Survey of Residential Wood Combustion Activity and Development of an Emissions Inventory for the MANE-VU Region

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Residential Wood Combustion (RWC)

- Background Information
- Survey methodology and sample frame
- Survey results
- Two approaches to analyze data
- Emission results
- Comparison to NEI

Residential Wood Combustion Project Background

- RWC Emissions
  - High contribution to regional haze
  - Contribute approx. 8% of PM fine in MANE-VU region
  - Large uncertainty
  - Important local source to Class I areas
  - States have the potential to improve the activity data

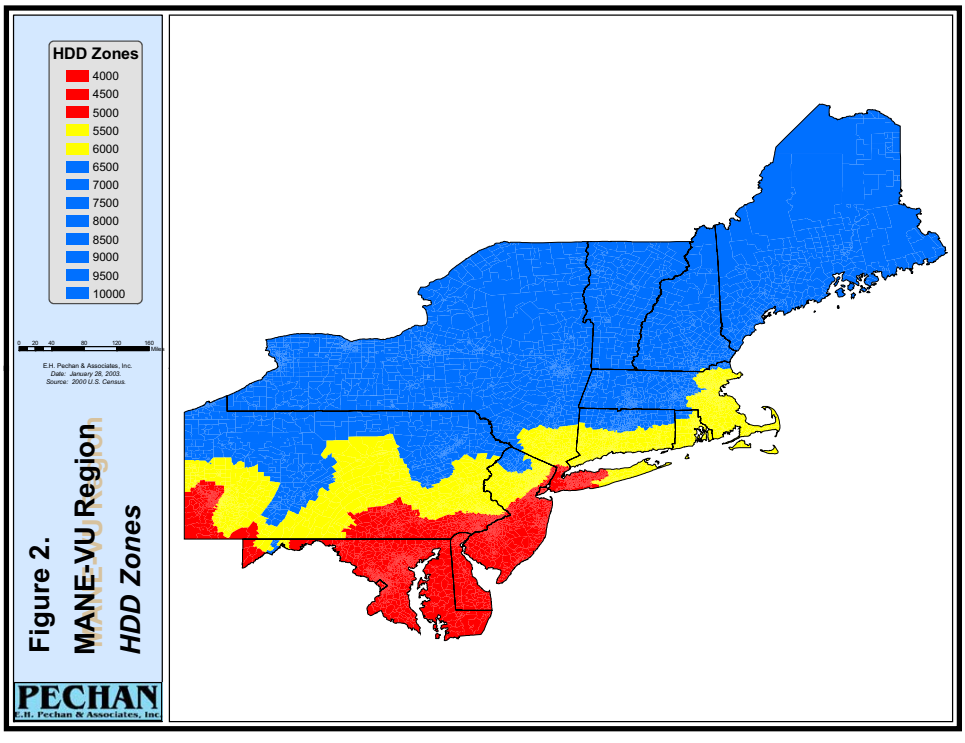
Telephone Survey Method

- Completed April 5, 2003 – May 20, 2003
- Intended to obtain information on wood burning equipment type and wood type
  - Indoor equipment: furnace/boilers, pellet stoves, fireplaces, woodstoves
  - Outdoor equipment: outdoor fireplaces, firepits, wood-fired barbecues

Survey Sample Frame

- Sample frame
  - Includes important variables that affect activity (i.e., annual wood consumption)
    - Urban, suburban, or rural locations
    - Type of housing (single versus multi-family homes)
    - Forested versus non-forested areas
    - Latitude

