Task 6
Technical Memorandum 4 (Final Report)

Control Analysis and Documentation for Residential Wood Combustion in the MANE-VU Region

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1. Introduction

OMNI Environmental Services, Inc. (OMNI), under contract with the Mid-Atlantic Regional Air Management Association, Inc. (MARAMA), conducted five tasks for the control analysis and documentation of residential wood combustion (RWC) in the 11 states and the District of Columbia that make up the MANE-VU region. The primary objectives of the tasks were to determine the number of RWC units, activities, and emission factors for the various RWC appliance types, then calculate an emissions inventory by county, state, and entire MANE-VU region, as well as provide a pollution reduction cost effectiveness analysis by state and MANE-VU region. The titles of the five tasks and the dates of completion are listed in Table 1.01.

Table 1.01 List of Tasks

Task Number (Technical Memorandum Number)	Title	Date Completed
Task 1	Work Plan	March 7, 2006
Task 2	Quality Assurance Plan	March 30, 2006
Task 3 (Technical Memorandum 1)	Activity	March 30, 2006
Task 4 (Technical Memorandum 2)	Emissions Inventory	August 29, 2006
Task 5 (Technical Memorandum 3)	Cost Benefit Analysis	October 3, 2006

The objective of the work plan task was to create a work plan in order to explain and outline the project and create a project timeline. The objective of the quality assurance plan task was to prepare an outline of the methods that would ensure quality data generation throughout the entire project. The Work Plan and Quality Assurance Plan provided the foundation on which to begin generating the documentation and calculations for the remaining tasks. The objective of the activity task was to calculate the RWC activity by county, state, entire MANE-VU region and Heating Degree Day (HDD) category for the 2002 base year. The objective of the emissions inventory task was to create an emissions inventory for the MANE-VU region by county, state, and HDD category using the activity data calculated in the activity task for the 2002 base year. In order to create an emissions inventory, target pollutant emission factors for each appliance type had to be calculated then multiplied by the activity. The cost benefit analysis task, originally an analysis of RWC reasonable/best available control measures, was changed to a pollution reduction cost effectiveness analysis based on a verbal agreement between OMNI and MARAMA.

This Final Report (Task 6) is a summary of the results from the previous tasks. Section 2 of this document summarizes the RWC activity data by county, state, and the total MANE-VU region, and contains a description of the methodology used. The number of RWC devices, fraction of households using RWC devices, and the amount of wood they burn are provided as maps with resolution to the county level, and as bar charts showing data to the state level. Section 3 contains emissions inventory data calculated in the emissions inventory task for the county, state, and total MANE-VU region, along with explanations of each category of RWC appliance types and the associated methodology used. Section 4 contains the discussion on RWC PM_{10} Reasonable Available Control Measures (RACM) and Best Available Control Measures (BACM) from the cost benefit analysis task. While the emphasis was placed on a cost-effectiveness analysis, the RACM/BACM discussion was included to illustrate control strategies already developed to reduce RWC emissions. Section 5 summarizes the pollution reduction cost effectiveness analyses calculated in the cost benefit analysis task by state for each pollutant, and explains the methodology supporting the analyses. The reader is referred to the cost benefit analysis task for data by Heating Degree Day (HDD) category. Key references for all data sources are included in Section 6.

There are several sources of data that have been published on RWC activity levels, emissions, and practices covering the Mid-Atlantic and New England states. These include: (1) The MANE-VU Residential Wood Combustion Emission Inventory published by the Mid-Atlantic Regional Air Management Association, Inc. (July 2004 report), (2) Residential Energy Consumption Surveys published by the Energy Information Administration, (3) the National Emission Inventory published by the U.S. Environmental Protection Agency, (4) Simmons Marketing Research reports, and (5) American Housing Surveys for the United States published by the U.S. Department of Commerce and the U.S. Department of Housing and Urban Development. In addition, the results of three RWC surveys at the state-level have been published in the last decade for the Mid-Atlantic and New England area, which allow for comparison of data extrapolated from the national- and regional-scale surveys to the state level for three states. These are (1) 1995 Delaware Fuelwood Survey, (2) Residential Fuelwood Use in Maine, Results of 1998/1999 Fuelwood Survey, and (3) Vermont Residential Fuel Wood Assessment for 1997-1998. OMNI has reviewed these various sources of data[1] and used their results in this evaluation. There is uncertainty in each of the approaches and MARAMA recommends that each state make the decision on which calculation method to use for their individual State Implementation Plans.

2. Activity

2.1. Methodology and Intermediate Data

There are four main categories considered for the development of activity: (1) Wood heaters and fireplaces without inserts used for heating, (2) Pellet heaters, (3) Centralized cordwood heating systems, and (4) Wax/fiber firelogs.

2.1.1. Wood Heaters and Fireplaces without Inserts Used for Heating

The calculation of the number of wood heaters (freestanding wood stoves plus fireplaces with inserts) by county that are used (in contrast to owned) was conducted by eight different methods. The calculation of the number of fireplaces without inserts used for heat (in contrast to owned or used for aesthetics) was calculated by six different methods. Not all of the methods were used for each county, as those methods that provided the most in depth results for a given county were used solely or averaged to determine the number of RWC devices. Fireplaces used for aesthetics were not included in the by county calculations because it has been calculated that the usage of cordwood in fireplaces for aesthetics represents less than 10% of the total cordwood used in fireplaces. However, for completeness, an estimate of the activity of fireplaces used for aesthetics has been compiled on a state level (see Figures 2.13 and 2.15). Sources of data used to calculate the number of wood heaters and fireplaces without inserts used for heat included the U.S. Census Bureau, American Housing Survey reports, Simmons Marketing Research data, Hearth, Patio, and Barbecue Association surveys, and various state surveys. Using a multiple ownership factor and the number of households using wood heaters and fireplaces without inserts, the total number of wood heaters and fireplaces without inserts were calculated. The distribution of tree species by state and the typical weight of a cord of wood on a dry basis (db) were calculated state by state. The mass of wood was corrected to 0% moisture from either the given moisture content of a mass per cord, or the average moisture content of "seasoned" or "aged" cordwood of 20% db. From the amount of wood used by appliance type, from the typical mass of a dry cord of wood by state, and from the number of appliances per county, the dry mass of wood burned by county, by state and by heating category was calculated for both wood heaters and fireplaces without inserts used for heating.

Calculation Method 1

Data for specific counties were taken directly from American Housing Survey's (AHS) Metropolitan Area Surveys[2,3]. For some counties the data from two subareas listed in the AHS documents were combined to obtain data for the entire county. In those documents, total stove usage is considered as the sum of households using stoves as other heat and households using stoves as main heat. Stove data are for solid fuel burning stoves only. Coal and other solid fuel are insignificant compared to wood. Total fireplace with insert usage is considered as the sum of households using fireplace inserts as main heat and households using fireplace inserts as other heat. Both gas and solid fuel appliances were included in the AHS, so those that use gas fuel were subtracted from the total number. Units using piped gas, using bottled gas, and area household numbers were estimated from the AHS documents.

Calculation Method 2

Data for specific counties were taken from three state surveys (Delaware, Maine, and Vermont).

Method 2 a. Delaware

Each of the three Delaware counties was included in a 1995 survey[4] that calculated the fraction of households with a wood burning appliance (WBA), as well as the type of WBA (if any). The number of households using wood heaters for heat was calculated using the fraction of households that own a wood burning appliance, the fraction of those owning a WBA that have a wood heater, the fraction of wood stoves used for heat nationally, and the estimated number of households in 2002 for each county. The number of households using fireplaces without inserts for heat was calculated using the same fraction of households that own a WBA as above, the fraction those owning a WBA that have a fireplace without an insert, the fraction of fireplaces without inserts used for heat nationally, and the estimated number of households in 2002 for each county.

Method 2 b. Maine

The number of wood heaters for Maine was obtained by using information from a 1998/1999 Maine residential fuel use survey[5] which contains the fraction of households, based on geographical county location, that used a woodstove or fireplace insert as a major heating appliance, as well as used wood as heating fuel.

Method 2 c. Vermont

The number of wood heaters and fireplaces without inserts used for heat in Vermont was obtained from a 1997-1998 Vermont residential fuelwood assessment study[6]. The fraction of wood burning households that use wood stoves, fireplaces with inserts and fireplaces without inserts were multiplied by the fraction of households with a wood burning appliance, also reported in the study, by county.

Calculation Method 3

For method 3, the average fractions of households that use a wood heater (wood stove and fireplace insert) or fireplace without insert for heat were taken from each applicable AHS Metropolitan Area Survey[2]. These fractions were then multiplied by the number of households that were in each county and a part of a specific metropolitan statistical area (MSA). For the three New England MSA's of Hartford, CT, Boston MA-NH, and Providence-Pawtucket-Warrick[3], partial counties make up portions of the MSA. Only counties that had the majority of their households in the MSA were used in method 3. This determination was made from U.S. Census Bureau population. The number of households in each county during 2002 was derived from the U.S. Census Bureau[7].

Calculation Method 4

For method 4, the average New York City data from subarea 1 of the AHS New York-Nassau-Suffolk-Orange Metropolitan Area Survey[2] was applied to each of the five counties (boroughs) that make up New York City in an analogous fashion as described in method 3. The five counties/boroughs are: Bronx, Kings, Queens, New York, and Richmond.

The American Housing Survey for the New York City Metropolitan Area in 2003 used New York City as one of its selected subareas, with the five aforementioned counties comprising the city. The fraction that each county was of the city was found by dividing the number of households in each county by the number of households in the city[7]. The resulting fraction was used to determine the fraction of New York City that was representative of each county, and when multiplied by the New York City survey numbers, a corresponding county number was calculated.

Calculation Method 5

For method 5, the fraction of households that own a wood heater (woodstove plus wood-burning fireplace insert) was obtained from Simmons Marketing Research[8] by county size (population). The fraction of wood stoves owned that were used for heat was obtained from a 2004 HPBA survey (regional values)[9] and the fraction of fireplace inserts used for heat as compared to those that were owned was obtained from the Minnesota state survey[10]. The number of households in each county during 2002 was obtained from the U.S. Census Bureau. No fireplace without insert data were available.

Calculation Method 6

For method 6 the fraction of households that own a wood heater (woodstove plus wood-burning fireplace insert) was obtained from Simmons Marketing Research by Nielsen Marketing Region. The fraction of wood stoves owned that were used for heat was obtained from the 2004 HPBA survey and the fraction of fireplace inserts used for heat as compared to those that were owned was obtained from the Minnesota state survey. The number of households in each county during 2002 was obtained from the U.S. Census Bureau. No fireplace without insert data were available.

Calculation Method 7

Calculation method 7 entailed using the fraction of households by county that use wood as the main heating fuel to index the total households using wood heaters and the total number of households using wood-burning fireplace without inserts for heating purposes. The fraction of households by county that use wood as the main heating fuel was obtained from the 2000 Census (long form results based on one-in-six houses). The ratios of the total number of households that use wood as a heating source (sum of main and other heating source) to those that use it as a main source only were determined by proportioning the relative wood-burning activity between the rural and urban portions of each county. This was done because the urban and rural ratios differ from one another. (The AHS has developed these data for a number of categories. Ratios for urban and rural areas both inside and outside MSAs were calculated). The fraction of urban and rural populations in each county was determined for all counties from the U.S. Census Bureau data. The number of households that used fireplaces without inserts for heat was determined by calculating the ratio of the number of households using fireplaces without inserts used for heating obtained for AHS categories to the total numbers of households in the urban and rural portion of each county that used wood as a main heating source. Once the fireplace without inserts number was determined it was subtracted from the total number of households using wood as heat to obtain the number of households that used wood heaters (freestanding stoves and fireplace inserts). The fireplace without insert numbers tabulated by the AHS included gas-fueled fireplaces, consequently, the fireplace without insert numbers had to be adjusted so that only wood-fueled fireplace inserts would be included. This was accomplished by using the HPBA 2004 survey data, which showed the national fraction of fireplaces without inserts that are wood-fueled, and adjusting that fraction to be applicable for each county. County adjustments were based on the number of households that reported gas (utility, bottled, tank or LP) as their main fuel by county ratioed to the national average (0.577).

Calculation Method 8

Method 8 cwas used due to the fact that method 7 was found to be less accurate for counties with high population densities and not all counties with high population densities were separately included in AHS's Metropolitan Surveys. Fortunately, after reviewing all counties in the MANE-VU region with population densities of more than 2000 people per square mile, most of them were accurately covered in specific AHS metropolitan surveys. For those counties not covered separately in AHS metropolitan surveys, the method used to more accurately estimate the number of households that used wood heaters and fireplaces without inserts was to interpolate between counties that bracketed them in terms of population density that were in the same MSA. The fraction of households in these counties that used wood heaters and fireplaces without inserts was adjusted based on the interpolation.

Final Estimate of the Number of Households Using Wood Heaters and Fireplaces without Inserts

The final estimate of the number of households using wood heaters for heating was determined one of three ways: (Scenario 1) If the county estimate was determined by method 1, 4, or 8 (which are mutually exclusive), then the number from method 1, 4, or 8 was directly used as the final number of households using wood heaters in the county. (Scenario 2) If method 1, 4, or 8 were not used, then the average of methods 2, 3, 5 and 7 was used, except if the county was in the New York Metro area and not calculated by method 1, 4, or 8. In this case (Scenario 3) the average of methods 2, 3, 6 and 7 was used.

Total households using fireplaces without inserts for heating was determined one of two ways: (Scenario 1) If the county estimate was determined by method 1, 4, or 8 (which are mutually exclusive), then the number from method 1,4, or 8 was directly used as the final number of households using fireplaces without inserts in the county. (Scenario 2) If method 1, 4, or 8 were not used, then the average of methods 2, 3 and 7 was used.

2.1.2. Centralized Cordwood Heating Systems

The activity of centralized cordwood heating systems (the sum of wood-fired furnaces and wood-fired boilers) was estimated using: (1) The fraction of households that reported using wood as their main heating fuel that used centralized heating systems (0.30) as estimated from a Department of Energy, Energy Information Administration 2001 national survey[11]. (2) The number of households by county that used wood as their main heating fuel as determined from the U.S. Census Bureau. (3) The average mass of fuel used per appliance in each of the three heating categories reported in the 2002 MARAMA survey. (4) Multiplication of the amount of wood used per appliance in a county (both in cords and by mass) based on the heating degree day category in which the county is located. Multiple appliance ownership is uncommon for centralized cordwood heating systems and was not taken into consideration in the calculations.

Because there is particular interest in outdoor wood boilers (OWB), an estimate of number of OWB as of 2002 in the MANE-VU states was made from (1) EPA 114 data[12], (2) a report entitled, "Smoke Gets in Your Lungs: Outdoor Wood Boilers in New York State, October 2005, prepared by the New York Office of the Attorney General[13], and (3) communication with the Vice President of Central Boiler[14]. The 2002 estimate for the MANE-VU states was 8,329 units. The 8,329 number was derived from (1) an estimate of 32,729 units sold nationally from 1995 to 2002, (2) an estimate of 5,132 units sold nationally before 1995 and still in use as of 2002, and (3) an estimate of 22% of the units that were sold nationally were sold in the MANE-VU states (Most units have been sold outside the MANE-VU states, mainly in the Midwest.). (32,729 + 5,132) X 0.22 = 8,329. As with the centralized heater category (of which OWB is a subset), the number of households reporting wood as their main heating fuel to the U.S. Census Bureau was used to index centralized wood heating system use by county. Because there are no estimates of the amount of wood burned in OWB separate from the centralized heating unit category in total, only the number of units, not the activities, were calculated and their activity is included as part of the centralized heater data.

2.1.3. Pellet Heaters

Pellet heater activity was calculated by using the Hearth, Patio, and Barbecue (HPBA)[15] and Pellet Fuel Institute (PFI)[16] manufacturer shipment records to determine the total number of pellet heaters (pellet stoves and pellet inserts) in the U.S. as of 2002. As there were no sales records, the shipment records were used. Out of business necessity, stove retailers do not maintain a large inventory of pellet heaters, hence stoves shipped to retailers is representative of stoves purchased by consumers. Pellet-fueled centralized heating systems were not included in the calculation since their number is small as compared to pellet stoves and pellet inserts and there are no records available for their shipment or sales. Multiple appliance ownership is uncommon and was not taken into consideration in the calculations. Once the total number of pellet heaters in the U.S. as of 2002 was calculated (518,884 units), the fraction of those units present in the MANE-VU region was estimated from PFI pellet shipment records. The PFI northeast region is composed of 10 of the MANE-VU states, therefore a small adjustment was made using the number of households using wood as their main heating fuel from the U.S. Census Bureau records (as an index) to include Maryland and Washington D.C. in the estimate. Once the total number of pellet heaters in the MANE-VU region was estimated, they were proportioned to each county by the number of households using wood as their main heating fuel as reported by the U.S. Census Bureau. Interestingly, the overall fraction of households calculated as owning pellet heaters (0.008) compared favorably with the number determined from the 2002 MARAMA survey (0.01)[17]. Because, the number of households reporting using pellet stoves in the 2002 MARMA survey was small (19), with one household reporting an unreasonable number of pellet stoves (4) and another reporting using 3 tons of pellets without a pellet heater, the average mass of pellets used per unit did not show any trends with heating categories nor was it reasonable when compared to estimates obtained from the HPBA and FPI data. Therefore, the latter data was used in calculating pellet heater activity. The typical moisture content of pellets is 3% and the mass of pellets used was corrected accordingly to obtain the activity in dry mass of pellets.

The number of pellet heaters used for each county was found by multiplying (1) the total number of pellet heaters reported to be in use in the MANE-VU region by (2) the fraction of the total MANE-VU households with wood as heating fuel by each individual county.

2.1.4. Wax/Fiber Firelogs

Even though the contribution of wax/fiber firelogs to the overall RWC activity is small, because the use of wax/fiber firelogs has been of concern and also offers an emission reduction option as compared to cordwood use in fireplaces, the activity for their use has been calculated. Further, wax/fiber firelogs are important to include in the activity level determination simply due to their widespread use and the perception that they need to be included for completeness. According to the survey conducted by the HPBA[9], 23% of fireplace users normally burn artificial firelogs in New England (defined by the HPBA surveyor as Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island and Vermont) and 19% in the South (includes the MANE-VU areas of Delaware, District of Columbia and Maryland). Although wax/fiber firelogs do not contribute to the amount of cordwood burned by fireplaces, their use does contribute to the activity of fireplaces.

There are two types of manufactured firelogs used in residential fireplaces without inserts – wax/fiber firelogs and densified firelogs. The use of densified firelogs in fireplaces in the MANE-VU states as compared to wax/fiber firelogs is insignificant. An industry survey revealed that 11,411,192 wax/fiber firelogs were used in the Northeast between September 1998 and September 1999[18]. The average weight of a wax/fiber firelog is 4.95 lbs (40% 6 lb logs, 35% 5 lb logs, 25% 3.2 lb logs and an insignificant number of 3 lb and 2.5 lb logs). The log weight distribution estimate was based on an interview with a major manufacturer of firelogs[19]. The typical moisture content of wax/fiber firelogs is 2% and the mass of firelogs was corrected to the mass on a dry basis. Adjusting the 11,411,192 number of firelogs used in the Northeast to the 2002 base year by using the number of usable fireplaces in the Northeast census region[20] and adding the estimated contribution of Maryland, Delaware and Washington, D.C. to the northeast number by apportioning the number of fireplaces used for heating in all the MANE-VU region to the number without Maryland, Delaware and Washington D.C. included, produces 13,887,242 firelogs, or 33,684 dry tons of firelogs used in the MANE-VU states in 2002. The total dry mass of firelogs used in the MANE-VU states was apportioned among the counties based on the ratio of the number of fireplaces without inserts used for heating in each county to the total number of fireplaces without inserts used for heating in the MANE-VU states (Figure 2.15). It needs to be noted that wax/fiber firelogs are used in fireplaces without inserts used for both aesthetics and for heating purposes. The number of fireplaces used for heating was used for indexing the firelog use among counties as the relative breakdown between aesthetic and heating use among counties was considered to be the same.

2.1.5. Cordwood Fuel Usage and Cordwood Mass

The number of cords burned by each of the main appliance types used for heat, by state, is shown in Table 2.01. These data were calculated from the 2002 MARAMA survey[17]. Because it was the best available data, the number of cords burned per appliance in each heating category from the MARAMA survey was used to determine the average number of cords burned per appliance by county, depending on the heating degree day category in which the county is located. The mass of cordwood burned in each appliance type can be found by multiplying the cords burned per year by the average mass per cord for each state.

Table 2.01 Average Number of Cords Burned per Appliance by State for Heat

State	Cords Burned by Wood Heaters Annually	Cords Burned by Fireplaces without Inserts Used for Heat Annually	Cords Burned by Cordwood Furnaces and Boilers Annually
Connecticut	2.15	0.74	3.41
Delaware	0.95	0.51	0.75
Maine	2.56	1.68	5.38
Maryland	1.05	0.53	1.26
Massachusetts	2.34	1.28	4.38
New Hampshire	2.56	1.68	5.38
New Jersey	1.40	0.51	1.22
New York	2.41	1.51	5.30
Pennsylvania	1.87	0.75	2.93
Rhode Island	2.17	0.54	1.96
Vermont	2.56	1.68	5.38
District of Columbia	0.86	0.46	0.68

Table 2.02 shows the percentage distribution of the main tree species by state, and the resulting average mass per cord by state. As studies have shown that people tend to use cordwood that is available in their immediate vicinity[21], determining the distribution of tree species in the MANE-VU region and their associated cord weights is an appropriate step in the calculation of the average mass per cord for each state. Average cord masses for each state were calculated by apportioning the mass per cord of each tree species by the percentage distribution of the species (Activity Table 13), and taking the sum of those fractions for each state. Table 2.02 is a summary of the percentage of tree species by state. Many similar tree species were grouped together in a species group in Table 2.02 in order to provide an overview. Those species that accounted for less than 0.01% of the total tree species for a state were only included as part of the "other" category. Species contained within the "other" category make up less than 10% of the total species in all states, less than 5% in seven states. The full list of species and their respective distributions by state can be found in the activity task, and was used in the calculation of the average cord masses in the activity task. Because the District of Columbia has little fuel wood resources, its average mass per cord resulting from the tree species percentage distribution is assumed to be equal to that of Maryland. These cord weights differ from previous studies because they are derived from the tree species distribution in each state, and as each species has a different mass per cord and each state has a different species distribution, each state will have a different average mass per cord.

Table 2.02 Main Tree Species Considered in the Average State Mass per Cord Calculation

Species	Connecticut	Delaware	Maine	Maryland	Massachusetts	New Hampshire	New Jersey	New York	Pennsylvania	Rhode Island	Vermont
American basswood	0.04%	-	0.03%	0.13%	0.27%	0.13%	0.14%	0.81%	0.41%	-	0.16%
American elm	0.57%	0.02%	0.13%	0.27%	0.28%	0.30%	0.58%	2.22%	0.86%	0.33%	0.65%
American holly	-	12.83%	-	7.52%	-	-	1.92%	-	-	0.16%	-
Apple	0.23%	0.97%	0.06%	0.22%	0.16%	0.07%	0.17%	2.21%	0.69%	0.03%	0.54%
Ash	2.69%	0.09%	1.97%	1.37%	3.36%	2.65%	2.62%	7.48%	3.45%	0.94%	3.60%
Aspen	0.39%	0.33%	3.42%	0.21%	1.02%	2.26%	0.12%	2.87%	1.66%	0.36%	2.10%
Balsam fir	-	-	35.29%	-	0.55%	15.25%	-	3.43%	-	-	12.16%
Beech	5.03%	0.77%	4.10%	2.57%	8.20%	8.04%	1.05%	8.69%	6.08%	1.29%	10.49%
Birch	15.79%	0.88%	11.67%	2.34%	11.16%	13.77%	3.39%	6.21%	11.57%	11.52%	10.96%
Black Locust	0.12%	0.70%	-	1.35%	0.07%	-	0.50%	0.27%	1.00%	0.02%	0.01%
Cedar	1.78%	0.85%	3.53%	0.63%	0.48%	0.10%	9.57%	1.82%	0.13%	0.32%	1.40%
Cherry	3.57%	2.54%	1.36%	5.45%	3.06%	2.53%	2.43%	3.81%	10.22%	2.02%	3.60%
Dogwood	0.39%	1.48%	-	2.30%	0.09%	-	0.77%	0.30%	0.90%	1.31%	-
Gum	0.96%	21.07%	-	15.69%	0.42%	-	9.77%	0.10%	3.09%	2.10%	-
Hemlock	6.25%	-	2.64%	0.14%	10.82%	7.29%	0.14%	5.07%	3.62%	1.06%	5.08%
Hickory	4.60%	0.88%	-	2.31%	0.99%	0.26%	1.27%	1.24%	1.67%	1.20%	0.30%
Hop-hornbeam	4.82%	1.00%	0.71%	1.73%	2.15%	0.92%	1.44%	6.26%	2.92%	0.66%	3.75%
Maple	31.95%	21.51%	19.44%	19.13%	29.45%	27.84%	18.19%	29.43%	28.22%	35.48%	32.90%
Oak	12.75%	10.61%	0.89%	9.43%	12.78%	4.74%	19.20%	3.00%	10.09%	24.00%	0.89%
Pine	4.56%	11.84%	2.04%	11.88%	11.39%	6.92%	18.43%	3.43%	2.78%	14.06%	2.38%
Poplar	0.21%	2.07%	-	4.24%	0.01%	-	1.21%	0.06%	1.13%	0.08%	-
Sassafras	1.23%	3.55%	-	2.68%	0.35%	-	2.55%	0.05%	1.95%	1.45%	-
Spruce	0.45%	0.00%	11.40%	-	1.19%	5.91%	0.01%	2.27%	0.14%	-	7.19%
Subtotal	98.36%	94.01%	98.71%	91.61%	98.24%	98.99%	95.48%	91.01%	92.58%	98.39%	98.15%
Other Species	1.64%	5.99%	1.29%	8.39%	1.76%	1.01%	4.52%	8.99%	7.42%	1.61%	1.85%
Total	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Dry Mass per Cord (tons)	1.47	1.33	1.23	1.34	1.41	1.34	1.33	1.42	1.44	1.47	1.38

Full tree species distribution table reference: 22
Species mass per cord references: 23-27
0% moisture db
Tree species with a contribution of greater than 0.01% only are included in the table.

2.2. Activity by County, State, and Total MANE-VU Region

Activity for RWC is the amount of fuel consumed by RWC devices. Activity data is provided here by individual appliance type by state and for the total MANE-VU region. There are four main appliance categories. (1) Wood heaters, which are shown as the sub-categories of a) uncertified conventional wood heaters, b) certified catalytic wood heaters, and c) certified non-catalytic wood heaters. (2) Data for cordwood fireplaces without inserts used for both heat and aesthetics are shown. While cordwood burned in fireplaces without inserts for aesthetic purposes are not shown in the emissions inventory task as the contribution to RWC is small, the amount of cordwood burned for aesthetics is included here for completeness. Fireplaces without inserts used for aesthetics burn about 0.069 cords/year[28]. From a 2002 HPBA survey[29], it can be estimated that for every one fireplace without an insert used for heating, 1.38 are used for aesthetics. From this ratio, the 0.069 cords/year fuel consumption and from the county by county estimates of fireplace without insert use for heating, an estimate can be made of the amount of cordwood burned in fireplaces without inserts used for aesthetics. The mass of wax/fiber firelogs burned by fireplaces without inserts is also included. (3) Data for pellet heaters are shown, as well as, (4) data for centralized cordwood heating systems. The activity data are shown in separate charts for each appliance type, and for total RWC units by state. Maps are also provided showing the total number of RWC devices, fraction of household using RWC devices, and the total wood consumed by the RWC devices by county in the MANE-VU region. It should be noted that the data shown in Figures 2.01-2.12 are for appliances used, not owned.

