RTP ENVIRONMENTAL ASSOCIATES, INC.®

Review of NYSDEC Modeling Study for NESCAUM Model Rule and NAAQS Compliance Evaluation for EPA Voluntary Phase 1 Compliant Outdoor Hydronic Heaters

Executive Summary

Atmospheric dispersion models are often used in the industrial permitting arena to assess compliance with the National Ambient Air Quality Standards (NAAQS), which specify ground-level concentration limits for pollutants (e.g., $PM_{2.5}$) that will protect public health and welfare, with an adequate margin of safety. Dispersion modeling uses mathematical formulations to characterize the atmospheric processes that disperse a pollutant emitted by a source. Based on emissions and meteorological inputs, a dispersion model can be used to predict concentrations at selected downwind locations.

The Hearth, Patio & Barbecue Association ("HPBA") retained RTP Environmental ("RTP") to review the January 26, 2007 air dispersion modeling study and report prepared by the New York State Department of Environmental Conservation ("NYSDEC"), which describes the results of an evaluation conducted in support of the NESCAUM model rule ("Model Rule") for outdoor wood-fired hydronic heaters ("OWHH"). RTP was also retained to model a large OWHH with $PM_{2.5}$ mass emissions that are compliant with the 0.60 lb/MMBtu emission level of EPA's Voluntary Phase 1 Partnership Agreement to assess compliance with the revised $PM_{2.5}$ NAAQS of 35 $\mu g/m^3$.

RTP determined that the NYSDEC model approach and procedures were consistent with common industry practice. However, the NYSDEC model input data pertaining to stack and building configurations deviated from expected OWHH manufacturer installation recommendations for Phase 1 units which state that the OWHH stack should be constructed at a height of at least two feet taller than the tallest adjacent structure. In addition, RTP determined that the modeled mass emissions were overstated for the heater sizes evaluated by the NYSDEC and were in excess of the emissions anticipated from a large OWHH. Based upon these discrepancies, RTP did not agree with one of the NYSDEC's principal conclusions that the majority of impacts associated with Model Rule Phase 1 compliant OWHHs exceed the $PM_{2.5}$ NAAQS. In fact, RTP determined through its modeling that OWHHs that are installed according to manufacturer installation requirements for Phase I units comply with the $PM_{2.5}$ NAAQS.

RTP found that the building wake effects, or the atmospheric turbulence caused by nearby structures, play a very important role in the calculation of ground level concentrations for the OWHHs. In the case of the NYSDEC modeling, this turbulence was found to have a more pronounced affect on the ground level concentration than did the mass emission rate.

RTP modeled several different OWHH stacks using the NYSDEC model as the basis for all inputs. Only the OWHH stack heights, building heights, and OWHH mass emission rates were altered. In each of RTP's model runs, the height of the OWHH stack was assumed to be two feet taller than the tallest nearby structure. In contrast, the NYSDEC's modeling generally assumed that the OWHH stack was shorter than the nearby structures. RTP's modeling demonstrates that OWHH stacks constructed at a height of two feet taller than the tallest nearby structure are compliant with the revised $PM_{2.5}$ NAAQS under both the EPA voluntary emission level of 0.60 lb/MMBtu and the NESCAUM model rule Phase 1 standard of 0.44 lb/MMBtu. Compliance was demonstrated at a distance of 30 feet from the base of the stack.

RTP ENVIRONMENTAL ASSOCIATES, INC.®

August 21, 2007

Mr. Greg Green, Director
USEPA Outreach and Information Division
109 T.W. Alexander Drive
Mail Drop C 304-01
Research Triangle Park, NC 27711

Subject: **Review of NYSDEC Modeling Study for NESCAUM Model Rule and NAAQS Compliance Evaluation for EPA Voluntary Phase 1 Compliant Outdoor Hydronic Heater**

Dear Mr. Green,

As requested by the Hearth, Patio & Barbecue Association ("HPBA"), RTP Environmental ("RTP") has reviewed the January 26, 2007 air dispersion modeling report prepared by the New York State Department of Environmental Conservation ("NYSDEC"). The modeling report describes the results of an evaluation conducted in support of the NESCAUM model rule ("Model Rule") for outdoor wood-fired hydronic heaters ("OWHH").[1] RTP has also modeled a large OWHH with $PM_{2.5}$ mass emissions that are compliant with the 0.60 lb/MMBtu emission level of EPA's Voluntary Phase 1 Partnership Agreement to assess compliance with the revised, 24-hour average $PM_{2.5}$ National Ambient Air Quality Standard ("NAAQS") of 35 µg/m^3.

The NYSDEC modeled OWHHs in a variety of stack-structure relationships, stack heights, and emission rates in efforts to assess the influence of OWHH placement, stack height, and the proposed model rule emission standards on ground level concentrations. Three different meteorological datasets were also evaluated to assess the influence of a wide variety of meteorological conditions. In addition, the NYSDEC evaluated the affects of elevated terrain on pollutant concentrations. In assessing impacts, the NYSDEC compares the model results to the revised, 24-hour average, $PM_{2.5}$ NAAQS.

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[1] The NYSDEC referred to outdoor wood-fired hydronic heaters as outdoor wood boilers, or OWBs, in the January 26, 2007 report.

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Raleigh, North Carolina 27609
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RTP obtained the electronic model input and output files as well as the meteorological data files used in the January 2007 analysis from the NYSDEC. The model procedures and inputs were evaluated and the models were re-run to verify results. RTP concludes that the appropriate model was employed and that the model was set-up and executed according to procedures that are widely accepted in the regulatory modeling arena. The model inputs and results were also consistent with those described in the January report.

While the NYSDEC model approach and procedures are consistent with common industry practice, the modeled input pertaining to stack and building configurations deviate from expected OWHH manufacturer installation recommendations for Phase 1 units. In addition, the modeled mass emissions were overstated for the heater sizes evaluated by the NYSDEC and are in excess of the emissions anticipated from a large OWHH. Based upon these discrepancies, RTP does not agree with one of the NYSDEC's conclusions that the majority of impacts associated with Model Rule Phase 1 compliant OWHHs exceed the $PM_{2.5}$ NAAQS.

In addition, the NYSDEC used the maximum value in lieu of the 3-year average of the 8th high value as representative of the design $PM_{2.5}$ value. The NYSDEC found that the use of the maximum value did not influence their conclusion that Phase 1 units do not comply with the $PM_{2.5}$ 24-hour NAAQS. However, this finding is premised on the model results obtained from an OWHH with a stack height that is not constructed according to expected manufacturer recommendations for Phase 1 units and with an emission rate that was overstated. The elevated concentrations projected from the NYSDEC modeled unit in this case would indeed not be reduced below the NAAQS if the 8th high value were used instead of the maximum value. However, use of the 8th high value is the appropriate design value and, in certain circumstances, could influence conclusions when an OWHH is modeled at a stack top elevation that conforms to vendor specifications and with a more realistic $PM_{2.5}$ emission rate.