HDD Zones for MANE-VU

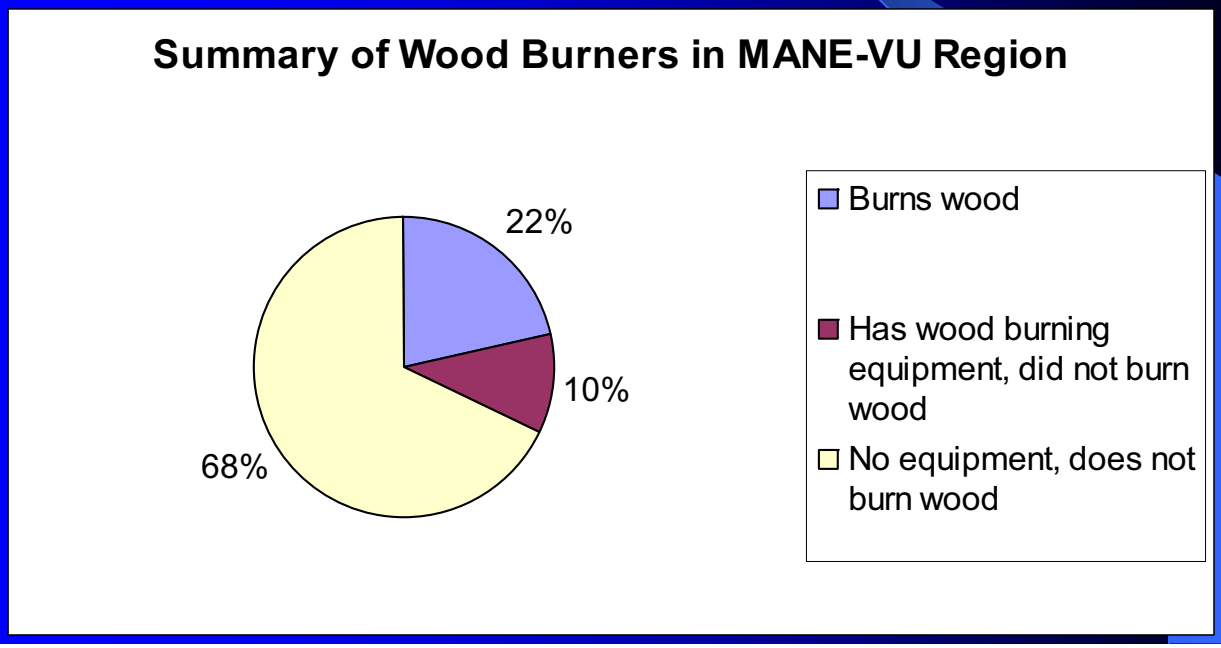


RWC Sample Frame and (Number of Respondents)

Geographic Zone	Rural-Forested		Rural-Non-Forested		Suburban		Urban	
	Single-Family	Other	Single-Family	Other	Single-Family	Other	Single-Family	Other
High HDD	**Cell 1** 61 (173)	**Cell 2** 61 (64)	**Cell 3** 61 (87)	**Cell 4** 61 (66)	**Cell 5** 61 (61)	**Cell 6** 61 (72)	**Cell 7** 61 (69)	**Cell 8** 61 (69)
Med HDD	**Cell 17** 61 (87)	**Cell 18** 61 (60)[1]	**Cell 19** 61 (91)	**Cell 20** 61 (64)	**Cell 21** 61 (71)	**Cell 22** 61 (60)[1]	**Cell 23** 61 (63)	**Cell 24** 61 (68)
Low HDD	**Cell 9** 61 (150)	**Cell 10** 61 (62)	**Cell 11** 61 (118)	**Cell 12** 61 (69)	**Cell 13** 61 (76)	**Cell 14** 61 (67)	**Cell 15** 61 (75)	**Cell 16** 61 (62)

[1]Number of responses ended up being less than the target value of 61 due to either: changes in the Disposition of one or more responses (i.e., change of address from the original sample); or dropping a response out of the final database (i.e., following QA of that response)

Survey Results - Activity Data



Respondents Reporting Usage of Indoor Burning Equipment

Geographic Zone	Rural-Forested		Rural-Non-Forested		Suburban		Urban	
	Single-Family	Other	Single Family	Other	Single Family	Other	Single Family	Other
High HDD	Cell 1 67	Cell 2 4	Cell 3 28	Cell 4 3	Cell 5 11	Cell 6 0	Cell 7 10	Cell 8 2
Med HDD	Cell 17 29	Cell 18 5	Cell 19 22	Cell 20 4	Cell 21 26	Cell 22 2	Cell 23 4	Cell 24 0
Low HDD	Cell 9 62	Cell 10 1	Cell 11 28	Cell 12 2	Cell 13 20	Cell 14 3	Cell 15 10	Cell 16 5

