0.067	0.2	0.3	9000	1.0E+06

Option 6: 0.025 lb/MMBtu

Basis: AP-42, September 2003. Table 1.6-2.

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Option 1: 0.017 lb/MMBtu

Basis: AP-42, September 2003. Table 1.6-3.

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Option 1: 195 lb CO_2e/MMBtu

Basis: (a) AP-42, September 2003. Table 1.6-3. (b) 40 CFR 98, Subpart A. Table A-1.

EF (lb CO_2e/MMBtu) = EF (lb CO_2/MMBtu) X GWP_{CO2} (lb CO_2e/lb CO_2)

AP-42 Calculated CO_2e EF (lb CO_2e/MMBtu)	AP-42 EF (lb CO_2/MMBtu)	40 CFR 98 GWP_{CO2} (lb CO_2e/lb CO_2)
195.0	195	1

Option 2: 206.8 lb CO_2e/MMBtu

Basis: (a) 40 CFR 98, Subpart C. Table C-1. (b) 40 CFR 98, Subpart A. Table A-1.

EF (lb CO_2e/MMBtu) = EF (kg CO_2/MMBtu) X $CF_{kg\rightarrow lb}$ (lb/kg) X GWP_{CO2} (lb CO_2e/lb CO_2)

40 CFR 98 Calculated CO_2e EF (lb CO_2e/MMBtu)	40 CFR 98 EF (kg CO_2/MMBtu)	$CF_{kg\rightarrow lb}$ (lb/kg)	40 CFR 98 GWP_{CO2} (lb CO_2e/lb CO_2)
206.8	93.8	2.20462262	1

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Option 1: 0.525 lb CO_2e/MMBtu

Basis: (a) AP-42, September 2003. Table 1.6-3. (b) 40 CFR 98, Subpart A. Table A-1.

EF (lb CO_2e/MMBtu) = EF (lb CH_4/MMBtu) X GWP_{CH4} (lb CO_2e/lb CH_4)

AP-42 Calculated CO_2e EF (lb CO_2e/MMBtu)	AP-42 EF (lb CH_4/MMBtu)	40 CFR 98 GWP_{CH4} (lb CO_2e/lb CH_4)
0.525	0.021	25

Option 2: 1.764 lb CO_2e/MMBtu

Basis: (a) 40 CFR 98, Subpart C. Table C-2. (b) 40 CFR 98, Subpart A. Table A-1.

EF (lb CO_2e/MMBtu) = EF (kg CH_4/MMBtu) X $CF_{kg\rightarrow lb}$ (lb/kg) X GWP_{CH4} (lb CO_2e/lb CH_4)

40 CFR 98 Calculated CO_2e EF (lb CO_2e/MMBtu)	40 CFR 98 EF (kg CH_4/MMBtu)	$CF_{kg\rightarrow lb}$ (lb/kg)	40 CFR 98 GWP_{CH4} GWP_{CH4} (lb CO_2e/lb CH_4)
1.764	0.032	2.20462262	25

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Option 1: 3.874 lb CO_2e/MMBtu

Basis: (a) AP-42, September 2003. Table 1.6-3. (b) 40 CFR 98, Subpart A. Table A-1.

EF (lb CO_2e/MMBtu) = EF (lb N_2O/MMBtu) X GWP_{N2O} (lb CO_2e/lb N_2O)

AP-42 Calculated CO_2e EF (lb CO_2e/MMBtu)	AP-42 EF (lb N_2O/MMBtu)	40 CFR 98 GWP_{N2O} (lb CO_2e/lb N_2O)
3.874	0.013	298

Option 2: 2.759 lb CO_2e/MMBtu

Basis: (a) 40 CFR 98, Subpart C. Table C-2. (b) 40 CFR 98, Subpart A. Table A-1.

EF (lb CO_2e/MMBtu) = EF (kg N_2O/MMBtu) X $CF_{kg\rightarrow lb}$ (lb/kg) X GWP_{N2O} (lb CO_2e/lb N_2O)

40 CFR 98 Calculated CO_2e EF (lb CO_2e/MMBtu)	40 CFR 98 EF (kg N_2O/MMBtu)	$CF_{kg\rightarrow lb}$ (lb/kg)	40 CFR 98 GWP_{N2O} (lb CO_2e/lb N_2O)
2.759	0.0042	2.20462262	298

Acronyms

ACF: Annual Capacity Factor for Wood
C: Construction
CF: Conversion Factor
EF: Emission Factor
FARR: Federal Air Rules for Reservations
GWP: Global Warming Potential
HV: Heating Value
M: Modification
MW: Molecular Weight
NESHAP: National Emission Standards for Hazardous Air Pollutants
PTE: Potential to Emit
R: Reconstruction