Figure 2.01 Total Number of RWC Devices

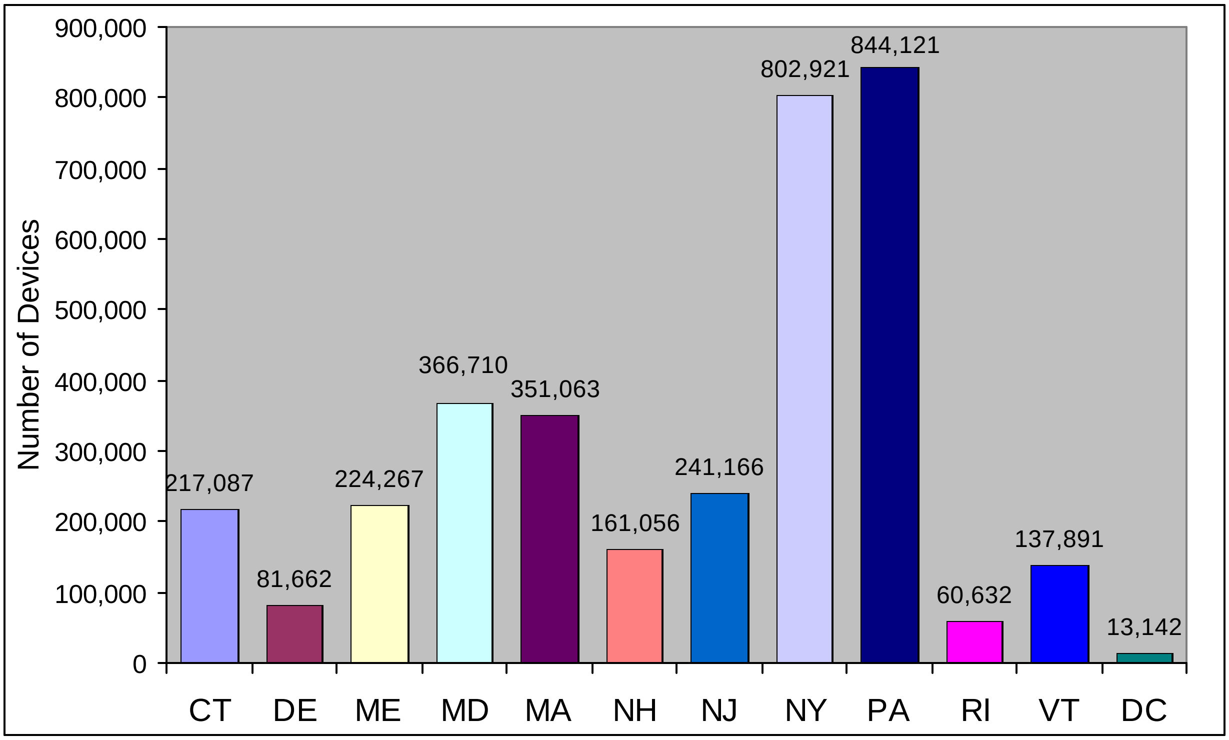


Figure 2.02 Total Number of Wood Heaters

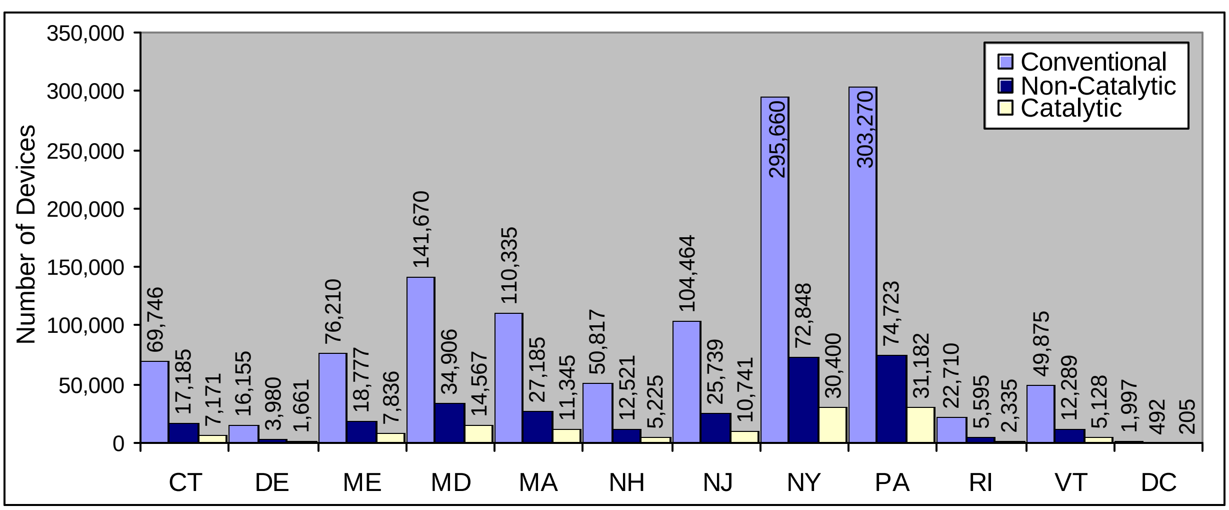


Figure 2.03 Total Number of Fireplaces without Inserts

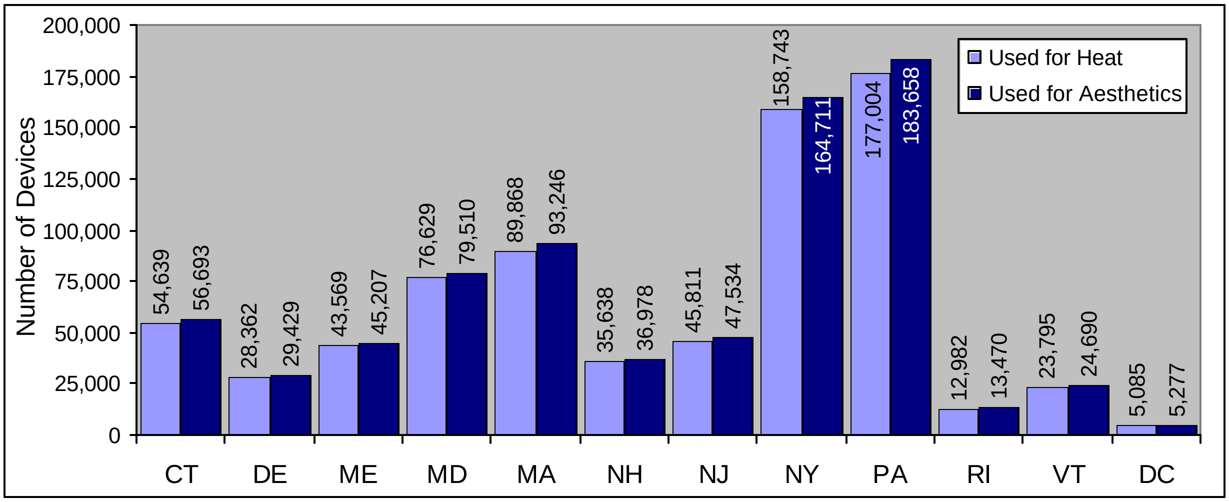


Figure 2.04 Total Number of Centralized Cordwood Heating Systems

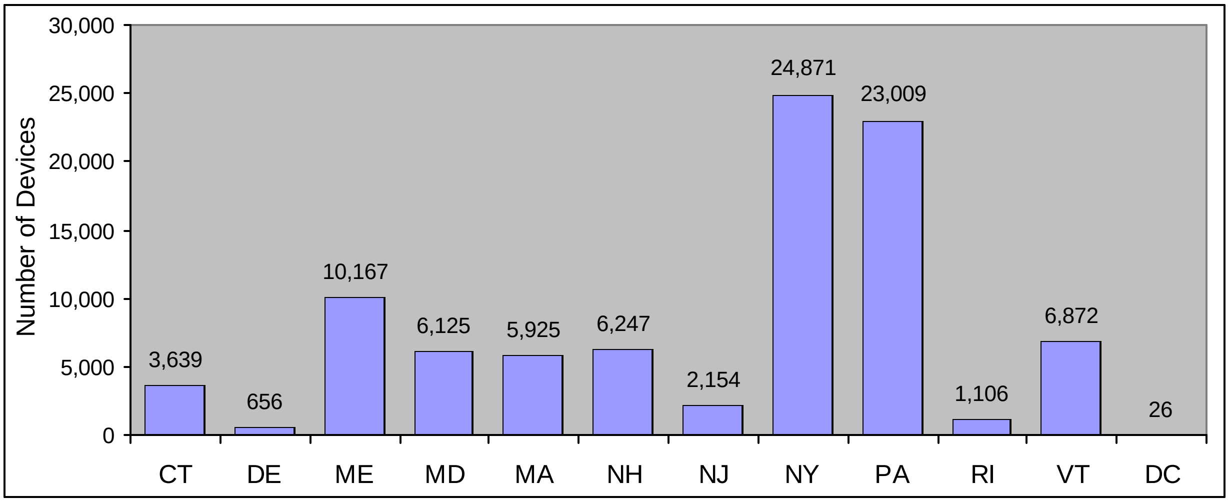


Figure 2.05 Total Number of Pellet Heaters

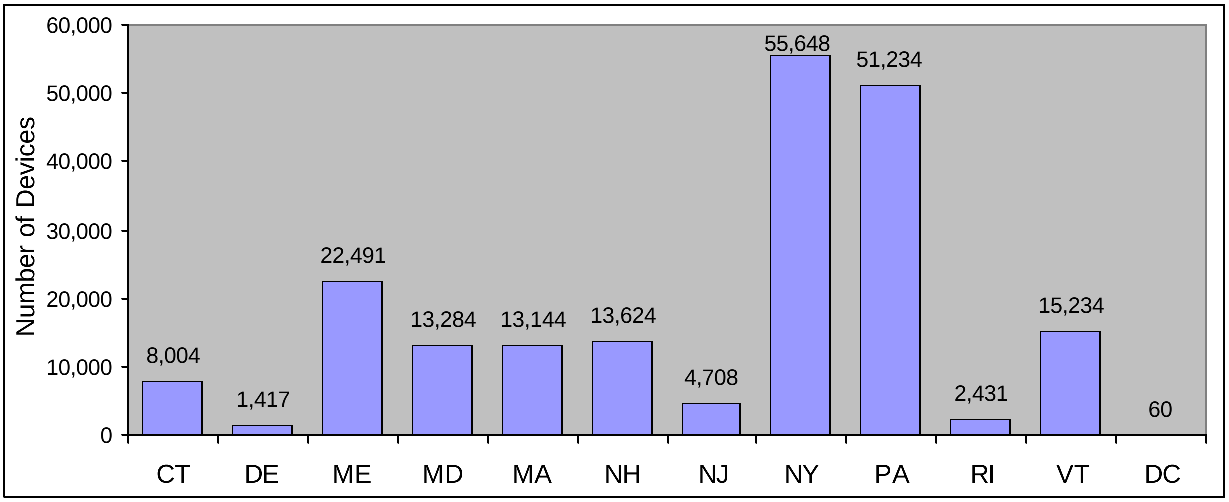


Figure 2.06 Map of the Total Number of RWC Devices Used for Heat in the MANE-VU Region by County

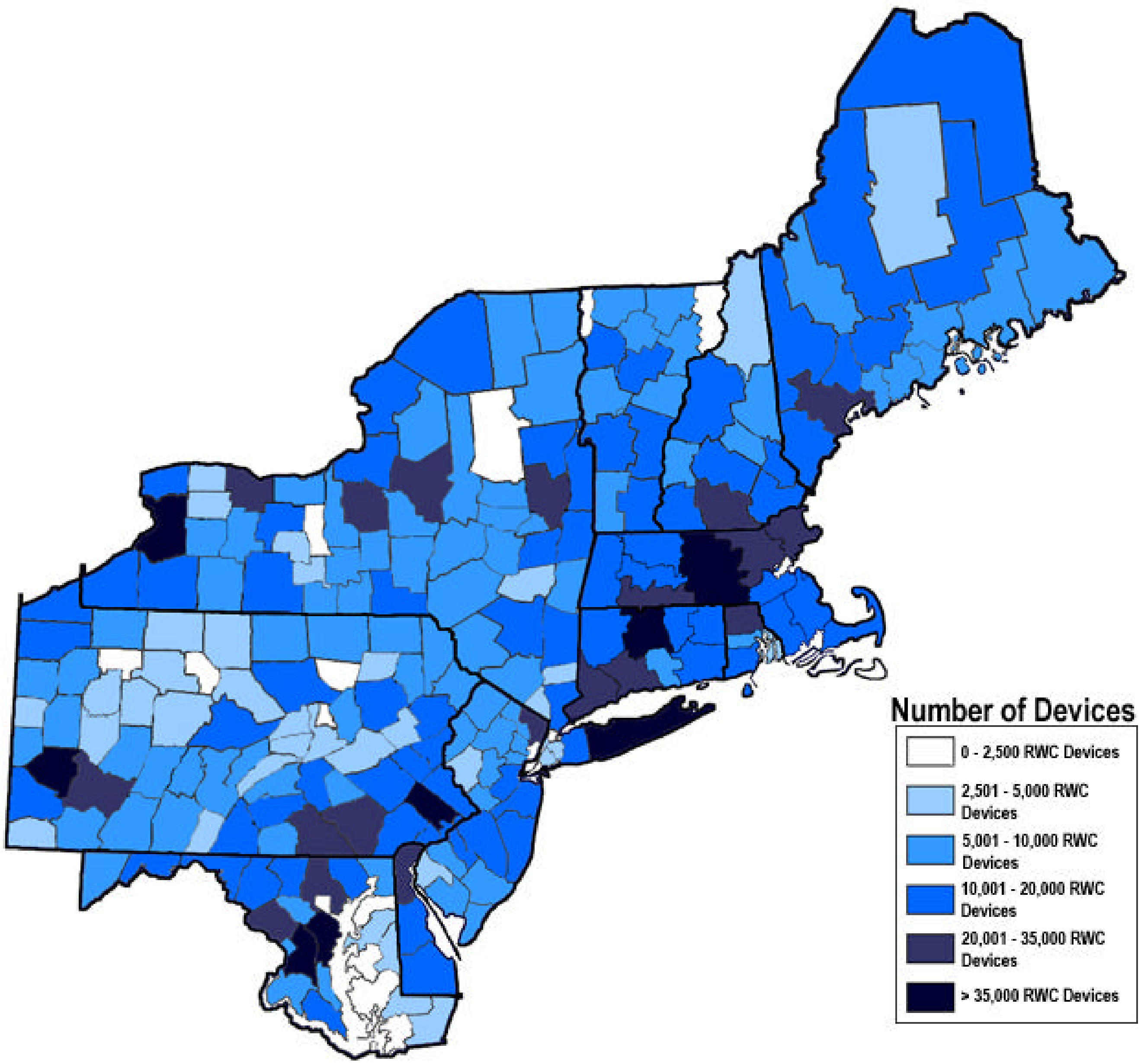


Figure 2.07 Fraction of Households Using RWC Devices

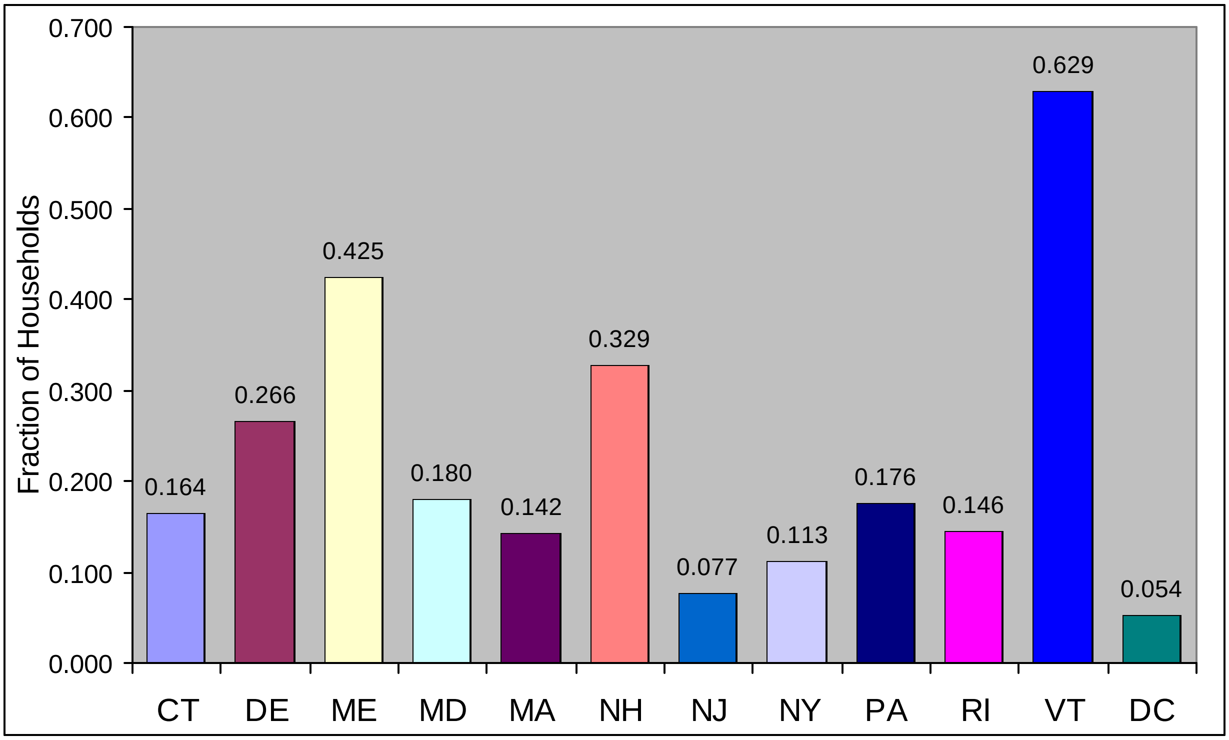


Figure 2.08 Fraction of Households Using Wood Heaters

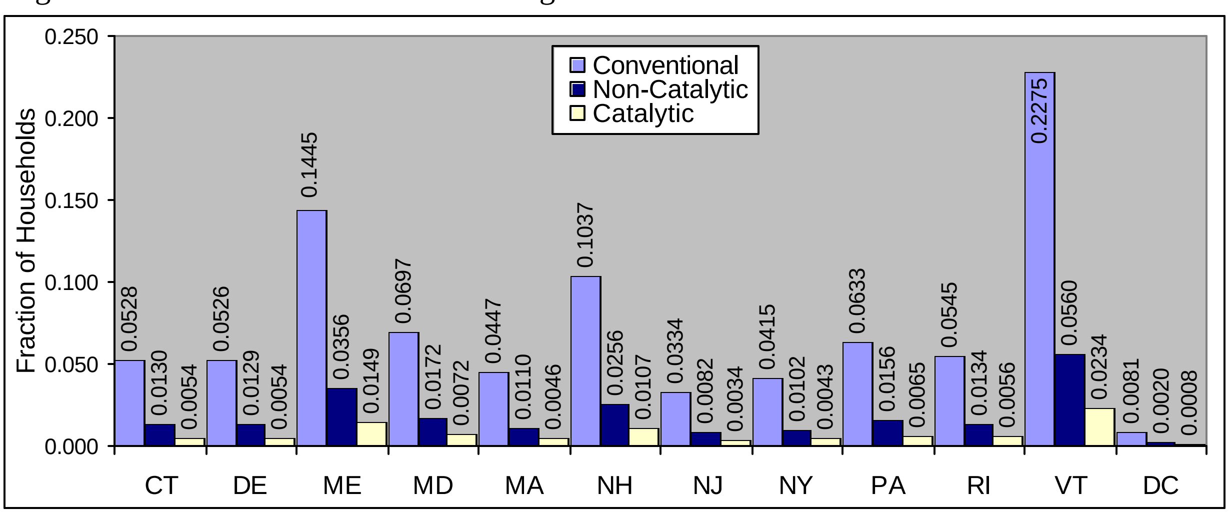


Figure 2.09 Fraction of Households Using Fireplaces without Inserts

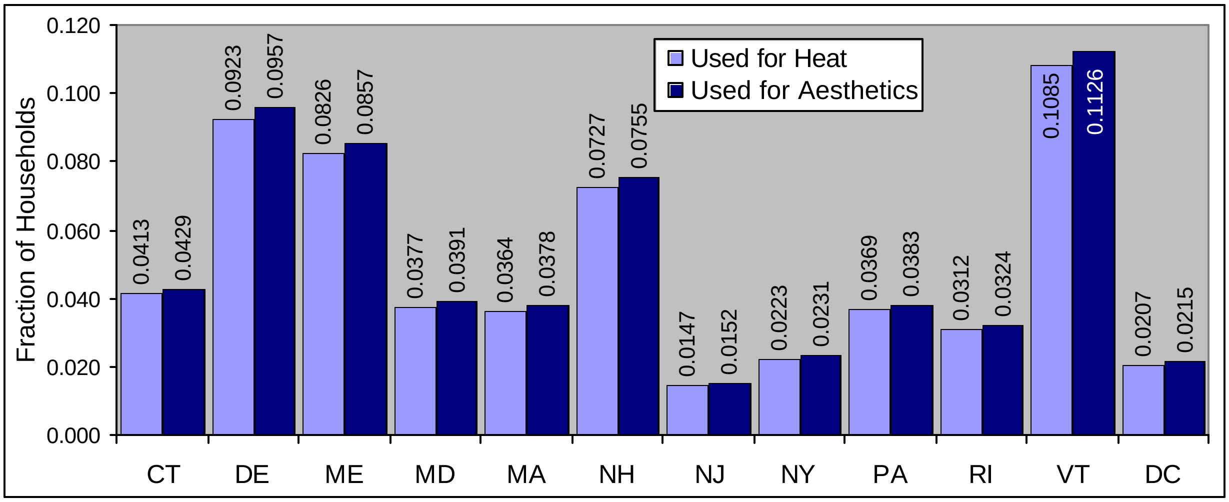


Figure 2.10 Fraction of Households Using Centralized Cordwood Heating Systems

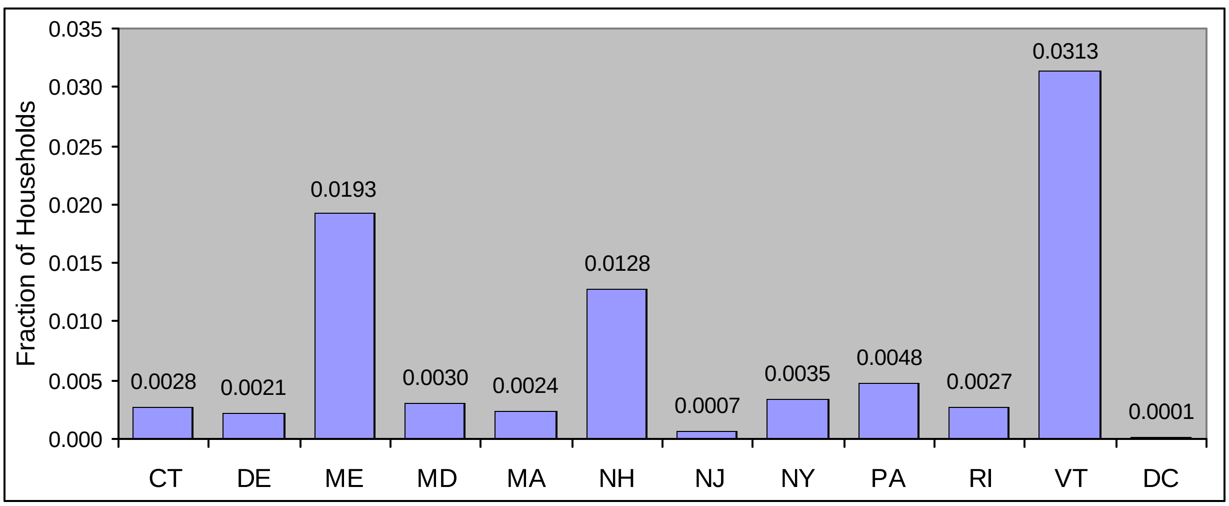


Figure 2.11 Fraction of Households Using Pellet Heaters

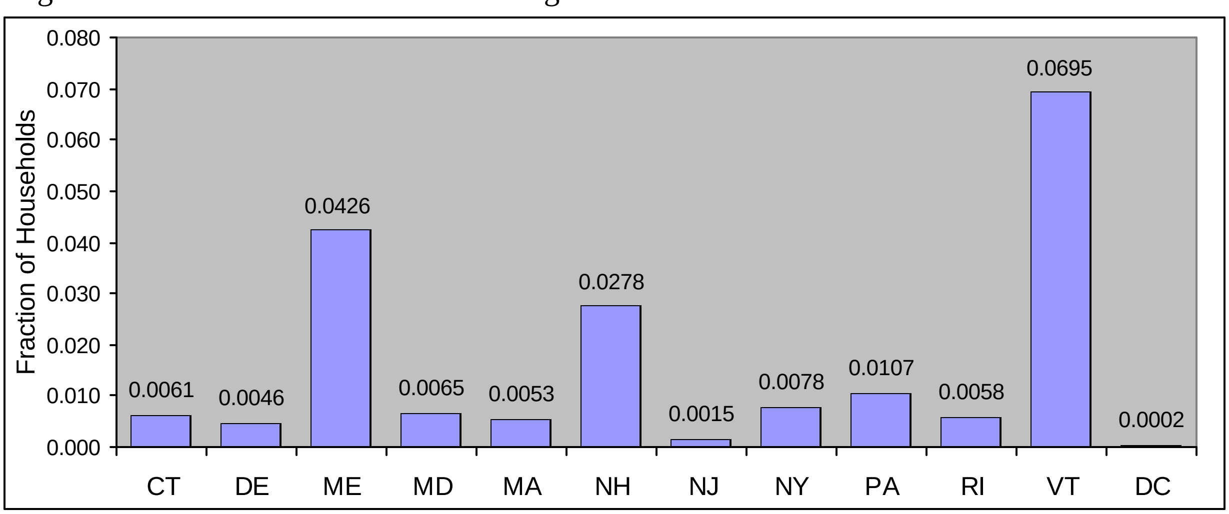


Figure 2.12 Map of the Fraction of Households Using RWC Devices for Heat in the MANE-VU Region by County