RED	below average of 22% burn wood
GREEN	above average of 22% burn wood

SCC	Description	Emission Factor (lbs/ton burned)						
		PM_{10}	$PM_{2.5}$	NO_x	CO	VOC	SO_2	NH_3
2104008001	Fireplaces[1]	34.6	34.6	2.6	252.6	229.0	0.4	1.8
2104008051	Non-Catalytic Woodstoves: Conventional[2]	30.6	30.6	2.8	230.8	53.0	0.4	1.7
2104008052	Non-Catalytic Woodstoves: Low-Emitting[2]	15.4	15.4	2.0	123.9	13.5	0.4	0.9
2104008053	Non-Catalytic Woodstoves: Pellet-Fired[3]	4.2	4.2	13.8	39.4	n/a	0.4	0.3
2104008060	Boilers and Furnaces[4]	28.8	28.8	2.6	252.6	229.0	0.4	1.8
2104008070	Outdoor Equipment[5]	34.6	34.6	2.6	252.6	229.0	0.4	1.8

Notes: Source - EIIP (2001), unless otherwise noted. NH_3 factors from Environ/Pechan (2002). n/a = not available; It is assumed that $PM_{10} = PM_{2.5}$.

[1] Includes masonry heaters. Masonry heaters were not broken out from fireplaces in the survey.

[2] These SCC's are proposed for non-certified and certified woodstoves, respectively.

[3] These include both certified and exempt pellet stoves. $PM_{10}/PM_{2.5}$ and CO emission factors are for certified pellet stoves based on the review by OMNI (1998). Emission factors for NO_x and SO_2 are taken for certified pellet stoves (emission factors for exempt stoves not available).

[4] Emission factors for $PM_{10}/PM_{2.5}$ from Acurex (1998); otherwise factors for fireplaces are used.

[5] Includes all outdoor wood-burning equipment (e.g. fireplaces, chimineas, barbecues, fire pits). Emission factors for fireplaces are used

Pechan's Original Analysis (used for Outdoor Equipment)

- Equipment specific wood consumption model
- Per census tract, for each type of equipment, the model would assign UF and AC.
  - User Fraction: fraction of households that actually burn wood
  - Annual Consumption: Amount of wood burned per household (cords/yr, or BTUs/yr) -- Normalized by HDD level
- Pechan combined data from cells that were not statistically different from one another
- Used for outdoor equipment types (not equipment specific)

Outdoor Wood Burning combining similar cells

Figure 1. Activity Variables for Outdoor RWC Equipment (UF = user fraction; AC = annual consumption in cords/yr).

	Rural-Forested		Rural-Non-Forested		Suburban		Urban	
Geographic Zone	Single-Family	Other	Single-Family	Other	Single-Family	Other	Single-Family	Other
High HDD	1 UF= 0.085 AC= 0.250	2 UF= 0.024 AC= 0.330	1 UF= 0.085 AC= 0.250	2 UF= 0.024 AC= 0.330	1 UF= 0.085 AC= 0.250	2 UF= 0.024 AC= 0.330	3 UF= 0.037 AC= 0.250	2 UF= 0.024 AC= 0.330
Low HDD	1 UF= 0.085 AC= 0.250	2 UF= 0.024 AC= 0.330	1 UF= 0.085 AC= 0.250	2 UF= 0.024 AC= 0.330	3 UF= 0.037 AC= 0.250	2 UF= 0.024 AC= 0.330	3 UF= 0.037 AC= 0.250	2 UF= 0.024 AC= 0.330
Med HDD	1 UF= 0.085 AC= 0.250	2 UF= 0.024 AC= 0.330	1 UF= 0.085 AC= 0.250	2 UF= 0.024 AC= 0.330	3 UF= 0.037 AC= 0.250	2 UF= 0.024 AC= 0.330	3 UF= 0.037 AC= 0.250	2 UF= 0.024 AC= 0.330

Emissions from outdoor wood burning equipment

- First known estimate of emissions from outdoor wood burning equipment (not included in the NEI)
- Only based on 121 respondents who burn wood
- Only 19 (about 15%) were from multi-unit dwellings
- Uncertainty in these emissions is high, however it provides a preliminary basis for emission estimates from outdoor wood burning equipment