NYSDEC OWHH Stack Height Lower Than Expected Manufacturer Recommendations for Phase 1 Units

The discrepancies noted in the NYSDEC modeling input are twofold. Primarily, in the majority of the NYSDEC modeling scenarios, the height of the heater stack was below the peak height of the adjacent structure. The NYSDEC used the dispersion model AERMOD to model both a 10 and 18 foot OWHH stack. The stacks were placed adjacent to either a 20 foot tall house or a 43 foot tall barn. These stack configurations are not consistent with the expected manufacturer installation recommendations for Phase 1 units. These recommendations will stipulate that the OWHH stack be constructed at least 2 feet taller than the roofline of nearby structures. The ground level concentrations from low level releases like an OWHH are heavily influenced by the aerodynamic influence of nearby structures. Therefore, the height of the OWHH is a very important element in evaluating the air quality impacts attributable to an OWHH.

NYSDEC Modeled Mass Emission Rate Was Overstated

The second discrepancy noted in the NYSDEC model pertains to the mass emission rate employed for assessing compliance with the Model Rule Phase 1 standard. In calculating the Model Rule Phase 1 mass emission rates input to the model, the NYSDEC used the Phase 1 emission standard of 0.44 lb PM/MMBtu heat input. This emission standard was converted to a maximum lb $PM_{2.5}$/hr emission rate and an average lb/hr emission rate using heater heat input rates of 350,000 and 215,000 Btu/hr, respectively. The resultant mass emission rates of 70 and 43 g/hr were input to the model and used to assess compliance.

This calculation overestimates the maximum emissions that would be anticipated from an OWHH for two reasons. Primarily, the $PM_{2.5}$ emission rate modeled by the NYSDEC for Phase 1 compliant OWHHs represents a maximum, worst-case hourly emission rate. A maximum hourly emission rate does not account for the variability in emissions attributable to the variation in heat demand placed on the unit and the combustion conditions within the unit that occur over the course of a 24-hour period. A maximum hourly emission rate is also not consistent with the either the averaging time of the underlying emissions standard (i.e., the $PM_{2.5}$ NAAQS is a 24-hour average) or the averaging time required by the test method (i.e., Method 28 OWHH) that the model rule mandates for evaluating compliance. Method 28 OWHH requires a weighted average calculation of emissions based upon the total time spent in each of four heat output categories, with the fourth category being the maximum achievable heat output of the unit. Since the $PM_{2.5}$ NAAQS is a 24-hour standard, the emissions should reflect a reasonable worst-case estimate of the average emissions during the averaging period, not the maximum emissions anticipated in any 1-hour period. The weighted average emission rates produced by the Method 28 OWHH test method are suitable for this purpose.

Secondly, the higher heat input of 350,000 Btu/hr used by the NYSDEC in calculating the maximum, hourly emission rate exceeds the typical heat input rating of a residential OWHH. A 350,000 Btu/hr heat input unit will produce between 170,000 and 220,000 Btu/hr heat output, depending upon the unit's heat transfer efficiency. The majority of OWHHs have a heat output rating of approximately 100,000 Btu/hr. A 100,000 Btu/hr heat output heater would be used to heat a typical 4-4,500 square foot house. The large, 350,000 Btu/hr heat input unit modeled by the NYSDEC approaches the size of a commercial unit that could be used to heat up to 10,000 square feet, or multiple smaller structures.[2] Since the estimated emissions are a direct function of the size of the heater, the emission rate modeled by the NYSDEC in assessing compliance with the $PM_{2.5}$ NAAQS under the Phase 1 standard is overstated.

HPBA Estimate of Mass Emission Rate for Compliant OWHHs

The HPBA has calculated the maximum mass emission rate from a large OWHH (i.e., 200,000 Btu/hr heat output) that would comply with the NESCAUM model rule standard of 0.44 lb/MMBtu heat input. The calculation uses the total energy input, heater efficiency, and the target emission factor as input. The calculation outputs the necessary Method 28 OWHH test duration, the burn rate, and the weighted average emission rate. The calculation uses the same four test heat output categories and the weighting factors as required by Method 28 OWHH. The calculated emission value is therefore directly comparable to the emission value that would be used to assess compliance with the Phase 1 emission standard. The calculation indicates that the heating season weighted average emission rate that would be anticipated from a 200,000 Btu/hr (heat output) unit meeting a 0.44 lb/MMBtu emission standard is 20.5 g/hr. The calculation and a more detailed description of it can be found in Attachment A.

The HPBA also calculated the mass emissions from a 200,000 Btu/hr heat output OWHH that complies with the 0.60 lb/MMBtu EPA Phase 1 Partnership Agreement. Two heater efficiencies (63% weighted average efficiency which has a Method 28 OWHH Category 4 heat output efficiency of 75% and 48% weighted average efficiency which has a Category 4 heat output efficiency of 60%) were evaluated at the 0.60 lb/MMBtu emission level due to uncertainties about combustion and heat exchanger efficiency for Phase 1 units. The heating season weighted average emission rates, as calculated according to the Method 28 OWHH weighting scheme, under this program are 29.8 g/hr, assuming 63% weighted average efficient heater, and 38.9 g/hr, assuming a 48% weighted average efficient heater.

The 3-yr Average of the Highest 8th High Values Should be Used to Assess Compliance with the $PM_{2.5}$ 24-hour NAAQS

For the vast majority of scenarios modeled, the NYSDEC used the maximum $PM_{2.5}$ modeled concentration from a single year of meteorology as the design value in assessing compliance with the $PM_{2.5}$ NAAQS. The NYSDEC used five years of meteorology from Syracuse to evaluate whether the high value accurately represented the 3-year average of the 8th highest values. The NYSDEC concludes that the use of the 8th high value can reduce the design concentration by 25-33%, as compared the maximum value, but that this

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[2] A general industry assumption is that 22 Btu/hr (heat output) is required to heat each square foot of a typical residence.

reduction does not affect the overall conclusions of the study. While the conclusions under the conditions modeled by the NYSDEC may not be affected, the 3-yr average of the 8th high value is the design value mandated by the revised PM2.5 NAAQS. In addition, a 25-33% reduction in modeled impacts (as demonstrated my the NYSDEC) could influence the ultimate determination of NAAQS compliance once vendor recommendations regarding stack top elevation and more realistic emission rates are modeled, if background pollutant concentrations are also considered.