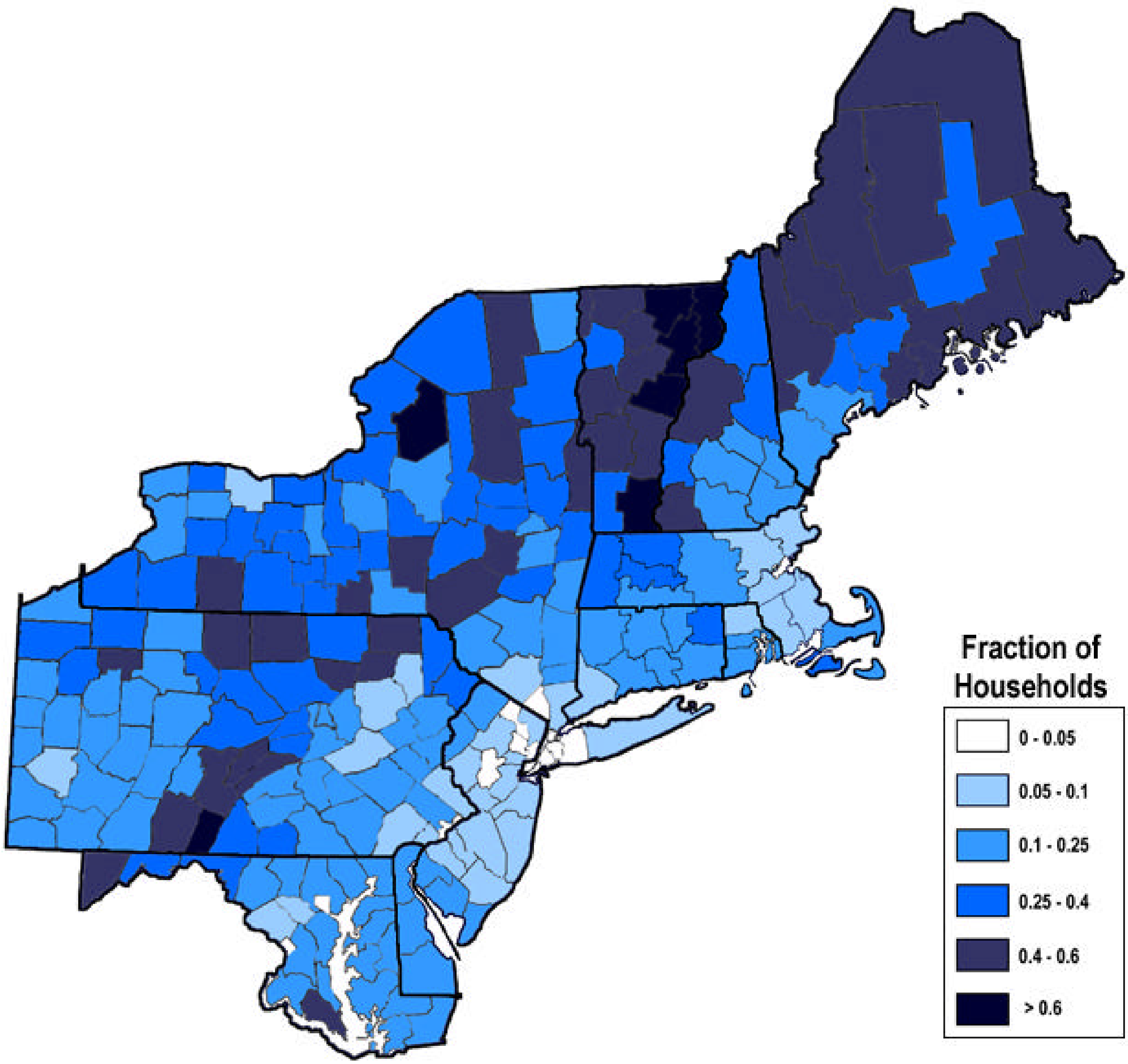


Figure 2.13 Total Mass of Fuel Burned by RWC Devices

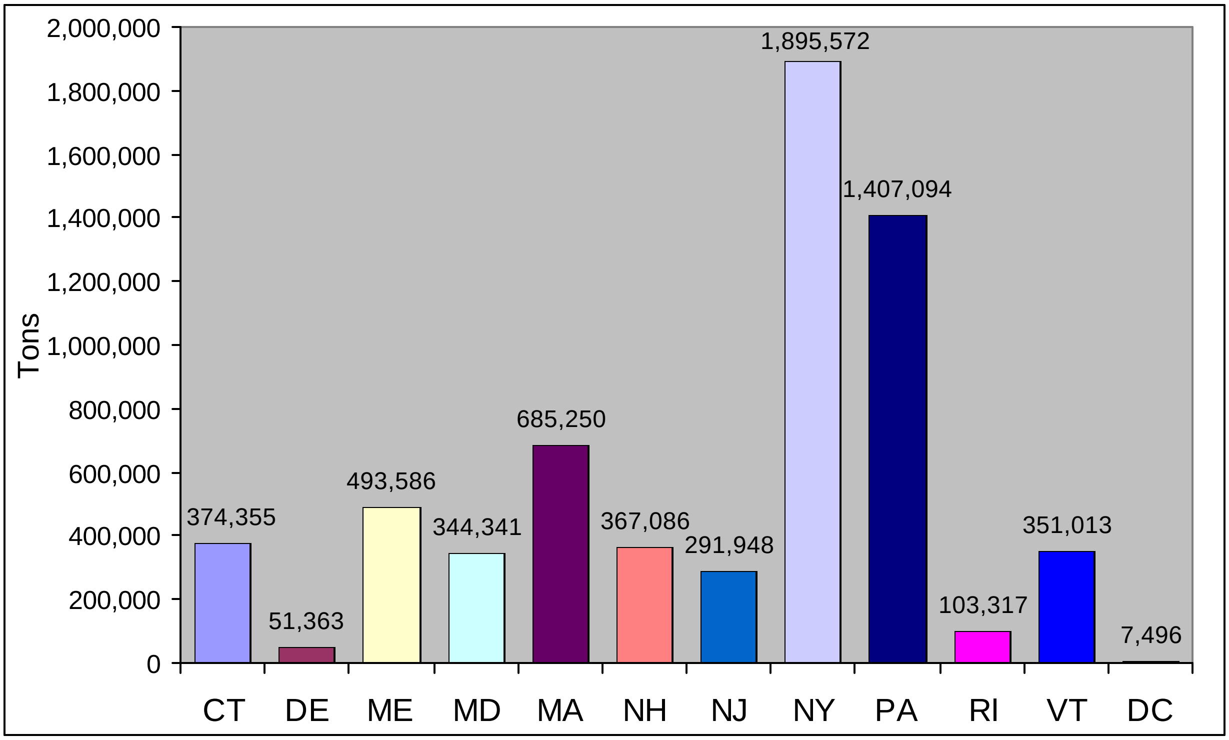


Figure 2.14 Total Mass of Cordwood and Firelogs Burned by Wood Heaters

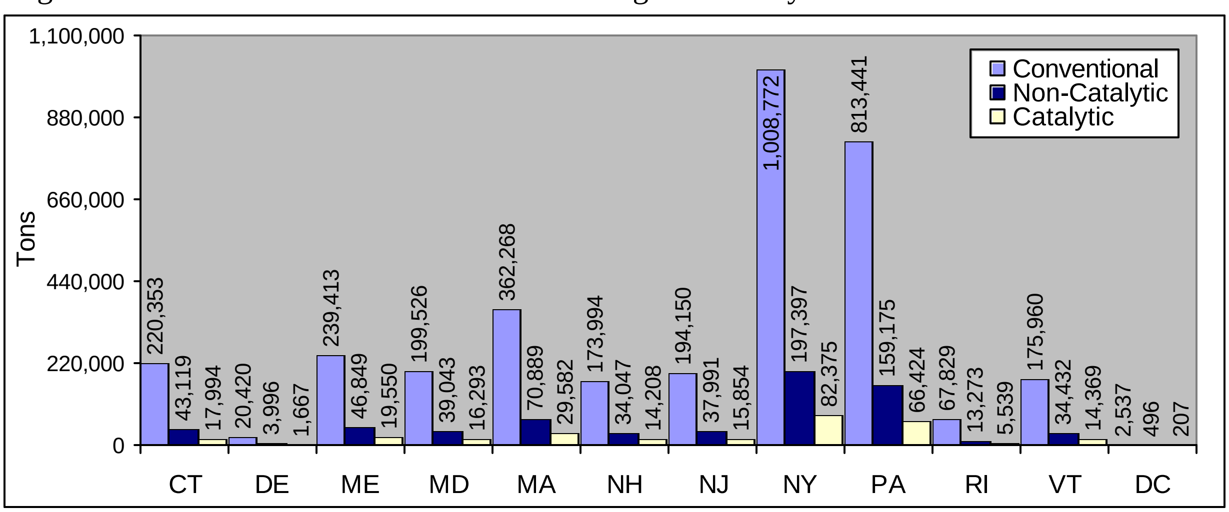


Figure 2.15 Total Mass of Cordwood Burned by Fireplaces Without Inserts

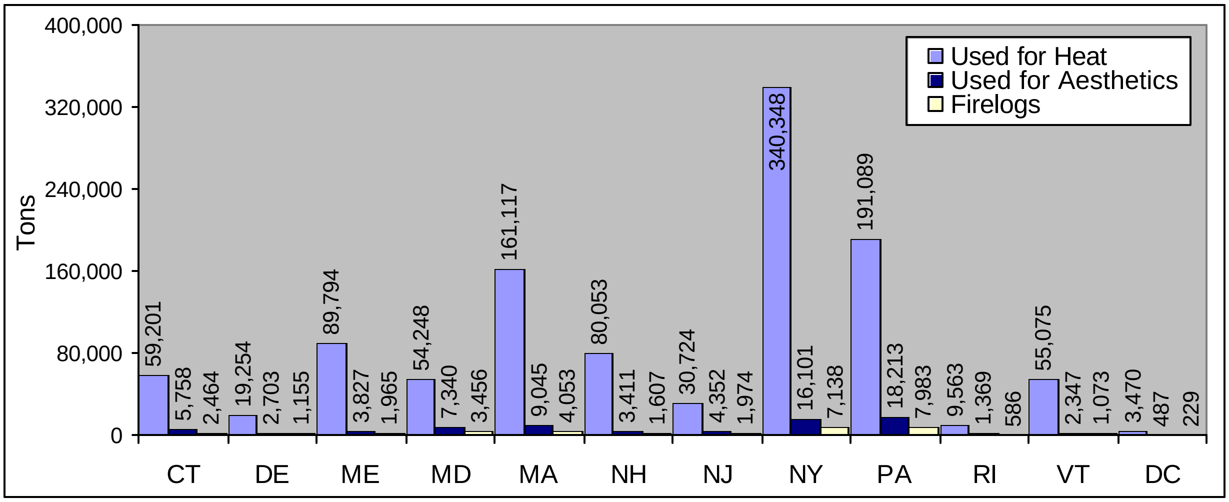


Figure 2.16 Total Mass of Cordwood Burned by Centralized Cordwood Heaters

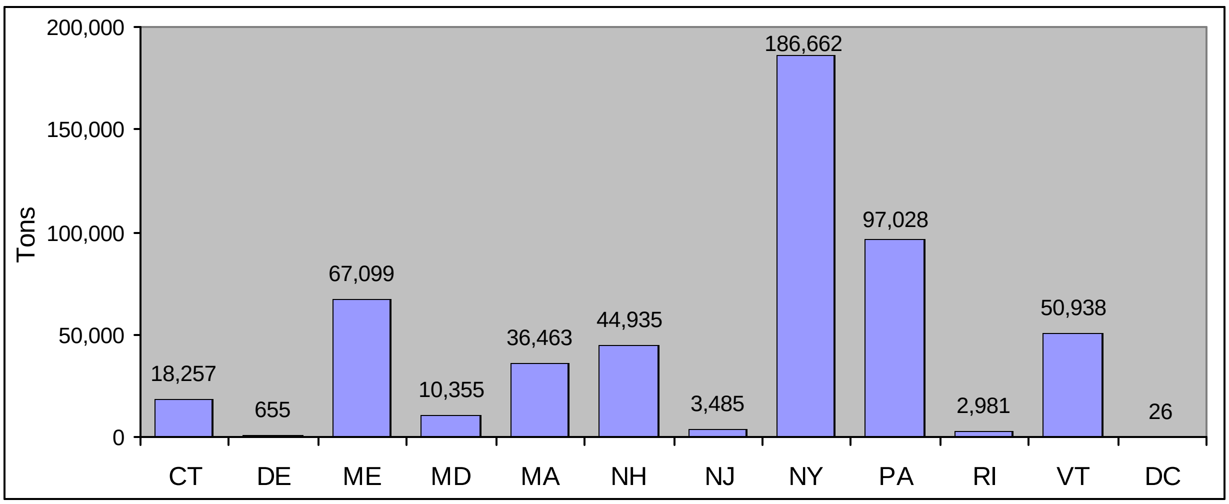


Figure 2.17 Total Mass of Pellets Burned by Pellet Heaters

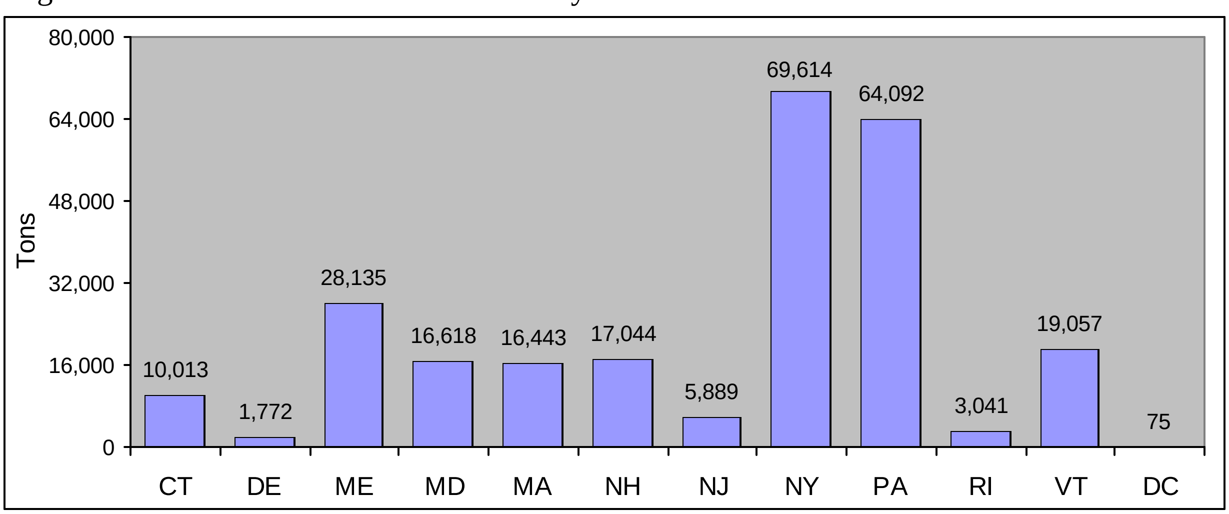
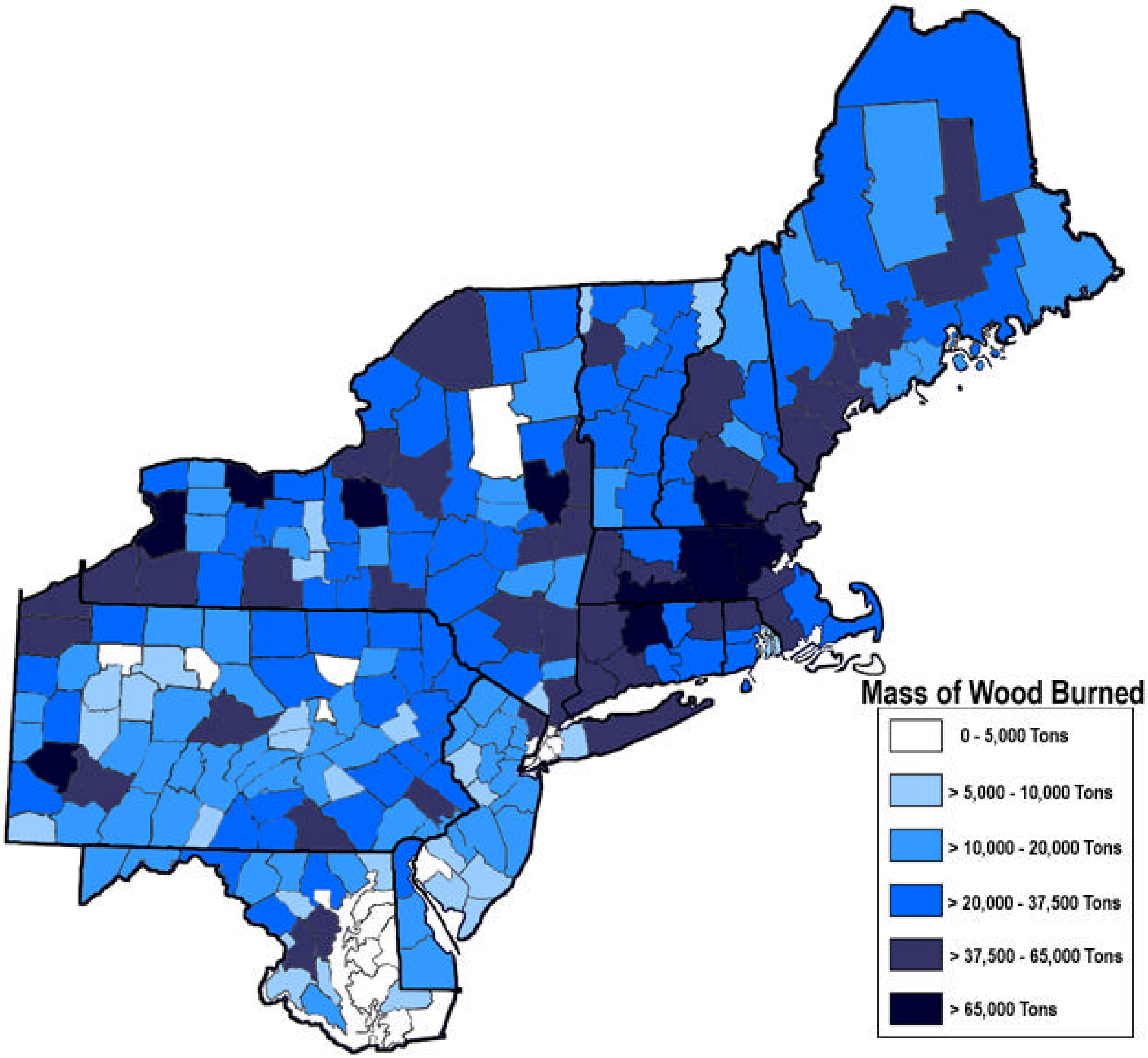


Figure 2.18 Map of the Total Dry Mass of Wood Burned by RWC Devices in the MANE-VU Region by County



3. Emissions Inventory

The emissions inventory was compiled by county, by state and for the entire MANE-VU region and has been provided for each of the major wood-burning device categories (Table 3.01). The air pollutants included in the inventory were selected based on their relevancy to RWC, availability of reasonable emission factors, and comments provided by MARAMA's review team. These air pollutants are listed in Table 3.02.

Table 3.01 Wood-Burning Device Categories

Category	Comments
Uncertified conventional cordwood heater	Sum of freestanding units and fireplace inserts
EPA-certified non-catalytic cordwood heater	
EPA-certified catalytic cordwood heater	
Cordwood-burning fireplace without insert	Separate emission inventories calculated for cordwood and manufactured wax/fiber fuel use, also for aesthetic and heating cordwood use.
Centralized Cordwood Systems	Sum of cordwood furnaces and boilers. Both inside and outside boilers included.
Pellet Heater	Sum of freestanding units and fireplace inserts. Both EPA-certified and exempt units included.

Table 3.02 Emissions Inventory Air Pollutants

Pollutant	Comments
$PM_{2.5}$	Assumed equivalent to PM, reported as 5H equivalent
PM_{10}	Assumed equivalent of PM, reported as 5H equivalent
Nitrogen oxides (NO_x)	Reported as NO_2
Carbon monoxide (CO)	
Sulfur dioxide (SO_2)	
Ammonia (NH_3)	
Benzene	
Phenol	
7-PAH	
16-PAH	
Benzo(a)pyrene	
Naphthalene	
1,3-Butadiene	
Formaldehyde	
Acetaldehyde	
Acrolein	
Creosols	Sum of o, m and p isomers
PCB_{TEQ}	
$Dioxin_{TEQ}$	
Methane	
Volatile Organic Compounds (VOC)	

The calculation of the emission inventory for each appliance type broken down to the county level, state level, and for the entire MANE-VU region is straightforward. The dry mass of fuel (activity) for cordwood, pellets, and manufactured wax/fiber firelogs, shown in units of kilograms, compiled in the activity task was multiplied by the applicable emission factor in the units of mass air pollutant per mass of dry fuel (g/kg, mg/kg, µg/kg, ng/kg, or pg/kg). The emission factors were obtained by reviewing and averaging (if multiple sources were available) data obtained from available reports and publications. The emission factor and emission inventory tables are offered with little narrative, as they are self-explanatory. It should be noted that while some of the emission factors tabulated in AP-42 (which are also the source of many subsequent tabulations that are in the public domain) were used, new sources of data were also used as the AP-42 data lack currency and are limited. For example, many pollutants are not provided for each category of wood-burning devices and some primary data sources referenced in AP-42 clearly have values that can be considered "outliers" in light of a review of more extensive and current data. (See VOC discussion for fireplaces without inserts under Section 3.1.2.)

It needs to be emphasized that there is considerable and unquantifiable uncertainty in the development of an emission inventory for RWC as the emission inventory is (1) the product of RWC emission factors and activity, (2) the activity is, in turn, the product of the number of RWC devices in use and the average mass of fuel burned in them annually, (3) the mass of fuel is calculated from the average number cords burned annually and the weighed mass of a cord of wood by state, and (4) the weighed mass of a cord of wood by state is dependent on the tree species endemic to the state. There is no standardized methodology for collecting or interpreting these data and they have been compiled by various research organizations, governmental agencies and hearth industry groups. As noted in the introduction to this report, OMNI has reviewed previous emission inventories (see reference 1) and used them as a basis, along with new data, to provide an improved emission inventory, however it is up to the individual states to assess the inventory most appropriate for their applications, such as would be used in an State Implementation Plan. The cost effectiveness portion of this report utilizes the emission inventory data generated by the methods outlined here.

3.1. Methodology

Emission factors for each of the wood-burning device categories (cordwood heaters, pellet heaters, fireplaces without inserts, and centralized cordwood heating systems) have been tabulated separately. The emission factors for cordwood heaters have been subdivided further into uncertified conventional, certified non-catalytic, and certified catalytic cordwood heaters. Emission factors for fireplaces without inserts have been tabulated for both their use of cordwood and manufactured wax/fiber firelogs.

As noted in the introduction, OMNI reviewed previous inventories and used their results and input data, along with aspects of their methodology, to develop the methodology presented here. As RWC is an area source, with numerous diverse appliance types and classifications, there is a higher inherent uncertainty than for many point sources or more uniform sources, such as transportation. The methodology developed by OMNI was based on best professional judgment and a corporate history with the hearth industry. It is necessarily limited and was steered by existing databases and it is, in general, consistent with methods used for the development of air quality emission inventories for other source categories. However, other methodologies have been and can be used.

Some sources for the emission factors are themselves reviews, rather than primary sources and hence the emission factors listed in them are already averages. In these cases, the primary references are included along with the reference to the review. Some sources included in reviews were not included in the averages because the data contained in them were clearly outliers or were misinterpretations when compared with data from subsequent and more current work.

The selection of data (references) for compiling average emission factors had a number of criteria. These were:

1. The wood-burning device tested was a commercially available unit, not a novel research unit, or an atypical unit not generally used by the public.
2. Reasonable burn rates and representative fuel were used in the testing.
3. A narrative was provided documenting established and/or technically sound testing and analytical methodologies.
4. If there was a large enough literature database available for a given pollutant, the reported emission factor or the emission factor calculated from data provided in the document was evaluated to determine if it were an outlier as compared to data from other sources (i.e., outside of two standard deviations of the mean of the other data). An outlier status could be indicative of a non-representative use of the wood-burning devices, or measurement or calculation errors.
5. Adequate supporting ancillary data was supplied along with the key emission factor data to establish the veracity of the results. These included fuel moisture, temperatures and pressures associated with gas volumes, operational temperatures, stack gas velocities, etc.
6. The emission factor units or the units of data used to calculate the emission factors, as well as units for supporting ancillary data, were provided.
7. Some of the references were review documents with the emission factors being the compilation of primary measurements from more than one source. Care was taken to insure that data form no reference was included in the calculation of the final recommended emission factors more than once.
8. Calculation methods were either provided or transparent.
9. Institutional and/or authorship information was provided with unpublished reports.

3.1.1. Cordwood Heaters

Emission factors for cordwood heaters are applicable to freestanding cordwood stoves and cordwood fireplace inserts. All cordwood heaters sold after July 1, 1990 in the United States have to be certified for low emissions unless they had an exemption. Two technologies have been used to achieve low emissions. These are catalytic and non-catalytic. Catalytic units, of course, rely on a catalyst to reduce air emissions. Non-catalytic technologies rely on the introduction of heated secondary air and other design features to achieve low emissions.

It has been generally recognized that uncertified conventional, certified catalytic and certified non-catalytic cordwood heaters have different characteristic emission factors; consequently the emission factors have been tabulated separately for each of the three types.

(1) Uncertified Conventional Cordwood Heaters

Emission factors for uncertified conventional cordwood heaters have been obtained from three categories of heaters. These are: (1) heaters manufactured before the NSPS July 1, 1990 certification requirement, (2) currently or recently manufactured exempt units which operate similarly to some old pre-EPA certification units, and (3) low-technology units sold outside the United States.

(2) Certified Non-Catalytic Cordwood Heaters

Emission factors for certified non-catalytic cordwood heaters were primarily obtained from: (1) units that are certified under the NSPS program, and (2) high-technology units sold outside of the United States that are equivalent to modern certified units sold in the U.S.

(3) Certified Catalytic Cordwood Heaters

Emission factors for certified catalytic cordwood heaters were primarily obtained from: (1) units that are certified under the NSPS program, (2) catalytic units sold outside of the United States that are equivalent to modern certified units sold in the U.S., and (3) research units that were never produced and were not certified, but are similar to certified units. Catalysts degrade with use, increasing emissions. Some of data used in the calculations of average emission factors were for new units, and some were from used units.

3.1.2. Fireplaces without Inserts

Emission factors for fireplaces include manufactured units and site-built masonry units both operated with and without glass doors.

(1) Cordwood

Emission factors for fireplaces burning cordwood were derived from fireplaces burning both cordwood and from laboratory studies, which used dimensional lumber as a reproducible surrogate for cordwood.

It is important to note that the VOC emission factor used in this report is much lower than the VOC emission factor in AP-42. This is due to the fact that the AP-42 used an average of nine emission factors from three documents created between 1977 and 1983[38.16,50,52.10]. Of those nine emission factors, two were clearly outliers (from reference 52.10) since they are 37 and 13 standard deviations larger than the mean of 12.9 g/kg (which excluded the two outliers). Since the report containing the two outliers only contained three emission factors, the entire report was omitted. After the report's three emission factors were removed, 11 emission factors from two more recent studies[37,51] were averaged with the remaining six factors from AP-42 to determine the more reasonable updated VOC emission factor for fireplaces without inserts burning cordwood.