Alternative Analysis Approach (Indoor Wood Burning Equipment)

- Emissions model
- Pollutant emissions estimates were calculated for each survey response
- A general linear model was developed for each pollutant
- Advantages
  - More detailed use of data
  - Provided error estimate

PM2.5 Emissions Model

Category	Mean EF (lb/household-yr)	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound	Std. Deviation	N
SFH,URBAN, All HDD Zones	1.863	-10.635	14.362	7.83	209
Other, RNF/S/U, All HDD Zones	1.912	-14.48	14.577	17.09	595
Other, RF, All HDD Zones	5.98	-14.123	22.357	32.871	185
Single, S, Low HDD Zone	18.14	-7.926	40.48	57.556	76
Single, RNF, Low HDD Zone	19.453	-3.273	38.452	53.975	117
Single, RF, Low HDD Zone	46.677	25.478	64.149	107.357	150
Single, S, Med HDD Zone	39.112	12.023	62.475	116.623	68
Single, RNF, Med HDD Zone	24.536	0.066	45.28	77.561	92
Single, RF, Med HDD Zone	54.684	29.673	75.969	163.524	86
Single, S, High HDD Zone	20.699	-7.459	45.131	62.227	61
Single, RNF, High HDD Zone	71.836	46.919	93.027	161.5	87
Single, RF, High HDD Zone	82.805	62.157	99.727	206.879	166

Multiplied the Mean EF (lbs/hh-yr) from the model by the # of households (single or multi) in that census tract

Indoor wood burning equipment combined cells

Geographic Zone	Rural-Forested		Rural-Non-Forested		Suburban		Urban	
	Single-Family	Other	Single Family	Other	Single Family	Other	Single Family	Other
High HDD	Cell 1 67	Cell 2 4	Cell 3 28	Cell 4 3	Cell 5 11	Cell 6 0	Cell 7 10	Cell 8 2
Med HDD	Cell 17 29	Cell 18 5	Cell 19 22	Cell 20 4	Cell 21 26	Cell 22 2	Cell 23 4	Cell 24 0
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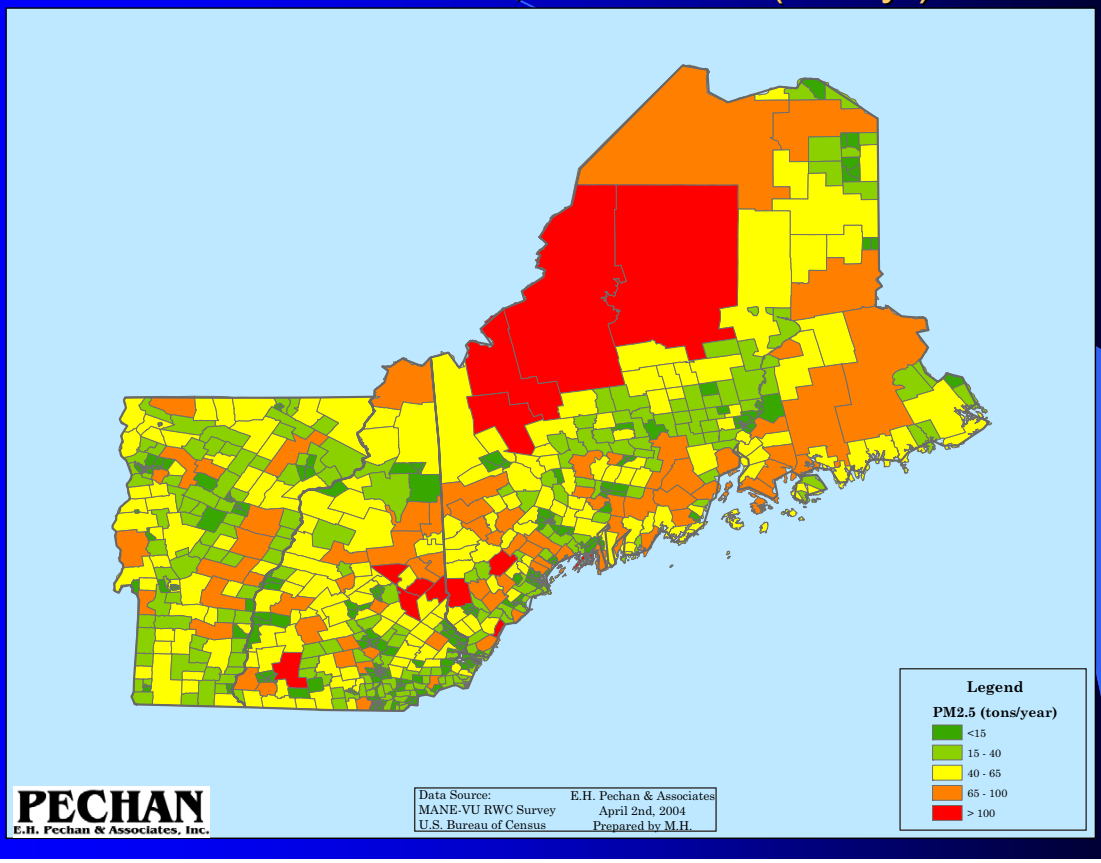
MANE-VU PM2.5 Emission results – Indoor equipment