Modeling Using Typical Manufacture's Recommended Stack Height and Average Emissions

RTP re-modeled using the NYSDEC model as the basis for all inputs (i.e., the OWHH stack was located 25' away from the adjacent structure, and stack parameters and receptors were identical to the NYSDEC model).[3] Only the stack heights, building heights, and OWHH mass emission rates have been altered. Five years of Syracuse data were used so that the 98th percentile value could also be calculated. Two stack/building configurations and three emission rates were evaluated. A 35 foot stack adjacent to a 33 foot tall structure (a typical 2 story house) and a 22 foot stack adjacent to a 20 foot structure (a typical single story house) were considered. In addition, the NESCUAM model rule Phase 1 standard of 0.44 lb/MMBtu standard as well as the EPA voluntary emission level of 0.60 lb/MMBtu were evaluated for each of the stack/building configurations. The mass emissions associated with two boiler efficiencies were evaluated at the 0.60 lb/MMBtu emission level. A large residential heater with a rated heat output equal to 200,000 Btu/hr was assumed in calculating the weighted average lb/hr $PM_{2.5}$ emission rates. To simplify the analysis, a one gram per second emission rate was modeled for each stack and building configuration and ambient impacts at each mass emission level were scaled from the results.

The modeled stack parameters and mass emission rates are presented in Table 1. The results of the modeling are shown in Table 2. As can be seen, each of the modeled scenarios is compliant with the revised $PM_{2.5}$ NAAQS of 35 µg/m^3. The modeling demonstrates that large OWHHs constructed according to expected manufacturer installation recommendations for Phase 1 units (e.g., at least two feet above the height of adjacent structures) are compliant with the revised $PM_{2.5}$ NAAQS at both the NESCAUM Phase 1 standard of 0.44 lb/MMBtu

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[3] Please note that the stack gas exit temperature and flow rate modeled by the NYSDEC are not typical of the majority of OWBs. A more typical stack gas exit temperature is 350F, while a more typical gas exit velocity is 6.5 ft/sec with an 8" diameter stack. However, RTP determined that the NYSDEC modeled parameters did little to influence concentrations when compared to more typical values and that building downwash has a much greater influence on maximum modeled concentrations.

heat input and the EPA Phase 1 Partnership Agreement emission level of 0.60 lb/MMBtu heat input.[4]

Figure 1 shows the 24-hour impacts for the 22’ stack and 20’ structure scenario with a 0.60 lb/MMBtu compliant, 63% weighted average efficient OWHH. As shown in the figure, the maximum concentrations occur within 30m (approximately 100 ft) of the OWHH and are reduced by one half their original value less than 20m (approximately 60 ft) from the point of maximum. Such a rapid decrease in concentration in such a short distance indicates that the maximum concentrations near the source are due the downwash caused by the influence of the nearby structures. Since such concentrations tend to diminish very rapidly downwind, they are not likely to affect a large area. The model summary results are provided in Attachment B.

Please call me at (919) 845-1422 x31 if you have any questions regarding our evaluation.

Sincerely,

David Keen

David Keen
RTP Environmental

cc: Mr. Alan Cagnoli, HPBA
Mr. David Menotti, Pillsbury Winthrop Shaw Pittman
Mr. John K Kehrwald, Heatmor, Inc

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[4] Please also note that RTP Environmental also modeled a more typically sized, 100,000 Btu/hr (heat output) OWB. The modeled impacts were one half of the impacts calculated with a 200,000 Btu/hr (heat output) OWB and also compliant with the revised $PM_{2.5}$ NAAQS.

Table 1. Modeled Input Data

Source Description	UTM Easting (m)	UTM Northing (m)	Base Elevation (ft)	Release Height (ft)	Exit Temp. (F)	Velocity (m/sec)	Diameter (ft)	$PM_{2.5}$ Emission Rate (g/sec)
0.44 lb/MMBtu Compliant OWHH	0.0	0.0	0.0	22[a]	294	1.05 (3.4 ft/sec)	0.5	5.7×10^{-3} (20.5 g/hr)
0.60 lb/MMBtu Compliant OWHH (63% Efficient)	0.0	0.0	0.0	22[a]	294	1.05 (3.4 ft/sec)	0.5	8.3×10^{-3} (29.8 g/hr)
0.60 lb/MMBtu Compliant OWHH (48% Efficient)	0.0	0.0	0.0	22[a]	294	1.05 (3.4 ft/sec)	0.5	1.08×10^{-2} (38.9 g/hr)

[a] A 22’ stack was modeled with an adjacent 20’ tall structure. In addition, a 35’ stack was modeled with an adjacent 33’ structure.

Table 2. 24-Hour $PM_{2.5}$ Model Summary Results

Building/Stack Scenario	Mass Emissions	3-yr Average of H8H ($\mu g/m^3$)[a]	Revised $PM_{2.5}$ NAAQS ($\mu g/m^3$)
22' stack, 20' Structure	0.44 lb/MMBtu Compliant OWHH	9.26	35
	0.60 lb/MMBtu Compliant OWHH (63% Efficient)	13.4	
	0.60 lb/MMBtu Compliant OWHH (48% Efficient)	17.6	
35' stack, 33' Structure	0.44 lb/MMBtu Compliant OWHH	4.03	
	0.60 lb/MMBtu Compliant OWHH (63% Efficient)	5.86	
	0.60 lb/MMBtu Compliant OWHH (48% Efficient)	7.65	

[a] The 1988-1990 years of meteorology were used in calculating the three year, 24-hr average impacts as this year range yielded the maximum results.