(2) Manufactured Wax/Fiber Firelogs

Separate emission factors were tabulated for manufactured wax/fiber firelogs burned in fireplaces. Because wax/fiber firelogs are typically composed of 40% to 60% wax or wax-like materials, their emission characteristics are considerably different than wood alone. Care should be taken when reviewing the emission factors for wax/fiber firelogs as they contain almost twice as much heat per unit mass as does wood, they do not require kindling and the manufacturers' instructions are for one-at-a-time use. Consequently, they are presented here for the purpose of calculating an emission inventory, not for a comparison of their emissions with cordwood.

3.1.3. Centralized Cordwood Heating Systems

Emission factors for centralized cordwood heating systems were calculated from data obtained from: (1) cordwood-fired hot-air furnaces, (2) cordwood-fired indoor boilers, and (3) cordwood-fired outdoor boilers (often referred to as hydronic heaters). Data from both more modern units with heat storage tanks and gasification-like designs and from more traditional units operating intermittently with thermostatic control were included.

3.1.4. Pellet Heaters

Emission factors for pellet heaters were obtained from (1) older models, (2) modern models (3) EPA-certified models, and (4) EPA-exempt models. Modern pellet heaters (stoves and fireplace inserts) are of two basic technology types: bottom-feed and top feed. Data from both types were used in the development of emission factors. For some pollutants, no data were available for pellet heaters. In some of these cases, data from centralized pellet heating systems operating under a continuous burning cycle were used to estimate emissions from pellet heaters, as combustion conditions are similar.

Table 3.03 Summary of Emission Factors

Pollutant	Units	Uncertified Conventional Cordwood Heaters	Certified Catalytic Cordwood Heaters	Certified Non-Catalytic Cordwood Heaters	Pellet Heaters	Fireplaces without Inserts Burning Cordwood	Fireplaces without Inserts Burning Manufactured Wax/Fiber Firelogs	Centralized Cordwood Heating Systems
$PM_{2.5}$ *	g/kg	16.9	8.37	7.51	1.53	15.27	24.1	13.82
PM_{10} *	g/kg	16.9	8.37	7.51	1.53	15.27	24.1	13.82
NO_x **	g/kg	1.28	1.00	1.14	1.90	1.45	3.23	0.92
CO	g/kg	78.4	53.5	70.40	7.96	74.6	68.5	91.8
SO_2	g/kg	0.10	0.20	0.20	0.16	0.20	2.08	1.01
NH_3	g/kg	0.85	0.45	0.45	0.15	0.90	0.002	0.90
Benzene	g/kg	1.08	1.12	0.48	0.01	0.34	0.45	1.38
Phenol	g/kg	0.15	0.20	0.24	0.01	0.24	0.02	0.12
7-PAH	g/kg	0.02	0.01	0.01	0.03	0.11	0.002	0.02
16-PAH	g/kg	0.32	0.14	0.16	0.35	0.38	0.06	0.26
Benzo(a)pyrene	mg/kg	0.84	1.97	1.09	3.34	0.37	0.48	1.37
Naphthalene	g/kg	0.09	0.08	0.07	0.21	0.13	0.03	0.07
1,3-Butadiene	g/kg	0.20	0.10	0.09	0.0005	0.08	0.01	0.01
Formaldehyde	g/kg	0.73	0.49	1.11	0.16	0.90	0.75	0.35
Acetaldehyde	g/kg	0.31	0.27	0.32	0.05	0.53	0.06	0.34
Acrolein	g/kg	0.05	0.02	0.02	0.01	0.06	0.02	0.02
Cresols***	g/kg	0.08	0.27	0.23	0.01	0.18	0.02	0.07
PCB_{TEQ}	pg/kg	0.50	0.25	1.40	0.10	0.38	1.63	0.55
$Dioxin_{TEQ}$	ng/kg	2.30	1.14	0.40	1.900	0.39	1.22	4.16
Methane	g/kg	32.0	13.0	14.2	0.12	7.21	38.75	13.05
VOC****	g/kg	18.4	8.60	10.1	0.02	9.43	16.9	5.85
References		30-38, 38.01-38.11, 39	30-31, 33-38, 38.01-38.03, 38.05-38.06, 38.09-38.15	30-34, 36-38, 38.01-38.13, 38.16, 39-40, 44	30, 32, 35-36, 38, 38.17-38.18, 40-48	21, 30, 32, 37, 38.11, 38.16, 41-43, 49-54	32, 37, 41-43, 49.01-49.02, 49.06-49.08, 49.11, 49.15, 51-52, 52.13, 52.21-52.24, 53, 55	30, 32, 35-38, 45, 47, 56-58

* Reported as EPA Method 5H equivalent
** NO_x is total nitrogen oxides reported as NO_2
*** Sum of o, m, and p isomers
**** If not specifically stated, assumed to be non-methane VOC

3.2. Emission Inventory by County, State, and Total MANE-VU Region

The emissions inventories are provided in Tables 3.05 – 3.23 for each pollutant by state and appliance category for the 2002 base year, and in Table 3.24 for the total MANE-VU region by pollutant and appliance category for the 2002 base year. As PM and VOC (an ozone precursor) are the main criteria pollutants of concern for RWC and non-attainment areas, their emission inventory levels are also included in bar charts by state, and as a set of maps showing the total PM and VOC emission distribution by county. The remaining 18 pollutants included in the emission inventory were not provided as maps or figures, but are compiled in Tables 3.06 - 3.23, as the pollutant distribution by county will closely follow the PM and VOC maps, which follow the distribution of activity by county.

The maps, figures, and tables in this section represent emissions from devices used for primary and secondary heating, and aesthetic fireplace without insert use. To obtain an intuitive understanding of the differences between counties and states, it may be helpful to view both the map of the fraction of households using RWC devices for heat (Figure 2.12) and the map of the total number of RWC devices used for heat (Figure 2.06), and compare them to the emission maps (Figure 3.06 and Figure 3.12).

Emission inventories are provided in units of english tons of pollutant, except for Benzo(a)pyrene, which is shown as pounds, $Dioxin_{TEQ}$, which is shown as milligrams, and PCB_{TEQ}, which is shown as micrograms.