State	Criteria Air Pollutant						
	CO	VOC	PM_{10}	$PM_{2.5}$	NO_X	NH_3	SO_2
Connecticut	61,903	38,031	8,062	8,062	787	446	115
Delaware	8,290	5,210	1,116	1,116	112	60	15
District of Columbia	1,655	1,211	223	223	27	12	3
Maine	97,150	57,547	12,227	12,227	1239	702	180
Maryland	56,108	34,841	7,500	7,500	699	405	99
Massachusetts	98,316	60,645	12,847	12,847	1269	709	184
New Hampshire	61,754	36,875	7,751	7,751	795	446	116
New Jersey	67,230	43,570	8,931	8,931	870	484	121
New York	313,978	190,091	40,043	40,043	4125	2,266	585
Pennsylvania	302,786	183,173	39,169	39,169	3826	2,185	556
Rhode Island	15,606	9,814	2,053	2,053	200	113	29
Vermont	46,062	27,904	5,771	5,771	591	332	85
Totals	**1,130,838**	**688,912**	**145,693**	**145,693**	**14,539**	**8,160**	**2,088**

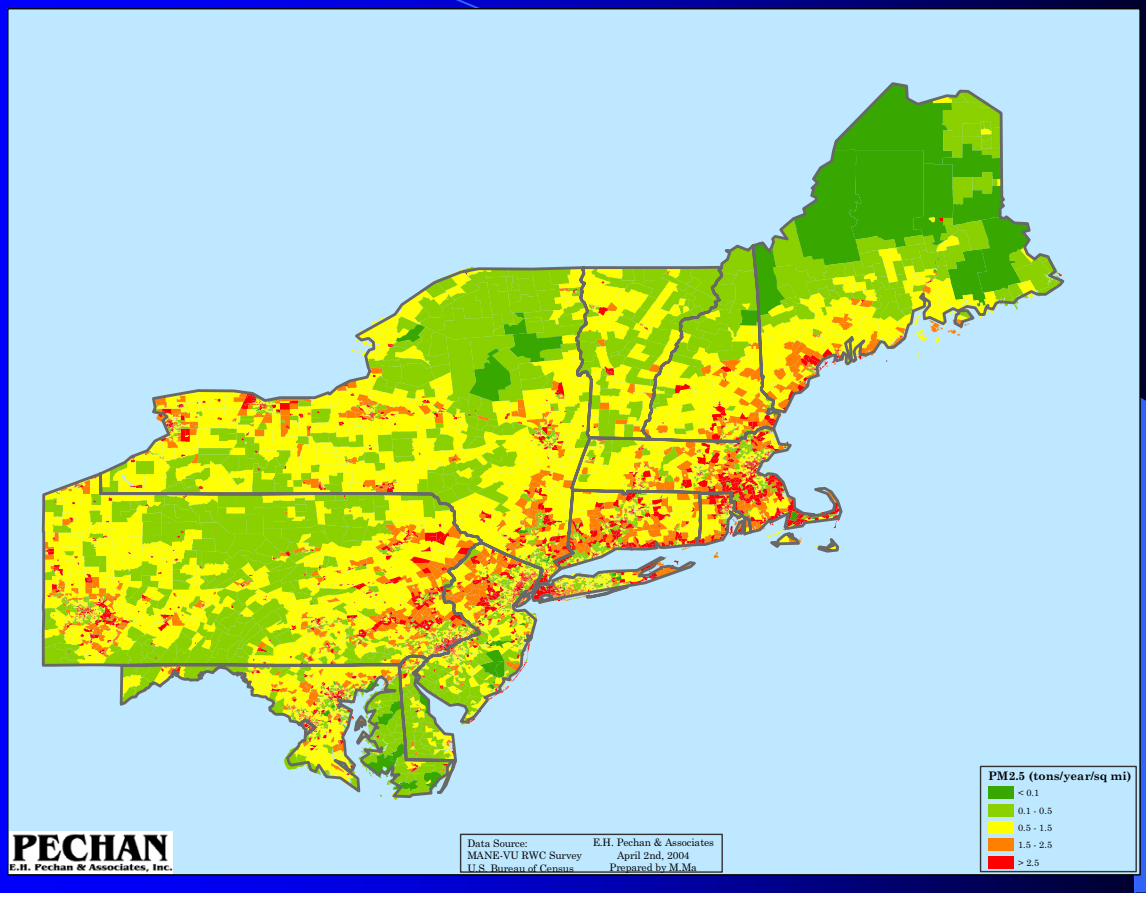
MANE-VU PM2.5 Emission results – Outdoor equipment