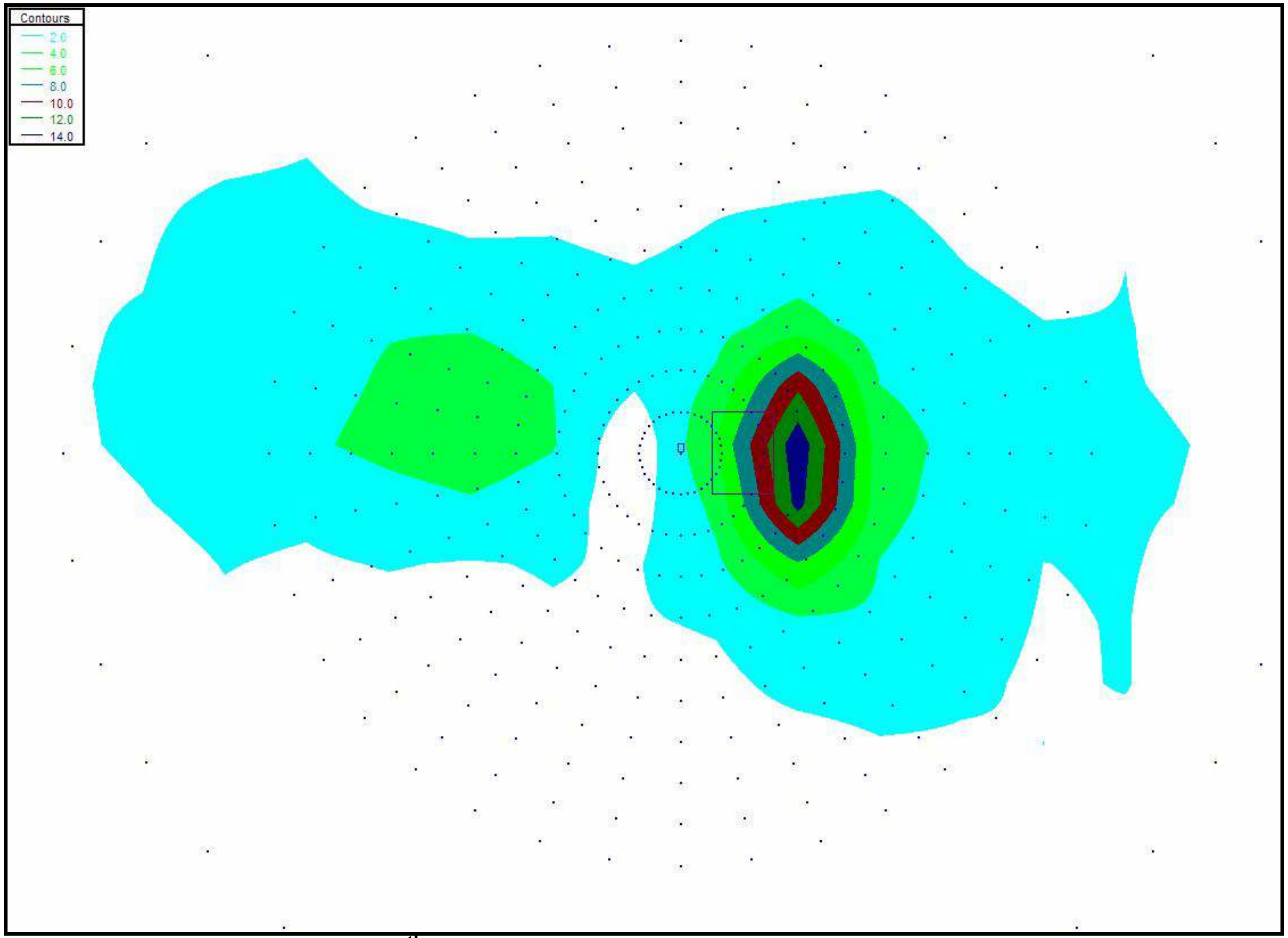


Figure 1. Maximum 8th High $PM_{2.5}$ 24-Hour Impact (22’ Stack, 0.60 lb/MMBtu)

Attachment A
OWHH Emission Rate Modeling Tool

EMISSIONS MODELING

Firebox Volume **20** Cubic Feet

Fuel Moisture Content **22%** %

Fuel Wt (wet) **200** Lb

Fuel Wt (dry) **163.93** Lb

74.36 Kg

Rated Output **200,000** Btu/Hr

This will be the CAT 4 Output

Efficiency @ Rated Output **75%** %

Slope of Efficiency Curve

If unknown, leave blank, Default is .2

Target Emissions Value **0.44** →

Slope of Emissions Curve

If unknown, leave blank; Default is -1 for Lb/MMBtu, 20 for g/Hr

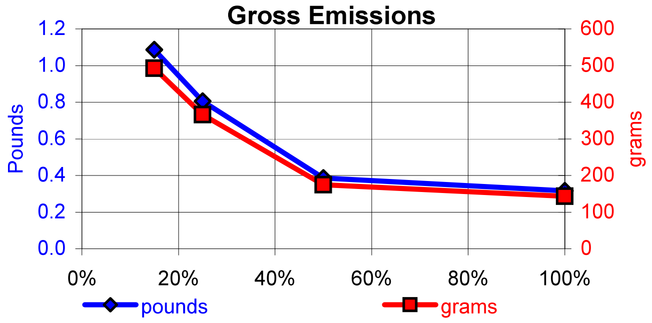
● Lb/MMBtu input
○ g/Hr

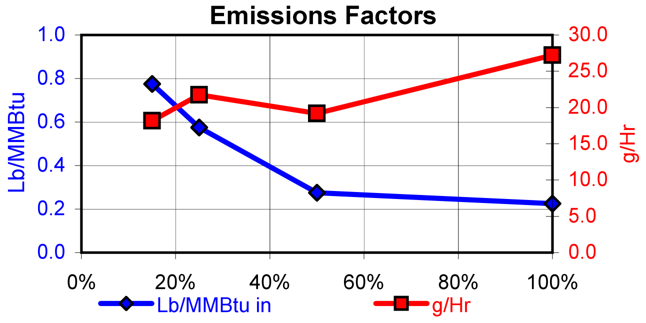
○ At Rated Outpt
● Wtd Avg (Htg)
○ Wtd Avg (Yr Rd)

CAT	Input Btu	Output Btu	Efficiency	Percent of Rated Output	Output Rate Btu/Hr	Burn Rate Kg/Hr	Duration Hr
1	1,401,639	812,951	58%	15%	30,000	2.74	27.10
2	1,401,639	840,984	60%	25%	50,000	4.42	16.82
3	1,401,639	911,066	65%	50%	100,000	8.16	9.11
4	1,401,639	1,051,230	75%	100%	200,000	14.15	5.26

	Total Emission Capture		Emissions Values				
CAT	Lb	g	Lb/MMBtu in	Lb/MMBtu out	g/Hr	g/Kg	g/MJ
1	1.09	492.72	0.78	1.34	18.18	6.63	0.57
2	0.81	365.57	0.58	0.96	21.73	4.92	0.41
3	0.39	174.84	0.28	0.42	19.19	2.35	0.18
4	0.32	143.05	0.23	0.30	27.22	1.92	0.13

Weighted Average							
		Burn Rate	Emissions Values				
	Efficiency	Kg/Hr	Lb/MMBtu in	Lb/MMBtu out	g/Hr	g/Kg	g/MJ
Htg	63%	6.78	0.44	0.72	20.52	3.76	0.31
Yr Rd	61%	5.20	0.56	0.94	19.76	4.81	0.41





EMISSIONS MODELING

Firebox Volume	20	Cubic Feet	Fuel Wt (wet)	200	Lb
Fuel Moisture Content	22%	%	Fuel Wt (dry)	163.93	Lb
				74.36	Kg

Rated Output	200,000	Btu/Hr

This will be the CAT 4 Output

Efficiency @ Rated Output	75%	%
Slope of Efficiency Curve		

If unknown, leave blank, Default is .2

Target Emissions Value	0.6	→
Slope of Emissions Curve		

● Lb/MMBtu input
○ g/Hr

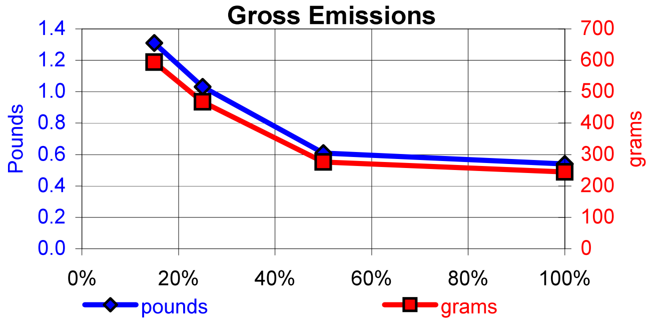
○ At Rated Outpt
● Wtd Avg (Htg)
○ Wtd Avg (Yr Rd)