Figure 3.01 Total PM Emissions from RWC Devices

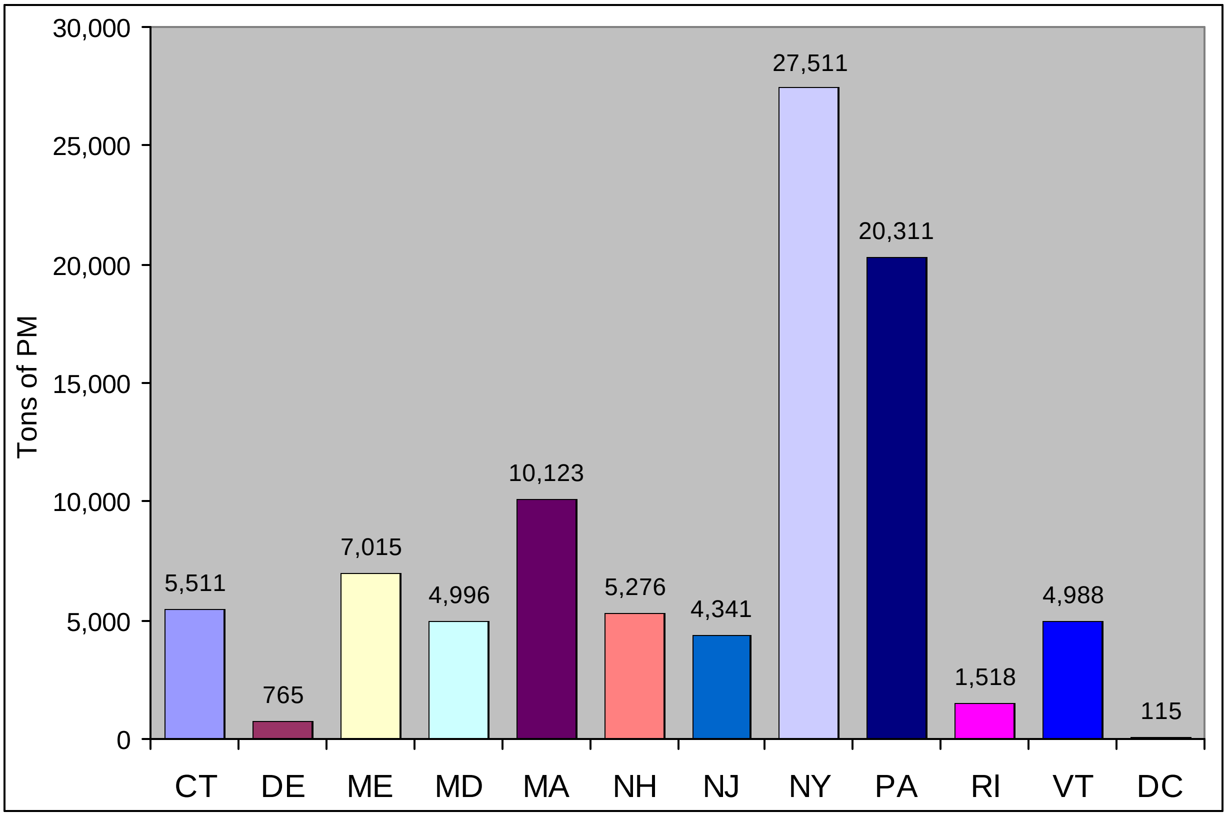


Figure 3.02 Total PM Emissions from Wood Heaters

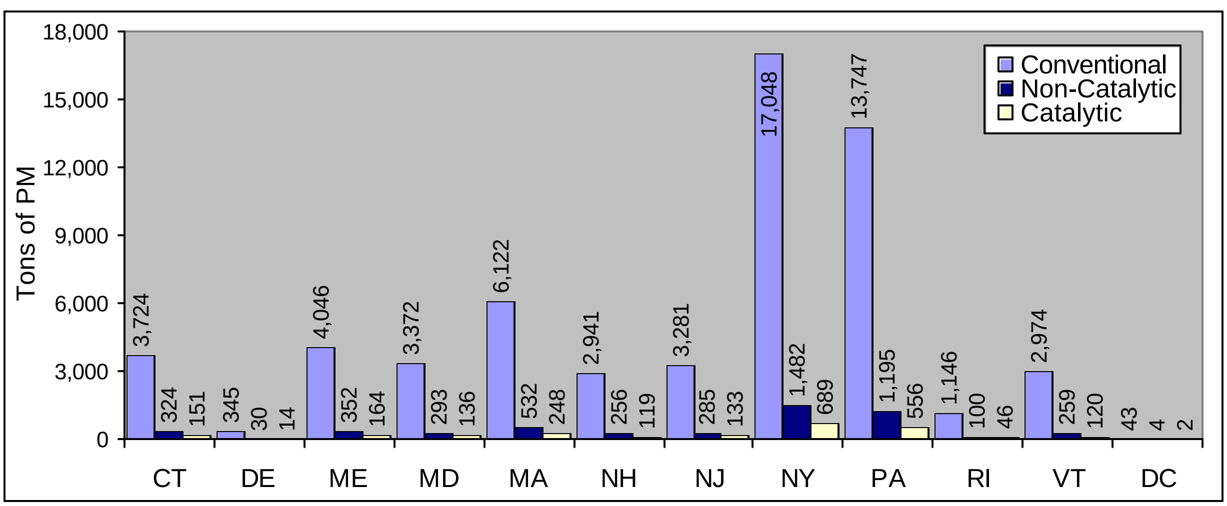


Figure 3.03 Total PM Emissions from Fireplaces without Inserts

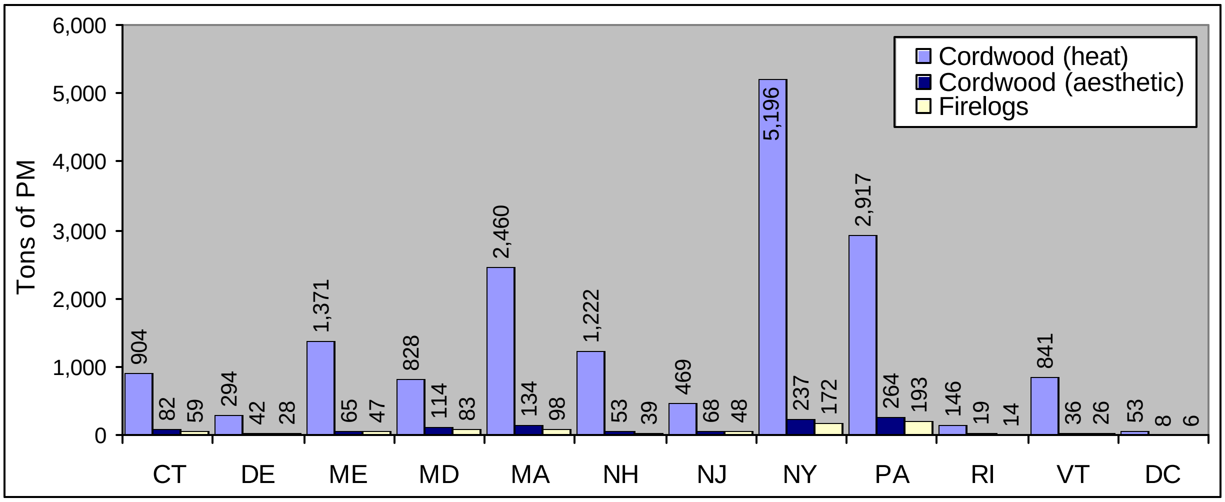


Figure 3.04 Total PM Emissions from Centralized Cordwood Heating Systems

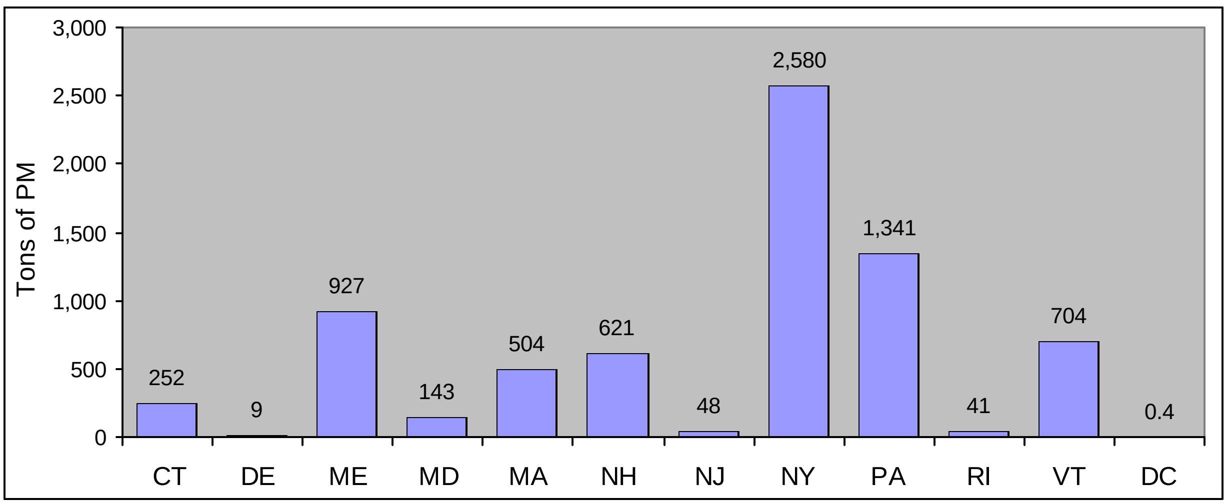


Figure 3.05 Total PM Emissions from Pellet Heaters

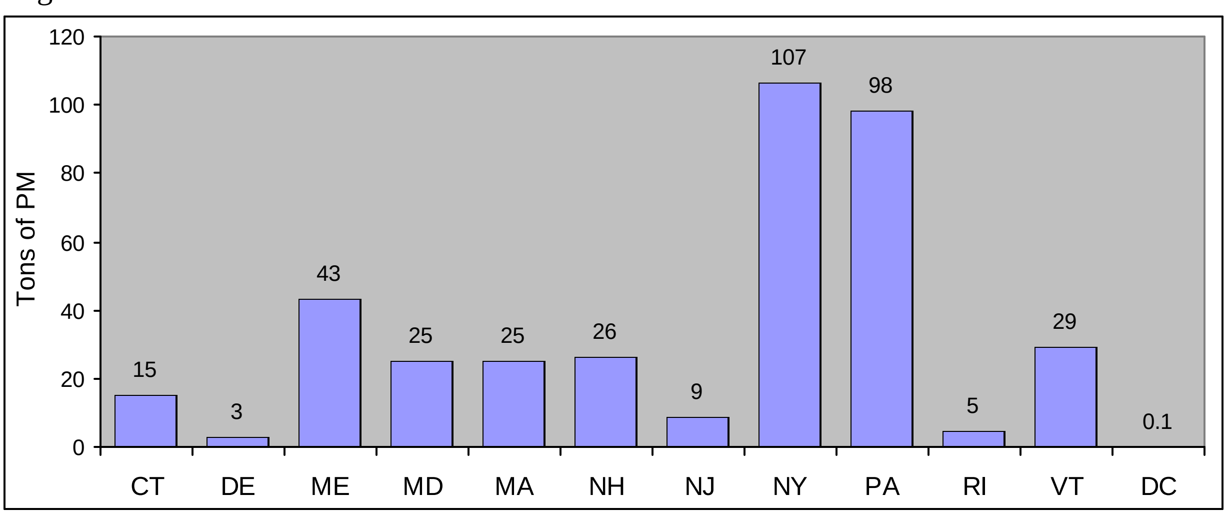


Figure 3.06 Map of the Total RWC PM Emissions for the MANE-VU Region by County

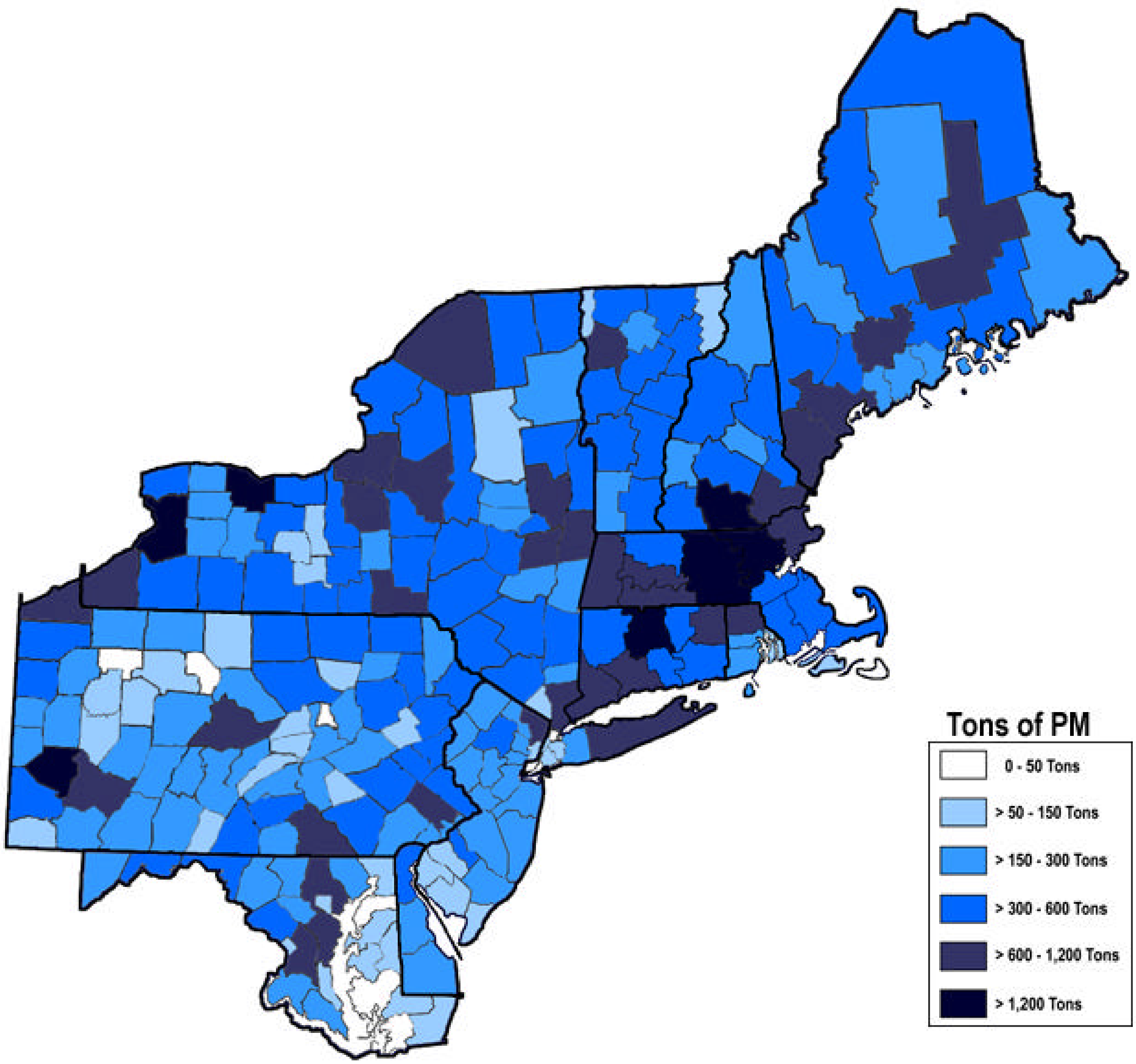


Figure 3.07 Total VOC Emissions from RWC Devices

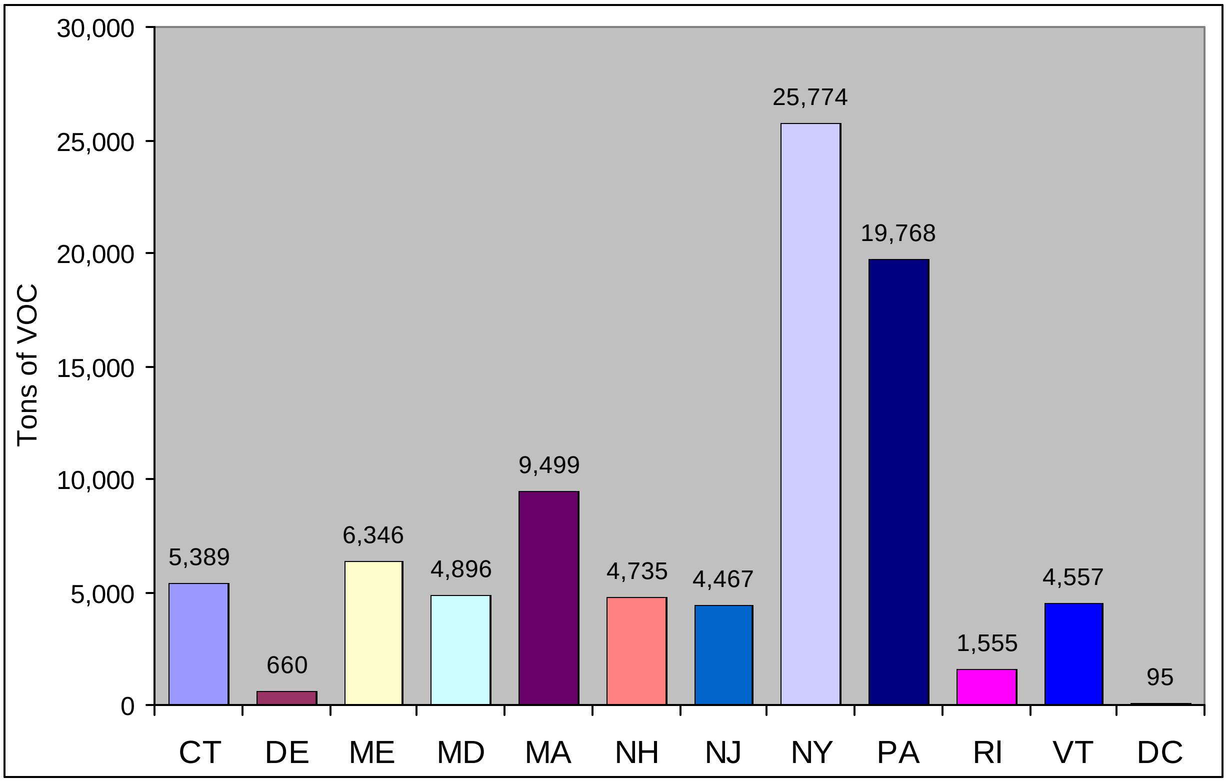


Figure 3.08 Total VOC Emissions from Wood Heaters

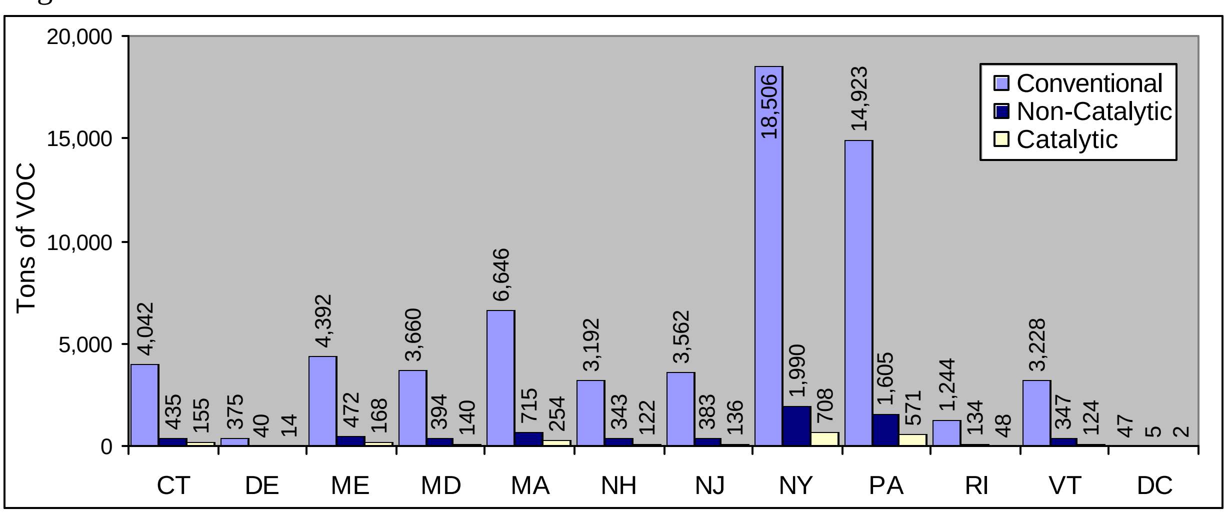


Figure 3.09 Total VOC Emissions from Fireplaces without Inserts

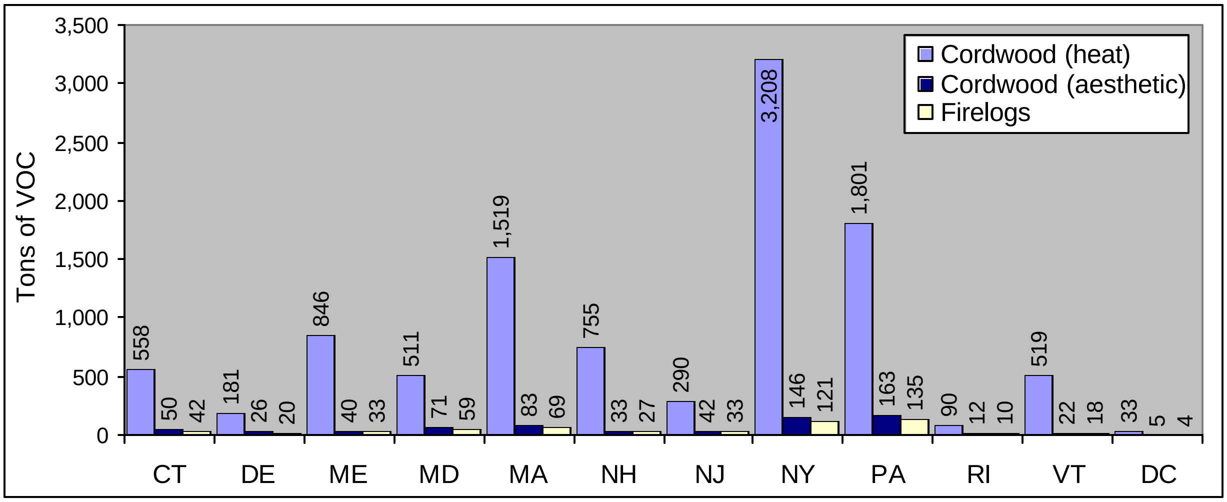


Figure 3.10 Total VOC Emissions from Centralized Cordwood Heating Systems

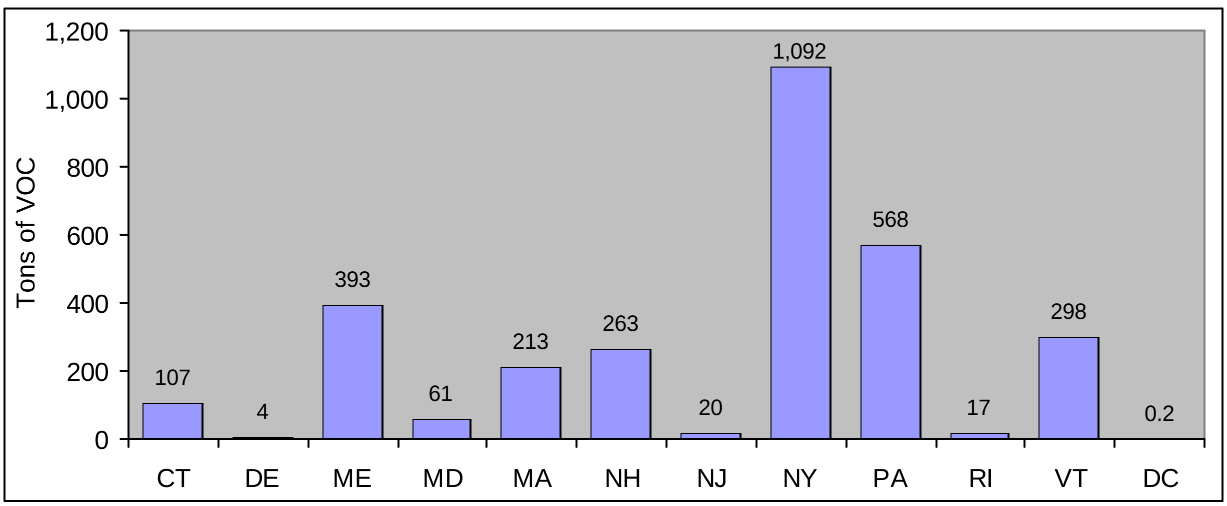


Figure 3.11 Total VOC Emissions from Pellet Heaters

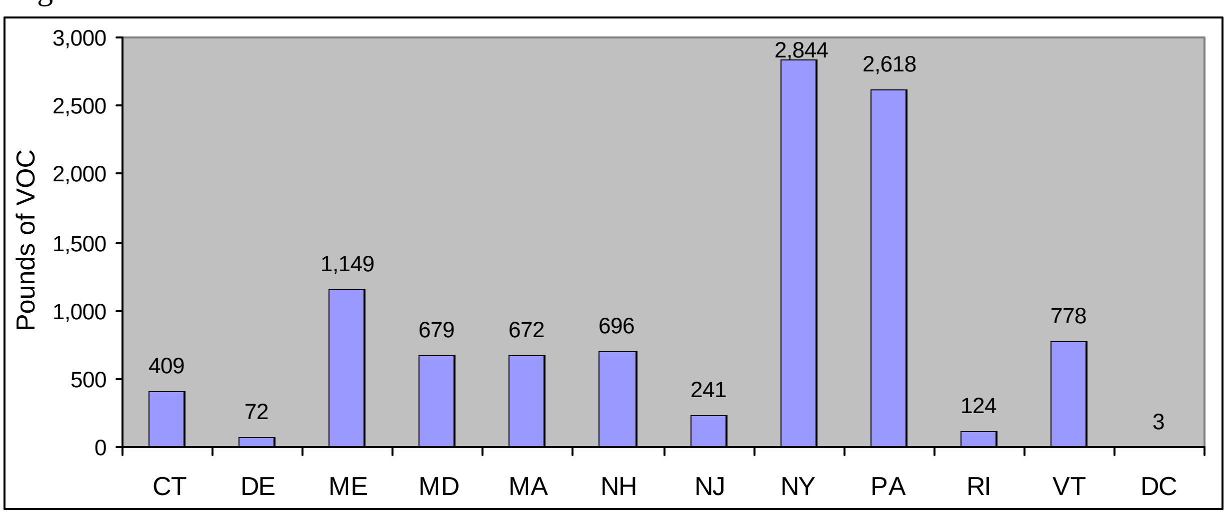


Figure 3.12 Map of the Total RWC VOC Emissions for the MANE-VU Region by County

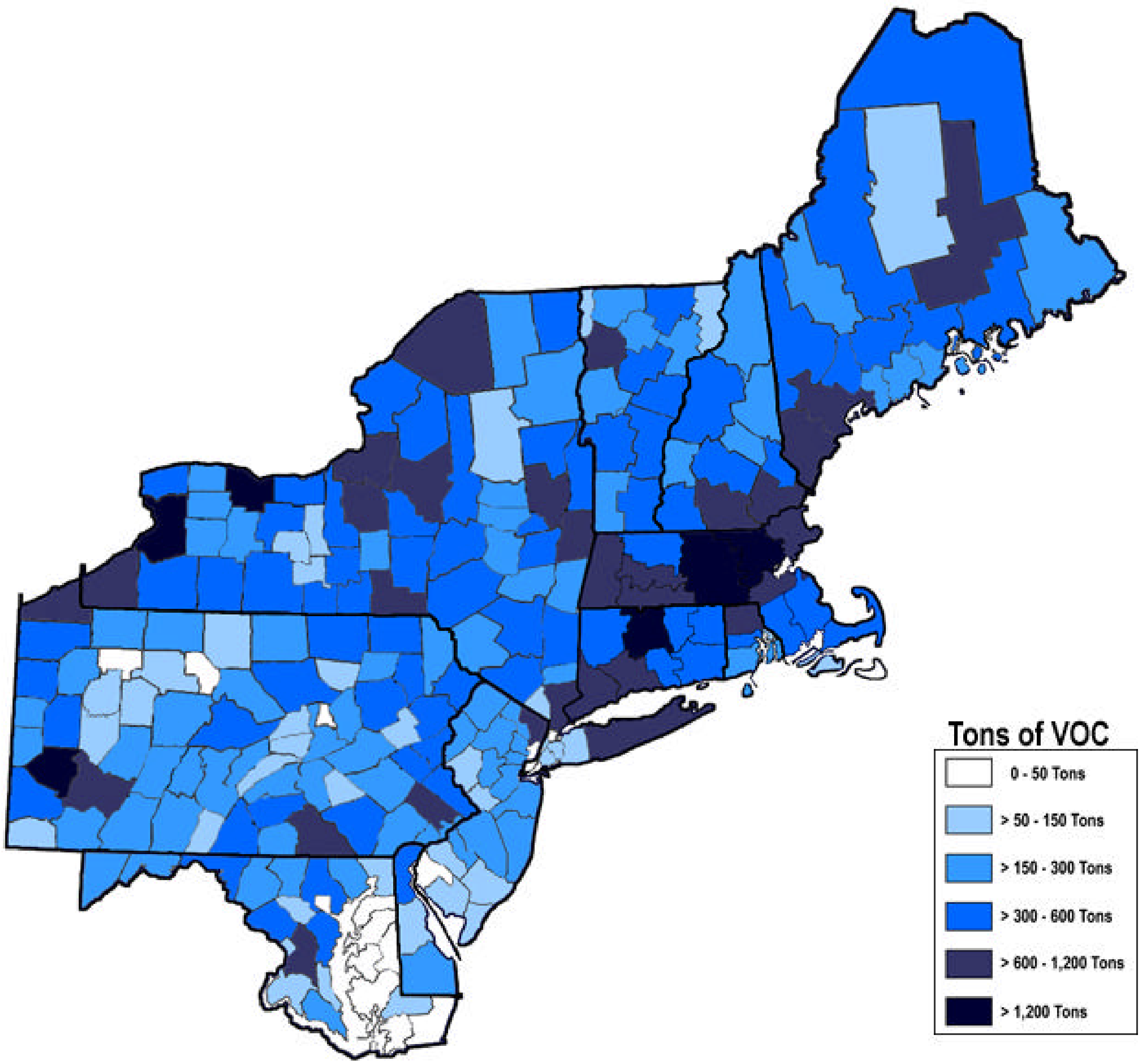


Table 3.04 PM Emission Inventory

State	Tons of PM								
	Total RWC	Wood Heaters			Fireplaces without Inserts			Centralized Cordwood Heating Systems	Pellet Heaters
		Conventional	Non-Catalytic	Catalytic	Cordwood (heat)	Cordwood (aesthetic)	Firelogs		
CT	5,511	3,724	324	151	904	82	59	252	15
DE	765	345	30	14	294	42	28	9	3
ME	7,015	4,046	352	164	1,371	65	47	927	43
MD	4,996	3,372	293	136	828	114	83	143	25
MA	10,123	6,122	532	248	2,460	134	98	504	25
NH	5,276	2,941	256	119	1,222	53	39	621	26
NJ	4,341	3,281	285	133	469	68	48	48	9
NY	27,511	17,048	1,482	689	5,196	237	172	2,580	107
PA	20,311	13,747	1,195	556	2,917	264	193	1,341	98
RI	1,518	1,146	100	46	146	19	14	41	5
VT	4,988	2,974	259	120	841	36	26	704	29
D.C.	115	43	4	2	53	8	6	0.4	0.1
M-V	92,471	58,789	5,112	2,377	16,701	1,122	813	7,171	386

M-V represents the MANE-VU region average

Table 3.05 VOC Emission Inventory

State	Tons of VOC								
	Total RWC	Wood Heaters			Fireplaces without Inserts			Centralized Cordwood Heating Systems	Pellet Heaters
		Conventional	Non-Catalytic	Catalytic	Cordwood (heat)	Cordwood (aesthetic)	Firelogs		
CT	5,389	4,042	435	155	558	50	42	107	0.2
DE	660	375	40	14	181	26	20	4	0.04
ME	6,346	4,392	472	168	846	40	33	393	0.6
MD	4,896	3,660	394	140	511	71	59	61	0.3
MA	9,499	6,646	715	254	1,519	83	69	213	0.3
NH	4,735	3,192	343	122	755	33	27	263	0.3
NJ	4,467	3,562	383	136	290	42	33	20	0.1
NY	25,774	18,506	1,990	708	3,208	146	121	1,092	1.4
PA	19,768	14,923	1,605	571	1,801	163	135	568	1.3
RI	1,555	1,244	134	48	90	12	10	17	0.06
VT	4,557	3,228	347	124	519	22	18	298	0.4
D.C.	95	47	5	2	33	5	4	0.2	0.002
M-V	87,740	63,817	6,864	2,443	10,312	693	570	3,036	5

M-V represents the MANE-VU region average

Table 3.06 NO_x Emission Inventory

State	Tons of NO_x								
	Total RWC	Wood Heaters			Fireplaces without Inserts			Centralized Cordwood Heating Systems	Pellet Heaters
		Conventional	Non-Catalytic	Catalytic	Cordwood (heat)	Cordwood (aesthetic)	Firelogs		
CT	487	283	49	18	86	8	8	17	19
DE	72	26	5	2	28	4	4	0.6	3
ME	638	307	53	20	130	6	6	62	54
MD	459	256	45	16	79	11	11	10	32
MA	899	465	81	30	234	13	13	34	31
NH	476	223	39	14	116	5	5	41	32
NJ	380	249	43	16	45	6	6	3	11
NY	2,445	1,294	225	82	494	22	23	172	133
PA	1,830	1,043	181	66	277	25	26	89	122
RI	134	87	15	6	14	2	2	3	6
VT	449	226	39	14	80	3	3	47	36
D.C.	11	3	0.6	0.2	5	0.7	0.7	0.02	0.1
M-V	8,280	4,462	776	284	1,586	107	109	478	479

*NO_x is total nitrogen oxides reported as NO_2
M-V represents the MANE-VU region average

Table 3.07 CO Emission Inventory

State	Tons of CO								
	Total RWC	Wood Heaters			Fireplaces without Inserts			Centralized Cordwood Heating Systems	Pellet Heaters
		Conventional	Non-Catalytic	Catalytic	Cordwood (heat)	Cordwood (aesthetic)	Firelogs		
CT	28,016	17,279	3,036	963	4,416	398	169	1,675	80
DE	3,768	1,601	281	89	1,436	207	79	60	14
ME	36,650	18,773	3,298	1,046	6,699	318	135	6,158	224
MD	25,191	15,646	2,749	872	4,047	559	237	950	132
MA	51,409	28,407	4,991	1,583	12,019	655	277	3,346	131
NH	27,402	13,644	2,397	760	5,972	260	110	4,124	136
NJ	21,875	15,224	2,675	848	2,292	334	135	320	47
NY	142,126	79,102	13,897	4,407	25,390	1,157	489	17,130	554
PA	104,052	63,785	11,206	3,554	14,255	1,290	547	8,904	510
RI	7,695	5,319	934	296	713	95	40	274	24
VT	26,172	13,798	2,424	769	4,109	173	73	4,675	152
D.C.	560	199	35	11	259	37	16	2	0.6
M-V	474,915	272,777	47,922	15,197	81,607	5,483	2,306	47,618	2,004

M-V represents the MANE-VU region average

Table 3.08 SO_2 Emission Inventory

State	Tons of SO_2								
	Total RWC	Wood Heaters			Fireplaces without Inserts			Centralized Cordwood Heating Systems	Pellet Heaters
		Conventional	Non-Catalytic	Catalytic	Cordwood (heat)	Cordwood (aesthetic)	Firelogs		
CT	73	23	9	4	12	1	5	18	2
DE	11	2	0.8	0.3	4	0.6	2	0.7	0.3
ME	133	25	9	4	18	0.9	4	68	4
MD	64	21	8	3	11	1	7	10	3
MA	140	38	14	6	32	2	8	37	3
NH	96	18	7	3	16	0.70	3	46	3
NJ	47	20	8	3	6	0.90	4	4	0.9
NY	447	105	39	16	68	3	15	189	11
PA	296	84	32	13	38	3	17	98	10
RI	18	7	3	1	2	0.3	1	3	0.5
VT	96	18	7	3	11	0.5	2	52	3
D.C.	2	0.3	0.1	0.04	0.7	0.1	0.5	0.03	0.01
M-V	1,423	361	136	57	219	15	70	525	39

M-V represents the MANE-VU region average

Table 3.09 NH_3 Emission Inventory

State	Tons of NH_3								
	Total RWC	Wood Heaters			Fireplaces without Inserts			Centralized Cordwood Heating Systems	Pellet Heaters
		Conventional	Non-Catalytic	Catalytic	Cordwood (heat)	Cordwood (aesthetic)	Firelogs		
CT	291	187	19	8	53	5	0.005	16	2
DE	41	17	2	0.8	17	2	0.002	0.6	0.3
ME	383	204	21	9	81	4	0.004	60	4
MD	262	170	18	7	49	7	0.007	9	2
MA	541	308	32	13	145	8	0.008	33	2
NH	288	148	15	6	72	3	0.003	40	3
NJ	225	165	17	7	28	4	0.004	3	0.9
NY	1,482	857	89	37	306	14	0.01	168	10
PA	1,077	691	72	30	172	16	0.02	87	10
RI	79	58	6	2	9	1	0.001	3	0.5
VT	272	150	15	6	50	2	0.002	46	3
D.C.	6	2	0.2	0.09	3	0.4	0.0005	0.02	0.01
M-V	4,947	2,957	306	128	985	66	0.07	467	38

M-V represents the MANE-VU region average

Table 3.10 Benzene Emission Inventory

State	Tons of Benzene								
	Total RWC	Wood Heaters			Fireplaces without Inserts			Centralized Cordwood Heating Systems	Pellet Heaters
		Conventional	Non-Catalytic	Catalytic	Cordwood (heat)	Cordwood (aesthetic)	Firelogs		
CT	327	238	21	20	20	2	1	25	0.1
DE	35	22	2	2	7	1	0.5	0.9	0.03
ME	429	258	22	22	31	1	0.9	93	0.4
MD	290	215	19	18	19	3	2	14	0.2
MA	569	391	34	33	55	3	2	50	0.2
NH	312	188	16	16	27	1	0.7	62	0.2
NJ	263	210	18	18	11	2	0.9	5	0.08
NY	1,660	1,089	95	92	117	5	3	258	1
PA	1,239	878	76	74	66	6	4	134	0.9
RI	94	73	6	6	3	0.4	0.3	4	0.04
VT	313	190	17	16	19	0.8	0.5	70	0.3
D.C.	5	3	0.2	0.2	1	0.2	0.1	0.04	0.001
M-V	5,535	3,755	326	317	375	25	15	718	4

M-V represents the MANE-VU region average

Table 3.11 Phenol Emission Inventory

State	Tons of Phenol								
	Total RWC	Wood Heaters			Fireplaces without Inserts			Centralized Cordwood Heating Systems	Pellet Heaters
		Conventional	Non-Catalytic	Catalytic	Cordwood (heat)	Cordwood (aesthetic)	Firelogs		
CT	64	33	11	4	14	1	0.05	2	0.1
DE	10	3	1	0.3	5	0.7	0.02	0.08	0.02
ME	81	35	11	4	21	1	0.04	8	0.4
MD	58	29	10	3	13	2	0.06	1	0.2
MA	122	53	17	6	38	2	0.07	4	0.2
NH	62	26	8	3	19	0.8	0.03	5	0.2
NJ	50	29	9	3	7	1	0.04	0.4	0.07
NY	321	149	48	17	80	4	0.13	23	0.9
PA	234	120	39	14	45	4	0.15	12	0.8
RI	17	10	3	1	2	0.3	0.01	0.4	0.04
VT	57	26	8	3	13	0.5	0.02	6	0.2
D.C.	1	0.4	0.1	0.04	0.8	0.1	0.004	0.003	0.0009
M-V	1,079	513	166	58	258	17	0.6	63	3

M-V represents the MANE-VU region average

Table 3.12 7-PAH Emission Inventory

State	Tons of 7-PAH								
	Total RWC	Wood Heaters			Fireplaces without Inserts			Centralized Cordwood Heating Systems	Pellet Heaters
		Conventional	Non-Catalytic	Catalytic	Cordwood (heat)	Cordwood (aesthetic)	Firelogs		
CT	13	5	0.6	0.2	7	0.6	0.004	0.3	0.3
DE	3	0.4	0.1	0.02	2	0.3	0.002	0.01	0.05
ME	19	5	0.6	0.3	10	0.5	0.004	1	0.9
MD	13	4	0.5	0.2	6	0.8	0.006	0.2	0.5
MA	29	8	1.0	0.4	18	1	0.007	0.7	0.5
NH	15	4	0.5	0.2	9	0.4	0.003	0.8	0.5
NJ	9	4	0.5	0.2	3	0.5	0.004	0.06	0.2
NY	71	22	3	1	37	2	0.01	3	2
PA	48	18	2	0.9	21	2	0.01	2	2
RI	3	1	0.2	0.1	1	0.1	0.001	0.05	0.09
VT	12	4	0.5	0.2	6	0.3	0.002	0.9	0.6
D.C.	1	0.06	0.007	0.003	0.4	0.05	0.0004	0.0005	0.002
M-V	235	77	9	4	120	8	0.06	9	8

M-V represents the MANE-VU region average

Table 3.13 16-PAH Emission Inventory

State	Tons of 16-PAH								
	Total RWC	Wood Heaters			Fireplaces without Inserts			Centralized Cordwood Heating Systems	Pellet Heaters
		Conventional	Non-Catalytic	Catalytic	Cordwood (heat)	Cordwood (aesthetic)	Firelogs		
CT	111	69	7	3	22	2	0.2	5	3
DE	16	6	0.6	0.2	7	1	0.07	0.2	0.6
ME	148	75	7	3	34	2	0.1	17	10
MD	103	63	6	2	20	3	0.2	3	6
MA	209	114	11	4	60	3	0.3	9	6
NH	111	55	5	2	30	1	0.1	12	6
NJ	86	61	6	2	12	2	0.1	0.9	2
NY	567	318	31	12	128	6	0.5	48	24
PA	417	256	25	9	72	6	0.5	25	22
RI	30	21	2	0.8	4	0.5	0.04	0.8	1
VT	104	55	5	2	21	0.9	0.07	13	7
D.C.	2	0.8	0.08	0.03	1	0.2	0.01	0.007	0.03
M-V	1,904	1,096	107	40	410	28	2	134	87

M-V represents the MANE-VU region average

Table 3.14 Benzo(a)pyrene Emission Inventory

State	Pounds of Benzo(a)pyrene								
	Total RWC	Wood Heaters			Fireplaces without Inserts			Centralized Cordwood Heating Systems	Pellet Heaters
		Conventional	Non-Catalytic	Catalytic	Cordwood (heat)	Cordwood (aesthetic)	Firelogs		
CT	702	370	94	71	44	4	2	50	67
DE	81	34	9	7	14	2	1	2	12
ME	1,025	402	102	77	66	3	2	183	188
MD	673	335	85	64	40	6	3	28	111
MA	1,219	609	155	117	119	6	4	100	110
NH	723	292	74	56	59	3	2	123	114
NJ	549	326	83	63	23	3	2	10	39
NY	3,696	1,695	431	325	252	11	7	510	465
PA	2,832	1,367	348	262	141	13	8	265	428
RI	202	114	29	22	7	0.9	0.6	8	20
VT	738	296	75	57	41	2	1	139	127
D.C.	10	4	1	0.8	3	0.4	0.2	0.07	0.5
M-V	12,449	5,844	1,487	1,121	809	54	32	1,418	1,683

M-V represents the MANE-VU region average

Table 3.15 Naphthalene Emission Inventory

State	Tons of Naphthalene								
	Total RWC	Wood Heaters			Fireplaces without Inserts			Centralized Cordwood Heating Systems	Pellet Heaters
		Conventional	Non-Catalytic	Catalytic	Cordwood (heat)	Cordwood (aesthetic)	Firelogs		
CT	37	20	3	1	8	0.7	0.09	1	2
DE	6	2	0.3	0.1	3	0.4	0.04	0.05	0.4
ME	50	22	3	2	12	0.6	0.07	5	6
MD	35	18	3	1	7	1	0.1	0.8	4
MA	69	33	5	2	21	1	0.1	3	3
NH	37	16	2	1	11	0.5	0.06	3	4
NJ	28	18	3	1	4	0.6	0.07	0.3	1
NY	188	92	14	6	45	2	0.2	14	15
PA	139	74	11	5	25	2	0.3	7	14
RI	10	6	0.9	0.4	1	0.2	0.02	0.2	0.6
VT	35	16	2	1	7	0.3	0.04	4	4
D.C.	1	0.2	0.03	0.02	0.5	0.07	0.008	0.002	0.02
M-V	633	316	47	22	145	10	1	39	53

M-V represents the MANE-VU region average

Table 3.16 1,3-Butadiene Emission Inventory

State	Tons of 1,3-Butadiene								
	Total RWC	Wood Heaters			Fireplaces without Inserts			Centralized Cordwood Heating Systems	Pellet Heaters
		Conventional	Non-Catalytic	Catalytic	Cordwood (heat)	Cordwood (aesthetic)	Firelogs		
CT	54	43	4	2	5	0.4	0.02	0.3	0.005
DE	6	4	0.3	0.2	2	0.2	0.01	0.01	0.0008
ME	61	47	4	2	7	0.3	0.02	1	0.01
MD	49	39	3	2	4	0.6	0.03	0.2	0.008
MA	94	71	6	3	13	0.7	0.03	0.5	0.008
NH	46	34	3	1	6	0.3	0.01	0.7	0.008
NJ	46	38	3	2	2	0.4	0.02	0.05	0.003
NY	254	198	17	8	27	1	0.06	3	0.03
PA	198	160	14	6	15	1	0.07	1	0.03
RI	16	13	1	0.5	0.8	0.1	0.005	0.04	0.001
VT	44	35	3	1	4	0.2	0.009	0.7	0.009
D.C.	1	0.5	0.04	0.02	0.3	0.04	0.002	0.0004	0.00004
M-V	871	684	59	28	86	6	0.3	8	0.1

M-V represents the MANE-VU region average

Table 3.17 Formaldehyde Emission Inventory

State	Tons of Formaldehyde								
	Total RWC	Wood Heaters			Fireplaces without Inserts			Centralized Cordwood Heating Systems	Pellet Heaters
		Conventional	Non-Catalytic	Catalytic	Cordwood (heat)	Cordwood (aesthetic)	Firelogs		
CT	285	160	48	9	53	5	2	6	2
DE	41	15	4	0.8	17	2	0.9	0.2	0.3
ME	349	174	52	10	81	4	1	23	4
MD	261	145	43	8	49	7	3	4	3
MA	527	263	79	15	144	8	3	13	3
NH	266	127	38	7	72	3	1	16	3
NJ	226	141	42	8	28	4	1	1	0.9
NY	1,394	734	219	40	305	14	5	65	11
PA	1,038	592	177	33	171	16	6	34	10
RI	78	49	15	3	9	1	0.4	1	0.5
VT	246	128	38	7	49	2	0.8	18	3
D.C.	6	2	0.6	0.1	3	0.4	0.2	0.009	0.01
M-V	4,719	2,530	756	139	981	66	25	182	40