State	Criteria Air Pollutant						
	CO	VOC	PM_{10}	$PM_{2.5}$	NO_X	SO_2	NH_3
Connecticut	3,349	3,037	459	459	34	5	24
Delaware	818	742	112	112	8	1	6
District of Columbia	536	486	73	73	6	1	4
Maine	2,503	2,269	343	343	26	4	18
Maryland	5,067	4,593	694	694	52	8	36
Massachusetts	6,146	5,572	842	842	63	10	44
New Hampshire	1,960	1,777	268	268	20	3	14
New Jersey	7,081	6,419	970	970	73	11	50
New York	18,737	16,987	2,567	2,567	193	30	134
Pennsylvania	14,108	12,790	1,933	1,933	145	22	101
Rhode Island	976	885	134	134	10	2	7
Vermont	1,132	1,026	155	155	12	2	8
Totals	**62,414**	**56,583**	**8,549**	**8,549**	**642**	**99**	**445**

Indoor Equipment Residential Wood Combustion PM2.5 Emissions in ME, NH and VT (tons/yr)



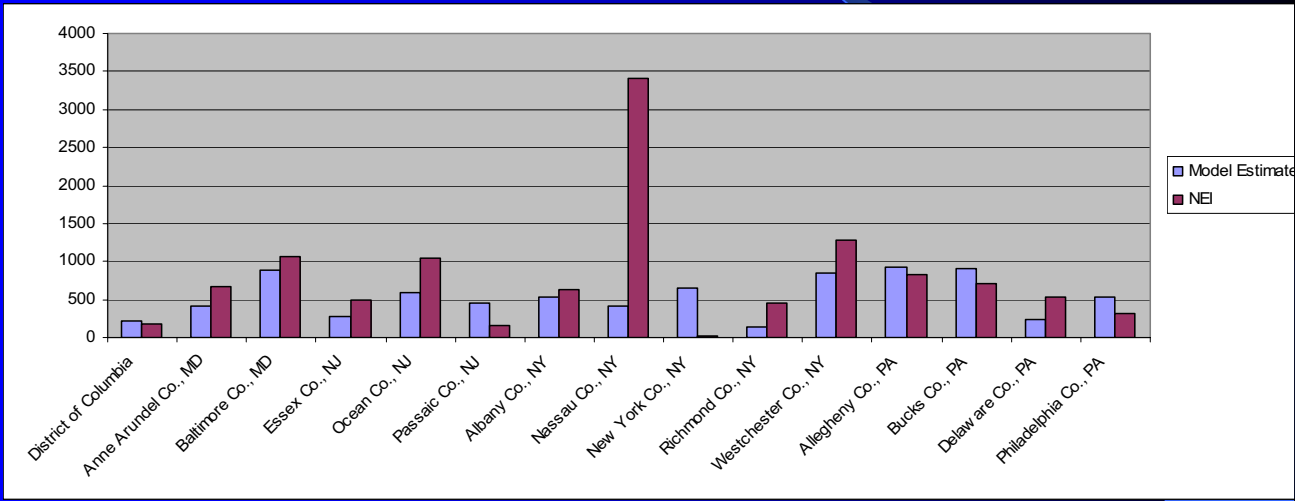
MANE-VU $PM_{2.5}$ Emission Density Plot for Indoor Equipment (ton/yr-mile^2)