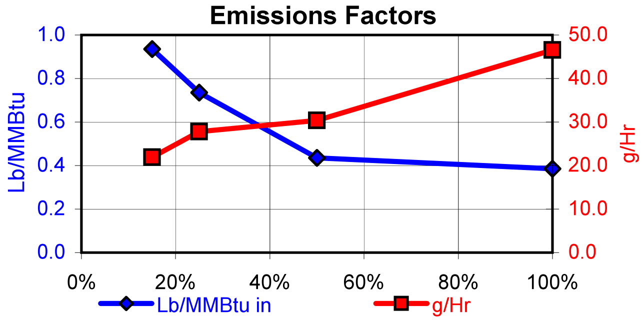
If unknown, leave blank; Default is -1 for Lb/MMBtu, 20 for g/Hr

	Input	Output	Efficiency	Percent of	Output Rate	Burn Rate	Duration
CAT	Btu	Btu		Rated Output	Btu/Hr	Kg/Hr	Hr
1	1,401,639	812,951	58%	15%	30,000	2.74	27.10
2	1,401,639	840,984	60%	25%	50,000	4.42	16.82
3	1,401,639	911,066	65%	50%	100,000	8.16	9.11
4	1,401,639	1,051,230	75%	100%	200,000	14.15	5.26

	Total Emission Capture		Emissions Values				
CAT	Lb	g	Lb/MMBtu in	Lb/MMBtu out	g/Hr	g/Kg	g/MJ
1	1.31	594.45	0.94	1.61	21.94	7.99	0.69
2	1.03	467.29	0.74	1.23	27.78	6.28	0.53
3	0.61	276.56	0.44	0.67	30.36	3.72	0.29
4	0.54	244.77	0.39	0.51	46.57	3.29	0.22

Weighted Average							
		Burn Rate	Emissions Values				
	Efficiency	Kg/Hr	Lb/MMBtu in	Lb/MMBtu out	g/Hr	g/Kg	g/MJ
Htg	63%	6.78	0.60	0.97	29.80	5.13	0.42
Yr Rd	61%	5.20	0.72	1.21	26.87	6.18	0.52





EMISSIONS MODELING

Firebox Volume 20 Cubic Feet

Fuel Moisture Content 22% %

Fuel Wt (wet) 200 Lb

Fuel Wt (dry) 163.93 Lb

74.36 Kg

Rated Output 200,000 Btu/Hr

This will be the CAT 4 Output

Efficiency @ Rated Output 60% %

Slope of Efficiency Curve

If unknown, leave blank, Default is .2

Target Emissions Value 0.6 →

Slope of Emissions Curve

If unknown, leave blank; Default is -1 for Lb/MMBtu, 20 for g/Hr

● Lb/MMBtu input

○ g/Hr

○ At Rated Outpt

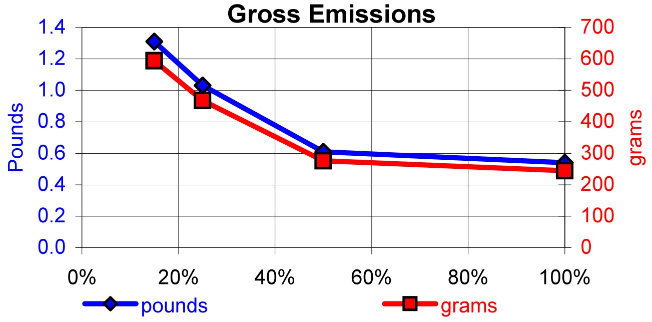
● Wtd Avg (Htg)

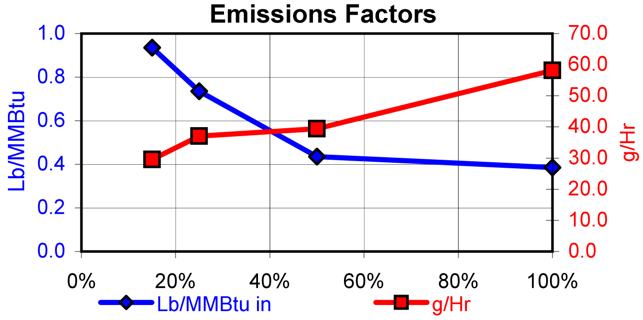
○ Wtd Avg (Yr Rd)

	Input	Output	Efficiency	Percent of	Output Rate	Burn Rate	Duration
CAT	Btu	Btu		Rated Output	Btu/Hr	Kg/Hr	Hr
1	1,401,639	602,705	43%	15%	30,000	3.70	20.09
2	1,401,639	630,738	45%	25%	50,000	5.89	12.61
3	1,401,639	700,820	50%	50%	100,000	10.61	7.01
4	1,401,639	840,984	60%	100%	200,000	17.68	4.20

	Total Emission Capture		Emissions Values				
CAT	Lb	g	Lb/MMBtu in	Lb/MMBtu out	g/Hr	g/Kg	g/MJ
1	1.31	594.45	0.94	2.17	29.59	7.99	0.94
2	1.03	467.29	0.74	1.63	37.04	6.28	0.70
3	0.61	276.56	0.44	0.87	39.46	3.72	0.37
4	0.54	244.77	0.39	0.64	58.21	3.29	0.28

Weighted Average							
		Burn Rate	Emissions Values				
	Efficiency	Kg/Hr	Lb/MMBtu in	Lb/MMBtu out	g/Hr	g/Kg	g/MJ
Htg	48%	8.81	0.60	1.29	38.94	5.13	0.55
Yr Rd	46%	6.82	0.72	1.61	35.51	6.18	0.69





OWHH Emission Rate Modeling Tool

PURPOSE:

Develop a spreadsheet based tool to allow theoretical modeling of several emissions profiles for comparison of emissions factors reported in various units of measure and various weighting schemes.