M-V represents the MANE-VU region average

Table 3.18 Acetaldehyde Emission Inventory

State	Tons of Acetaldehyde								
	Total RWC	Wood Heaters			Fireplaces without Inserts			Centralized Cordwood Heating Systems	Pellet Heaters
		Conventional	Non-Catalytic	Catalytic	Cordwood (heat)	Cordwood (aesthetic)	Firelogs		
CT	128	68	14	5	32	3	0.2	6	0.5
DE	20	6	1	0.4	10	1	0.07	0.2	0.08
ME	168	74	15	5	48	2	0.1	23	1
MD	116	61	12	4	29	4	0.2	4	0.8
MA	246	112	22	8	86	5	0.2	12	0.8
NH	129	54	11	4	43	2	0.1	15	0.8
NJ	96	60	12	4	16	2	0.1	1	0.3
NY	653	311	62	22	182	8	0.4	64	3
PA	467	251	50	18	102	9	0.5	33	3
RI	34	21	4	1	5	0.7	0.04	1	0.1
VT	118	54	11	4	29	1	0.07	17	0.9
D.C.	3	0.8	0.2	0.06	2	0.3	0.01	0.009	0.004
M-V	2,178	1,072	215	75	585	39	2	177	12

M-V represents the MANE-VU region average

Table 3.19 Acrolein Emission Inventory

State	Tons of Acrolein								
	Total RWC	Wood Heaters			Fireplaces without Inserts			Centralized Cordwood Heating Systems	Pellet Heaters
		Conventional	Non-Catalytic	Catalytic	Cordwood (heat)	Cordwood (aesthetic)	Firelogs		
CT	16	10	0.9	0.3	4	0.3	0.04	0.4	0.05
DE	2	0.9	0.08	0.03	1	0.2	0.02	0.01	0.009
ME	20	11	0.9	0.3	6	0.3	0.04	1	0.1
MD	14	9	0.8	0.3	3	0.5	0.06	0.2	0.08
MA	30	16	1	0.5	10	0.5	0.07	0.8	0.08
NH	15	8	0.7	0.2	5	0.2	0.03	1.0	0.09
NJ	12	9	0.8	0.2	2	0.3	0.04	0.08	0.03
NY	78	46	4	1	21	1	0.1	4	0.4
PA	57	37	3	1	12	1	0.1	2	0.3
RI	4	3	0.3	0.09	0.6	0.08	0.01	0.07	0.02
VT	14	8	0.7	0.2	3	0.1	0.02	1	0.1
D.C.	0	0.1	0.01	0.003	0.2	0.03	0.004	0.0006	0.0004
M-V	262	158	14	4	67	5	0.6	11	1

M-V represents the MANE-VU region average

Table 3.20 Cresol Emission Inventory

State	Tons of Cresol								
	Total RWC	Wood Heaters			Fireplaces without Inserts			Centralized Cordwood Heating Systems	Pellet Heaters
		Conventional	Non-Catalytic	Catalytic	Cordwood (heat)	Cordwood (aesthetic)	Firelogs		
CT	16	10	0.9	0.3	4	1	0.04	0.4	0.05
DE	3	0.9	0.08	0.03	1	0.5	0.02	0.01	0.009
ME	20	11	0.9	0.3	6	0.8	0.04	1	0.1
MD	15	9	0.8	0.3	3	1	0.06	0.2	0.08
MA	31	16	1	0.5	10	2	0.07	0.8	0.08
NH	15	8	0.7	0.2	5	0.6	0.03	1	0.09
NJ	13	9	0.8	0.2	2	0.8	0.04	0.08	0.03
NY	80	46	4	1	21	3	0.1	4	0.4
PA	59	37	3	1	12	3	0.1	2	0.3
RI	4	3	0.3	0.09	0.6	0.2	0.01	0.07	0.02
VT	14	8	0.7	0.2	3	0.4	0.02	1	0.1
D.C.	0	0.1	0.01	0.003	0.2	0.09	0.004	0.0006	0.0004
M-V	270	158	14	4	67	13	0.6	11	1

*Sum of o-, m-, and p- cresol isomers
M-V represents the MANE-VU region average

Table 3.21 PCB_{TEQ} Emission Inventory

State	Micrograms of PCB_{TEQ}								
	Total RWC	Wood Heaters			Fireplaces without Inserts			Centralized Cordwood Heating Systems	Pellet Heaters
		Conventional	Non-Catalytic	Catalytic	Cordwood (heat)	Cordwood (aesthetic)	Firelogs		
CT	194	100	55	4	20	2	4	9	0.9
DE	24	9	5	0.4	7	0.9	2	0.3	0.2
ME	243	109	60	4	31	1	3	33	3
MD	177	91	50	4	18	3	5	5	2
MA	345	164	90	7	55	3	6	18	1
NH	180	79	43	3	27	1	2	22	2
NJ	157	88	48	4	10	2	3	2	0.5
NY	958	458	251	19	116	5	11	93	6
PA	723	369	202	15	65	6	12	48	6
RI	55	31	17	1	3	0.4	0.9	1	0.3
VT	175	80	44	3	19	0.8	2	25	2
D.C.	4	1	0.6	0.05	1	0.2	0.3	0.01	0.007
M-V	3,235	1,578	865	64	373	25	50	259	23

M-V represents the MANE-VU region average

Table 3.22 $Dioxin_{TEQ}$ Emission Inventory

State	Milligrams of $Dioxin_{TEQ}$								
	Total RWC	Wood Heaters			Fireplaces without Inserts			Centralized Cordwood Heating Systems	Pellet Heaters
		Conventional	Non-Catalytic	Catalytic	Cordwood (heat)	Cordwood (aesthetic)	Firelogs		
CT	606	460	16	19	21	2	3	69	17
DE	60	43	1	2	7	1	1	2	3
ME	875	500	17	20	32	2	2	253	48
MD	541	417	14	17	19	3	4	39	29
MA	1,044	756	26	31	58	3	4	138	28
NH	621	363	12	15	29	1	2	170	29
NJ	474	405	14	16	11	2	2	13	10
NY	3,222	2,106	71	85	121	6	8	705	120
PA	2,384	1,698	57	69	68	6	9	366	110
RI	173	142	5	6	3	0.5	0.6	11	5
VT	642	367	12	15	20	0.8	1	192	33
D.C.	8	5	0.2	0.2	1	0.2	0.3	0.1	0.1
M-V	10,649	7,263	245	294	390	26	37	1,959	434

M-V represents the MANE-VU region average

Table 3.23 Methane Emission Inventory

State	Tons of Methane								
	Total RWC	Wood Heaters			Fireplaces without Inserts			Centralized Cordwood Heating Systems	Pellet Heaters
		Conventional	Non-Catalytic	Catalytic	Cordwood (heat)	Cordwood (aesthetic)	Firelogs		
CT	8,698	7,051	613	234	427	38	95	238	1
DE	944	653	57	22	139	20	45	9	0.2
ME	10,215	7,661	666	254	647	31	76	876	3
MD	7,868	6,385	555	212	391	54	134	135	2
MA	14,845	11,593	1,008	385	1,161	63	157	476	2
NH	7,490	5,568	484	185	577	25	62	586	2
NJ	7,336	6,213	540	206	221	32	76	45	0.7
NY	41,445	32,281	2,807	1,071	2,453	112	277	2,436	9
PA	32,243	26,030	2,263	864	1,377	125	309	1,266	8
RI	2,571	2,171	189	72	69	9	23	39	0.4
VT	7,430	5,631	490	187	397	17	42	665	2
D.C.	129	81	7	3	25	4	9	0.3	0.009
M-V	141,212	111,317	9,680	3,693	7,884	530	1,305	6,772	31

M-V represents the MANE-VU region average

Of the 20 pollutants in Table 3.24, 17 of the emissions are in tons of pollutant. The remaining three pollutants have their emission units listed in parentheses below the name of the pollutant (Benzo(a)pyrene, PCB_{TEQ}, and $Dioxin_{TEQ}$).

Table 3.24 MANE-VU Region Emission Inventory

Pollutant	Tons of Emission in the MANE-VU Region								
	Total RWC	Wood Heaters			Fireplaces without Inserts			Centralized Cordwood Heating Systems	Pellet Heaters
		Conventional	Non-Catalytic	Catalytic	Cordwood (heat)	Cordwood (aesthetic)	Firelogs		
PM	92,471	58,789	5,112	2,377	16,701	1,122	813	7,171	386
VOC	87,740	63,817	6,864	2,443	10,312	693	570	3,036	5
NO_x*	8,280	4,462	776	284	1,586	107	109	478	479
CO	474,915	272,777	47,922	15,197	81,607	5,483	2,306	47,618	2,004
SO_2	1,423	361	136	57	219	15	70	525	39
NH_3	4,947	2,957	306	128	985	66	0.07	467	38
Benzene	5,535	3,755	326	317	375	25	15	718	4
Phenol	1,079	513	166	58	258	17	0.6	63	3
7-PAH	235	77	9	4	120	8	0.06	9	8
16-PAH	1,904	1,096	107	40	410	28	2	134	87
Benzo(a)pyrene (lbs)	12,449	5,844	1,487	1,121	809	54	32	1,418	1,683
Naphthalene	633	316	47	22	145	10	1	39	53
1,3-Butadiene	871	684	59	28	86	6	0.3	8	0.1
Formaldehyde	4,719	2,530	756	139	981	66	25	182	40
Acetaldehyde	2,178	1,072	215	75	585	39	2	177	12
Acrolein	262	158	14	4	67	5	0.6	11	1
Cresol**	270	158	14	4	67	13	0.6	11	1
PCB_{TEQ} (µg)	3,235	1,578	865	64	373	25	50	259	23
$Dioxin_{TEQ}$ (mg)	10,649	7,263	245	294	390	26	37	1,959	434
Methane	141,212	111,317	9,680	3,693	7,884	530	1,305	6,772	31

*NO_x is total nitrogen oxides reported as NO_2
**Cresols is the sum of o-, m-, and p- isomers

3.3. PM and VOC Emissions Inventory Apportioned by Month

Residential wood combustion can be apportioned by month by determining the average number of heating degree days for each month (based on a 30 year average, see Table 3.25). The RWC monthly percentage distribution can be calculated by dividing the average annual HDD, for each state, by each of the monthly HDDs. (Table 3.26, Figure 3.13). The resulting fraction of HDD can be used as a metric for apportioning RWC emissions by month simply by multiplying the annual RWC emissions by the monthly HDD fractions. The PM and VOC emissions by month are shown in Table 3.27 and Table 3.28.

Table 3.25 Average Total Heating Degree Days Apportioned by Month*

State	Annual	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
CT	6,069	1,177	997	846	522	232	42	4	14	115	421	681	1,018
DE	4,740	996	836	670	371	127	10	0	1	42	285	552	850
ME	8,012	1,456	1,234	1,071	706	386	125	35	58	242	579	860	1,260
MD	4,849	1,019	840	669	364	131	12	1	2	50	303	579	879
MA	6,407	1,209	1,031	891	573	276	62	7	19	141	450	703	1,045
NH	7,588	1,405	1,186	1,018	653	320	85	18	49	221	565	842	1,226
NJ	5,444	1,091	920	763	450	183	24	1	5	77	366	622	942
NY	6,116	1,188	1,017	867	528	233	45	8	18	113	405	678	1,016
PA	5,909	1,159	974	809	478	214	41	8	18	110	411	681	1,006
RI	5,889	1,113	958	840	549	270	58	5	13	105	388	635	955
VT	8,110	1,487	1,277	1,097	693	337	97	31	68	250	596	886	1,291
D.C.	4,571	977	807	641	332	108	6	0	1	35	283	544	837

* Reference 59 and 60

Table 3.26 Monthly Percent of Average Total Heating Degree Days

State	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
CT	19%	16%	14%	9%	4%	1%	0%	0%	2%	7%	11%	17%
DE	21%	18%	14%	8%	3%	0%	0%	0%	1%	6%	12%	18%
ME	18%	15%	13%	9%	5%	2%	0%	1%	3%	7%	11%	16%
MD	21%	17%	14%	8%	3%	0%	0%	0%	1%	6%	12%	18%
MA	19%	16%	14%	9%	4%	1%	0%	0%	2%	7%	11%	16%
NH	19%	16%	13%	9%	4%	1%	0%	1%	3%	7%	11%	16%
NJ	20%	17%	14%	8%	3%	0%	0%	0%	1%	7%	11%	17%
NY	19%	17%	14%	9%	4%	1%	0%	0%	2%	7%	11%	17%
PA	20%	16%	14%	8%	4%	1%	0%	0%	2%	7%	12%	17%
RI	19%	16%	14%	9%	5%	1%	0%	0%	2%	7%	11%	16%
VT	18%	16%	14%	9%	4%	1%	0%	1%	3%	7%	11%	16%
D.C.	21%	18%	14%	7%	2%	0%	0%	0%	1%	6%	12%	18%

Figure 3.13 Monthly Percentage of Average Total Heating Degree Days Chart

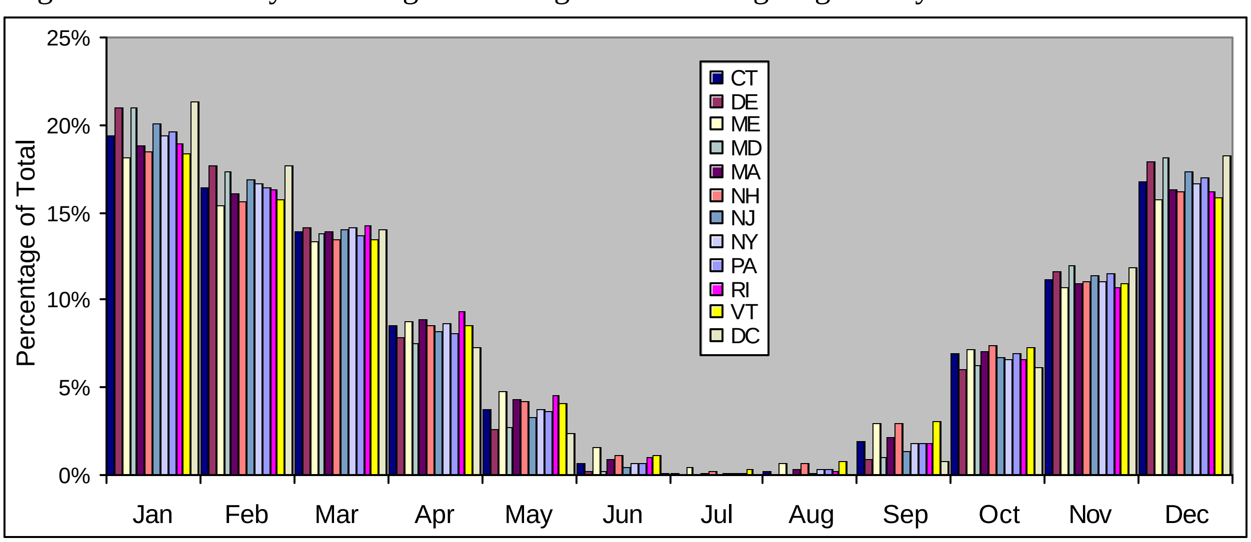


Table 3.27 Total PM Emissions Apportioned by Month

State	Annual (tons)*	Jan (tons)	Feb (tons)	Mar (tons)	Apr (tons)	May (tons)	Jun (tons)	Jul (tons)	Aug (tons)	Sep (tons)	Oct (tons)	Nov (tons)	Dec (tons)
CT	5,429	1,053	892	757	467	208	38	4	13	103	377	609	911
DE	723	152	127	102	57	19	2	0	0	6	43	84	130
ME	6,950	1,263	1,070	929	612	335	108	30	50	210	502	746	1,093
MD	4,882	1,026	846	674	366	132	12	1	2	50	305	583	885
MA	9,989	1,885	1,607	1,389	893	430	97	11	30	220	702	1,096	1,629
NH	5,223	967	816	701	449	220	59	12	34	152	389	580	844
NJ	4,273	856	722	599	353	144	19	1	4	60	287	488	739
NY	27,274	5,298	4,535	3,866	2,355	1,039	201	36	80	504	1,806	3,024	4,531
PA	20,047	3,932	3,304	2,745	1,622	726	139	27	61	373	1,394	2,310	3,413
RI	1,498	283	244	214	140	69	15	1	3	27	99	162	243
VT	4,952	908	780	670	423	206	59	19	42	153	364	541	788
D.C.	107	23	19	15	8	3	0	0	0	1	7	13	20

*From Table 3.04

Table 3.28 Total VOC Emissions Apportioned by Month

State	Annual (tons)*	Jan (tons)	Feb (tons)	Mar (tons)	Apr (tons)	May (tons)	Jun (tons)	Jul (tons)	Aug (tons)	Sep (tons)	Oct (tons)	Nov (tons)	Dec (tons)
CT	5,339	1,035	877	744	459	204	37	4	12	101	370	599	896
DE	634	133	112	90	50	17	1	0	0	6	38	74	114
ME	6,306	1,146	971	843	556	304	98	28	46	190	456	677	992
MD	4,825	1,014	836	666	362	130	12	1	2	50	301	576	875
MA	9,416	1,777	1,515	1,309	842	406	91	10	28	207	661	1,033	1,536
NH	4,703	871	735	631	405	198	53	11	30	137	350	522	760
NJ	4,425	887	748	620	366	149	20	1	4	63	297	506	766
NY	25,628	4,978	4,262	3,633	2,212	976	189	34	75	474	1,697	2,841	4,257
PA	19,605	3,845	3,231	2,684	1,586	710	136	27	60	365	1,364	2,259	3,338
RI	1,543	292	251	220	144	71	15	1	3	28	102	166	250
VT	4,535	831	714	613	387	188	54	17	38	140	333	495	722
D.C.	90	19	16	13	7	2	0	0	0	1	6	11	16

*From Table 3.05

4. Residential Wood Combustion PM_{10} Reasonable/Best Available Control Measures (RACM/BACM)

While the emphasis was placed on a cost-effectiveness analysis, the RACM/BACM discussion was included to illustrate control strategies already developed by the U.S. EPA to reduce RWC PM_{10} emissions. In addition, some state and local air quality agencies have developed and implemented their own RWC control strategies, and this section is aimed at helping agencies in the MANE-VU region develop strategies to effectively minimize RWC emissions. Many of the applicable control strategies define the number and type of RWC devices that can be installed, while others implement no-burn periods during episodes of high emissions. Regulatory control strategies can be applied either to changing out existing higher emitting appliances or controlling the installation of appliances in new construction. The cost effectiveness evaluation discussed in section 5 of this document specifically targets costs associated with the replacement of existing appliances, as it compares the difference in "before-and-after" emissions and the commensurate costs associated with the change out. It needs to be remembered that while controlling new installations is important, the impact of the change out of existing appliances will potentially have a far more dramatic affect on air quality due to the very large number of fireplaces and older technology wood heaters already in homes.

The U.S. Environmental Protection Agency (EPA) was required under Section 190 of the 1990 Amendments to the Clean Air Act (CAA) to issue RACM and BACM technical guidance for PM_{10} for the RWC source category. The September 1989 publication, "Guidance Document for Residential Wood Combustion Emission Control Measures" (EPA-450/2-89-015)[61] was considered as fulfilling the RACM technical guidance requirement. A subsequent document published in 1992, "Technical Information Document for Residential Wood Combustion, Best Available Control Measures," (EPA-450/2-92-002)[62] fulfilled the BACM requirement. Because most of the products of incomplete combustion (PIC) emitted by RWC are submicron (less than one micron in size), the PM_{10} control measures that have been developed for RWC are directly applicable for the control of $PM_{2.5}$. Stated another way, submicron particles from RWC are both $PM_{2.5}$ and PM_{10} because they have aerodynamic diameters less than 2.5 microns and less than 10 microns, respectively, i.e., the same particles will be controlled by both $PM_{2.5}$ and PM_{10} control measures. Similarly, since most key air pollutants that are emitted from RWC are PIC, control measures for particles (which are PIC) will also reduce the emission of other key RWC air emissions.

Table 4.01 summarizes measures for RWC RACM developed by the U.S. EPA in EPA-450/2-89-015[61]. The RACM fall in three primary categories: (1) Improvement of performance, (2) Reducing the use of RWC devices, and (3) Episodic curtailment. The effectiveness in reducing RWC emissions and a related discussion of each of the various activities are also provided in Table 4.01. In addition to the three primary categories for RWC RACM, the RACM document emphasizes the importance of public awareness in any RWC emission control program and provides considerable narrative on the subject

Table 4.01 Summary of Measures Available for RWC RACM – PM_{10}

Program Elements	Effectiveness (%)	Discussion
1. IMPROVEMENT OF PERFORMANCE		
State implementation of NSPS	0	States are not expected to adopt this program element at levels that would affect program effectiveness significantly.
Ban on resale of uncertified devices	0	No credit recognized because requirement is largely unenforceable: other elements will be required to include disabling of retired used devices.
Installer Training Certification or Inspection Program	= 5	Reduction in emissions from each new certified RWC device where either the installer is trained/certified or the installation is inspected.
Pellet stoves	90	Reduction in emissions from each new or existing conventional, uncertified RWC device replaced with a pellet stove.
	75	Reduction in emissions from each new or existing Phase II EPA certified RWC device replaced with a pellet stove.
EPA Phase II certified RWC devices	~50	Reduction in emissions from each new or existing conventional, uncertified RWC device replaced with an EPA Phase II certified RWC device.
Retrofit requirement	<5	Reduction in emissions from each existing conventional, uncertified RWC device equipped with a retrofit catalyst or pellet hopper (to maximum when all existing uncertified RWC devices have retrofit devices installed).
Accelerated changeover requirement	~50	Reduction in emissions from each existing conventional, uncertified RWC device replaced with Phase II certified device.
	100	Reduction in emissions from each existing conventional, uncertified RWC device removed and not replaced: requires existing device to be disabled and not resold.
Accelerated changeover inducement	~50	Reduction in emissions from each existing conventional, uncertified RWC device replaced with Phase II certified device.
	100	Reduction in emissions from each existing conventional, uncertified RWC device removed and not replaced: requires existing device to be disabled and not resold.
Require fireplace inserts	0	No credit recognized for fireplace inserts, since inserts change use of fireplace from aesthetic to primary heat source, resulting in an increase in amount of wood combusted and higher overall emissions.
Wood moisture	<5	Reduction in total emissions from all RWC devices in the community/airshed.
Trash burning prohibition	0	No credit recognized for eliminating trash burning in RWC devices.

Table 4.01 (continued) Summary of Measures for RWC RACM – PM_{10}

Program Elements	Effectiveness (%)	Discussion
Weatherization of residences	<5	Reduction in total emissions from all RWC devices in the community/airshed.
Opacity limits	<5	Reduction in total emissions from all RWC devices in the community/airshed.
2. REDUCING USE OF RWC DEVICES		
Availability of alternative fuels	100	Reduction in emissions from each RWC device removed from service and replaced with device using natural gas: recognize no more than 10% of RWC devices replaced under program with no additional incentives.
Emission trading	Computation required	For a 2:1 trading ratio, the reduction in emissions from each new stove would be calculated as the difference between emissions of a new RWC device and 2 times the average emissions per stove in the community: multiplier would change for other trading ratios.
Taxes on RWC devices	Variable	Emission reduction credit would vary with utility or tax rate structure adopted and extent to which this structure resulted in reduction in number of RWC devices in the community versus reduction in use of RWC devices.
Regulatory ban on RWC devices in new dwellings	100	Reduction in emissions from new RWC devices purchased for installation in new dwellings.
Regulatory ban on existing RWC devices	100	Reduction in emissions from each RWC device removed.
3. EPISODIC CURTAILMENT		
Voluntary	10	Reduction in emissions for all RWC devices not exempted.
Mandatory	60% fireplace 50% woodstoves	Reduction in emissions for all RWC devices not exempted.

Table 4.02 summarizes measures for RWC BACM developed by the U.S. EPA in EPA-450/2-92-002[62]. As shown in Table 4.02, the BACM fall into two primary categories: (1) Integral measures which are necessary for the success of a long-term RWC pollutant reduction programs but, by themselves, are not adequate to provide long-term reductions. (2) Flexible (long-term) measures to reduce, eliminate, or prevent increases in pollutant emissions for existing and/or new installations. With the exceptions of the device and upgrade offsets, the specific elements of the BACM are essentially those described in the RACM document with the various efficiencies listed in Table 4.01 being applicable. The

methods for calculating device and offset ratios are provided as Appendix B to EPA 450/2-92-002.

Table 4.02 Summary of Measures Available for RWC BACM – PM_{10}

Integral Measures*	Flexible Measures that Reduce or Eliminate Emissions from Existing Installations**	Flexible Measures that Reduce Emissions or Prevent Emission Increases from New Installations**	Flexible Measures that Reduce Emissions from New and Existing Installations**
1. Public awareness and education.	1. Conversion of existing wood-burning fireplaces to gas logs.	1. Gas fireplaces or gas logs in new wood burning fireplace installations.	1. Device offset.****
2. Mandatory curtailment during predicted periods of high PM_{10} concentrations.	2. Changeover to EPA-certified, Phase II stoves or equivalent.	2. Upgrade offset. ****	2. Upgrade offset.****
3. All new stove installations EPA-certified, Phase II stoves or equivalent.	3. Changeover to low emitting device.***	3. Restriction on number and density of new wood-burning stove and/or fireplace installations.	
4. Measures to improve wood burning performance: -control of wood moisture content -weatherization of homes with wood stoves -educational opacity program		4. Requirement that new stove installations be low emitting.	

* Integral measures are regarded as critical for the success of a RWC control program, but by themselves are not intended to result in long-term attainment of the PM_{10} NAAQS for serious PM_{10} nonattainment areas.

** Flexible measures are designed for permanent control of RWC emissions and thus long-term attainment of the PM_{10} NAAQS

*** This measure is virtually identical to item 2, except that the changeover is recommended to a "low-emitting" device that can document "in-home" field test emissions less than the emission factor averages of "in-home" field test emissions data for EPA-certified stoves. This can include classes of devices that are demonstrated to be capable as a class of producing lower field emissions, as well as, specific model units that perform better in the field than the class collectively. (An example might include masonry heaters, uncertified pellet-fueled devices, and wood fired gasification centralized heating systems)

**** Offsets are intended to achieve emission reductions, when retiring (device offset) or changing-out (upgrade offset) conventional stoves, greater than the emissions increase resulting from new stove installations.

The RWC RACM and BACM have been the basis for PM_{10} innovative strategies implemented in various western states and in their local jurisidcitons[63] and have also been, in-large part, the basis for a number of western state and their local RWC regulations. Table 4.03 lists notable RWC regulations. These regulations were provided as Appendix A to the cost benefit analysis task for the convenience of MANE-VU state air quality planners and regulators.

Table 4.03 RWC Regulations

State	Jurisdiction/Agency
Arizona	Maricopa County
Bi-State (California and Nevada)	Tahoe Regional Planning Agency
California	Bay Area Air Quality Management District
	Butte County Air Quality Management District
	Feather River Air Quality Management District
	Glenn County Air Pollution Control District
	Great Basin Unified Pollution Control District
	Kern County Air Pollution Control District
	Placer County
	San Joaquin Valley Unified Air Pollution Control District
	San Luis Obispo County Air Pollution Control District
	Shasta County Air Quality Management District
	Yolo-Solano Air Quality Management District
Colorado	State of Colorado
	City of Aspen and Pitkin County
	City of Fort Collins[1]
Montana	Lincoln County
	Missoula County
Nevada	Clark County
	Washoe County
Oregon	State of Oregon
Washington	State of Washington

1. The regulation contains information on RWC regulations for the State of Colorado, Larimer County, Poudre Fire Authority, City and County of Denver, Weld County/Greeley, Loveland, Boulder, El Paso County/Colorado Springs, Mesa County, Grand Junction, Fruita, and Telluride.