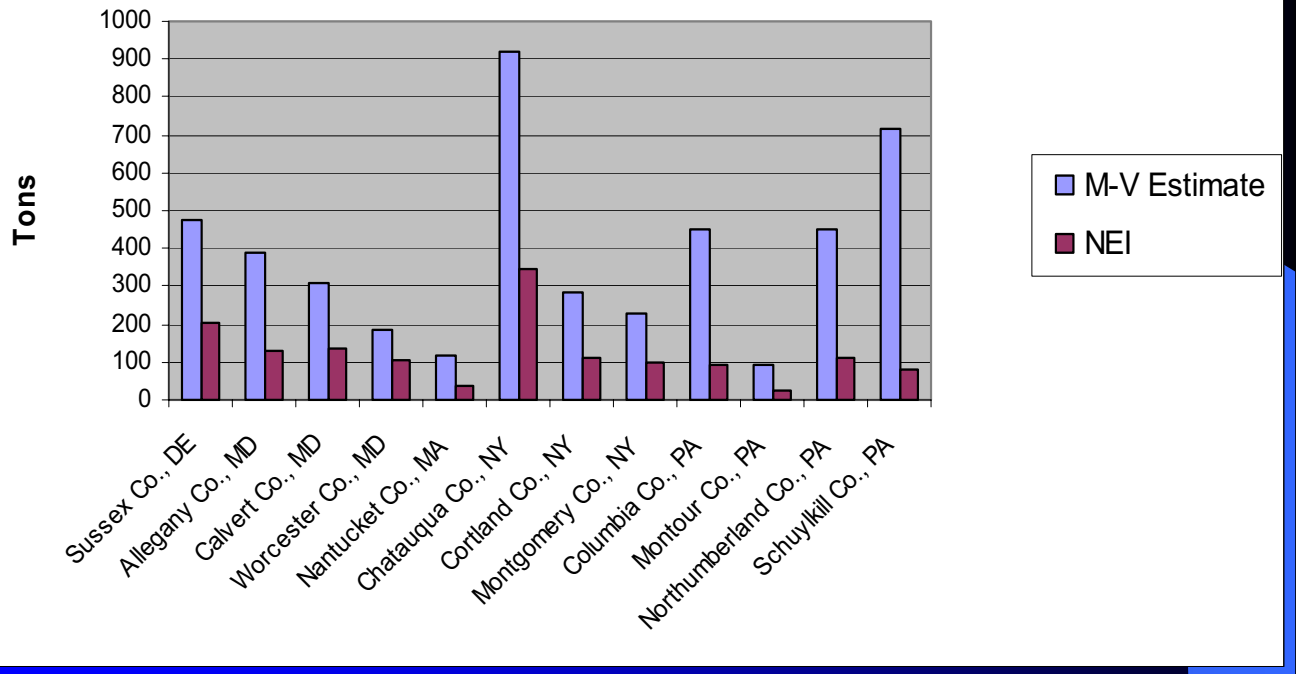
Differences between the MANE-VU and NEI Estimates

- MANE-VU $PM_{2.5}$ inventory = 145,693 tons
  - Includes pellet stoves and furnace/boilers
  - Factor to convert wood consumption (cords) to tons = 1.8 tons/cord (few responses of softwood burning)
  - Bottom up inventory from census tract level
  - Allocates more emissions to rural areas
- $PM_{2.5}$ NEI for MANE-VU region = 77,393 tons
  - Does not include pellet stoves or furnace/boilers
  - Factor used to convert volume to mass = 1.163 tons/cord
  - National stats allocated to regions, then to counties
  - Allocates more emissions to urban areas