INPUTS:

Total Energy Input (based on Wood Weight (dry) and Moisture Content)
Total Efficiency (including an assumption as to the shape of the efficiency curve)
Target Emission Factor/Rate (either as a single point or a weighted average)

OUTPUTS:

Test Duration
Burn Rate
Total Emission Capture
Weighted Emission Factor/Rate

DEFINITIONS:

Vfb	Fire Box Volume (cubic feet)
MC	Moisture Content (%)
r	Fire Box Loading Density (10 lb wood/cubic foot)
HHV	Higher Heating Value of wood input (8550 Btu/cubic foot)
WWwet	Weight of Wood on a wet basis (lb)
WWdry	Weight of Wood on a dry basis – moisture correctec (lb or Kg)
Qin	Total Energy Input (Btu)
N	Efficiency
Qout	Total Energy Output (Btu)
q	Energy Output Rate (Btu/Hr)
f	Emissions Weighting Factor
E	Emissions Factor (Lb/MMBtu or g/Hr)
WA	Emissions Weighted Average
D	Burn Duration (Hr)
BR	Burn Rate (Kg/Hr)
m	Slope of a linear curve

WEIGHTING SCHEMES:

CAT		Htg	Yr Rd
1	15%	17.5%	43.7%
2	25%	27.5%	23.8%
3	50%	45.0%	27.5%
4	100%	10.0%	5.0%

I. CALCULATE PERFORMANCE VALUES

A. WWwet = Vfb x r
WWdry = WWwet / (1 + MC) … note MC is a percentage, i.e. .25
This gives WWdry in pounds
Qin = WWdry x HHV

WWdry = WWdry x .45359237 … This gives WWdry in Kg for calculating Burn Rates

B. Calculate the Efficiency at each of the Output Rates
Assuming that the efficiency curve is linear, then based on y = mx + b
Therefore: b = y – mx

Given that x = 100% (max output rate)
And that slope (m) = -.2 (unless entered by the operator)
And that y = N (operator entered efficiency at the max burn rate)

B = N + (.2 x 1.0) = N + .2

Ni = (-.2 x Xi) + B …. Calculate Efficiency at each Output Rate
(Xi = .15, .25, .5, 1.0)

C. Calculate the Total Output at each Output Rate (based on Efficiency)
Qouti = Qin x Ni

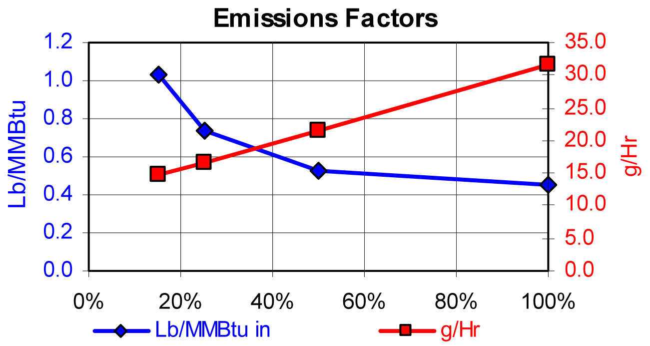
D. Calculate Target Output Rates based on the Maximum (Rated) Output Rate
qi = Xi x q4 …. Note: q4 is the Rated Output Rate entered by the operator

E. Calculate Burn Durations at each Output Rate
Di = Qouti / qi

F. Calculate Burn Rates at each Output Rate
BRi = WWdry / Di … Note: WWdry is in Kg to give a solution in Kg/Hr

II. CALCULATE EMISSIONS VALUES

The target emissions value is input as either Lb/MMBtu in or as g/Hr. Further, the operator selects whether this value is a Weighted Average value or the value at the Rated Output rate. The input value is used to calculate the Total Emissions capture at each Output Category. The shape of the emissions curve (Lb/MMBtu in or g/Hr) must be assumed … linear models have been chosen to ease the calculations.



The g/Hr curve is assumed to be linear with a slope of 20 (unless input by operator). The y intercept = E4 – m.

The Lb/MMBtu in curve is assumed to consist of a family of linear curves related as follows: (Slope m is assumed to be -1 unless entered by the operatore)

CAT 1 to CAT 2 (15% to 25%)	2 x m
CAT 2 to CAT 3 (25% to 50%)	m
CAT 3 to CAT 4 (50% to 100%)	.1 x m

A. Calculate the Total Emissions Capture:

Calculate the individual emissions factors based on the selected input emissions. If the input is simply the CAT 4 value, then (obviously) the CAT 4 value is known and the CAT 1 through 3 values can be determined based on the assumed shape of the curve (slopes given above).

If the input emission factor is a Weighted Average value (WA), then the estimated shape of the emissions curve is used determine the relationship of the various emissions factors.

WA = (E1 x f1) + (E2 x f2) + (E3 x f3) + (E4 x f4)

For g/Hr (based on a fixed slope as discussed above)
y intercept = WA – m x ((.15 x f1) + (.25 x f2) + (.5 x f3) + (1 x f4))

and the individual Emissions Factors can be found from:
E = m x X + y intercept

Combining the equations yields:

$E1 = WA - m \times ((.15 \times (1 + f1)) + (.25 \times f2) + (.5 \times f3) + (1 \times f4))$

$E2 = E1 + (m \times (X2 - X1) = E1 + (.1 \times m)$

$E3 = E1 + (.35 \times m)$

$E4 = E1 + (.85 \times m)$

The derivation is similar for Lb/MMBtu, except that the slope changes between each pair of points. So:

$WA = (E1 \times f1) + (E2 \times f2) + (E3 \times f3) + (E4 \times f4)$

Where the relationship of the points is:

$E2 = E1 + (m1\text{-}2) \times (X2 - X1) = E1 + (2.5 \times m) \times (.25 - .15) = E1 + (.25 \times m)$

$E3 = E2 + (m2\text{-}3) \times (X3 - X2) = E1 + (.5 \times m)$

$E4 = E3 + (m3\text{-}4) \times (X4 - X3) = E1 + (.55 \times m)$

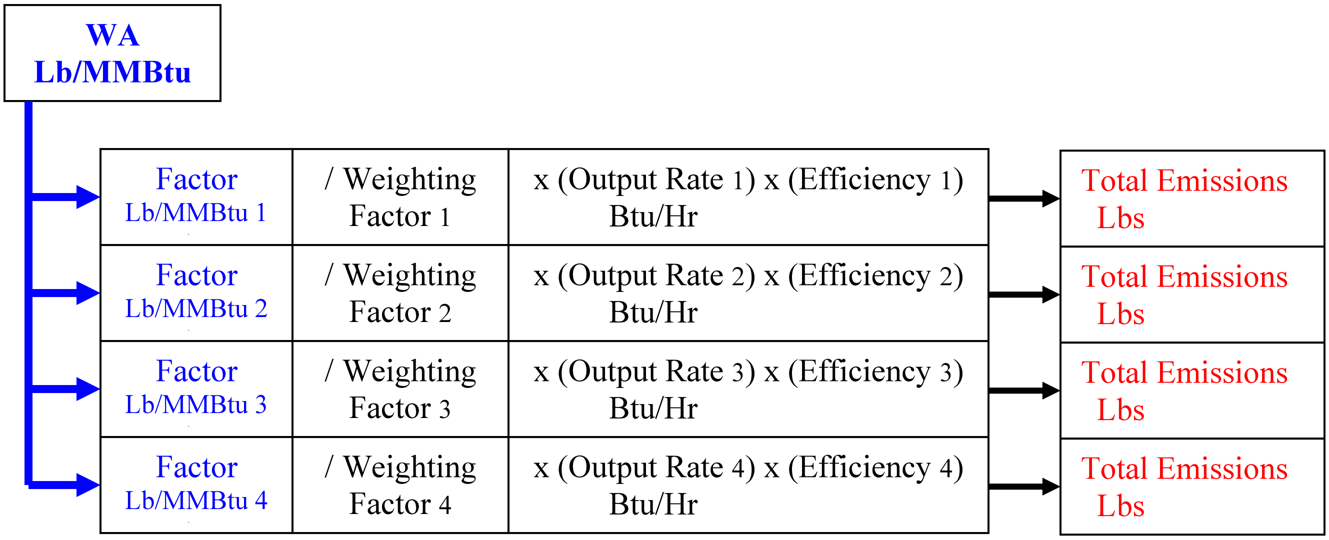
Substituting yields:

$E1 = WA / (f1 + (m \times ((.2 \times f2) + (.5 \times f3) + (.55 \times f4))))$

$E2 = E1 + (.2 \times m)$

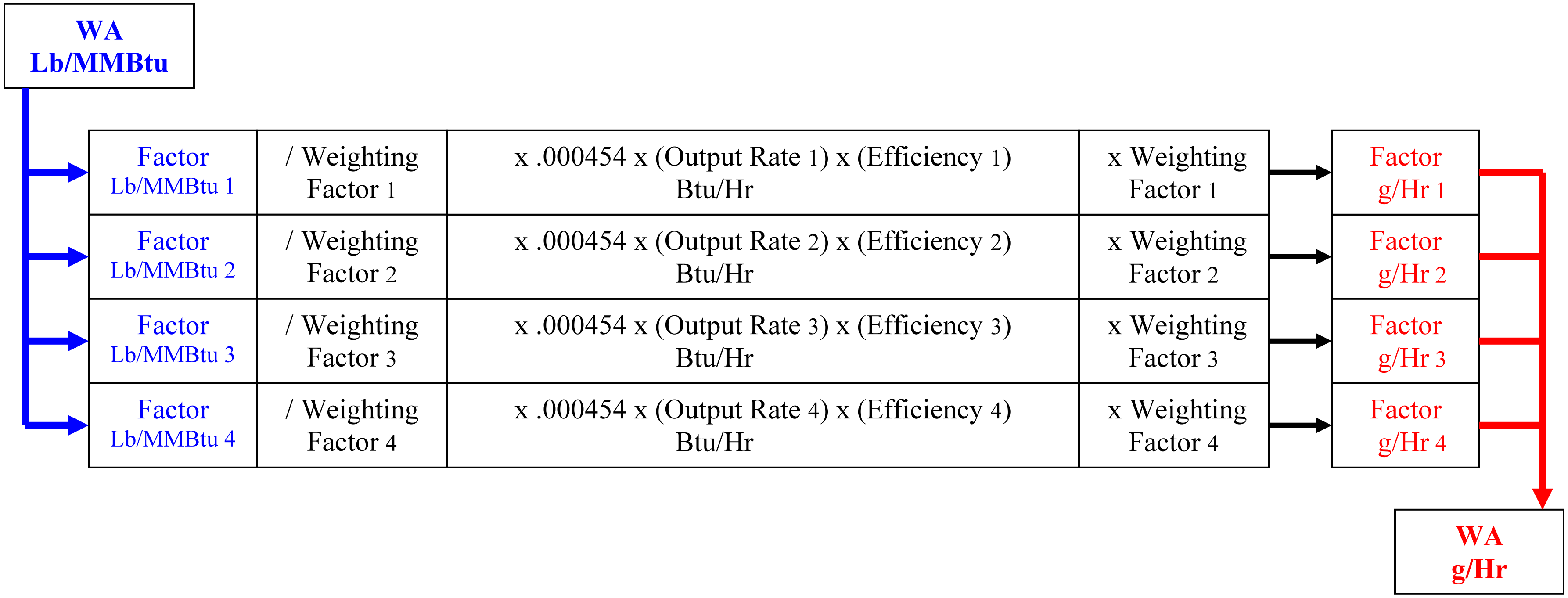
$E3 = E1 + (.5 \times m)$

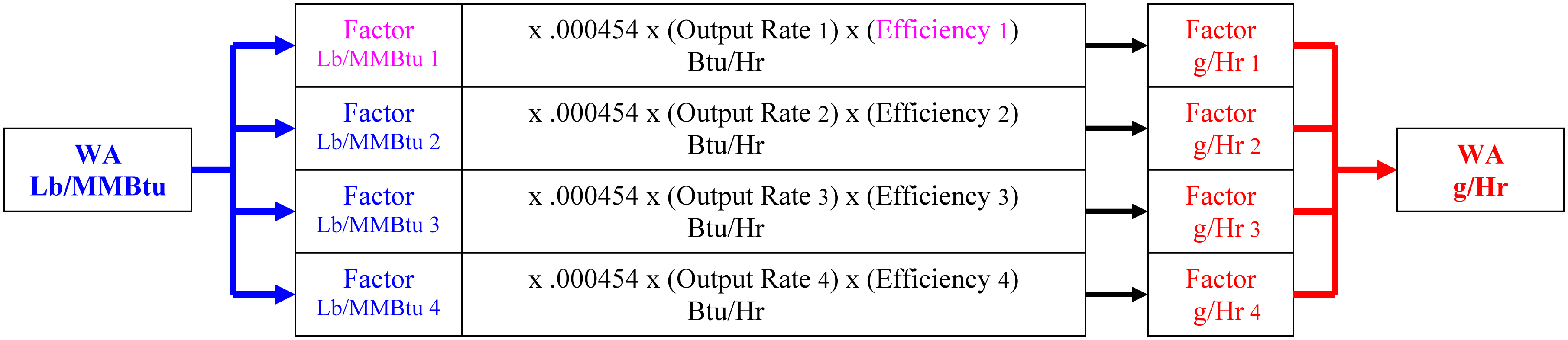
$E4 = E1 + (.55 \times m)$



B. Calculate various Emissions Values

Once the Total Emissions Capture is known (Lb or g), it is fairly easy to convert to Lb/MMBtu in, Lb/MMBtu out, g/Hr, g/Kg, g/MJ and to apply any desired weighting scheme.