The northeast states, through NESCAUM, are developing a model rule for regulation outdoor hydronic heaters. As part of this rule, strict particulate emission standards have been developed which will take effect in 2008. In order to meet these limits, these appliances may need to be redesigned.

Notable among state and local regulations is the Washington State standard. Washington State has implemented more stringent standards for residential wood burning devices, so devices installed in Washington State must be certified to the more stringent standard. This has affected the stove marked because many U.S. certified stove manufacturers choose to have their appliances certified to the more stringent Washington State standard, unless the manufacturer can or does not choose to test to the tighter standard. To provide a sense of the stringency of the Washington State standard as compared to the NSPS (generally referred to as the EPA standard), as of January 2006 approximately 40% of non-catalytic wood heaters certified for the U.S. EPA for sale did not meet the Washington State standard.

Other factors beyond $PM_{2.5}$ and regional haze (i.e., VOC and fine particles), their corresponding emissions and associated control costs covered by the scope of this project can, and should, also influence RWC regulatory policy. The greenhouse gas benefits of biomass combustion and the minimal acid gas emissions (acid precipitation impacts) from wood combustion are strong environmental advantages. Further, the fact that wood is a domestic renewable energy source and the fact that the cost of the widely used home fuels of natural gas, propane, and fuel oil have a history of rising together have been responsible for the increase of RWC. For example, several states, notably New York, are encouraging the use of renewable energy sources such as wood.

5. Pollution Reduction Cost Effectiveness

The cost benefit analysis task of the Control Analysis and Documentation for Residential Wood Combustion Emissions in the MANE-VU Region project is a cost effectiveness analysis for air pollutant reductions. The term "cost benefit analysis (cba)" that has been used in the previous task is the general term typically used for the type of analysis provided here, but it has been replaced with the term "cost effectiveness analysis" in this final report as it is more descriptive of the specific analysis that has been conducted. The analysis focuses on the cost per unit mass of pollutant reduced when converting to improved technology and alternative fuels from traditional uncertified cordwood-burning units (summarized in Tables 5.11 – 5.23). In addition to the total cost effectiveness of the conversions, the costs associated with each component of such conversions are provided (Tables 5.06 –5.10). All costs are based on cash purchases or expenditures and, as such, neither discount nor interest rates were taken into consideration. Also, all costs were based on nominal 2006 dollars and no attempt was made to make adjustments to another year dollar basis. The cost effectiveness analysis is for criteria air pollutant reductions with emphasis being placed on PM and volatile organic compounds (VOC) due to $PM_{2.5}$ and ozone nonattainment, as well as regional haze, being topical issues. As directed by MARAMA, the emphasis of the cost benefit analysis task was shifted from a RACM analysis to a cost effectiveness analysis to provide air quality planners and regulators supporting information for their individual development of RACM. Also as requested by MARAMA's Technical Oversight Committee, vent-free devices are not included in the tables for heating appliances as there is considerable concern regarding indoor air quality and damage to homes by moisture created from their use, as combustion gases are vented indoors. For completeness, the cost effectiveness analyses for vent-free appliances can be found in the cost benefit analysis task. The vent-free appliance data are also included for the fireplace aesthetic use scenario as aesthetic use is the primary application of vent-free devices.

5.1. Methodology

There are five categories of widely existing, older technology wood-burning devices used for the air pollutant reduction cost effectiveness analyses. These are: (1) Freestanding cordwood stoves, (2) Cordwood-fueled fireplace inserts, (3) Cordwood fireplaces (without inserts) used for heating purposes, (4) Centralized cordwood heating systems and (5) Cordwood fireplaces used for aesthetic purposes. Table 5.01 lists these five categories with the improved technology replacement and installation scenarios, as well as fuel alternatives that would reduce particulate and VOC emissions, which are commonly used and are readily available to the public. Except for the fireplaces used for aesthetics category, the cost effectiveness analyses are presented by state. For the fireplaces used for aesthetics, a single set of tables is provided for the MANE-VU region as the fuel usage in fireplaces used for aesthetics will not change significantly within the MANE-VU region.

Table 5.01 Improved Technologies and Fuel Alternatives

Existing Cordwood Device	High Technology Replacement, Installation or Alternative Fuel
Uncertified Freestanding Cordwood Stove	Replacement with Certified NSPS Non-Catalytic Cordwood Stove
	Replacement with Certified NSPS Catalytic Cordwood Stove
	Replacement with Pellet Stove
	Replacement with Gas Stove – natural gas (B vent, direct vent)
	Replacement with Gas Stove – LPG (B vent, direct vent)
Uncertified Cordwood Fireplace Insert	Replacement with Certified NSPS Non-Catalytic Cordwood Insert
	Replacement with Certified NSPS Catalytic Cordwood Insert
	Replacement with Pellet Insert
	Replacement with Gas Insert – natural gas (B vent, direct vent)
	Replacement with Gas Insert – LPG (B vent, direct vent)
Cordwood Fireplace without Insert Used for Heating	Installation of Certified NSPS Non-Catalytic Cordwood Insert
	Installation of Certified NSPS Catalytic Cordwood Insert
	Installation of Pellet Insert
	Installation of Gas Insert – natural gas (B-vent, direct vent)
	Installation of Gas Insert – LPG (B-vent, direct vent)
Cordwood Fireplace Used for Aesthetic Purposes	Installation of Gas Log Set – natural gas (vented and vent free)
	Installation of Gas Log Set – LPG (vented and vent free)
	Wax/Fiber Firelog Fuel
Centralized Cordwood Heating System	Pellet Furnace or Boiler
	Gas Furnace or Boiler – natural gas
	Gas Furnace or Boiler – LPG

To facilitate understanding of the cost effectiveness analyses, descriptions of the various appliances used, as well as a brief discussion of efficiency, are provided.

Cordwood-Fired Stoves and Fireplace Inserts
Uncertified, certified catalytic, and certified non-catalytic cordwood stoves and fireplace inserts together are considered cordwood heaters. They are designed to burn bulk cordwood and are room space heaters, i.e., they primarily rely on radiant and convection heat transfer, in contrast to centralized heating systems such as warm-air furnaces or boilers which utilized heat distribution systems to heat multiple rooms. Fireplace inserts are essentially wood stoves that are designed to be inserted into an existing fireplace cavity. Because of the heat transfer shielding effect of the fireplace cavity and the fact the majority of existing fireplace chimneys are against an outside wall, their heating efficiency is less than a similar freestanding woodstove model. Many fireplace inserts have fans to facilitate transfer of heat from the portion that is inside the fireplace cavity. Both freestanding cordwood stoves and fireplace inserts rely on a natural draft using room air for combustion, and the venting of exhaust. Though the majority of cordwood heaters use room air for combustion, some insert installations, such as in mobile homes, require the use of outside air for combustion.

Uncertified Conventional Cordwood-Fired Stoves and Fireplace Inserts
Uncertified cordwood fired stoves and fireplace inserts include units manufactured before the NSPS July 1, 1990 certification requirement, and currently or recently manufactured exempt units which operate similarly to some old pre-EPA certification units.

NSPS Certified Catalytic Cordwood-Fired Stoves and Fireplace Inserts
Certified catalytic units pass the exhaust through a catalyst to achieve emission reductions. Generally, a coated ceramic honeycomb catalyst is located inside the stove where the incompletely combusted gases and particles ignite and are combusted further, thus reducing air emissions and increasing overall efficiency.

NSPS Certified Non-Catalytic Cordwood-Fired Stoves and Fireplace Inserts
Certified non-catalytic stoves and fireplace insets rely on design features to reduce air emission and increase efficiency. They generally rely on the introduction of heated secondary air to improve combustion, as well as firebox insulation, and baffles to produce a longer, hotter gas flow path, as well as other design features to achieve low emissions and higher efficiency.

Pellet Stoves and Fireplace Inserts
Analogous to cordwood stoves and fireplace inserts, pellet stoves and fireplace inserts are considered room heaters. They burn pellets generally made from wood sawdust, although there has been, and continues to be, research into utilizing other biomass fuels to make pellets. Combustion air is drawn from the room for most models, and exhaust is vented outdoors. Some pellet appliances utilize outside air for combustion if warranted. Pellet stoves and inserts require the use of electric motors to power the combustion air and heat transfer fans and the pellet-feeding auger. Modern pellet units utilize electronic sensors and controls. Pellets are introduced into the hopper, and the auger continuously feeds a consistent amount of pellets into the firebox. The feed rate is controlled electronically by a feed rate setting selected by the user. There are two basic designs: bottom-feed and top-feed models. Pellet units have a high efficiency and low

emissions due to the use of the electric auger and fan that produce uniform and controlled combustion conditions. Some units are certified by the NSPS process and some are not. The performance of the certified and uncertified models are similar. What is considered by most as a "loop-hole" in the NSPS regulations essentially allows certification to be bypassed.

Wood-burning Fireplaces without Inserts

Fireplaces without inserts include manufactured units (often referred to as "zero-clearance" fireplaces) and site-built masonry units operated both with and without glass doors. Combustion air is drawn from the natural draft created by fire, and that same draft vents the exhaust through the chimney. Fireplaces without inserts have low efficiency due to the large amount of heated room air that is exhausted out of the chimney from the draft. Many fireplaces without inserts are not used in a given year, some are used for aesthetic purposes and some are used for heating. Those that are used for heating are almost always used for secondary heating purposes and not primary heating due to their low efficiency and lack of heat transfer capabilities. Manufactured wax/fiber firelogs are often used as a fuel in them with about 30% of fireplace users nationwide claiming that they use wax/fiber firelogs some of the time. Most fireplaces are wall-mounted, however, this category also includes some free-standing models.

Direct Vent Gas Stoves and Fireplace Inserts (LPG and Natural Gas)

Direct vent gas stoves and inserts are sealed units that draw their combustion air from, and vent their exhaust to, the outside air. Venting can be extended vertically or horizontally out of the home. A common type of venting is coaxial, which has the exhaust pipe contained within the air inlet pipe, so the temperature of the combustion air is raised, and the temperature of the exhaust is lowered, creating more efficient combustion.

Vent-Free Gas Stoves and Fireplace Inserts (LPG and Natural Gas)

Vent-free gas stoves and inserts receive their combustion air from the room in which the unit is placed, and all of the products of combustion are exhausted into the room as well. The high efficiency of vent free units is due to the fact that the heat produced is kept in the room. Vent free gas stoves and inserts have a maximum heat input in order to avoid emitting excess CO, CO_2, or NO_x into the room, and the units also have an O_2 depletion sensor or other device to shut the unit down if oxygen levels become too low. It is important to note that vent-free natural gas and LPG stoves, inserts and log sets should not be considered options for primary or even significant secondary heating use. There is considerable concern regarding indoor air quality and damage to homes by moisture created from their use, as combustion gases are not vented. If the devices are used prudently, these problems are minimized. Their appropriate role is for aesthetics and minor secondary heating.

B-Vent Gas Stoves and Fireplace Inserts (LPG and Natural Gas)

B-vent gas stoves and inserts draw their combustion air from the room, and exhaust is vented outdoors. These units use a draft hood for the proper venting of exhaust. B-vent gas stoves and inserts have lower efficiency than direct vent due to the fact that already heated room air is used as combustion air, which is then exhausted to the outdoors, taking heat away from the room.

Vent-Free Gas Log Sets (LPG and Natural Gas)
Vent-free gas log sets can be used in a fireplace with the damper closed, or can be in its own enclosure placed in a fireplace. As with vent free gas stoves and inserts, all of the products of combustion are exhausted into the room, causing the unit to have a high efficiency. Also, the same concerns of air quality and home damage as vent-free stoves and inserts apply.

Vented Gas Log Sets (LPG and Natural Gas)
Vented gas log sets are used in fireplaces with the damper open. They are primarily used for aesthetics because all products of combustion (including the vast majority of the heat produced) are vented up and out of the chimney, causing the unit to have a low efficiency.

Centralized Cordwood Heating Systems
The centralized cordwood heating system category consist of both cordwood-fired furnaces and boilers. Furnaces rely on the transfer of warmed air through ductwork to heat multiple rooms. Boilers rely on pumps to transfer warm water to multiple rooms and radiators to provide heat. Cordwood boilers are commonly either located inside or outside of the home. Cordwood boilers are often referred to as hydronic heaters, as the water is generally not "boiled."

Pellet-Fired Furnaces and Boilers
Pellet-fired furnaces and boilers use the same technology as pellet stove and fireplace insert room heaters, except that they use a either a warmed air heat transfer system (furnaces) or water heat transfer system (boilers) to heat multiple rooms.

Gas-Fired Furnaces and Boilers (LPG and Natural Gas)
Gas-fired furnace and boilers can either be natural gas or liquid propane gas (LPG) fueled. Natural gas-fueled furnaces are the single most commonly used home heating appliance category in the United States. Newer technology units with more efficient heat exchangers exhaust systems allowing for the condensation of water, and technologies that minimize the use of pilot lights have caused an improvement in efficiency.

Efficiency
There are different standards and methods used to measure efficiency, but in general efficiency is the percentage of available heat that is put into the home divided by the available heat content of the fuel. With the exception of some modern "condensing" gas furnaces, it is assumed that water leaves the stack in the vapor phase, and thus the energy associated with state change of any water, either in the fuel or created by combustion, is not available for heating. The vast majority of the available heat that is not used for heating the room during combustion is exhausted out of the stack with the heated stack gases, water vapor, and particles created from combustion. A small amount of unutilized energy is associated with the incomplete combustion of fuel, which also reduces efficiency. Therefore, the more available heat that is kept in the room during combustion and the more complete the combustion, the higher the efficiency of the device, and visa versa.

5.1.1. Criteria Pollutants

As noted, the cost effectiveness analysis focused on particles and VOC. However, the cost effectiveness for other relevant criteria pollutants are also included in the cost benefit analysis task. The criteria pollutants and their treatment in this analysis are summarized in Table 5.02. While results for all criteria pollutants (except for lead) have been included in the cost benefit analysis task, to facilitate the interpretation of the lengthy result tables, data for the less relevant pollutants of NO_2 and SO_2 were not included in this final report. Results for the key pollutants of PM, VOC and CO only were included in the final report.

Table 5.02 Criteria Pollutants

Criteria Pollutant	Treatment/Rationale
$PM_{2.5}$	Total PM evaluated, majority of RWC particles submicron
PM_{10}	Total PM evaluated, majority of RWC particles submicron
O_3	NMVOC evaluated (simply listed as VOC), VOC are ozone precursors
NO_2	NO_x reported as NO_2 evaluated (in cost benefit analysis task only), NO and NO_2 emitted from RWC, NO converted to NO_2 in atmosphere
CO	Evaluated
SO_2	Evaluated (in cost benefit analysis task only)
Pb	Not relevant, not evaluated, extremely low levels emitted, little data available

5.1.2. Cost Effectiveness Calculations

The cost of pollutant reduction, in $/ton, was calculated by dividing the difference in cost by the difference in total emissions, both resulting from the installation or replacement of the existing wood burning device with an improved technology/alternative fuel. Total pollutant emissions were calculated by multiplying the emission factor for each of the five pollutants by the total annual fuel input for each appliance and fuel type. Emission factors were calculated directly using the best available research data for the improved technology appliances and alternative fuels. The emission factors for the improved cordwood stove and insert, and pellet stove and insert technologies, for which the emission factors were developed in the emission inventory task, are shown in Table 3.03. The emission factors for the existing appliances were also developed in the emission inventory task, and are also shown in Table 3.03. Emission factors for the gas appliances used for heat are shown in Table 5.03. Emission rates for the appliances used for aesthetics are shown in Table 5.04. The sources used to develop each emission factor/emission rate are referenced in the far right column.

Table 5.03 Emission Factors for Gas Appliances Used for Heat

Gas Stoves/Inserts	Pollutant Emission Factors (g/input MJ)			References
	PM	VOC	CO	
Natural Gas Stove/Insert, B Vent	3.74E-03	2.30E-03	1.94E-02	64-68
Natural Gas Stove/Insert, Direct Vent	3.74E-03	2.30E-03	1.94E-02	64-68
LPG Stove/Insert, B Vent	8.40E-03	2.50E-02	5.84E-03	69-70
LPG Stove/Insert, Direct Vent	8.40E-03	2.50E-02	5.84E-03	69-70
Natural Gas Furnaces and Boilers	3.74E-03	2.30E-03	1.73E-02	65-67
LPG Furnaces and Boilers	8.40E-03	2.50E-02	5.84E-03	69-70

Table 5.04 Emission Rates for Appliances Used for Aesthetics

Aesthetic Appliance / Fuel Category	Pollutant Emission Rates (g/hr)			References
	PM	VOC	CO	
Cordwood Fireplace Used for Aesthetics	64.30	39.60	313.0	37, 49-52
Vent-Free Gas Log Set-Natural Gas	.0987	.0715	.554	64-67
Vent-Free Gas Log Set-LPG	.221	.66	.154	69-70
Vented Gas Log Set-Natural Gas	.158	.0971	1.17	64-67
Vented Gas Log Set-LPG	.354	1.06	.246	69-70
Wax/Fiber Firelog Fuel	9.0	12.20	41.9	55

Annual fuel inputs for the improved technology/alternative fuel categories were calculated in a way that ensures the amount of fuel input for each appliance type would deliver an equal amount of heat to a home, as determined by the annual fuel input of the existing appliance. This was calculated by multiplying the existing appliance annual fuel input by the ratio of the existing device's efficiency to the replacement/installation device's efficiency. Therefore, the higher the efficiency of the improved technology and alternative fuel replacement/installation, the less input fuel is needed to reach the same level of heat output. Existing appliance annual fuel inputs were calculated as shown in Table 5.05, and the appliance efficiencies are shown in Tables 5.06 – 5.09. As the annual fuel input varies with the number of cords burned in each state, the annual fuel inputs will differ from state to state.

Table 5.05 Existing Appliance Annual Fuel Input Calculations

State	Mass per Cord (kg) [C1]	Wood Heaters			Fireplaces without Inserts Used for Heat			Centralized Cordwood Heating Systems		
		Cords Burned Annually per Unit [C2b]	Total Mass of Wood Used per Unit (kg) [C3b]	Annual Fuel Input (MJ) [C4b]	Cords Burned Annually per Unit [C2a]	Total Mass of Wood Used per Unit (kg) [C3a]	Annual Fuel Input (MJ) [C4a]	Cords Burned Annually per Unit [C2c]	Total Mass of Wood Used per Unit (kg) [C3c]	Annual Fuel Input (MJ) [C4c]
CT	1335.0	2.15	2866	55,496	0.74	983	19,032	3.41	4551	88,124
DE	1207.3	0.95	1147	22,203	0.51	616	11,924	0.75	906	17,536
ME	1112.7	2.56	2850	55,181	1.68	1870	36,201	5.38	5987	115,931
MD	1213.5	1.05	1278	24,739	0.53	642	12,435	1.26	1534	29,695
MA	1275.1	2.34	2979	57,673	1.28	1626	31,492	4.38	5583	108,108
NH	1212.8	2.56	3106	60,143	1.68	2038	39,457	5.38	6526	126,355
NJ	1203.4	1.40	1686	32,646	0.51	608	11,780	1.22	1468	28,416
NY	1285.0	2.41	3095	59,932	1.51	1945	37,660	5.30	6809	131,834
PA	1303.6	1.87	2433	47,114	0.75	979	18,963	2.93	3826	74,072
RI	1248.6	2.17	2710	52,464	0.54	668	12,939	1.96	2446	47,358
VT	1249.6	2.56	3201	61,971	1.68	2100	40,656	5.38	6724	130,194
D.C.	1213.5	0.86	1047	20,266	0.46	562	10,884	0.68	827	16,006
M-V	1238.3	2.03	2518	48,759	1.06	1309	25,339	4.15	5142	99,560

[C2] Reference 17
[C3] = [C1] X [C2]
[C4] = [C3] X 19.36 MJ/kg (average lower heating value of cordwood)[71]
M-V represents the MANE-VU region average

Each of the cost effectiveness sections takes into account the costs associated with the use and maintenance of each appliance category, and the installation/replacement of each newer technology/alternative fuel category. Installation/replacement costs are based on the typical or average costs and lifetimes of each appliance, as estimated by hearth products retailers from Pennsylvania, New York, and Massachusetts[72], including appliance costs, labor (carpentry and masonry work), auxiliary hardware (chimney and chimney connector pipe), disposal of old appliance, and gas plumbing. (For gas appliances it was assumed that the homes had natural gas or LPG hook-ups in place.) The estimates were attached as Appendix B to the cost benefit analysis task. Additional Installation costs for gas log sets were obtained from the 2006 Hearth and Home Buyer's Guide[73]. Ancillary costs per year include three components (where applicable): chimney sweeping, electricity, and catalyst replacement. (1) Chimney sweeping costs (only necessary for wood burning appliances) were determined through personal communication with the Chimney Safety Institute of America (CSIA)[74]. Estimates from the CSIA were attached as Appendix B to the cost benefit analysis task. (2) Electricity costs (using a nominal rate of $0.1275/kw-h)[75] are relevant for stoves that have electrical components. For example, pellet stoves require electricity to run their fan, auger, and other control components, and inserts, as well as gas stoves, often use an electric fan to circulate hot air into the room. (3) Catalyst replacement cost, relevant only to the certified catalytic cordwood stoves and inserts, was annualized from the data provided by the hearth products retailers. Annual fuel costs for cordwood, pellet, natural gas, and LPG fired appliances used for heat were calculated by multiplying the annual fuel input by the fuel cost in $/MJ. The total annual cost per appliance is the sum of the annualized replacement/installation cost, annual ancillary cost, and annual fuel cost.

Table 5.06 Cost Calculations for the Replacement of an Existing Uncertified Freestanding Cordwood Stove

Scenario	Replacement of an Existing Uncertified Freestanding Cordwood Stove							
Heating Device	**Uncertified Freestanding Cordwood Stove**	Certified NSPS Non-Catalytic Cordwood Stove	Certified NSPS Catalytic Cordwood Stove	Pellet Stove	Gas Stove - Natural Gas, B Vent	Gas Stove - Natural Gas, Direct Vent	Gas Stove - LPG, B Vent	Gas Stove - LPG, Direct Vent
Install/ Replacement Cost ($)	**-**	3367	4150	3850	3400	3400	3367	3367
Lifetime (yrs)	**-**	19.3	19.3	15.0	17.7	17.7	17.7	17.7
Annualized Install/ Replacement ($/yr)	**-**	174.1	214.7	256.7	192.5	192.5	190.6	190.6
Chimney Cleaning ($/ cleaning)	**150**	150	150	125	-	-	-	-
Frequency (cleaning/ year)	**1.5**	1	1	1	-	-	-	-
Annualized ($/yr)	**225**	150	150	125	-	-	-	-
Cat replace ($/yr)	**-**	-	43.00	-	-	-	-	-
Power Usage (kw)*	**-**	-	-	0.380	0.144	0.144	0.144	0.144
Hours of Use Annually*	**-**	-	-	1,368	1,368	1,368	1,368	1,368
Annual Electricity Cost ($/yr)	**-**	-	-	66.28	25.12	25.12	25.12	25.12
Ancillary Cost ($/yr)	**225**	150.00	193.00	191.28	25.12	25.12	25.12	25.12
Install/Ancillary Cost ($/yr)	**225.00**	324.14	407.66	447.94	217.57	217.57	215.68	215.68
Efficiency**	**54**	65	70	75	65	75	65	75
Fuel Cost***	**0.0078**	0.0078	0.0078	0.0157	0.0158	0.0158	0.0241	0.0241

* Reference 85 and professional judgment of OMNI-Test Laboratories employees.

** Wood efficiency references: 33, 38, 77; Gas efficiencies based on OMNI-Test Laboratories Testing

*** Fuel cost references: wood and pellets: 78; natural gas: 79; LPG: 80

Table 5.07 Cost Calculations for the Replacement of an Existing Uncertified Cordwood Fireplace Insert

Scenario	Replacement of an Existing Uncertified Cordwood Fireplace Insert							
Heating Device	**Uncertified Cordwood Fireplace Insert**	Certified NSPS Non-Catalytic Cordwood Insert	Certified NSPS Catalytic Cordwood Insert	Pellet Insert	Gas Insert-Natural Gas, B Vent	Gas Insert-Natural Gas, Direct Vent	Gas Insert-LPG, B Vent	Gas Insert-LPG, Direct Vent
Install/ Replacement Cost ($)	-	3767	3700	3667	3350	3350	3300	3300
Lifetime (yrs)	-	19.3	19.3	15.0	17.7	17.7	17.7	17.7
Annualized Install/ Replacement ($/yr)	-	194.8	191.4	244.4	189.6	189.6	186.8	186.8
Chimney Cleaning ($/ cleaning)	**175**	150	150	125	-	-	-	-
Frequency (cleaning/ year)	**2**	1	1	1	-	-	-	-
Annualized ($/yr)	**350**	150	150	125	-	-	-	-
Cat replace ($/yr)	-	-	43.00	-	-	-	-	-
Power Usage (kw)*	0.144	0.144	0.144	0.380	0.144	0.144	0.144	0.144
Hours of Use Annually*	1,368	1,368	1,368	1,368	1,368	1,368	1,368	1,368
Annual Electricity Cost ($/yr)	**25.12**	25.12	25.12	66.28	25.12	25.12	25.12	25.12
Ancillary Cost ($/yr)	**375.12**	175.12	218.12	191.28	25.12	25.12	25.12	25.12
Install/Ancillary Cost ($/yr)	**375.12**	369.94	409.50	435.72	214.74	214.74	211.91	211.91
Efficiency**	**49**	60	65	70	60	70	60	70
Fuel Cost	**0.0078**	0.0078	0.0078	0.0157	0.0158	0.0158	0.0241	0.0241

* Reference 85 and professional judgment of OMNI-Test Laboratories employees.

** Insert efficiencies are generally 5% lower than analogous stove type efficiencies due to heat lost into firebox cavity, and the fact that inserts are generally against the outside wall of a house, which radiates heat out of the house. This is especially true for masonry chimneys, which lose heat through un-insulated masonry material.