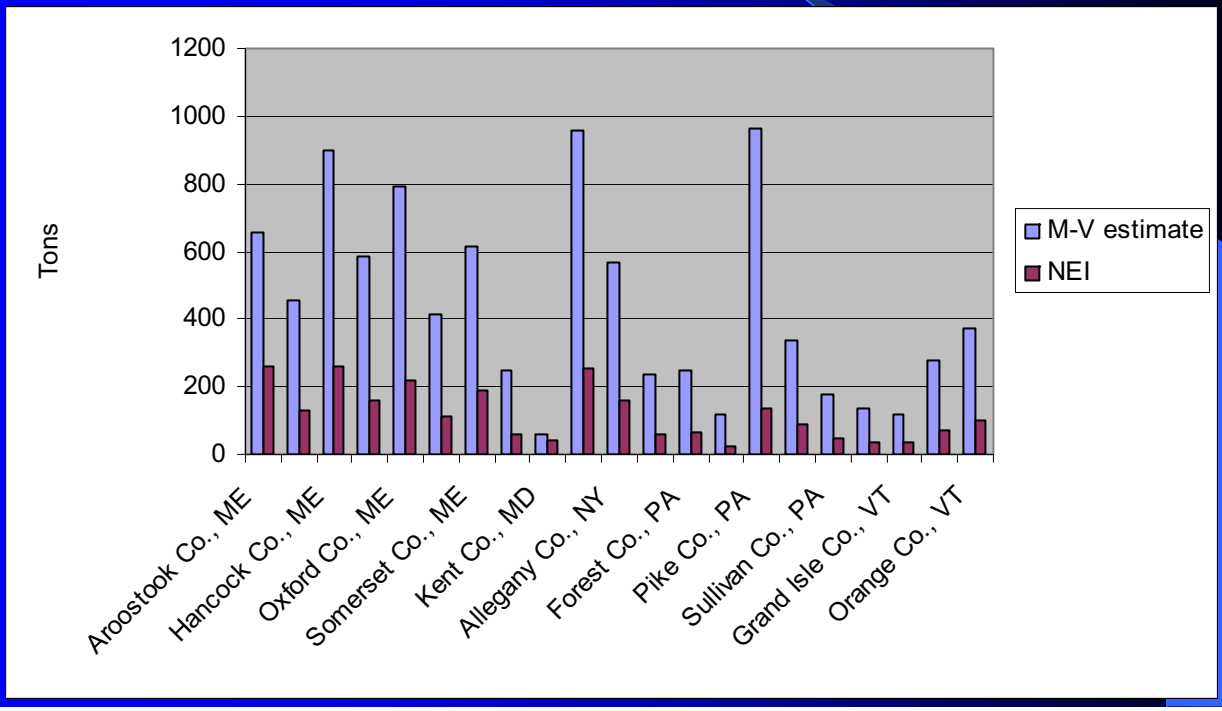
Comparison of Indoor MANE-VU RWC and NEI PM2.5 emissions in urban counties



Comparison of Indoor MANE-VU RWC and NEI PM2.5 emissions in suburban counties



Comparison of Indoor MANE-VU RWC and NEI PM2.5 emissions in rural counties



Conclusions

- Higher emissions estimates in MANE-VU inventory can be attributed to including more equipment types, regional differences (differences in both amount and type of wood burned)
- Distribution of emissions within region is more realistic

For future similar studies

- Need to obtain larger sample sizes in urban areas
- Simpler questionnaire for wood burners in urban areas (not experienced)
- Design survey to characterize wood consumption for primary vs. pleasure burners.
- Refer to EIIP Residential Wood Combustion Report prepared by OMNI Consulting Services for MARAMA www.marama.org/rtc/ResWoodCombustion/docs/rwc-report.pdf

MARAMA website

All technical memos, Final Report and NIF files

http://www.marama.org/visibility/ResWoodCombustion/

Acknowledgements

- MANE-VU Emissions Inventory workgroup, under the leadership of Ray Malenfant and the RWC Technical Oversight Committee
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