WA
Lb/MMBtu
Factor Lb/MMBtu 1
/ Weighting Factor 1
x .000454 x (Output Rate 1) x (Efficiency 1) Btu/Hr
x Weighting Factor 1
Factor g/Hr 1
Factor Lb/MMBtu 2
/ Weighting Factor 2
x .000454 x (Output Rate 2) x (Efficiency 2) Btu/Hr
x Weighting Factor 2
Factor g/Hr 2
Factor Lb/MMBtu 3
/ Weighting Factor 3
x .000454 x (Output Rate 3) x (Efficiency 3) Btu/Hr
x Weighting Factor 3
Factor g/Hr 3
Factor Lb/MMBtu 4
/ Weighting Factor 4
x .000454 x (Output Rate 4) x (Efficiency 4) Btu/Hr
x Weighting Factor 4
Factor g/Hr 4
WA
g/Hr


WA
Lb/MMBtu
Factor Lb/MMBtu 1
x .000454 x (Output Rate 1) x (Efficiency 1) Btu/Hr
Factor g/Hr 1
Factor Lb/MMBtu 2
x .000454 x (Output Rate 2) x (Efficiency 2) Btu/Hr
Factor g/Hr 2
Factor Lb/MMBtu 3
x .000454 x (Output Rate 3) x (Efficiency 3) Btu/Hr
Factor g/Hr 3
Factor Lb/MMBtu 4
x .000454 x (Output Rate 4) x (Efficiency 4) Btu/Hr
Factor g/Hr 4
WA
g/Hr

x .000454

Attachment B
Model Summary Results

HPBA Model Summary Results

5 yr Syracuse MET, OWHH 8m from house, 35' and 22' stacks (2' taller than house), receptors 10m from stack, flat terrain, NYSDEC and Caucus stack parameters, 1 gps emissions

Model	File	Pol	Average	Group	Rank	1 gps Conc.	East(X)	North(Y)	Elev	Time	Met File	Sources	Groups	Rec.
AERMOD	OWB Final-22'_88_PM2.5.USF	PM2.5	24-HR	CAUCUS	8TH	1695.81189	30	0	515.7	88091024	SYR88.SFC	2	2	648
AERMOD	OWB Final-22'_89_PM2.5.USF	PM2.5	24-HR	CAUCUS	8TH	1373.11377	29.54	-5.21	515.7	89080724	SYR89.SFC	2	2	648
AERMOD	OWB Final-22'_90_PM2.5.USF	PM2.5	24-HR	CAUCUS	8TH	1314.40393	29.54	-5.21	515.7	90021024	SYR90.SFC	2	2	648
AERMOD	OWB Final-22'_91_PM2.5.USF	PM2.5	24-HR	CAUCUS	8TH	1163.51135	30	0	515.7	91082224	SYR91.SFC	2	2	648
AERMOD	OWB Final-22'_92_PM2.5.USF	PM2.5	24-HR	CAUCUS	8TH	1167.46375	30	0	515.7	92080924	SYR92.SFC	2	2	648
AERMOD	OWB Final-35'_88_PM2.5.USF	PM2.5	24-HR	CAUCUS	8TH	747.27191	28.19	-10.26	515.7	88041124	SYR88.SFC	2	2	648
AERMOD	OWB Final-35'_89_PM2.5.USF	PM2.5	24-HR	CAUCUS	8TH	627.36523	30	0	515.7	89022724	SYR89.SFC	2	2	648
AERMOD	OWB Final-35'_90_PM2.5.USF	PM2.5	24-HR	CAUCUS	8TH	582.10529	29.54	-5.21	515.7	90062824	SYR90.SFC	2	2	648
AERMOD	OWB Final-35'_91_PM2.5.USF	PM2.5	24-HR	CAUCUS	8TH	531.20532	30	0	515.7	91081524	SYR91.SFC	2	2	648
AERMOD	OWB Final-35'_92_PM2.5.USF	PM2.5	24-HR	CAUCUS	8TH	504.08752	29.54	-5.21	515.7	92073024	SYR92.SFC	2	2	648
AERMOD	OWB Final-22'_88_PM2.5.USF	PM2.5	24-HR	NYSDEC	8TH	1913.18982	30	0	515.7	88061124	SYR88.SFC	2	2	648
AERMOD	OWB Final-22'_89_PM2.5.USF	PM2.5	24-HR	NYSDEC	8TH	1525.54895	30	0	515.7	89082224	SYR89.SFC	2	2	648
AERMOD	OWB Final-22'_90_PM2.5.USF	PM2.5	24-HR	NYSDEC	8TH	1434.08936	29.54	-5.21	515.7	90021024	SYR90.SFC	2	2	648
AERMOD	OWB Final-22'_91_PM2.5.USF	PM2.5	24-HR	NYSDEC	8TH	1241.95642	30	0	515.7	91081524	SYR91.SFC	2	2	648
AERMOD	OWB Final-22'_92_PM2.5.USF	PM2.5	24-HR	NYSDEC	8TH	1272.15588	30	0	515.7	92062124	SYR92.SFC	2	2	648
AERMOD	OWB Final-35'_88_PM2.5.USF	PM2.5	24-HR	NYSDEC	8TH	819.82117	30	0	515.7	88061124	SYR88.SFC	2	2	648
AERMOD	OWB Final-35'_89_PM2.5.USF	PM2.5	24-HR	NYSDEC	8TH	682.10443	30	0	515.7	89022724	SYR89.SFC	2	2	648
AERMOD	OWB Final-35'_90_PM2.5.USF	PM2.5	24-HR	NYSDEC	8TH	621.49976	29.54	-5.21	515.7	90111924	SYR90.SFC	2	2	648
AERMOD	OWB Final-35'_91_PM2.5.USF	PM2.5	24-HR	NYSDEC	8TH	580.85205	30	0	515.7	91081524	SYR91.SFC	2	2	648
AERMOD	OWB Final-35'_92_PM2.5.USF	PM2.5	24-HR	NYSDEC	8TH	545.22699	29.54	-5.21	515.7	92073024	SYR92.SFC	2	2	648

5-yr Summary

					24hr Concentration (ug/m3)		
Average	Scenario	Rank	3-yr avg H8H 1 g/sec Conc. (ug/m3)		.44 lb/MMBtu	.60 lb/MMBtu @ 63% Efficiency	.60 lb/MMBtu @ 48% Efficiency
				g/hr -->	20.52	29.8	38.9
				g/sec -->	0.0057	0.0083	0.0108
24-HR	NYSDEC - 22' Stack, 20' Building	8TH	1624.276		9.26	13.4	17.6
	CAUCUS - 22' Stack, 20' Building		1461.110		8.33	12.1	15.8
24-HR	NYSDEC - 35' Stack, 33' Building	8TH	707.808		4.03	5.86	7.65
	CAUCUS - 35' Stack, 33' Building		652.247		3.72	5.40	7.05

Note: A weighted average efficiency of 63% corresponds to a Method 28 OWHH Category 4 Heat Output Efficiency of 75%.
A weighted average efficiency of 48% corresponds to a Method 28 OWHH Category 4 Heat Output Efficiency of 60%.