Table 5.08 Cost Calculations for the Addition of an Insert or Gas Log Set to an Existing Cordwood Fireplace without Insert Used for Heat

Scenario	Addition of an Insert or Gas Log-Set to an Existing Cordwood Fireplace without Insert Used for Heating							
Heating Device	**Cordwood Fireplace Used for Heating**	Certified NSPS Non-Catalytic Cordwood Insert	Certified NSPS Catalytic Cordwood Insert	Pellet Insert	Gas Insert-Natural Gas, B Vent	Gas Insert-Natural Gas, Direct Vent	Gas Insert-LPG, B Vent	Gas Insert-LPG, Direct Vent
Install/ Replacement Cost ($)	**-**	3600	3500	3500	3233	3233	3200	3200
Lifetime (yrs)	**-**	19.3	19.3	15.0	17.7	17.7	17.7	17.7
Annualized Install/ Replacement ($/yr)	**-**	186.2	181.0	233.3	183.0	183.0	181.1	181.1
Chimney Cleaning ($/ cleaning)	**150**	150	150	125	-	-	-	-
Frequency (cleaning/ year)	**1**	1	1	1	-	-	-	-
Annualized ($/yr)	**150**	150	150	125	-	-	-	-
Cat replace ($/yr)	**-**	-	43.00	-	-	-	-	-
Power Usage (kw)*	**-**	0.144	0.144	0.380	0.144	0.144	0.144	0.144
Hours of Use Annually*	**-**	1,368	1,368	1,368	1,368	1,368	1,368	1,368
Annual Electricity Cost ($/yr)	**-**	25.12	25.12	66.28	25.12	25.12	25.12	25.12
Ancillary Cost ($/yr)	**150**	175.12	218.12	191.28	25.12	25.12	25.12	25.12
Install/Ancillary Cost ($/yr)	**150.00**	361.32	399.15	424.61	208.13	208.13	206.25	206.25
Efficiency*	**18**	60	65	70	60	70	60	70
Fuel Cost	**0.0078**	0.0078	0.0078	0.0157	0.0158	0.0158	0.0241	0.0241

* Reference 85 and professional judgment of OMNI-Test Laboratories employees.

** Fireplace without Insert Used for Heat Efficiency: reference 81. Insert efficiencies are generally 5% lower than analogous stove type efficiencies due to heat lost into firebox cavity, and the fact that inserts are generally against the outside wall of a house, which radiates heat out of the house. This is especially true for masonry chimneys, which lose heat through un-insulated masonry material.

Table 5.09 Cost Calculations for the Replacement of an Existing Centralized Cordwood Heating System

Scenario	Replacement of an Existing Cordwood Furnace or Boiler			
Heating Device	**Centralized Cordwood Heating System**	Pellet Furnace or Boiler	Gas Furnace or Boiler-Natural Gas	Gas Furnace or Boiler-LPG
Install/ Replacement Cost ($)	**-**	4575	3675	3675
Lifetime (yrs)	**-**	16.0	16.0	16.0
Annualized Install/ Replacement ($/yr)	**-**	285.9	229.7	229.7
Chimney Cleaning ($/ cleaning)	**150**	150	-	-
Frequency (cleaning/ year)	**1**	1	-	-
Annualized ($/yr)	**150**	150	-	-
Cat replace ($/yr)	**-**	-	-	-
Power Usage (kw)*	**0.489**	0.739	0.489	0.489
Hours of Use Annually*	**2,548**	2,548	2,548	2,548
Annual Electricity Cost ($/yr)*	**158.69**	239.91	158.69	158.69
Ancillary Cost ($/yr)	**308.69**	389.91	158.69	158.69
Install/Ancillary Cost ($/yr)	**308.69**	675.85	388.38	388.38
Efficiency**	**47**	75	79	79
Fuel Cost	**0.0078**	0.0157	0.0158	0.0241

* Reference 85 and professional judgment of OMNI-Test Laboratories employees
** Efficiency references: cordwood: 13, 47, 58; pellet: same as pellet stove; gas: 82;

The pollution reduction cost effectiveness analyses for existing fireplaces without inserts used for aesthetic purposes were not conducted in the same manner as the aforementioned categories, which are used for heat. The most likely changes to an existing fireplace without insert used for aesthetic purposes include using wax/fiber firelogs, adding a vent-free gas log set, or adding a vented gas log set (gas includes both LPG and natural gas). Since aesthetic use is more concerned with the look and feel of the fire and not the total heat produced from fire, the fuel use rate was used instead of efficiency. Total fuel used for each appliance and fuel category was calculated by multiplying the fuel use rate by the average use of a fireplace without insert used for aesthetics, since it is assumed that the average appliance annual usage for aesthetics will be the same regardless of the appliance type. Annual fuel cost was calculated by multiplying the annual appliance usage (20 hrs/yr) by the applicable fuel usage rate (i.e. dry kg/hr, m^3/hr, or l/hr), as well as by the fuel cost ($/dry kg, $/$m^3$, or $/l). On the same note, pollution reduction cost effectiveness analyses for each state are not included, as average appliance usage for aesthetics does not vary significantly with the state within the limited climatic range of the MANE-VU states, and hence, the analysis is representative of the entire MANE-VU region.

Table 5.10 Cost Calculations for the Addition of a Gas Log Set or Use of Wax/Fiber Firelogs with an Existing Fireplace Used for Aesthetics

Scenario	Addition of a Gas Log Set or Use of Wax/Fiber Firelogs with an Existing Fireplace Used for Aesthetics					
Heating Device	**Cordwood Fireplace Used for Aesthetic Purposes**	Vent-Free Gas Log Set-Natural Gas	Vented Gas Log Set-Natural Gas	Vent-Free Gas Log Set-LPG	Vented Gas Log Set-LPG	Wax/Fiber Firelog Fuel
Install/ Replacement Cost ($)	**-**	1493	1483	1477	1467	NA
Lifetime (yrs)	**-**	12.7	12.7	12.7	12.7	-
Annualized Install/ Replacement ($/yr)	**-**	117.9	116.8	116.6	115.5	-
Chimney Cleaning ($/ cleaning)	**150**	-	-	-	-	150
Frequency (cleaning/ year)	**0.5**	-	-	-	-	0.5
Annualized ($/yr)	**75**	-	-	-	-	75
Cat replace ($/yr)	**-**	-	-	-	-	-
Power Usage (kw)	**-**	0.144	0.144	0.144	0.144	-
Hours of Use Annually*	**-**	21	21	21	21	-
Annual Electricity Cost ($/yr)	**-**	0.39	0.39	0.39	0.39	-
Ancillary Cost ($/yr)	**75.00**	0.39	0.39	0.39	0.39	75.00
Install/Ancillary Cost ($/yr)	**75.00**	118.28	117.18	116.96	115.87	75.00
Appliance Usage (hr/yr)	**20**	20	20	20	20	20
Fuel Usage Rate**	**4.2 dry kg/hr**	0.69 m^3/hr (25,000 Btu/hr)	1.11 m^3/hr (40,000 Btu/hr)	.063 l/hr (25,000 Btu/hr)	.101 l/hr (40,000 Btu/hr)	0.74 dry kg/hr
Fuel Cost***	**$0.15/dry kg**	$0.605/$m^3$	$0.605/$m^3$	$0.612/l	$0.612/l	$1.06/dry kg[8]

NA = Not Applicable

* Hours of use = 0.069 cords/yr burned for aesthetics X 1238.3 kg/cord (MANE-VU average) / 4.2 dry kg/hr = 20 hr/yr

** Firelog usage rate references: firelogs: 49.01, 49.02, 49.06, 49.08, 49.11, 49.15, 52.13, 52.21, 52.24

*** Firelog cost references 83-84

5.2. Pollution Reduction Cost Effectiveness by State and Average MANE-VU Region

The following tables summarize the cost effectiveness analyses for each improved technology and alternative fuel replacement or installation. There are separate tables for each pollutant, organized by state and the total MANE-VU region, except for the aesthetics category, which only has one table organized by pollutant. If the total annual cost of the improved technology and alternative fuel replacement or installation is less than the total annual cost of the existing device, and there is corresponding pollutant reduction after installation or replacement, then there is no cost for the pollution reduction, and the cell is marked as "**". The cost effectiveness tables are in reference to the replacement of an existing RWC device, and do not include new construction. This is not a cost-effectiveness project for other RWC control measures such as described in the U.S. EPA's PM_{10} RACM/BACM guideline documents[61,62]. Costs associated with these measures are predominantly organizational and administrative associated with the implementation of regulations and are outside the scope of this project.

The magnitude of pollutant reduction combined with the cost of the various mitigation scenarios are what primarily drive the cost effectiveness analyses. Replacement units, new installations, or alternative fuels that allow for greater emission reductions would have a lower cost per unit mass of pollutant reduction if all costs were equal. Similarly, replacement units, installations or alternative fuels with lower costs would have a lower cost per unit mass of pollutant reduction if the magnitude of pollutant reductions were equal. However, due to climate and sociodemographic differences, the cost per unit mass of pollutant reduction for the same mitigation scenarios vary from state to state as different amounts of fuel are characteristically burned per appliance in the different states with commensurately different amounts of total emissions. While the emission factors and the corresponding pollutant reductions for the same amount of fuel used, for a given scenario, are the same from state to state, the total amount of emission varies along with the total amount of fuel consumed. (More total emissions in cold climates and in rural settings.) This, combined with fixed costs that are part of the cost component and do not differ with location, produces higher costs per unit mass primarily in states with warmer climates. For example, Delaware and Washington D.C. generally have lower costs per unit mass of pollutant reductions as compared to New Hampshire, New York, and Vermont.

Table 5.11 PM Reduction Cost Effectiveness for the Replacement of an Existing Uncertified Freestanding Cordwood Stove

State	PM Reduction Cost Effectiveness ($/ton)						
	Certified NSPS Non-Catalytic Cordwood Stove	Certified NSPS Catalytic Cordwood Stove	Pellet Stove	Gas Stove - Natural Gas, B Vent	Gas Stove - Natural Gas, Direct Vent	Gas Stove - LPG, B Vent	Gas Stove - LPG, Direct Vent
CT	7.68E+02	2.54E+03	8.34E+03	5.37E+03	3.55E+03	1.26E+04	9.79E+03
DE	5.18E+03	1.08E+04	1.50E+04	5.16E+03	3.34E+03	1.23E+04	9.52E+03
ME	7.85E+02	2.57E+03	8.37E+03	5.37E+03	3.55E+03	1.26E+04	9.79E+03
MD	4.43E+03	9.42E+03	1.39E+04	5.20E+03	3.38E+03	1.24E+04	9.57E+03
MA	6.57E+02	2.33E+03	8.17E+03	5.38E+03	3.56E+03	1.26E+04	9.79E+03
NH	5.40E+02	2.11E+03	8.00E+03	5.38E+03	3.56E+03	1.26E+04	9.80E+03
NJ	2.83E+03	6.41E+03	1.15E+04	5.27E+03	3.45E+03	1.25E+04	9.66E+03
NY	5.50E+02	2.13E+03	8.01E+03	5.38E+03	3.56E+03	1.26E+04	9.80E+03
PA	1.29E+03	3.52E+03	9.14E+03	5.35E+03	3.53E+03	1.26E+04	9.76E+03
RI	9.38E+02	2.86E+03	8.60E+03	5.36E+03	3.54E+03	1.26E+04	9.78E+03
VT	4.60E+02	1.96E+03	7.88E+03	5.39E+03	3.56E+03	1.26E+04	9.80E+03
D.C.	5.88E+03	1.22E+04	1.61E+04	5.13E+03	3.31E+03	1.23E+04	9.48E+03
M-V	1.17E+03	3.30E+03	8.96E+03	5.35E+03	3.53E+03	1.26E+04	9.76E+03

M-V represents the MANE-VU region average

Table 5.12 VOC Reduction Cost Effectiveness for the Replacement of an Existing Uncertified Freestanding Cordwood Stove

State	VOC Reduction Cost Effectiveness ($/ton)						
	Certified NSPS Non-Catalytic Cordwood Stove	Certified NSPS Catalytic Cordwood Stove	Pellet Stove	Gas Stove - Natural Gas, B Vent	Gas Stove - Natural Gas, Direct Vent	Gas Stove - LPG, B Vent	Gas Stove - LPG, Direct Vent
CT	8.26E+02	2.27E+03	7.20E+03	4.95E+03	3.27E+03	1.18E+04	9.15E+03
DE	5.57E+03	9.70E+03	1.30E+04	4.76E+03	3.08E+03	1.15E+04	8.90E+03
ME	8.44E+02	2.30E+03	7.23E+03	4.95E+03	3.27E+03	1.18E+04	9.15E+03
MD	4.76E+03	8.43E+03	1.20E+04	4.79E+03	3.11E+03	1.16E+04	8.95E+03
MA	7.07E+02	2.08E+03	7.06E+03	4.96E+03	3.28E+03	1.18E+04	9.16E+03
NH	5.81E+02	1.89E+03	6.91E+03	4.96E+03	3.28E+03	1.18E+04	9.16E+03
NJ	3.04E+03	5.74E+03	9.91E+03	4.86E+03	3.18E+03	1.17E+04	9.03E+03
NY	5.92E+02	1.90E+03	6.92E+03	4.96E+03	3.28E+03	1.18E+04	9.16E+03
PA	1.39E+03	3.15E+03	7.89E+03	4.93E+03	3.25E+03	1.18E+04	9.12E+03
RI	1.01E+03	2.56E+03	7.43E+03	4.95E+03	3.27E+03	1.18E+04	9.14E+03
VT	4.95E+02	1.75E+03	6.80E+03	4.97E+03	3.29E+03	1.18E+04	9.17E+03
D.C.	6.33E+03	1.09E+04	1.39E+04	4.73E+03	3.05E+03	1.15E+04	8.86E+03
M-V	1.26E+03	2.96E+03	7.74E+03	4.94E+03	3.26E+03	1.18E+04	9.13E+03

M-V represents the MANE-VU region average

Table 5.13 CO Reduction Cost Effectiveness for the Replacement of an Existing Uncertified Freestanding Cordwood Stove

State	CO Reduction Cost Effectiveness ($/ton)						
	Certified NSPS Non-Catalytic Cordwood Stove	Certified NSPS Catalytic Cordwood Stove	Pellet Stove	Gas Stove - Natural Gas, B Vent	Gas Stove - Natural Gas, Direct Vent	Gas Stove - LPG, B Vent	Gas Stove - LPG, Direct Vent
CT	4.11E+02	7.13E+02	1.81E+03	1.16E+03	7.66E+02	2.70E+03	2.10E+03
DE	2.77E+03	3.05E+03	3.27E+03	1.11E+03	7.20E+02	2.64E+03	2.04E+03
ME	4.20E+02	7.22E+02	1.82E+03	1.16E+03	7.65E+02	2.70E+03	2.10E+03
MD	2.37E+03	2.65E+03	3.02E+03	1.12E+03	7.28E+02	2.65E+03	2.05E+03
MA	3.52E+02	6.55E+02	1.78E+03	1.16E+03	7.67E+02	2.70E+03	2.10E+03
NH	2.89E+02	5.93E+02	1.74E+03	1.16E+03	7.68E+02	2.70E+03	2.10E+03
NJ	1.51E+03	1.80E+03	2.50E+03	1.14E+03	7.44E+02	2.67E+03	2.07E+03
NY	2.94E+02	5.98E+02	1.74E+03	1.16E+03	7.68E+02	2.70E+03	2.10E+03
PA	6.91E+02	9.90E+02	1.99E+03	1.15E+03	7.60E+02	2.69E+03	2.09E+03
RI	5.02E+02	8.03E+02	1.87E+03	1.16E+03	7.64E+02	2.69E+03	2.09E+03
VT	2.46E+02	5.51E+02	1.71E+03	1.16E+03	7.69E+02	2.70E+03	2.10E+03
D.C.	3.15E+03	3.42E+03	3.50E+03	1.11E+03	7.13E+02	2.63E+03	2.03E+03
M-V	6.29E+02	9.29E+02	1.95E+03	1.15E+03	7.61E+02	2.69E+03	2.09E+03

M-V represents the MANE-VU region average

Table 5.14 PM Reduction Cost Effectiveness for the Replacement of an Existing Uncertified Cordwood Fireplace Insert

State	PM Reduction Cost Effectiveness ($/ton)						
	Certified NSPS Non-Catalytic Cordwood Insert	Certified NSPS Catalytic Cordwood Insert	Pellet Insert	Gas Insert-Natural Gas, B Vent	Gas Insert-Natural Gas, Direct Vent	Gas Insert-LPG, B Vent	Gas Insert-LPG, Direct Vent
CT	**	**	4.98E+03	2.32E+03	4.01E+02	9.40E+03	6.45E+03
DE	**	1.12E+03	7.16E+03	**	**	4.89E+03	1.94E+03
ME	**	**	4.98E+03	2.30E+03	3.84E+02	9.38E+03	6.43E+03
MD	**	6.80E+02	6.79E+03	**	**	5.66E+03	2.71E+03
MA	**	**	4.92E+03	2.43E+03	5.13E+02	9.51E+03	6.56E+03
NH	**	**	4.86E+03	2.55E+03	6.30E+02	9.63E+03	6.68E+03
NJ	**	**	6.00E+03	2.46E+02	**	7.29E+03	4.35E+03
NY	**	**	4.87E+03	2.54E+03	6.20E+02	9.62E+03	6.67E+03
PA	**	**	5.23E+03	1.79E+03	**	8.86E+03	5.92E+03
RI	**	**	5.06E+03	2.15E+03	2.30E+02	9.22E+03	6.28E+03
VT	**	**	4.82E+03	2.63E+03	7.11E+02	9.71E+03	6.76E+03
D.C.	**	1.53E+03	7.51E+03	**	**	4.17E+03	1.22E+03
M-V	**	**	5.18E+03	1.91E+03	**	8.98E+03	6.04E+03

M-V represents the MANE-VU region average

Table 5.15 VOC Reduction Cost Effectiveness for the Replacement of an Existing Uncertified Cordwood Fireplace Insert

State	VOC Reduction Cost Effectiveness ($/ton)						
	Certified NSPS Non-Catalytic Cordwood Insert	Certified NSPS Catalytic Cordwood Insert	Pellet Insert	Gas Insert-Natural Gas, B Vent	Gas Insert-Natural Gas, Direct Vent	Gas Insert-LPG, B Vent	Gas Insert-LPG, Direct Vent
CT	**	**	4.30E+03	2.14E+03	3.70E+02	8.80E+03	6.03E+03
DE	**	1.01E+03	6.19E+03	**	**	4.57E+03	1.82E+03
ME	**	**	4.31E+03	2.12E+03	3.55E+02	8.78E+03	6.01E+03
MD	**	6.09E+02	5.87E+03	**	**	5.30E+03	2.54E+03
MA	**	**	4.26E+03	2.24E+03	4.73E+02	8.91E+03	6.13E+03
NH	**	**	4.21E+03	2.35E+03	5.81E+02	9.02E+03	6.25E+03
NJ	**	**	5.19E+03	2.27E+02	**	6.83E+03	4.06E+03
NY	**	**	4.21E+03	2.34E+03	5.72E+02	9.01E+03	6.24E+03
PA	**	**	4.53E+03	1.65E+03	**	8.30E+03	5.53E+03
RI	**	**	4.38E+03	1.98E+03	2.12E+02	8.64E+03	5.87E+03
VT	**	**	4.17E+03	2.42E+03	6.55E+02	9.10E+03	6.32E+03
D.C.	**	1.37E+03	6.50E+03	**	**	3.90E+03	1.14E+03
M-V	**	**	4.48E+03	1.76E+03	**	8.41E+03	5.64E+03

M-V represents the MANE-VU region average

Table 5.16 CO Reduction Cost Effectiveness for the Replacement of an Existing Uncertified Cordwood Fireplace Insert

State	CO Reduction Cost Effectiveness ($/ton)						
	Certified NSPS Non-Catalytic Cordwood Insert	Certified NSPS Catalytic Cordwood Insert	Pellet Insert	Gas Insert-Natural Gas, B Vent	Gas Insert-Natural Gas, Direct Vent	Gas Insert-LPG, B Vent	Gas Insert-LPG, Direct Vent
CT	**	**	1.08E+03	5.00E+02	8.65E+01	2.01E+03	1.38E+03
DE	**	3.12E+02	1.56E+03	**	**	1.05E+03	4.16E+02
ME	**	**	1.08E+03	4.96E+02	8.29E+01	2.01E+03	1.38E+03
MD	**	1.89E+02	1.48E+03	**	**	1.21E+03	5.81E+02
MA	**	**	1.07E+03	5.24E+02	1.11E+02	2.04E+03	1.41E+03
NH	**	**	1.06E+03	5.49E+02	1.36E+02	2.06E+03	1.43E+03
NJ	**	**	1.30E+03	5.30E+01	**	1.56E+03	9.32E+02
NY	**	**	1.06E+03	5.47E+02	1.34E+02	2.06E+03	1.43E+03
PA	**	**	1.14E+03	3.86E+02	**	1.90E+03	1.27E+03
RI	**	**	1.10E+03	4.63E+02	4.97E+01	1.98E+03	1.35E+03
VT	**	**	1.05E+03	5.67E+02	1.53E+02	2.08E+03	1.45E+03
D.C.	**	4.26E+02	1.63E+03	**	**	8.92E+02	2.62E+02
M-V	**	**	1.13E+03	4.12E+02	**	1.92E+03	1.29E+03

M-V represents the MANE-VU region average

Table 5.17 PM Reduction Cost Effectiveness for the Addition of an Insert or Gas Log Set into an Existing Fireplace without Insert Used for Heating

State	PM Reduction Cost Effectiveness ($/ton)						
	Certified NSPS Non-Catalytic Cordwood Insert	Certified NSPS Catalytic Cordwood Insert	Pellet Insert	Gas Insert- Natural Gas, B Vent	Gas Insert- Natural Gas, Direct Vent	Gas Insert- LPG, B Vent	Gas Insert- LPG, Direct Vent
CT	7.60E+03	1.01E+04	1.26E+04	**	**	2.73E+03	1.54E+03
DE	1.65E+04	2.06E+04	2.27E+04	2.07E+03	1.29E+03	4.76E+03	3.57E+03
ME	5.06E+02	1.68E+03	4.49E+03	**	**	1.12E+03	**
MD	1.55E+04	1.95E+04	2.16E+04	1.84E+03	1.06E+03	4.54E+03	3.35E+03
MA	1.68E+03	3.07E+03	5.83E+03	**	**	1.38E+03	1.95E+02
NH	**	9.10E+02	3.76E+03	**	**	9.68E+02	**
NJ	1.68E+04	2.10E+04	2.30E+04	2.14E+03	1.36E+03	4.83E+03	3.64E+03
NY	2.01E+02	1.32E+03	4.15E+03	**	**	1.05E+03	**
PA	7.65E+03	1.01E+04	1.26E+04	**	**	2.74E+03	1.55E+03
RI	1.46E+04	1.84E+04	2.06E+04	1.63E+03	8.52E+02	4.33E+03	3.14E+03
VT	**	6.58E+02	3.52E+03	**	**	9.19E+02	**
D.C.	1.88E+04	2.33E+04	2.53E+04	2.60E+03	1.83E+03	5.28E+03	4.09E+03
M-V	3.88E+03	5.67E+03	8.33E+03	**	**	1.88E+03	6.95E+02

M-V represents the MANE-VU region average

Table 5.18 VOC Reduction Cost Effectiveness for the Addition of an Insert or Gas Log Set into an Existing Fireplace without Insert Used for Heating

State	VOC Reduction Cost Effectiveness ($/ton)						
	Certified NSPS Non-Catalytic Cordwood Insert	Certified NSPS Catalytic Cordwood Insert	Pellet Insert	Gas Insert- Natural Gas, B Vent	Gas Insert- Natural Gas, Direct Vent	Gas Insert- LPG, B Vent	Gas Insert- LPG, Direct Vent
CT	1.55E+04	1.86E+04	1.99E+04	**	**	4.48E+03	2.53E+03
DE	3.37E+04	3.80E+04	3.59E+04	3.35E+03	2.10E+03	7.82E+03	5.85E+03
ME	1.03E+03	3.09E+03	7.11E+03	**	**	1.83E+03	**
MD	3.17E+04	3.59E+04	3.41E+04	2.98E+03	1.72E+03	7.45E+03	5.49E+03
MA	3.43E+03	5.66E+03	9.22E+03	**	**	2.27E+03	3.20E+02
NH	**	1.68E+03	5.94E+03	**	**	1.59E+03	**
NJ	3.42E+04	3.86E+04	3.64E+04	3.47E+03	2.21E+03	7.93E+03	5.96E+03
NY	4.11E+02	2.43E+03	6.56E+03	**	**	1.72E+03	**
PA	1.56E+04	1.87E+04	2.00E+04	**	**	4.50E+03	2.55E+03
RI	2.98E+04	3.39E+04	3.25E+04	2.64E+03	1.38E+03	7.12E+03	5.15E+03
VT	**	1.21E+03	5.56E+03	**	**	1.51E+03	**
D.C.	3.83E+04	4.30E+04	4.00E+04	4.22E+03	2.96E+03	8.67E+03	6.70E+03
M-V	7.90E+03	1.04E+04	1.32E+04	**	**	3.09E+03	1.14E+03

M-V represents the MANE-VU region average

Table 5.19 CO Reduction Cost Effectiveness for the Addition of an Insert or Gas Log Set into an Existing Fireplace without Insert Used for Heating

State	CO Reduction Cost Effectiveness ($/ton)						
	Certified NSPS Non-Catalytic Cordwood Insert	Certified NSPS Catalytic Cordwood Insert	Pellet Insert	Gas Insert-Natural Gas, B Vent	Gas Insert-Natural Gas, Direct Vent	Gas Insert-LPG, B Vent	Gas Insert-LPG, Direct Vent
CT	1.85E+03	2.19E+03	2.58E+03	**	**	5.58E+02	3.15E+02
DE	4.03E+03	4.48E+03	4.66E+03	4.24E+02	2.65E+02	9.73E+02	7.30E+02
ME	1.23E+02	3.65E+02	9.24E+02	**	**	2.28E+02	**
MD	3.79E+03	4.23E+03	4.44E+03	3.77E+02	2.18E+02	9.28E+02	6.85E+02
MA	4.10E+02	6.67E+02	1.20E+03	**	**	2.83E+02	4.00E+01
NH	**	1.98E+02	7.72E+02	**	**	1.98E+02	**
NJ	4.10E+03	4.56E+03	4.73E+03	4.38E+02	2.79E+02	9.87E+02	7.44E+02
NY	4.91E+01	2.86E+02	8.52E+02	**	**	2.14E+02	**
PA	1.87E+03	2.20E+03	2.59E+03	**	**	5.61E+02	3.18E+02
RI	3.57E+03	4.00E+03	4.23E+03	3.34E+02	1.75E+02	8.86E+02	6.43E+02
VT	**	1.43E+02	7.22E+02	**	**	1.88E+02	**
D.C.	4.58E+03	5.07E+03	5.20E+03	5.34E+02	3.75E+02	1.08E+03	8.37E+02
M-V	9.45E+02	1.23E+03	1.71E+03	**	**	3.85E+02	1.42E+02

M-V represents the MANE-VU region average

Table 5.20 PM Reduction Cost Effectiveness for the Replacement of an Existing Centralized Cordwood Heating System

State	PM Reduction Cost Effectiveness ($/ton)		
	Pellet Furnaces and Boilers	Gas Furnaces and Boilers-Natural Gas	Gas Furnaces and Boilers-LPG
CT	8.46E+03	3.16E+03	9.50E+03
DE	3.14E+04	7.81E+03	1.42E+04
ME	7.09E+03	2.88E+03	9.23E+03
MD	1.97E+04	5.43E+03	1.18E+04
MA	7.41E+03	2.94E+03	9.29E+03
NH	6.74E+03	2.81E+03	9.15E+03
NJ	2.04E+04	5.58E+03	1.19E+04
NY	6.57E+03	2.78E+03	9.12E+03
PA	9.54E+03	3.38E+03	9.72E+03
RI	1.34E+04	4.15E+03	1.05E+04
VT	6.62E+03	2.78E+03	9.13E+03
D.C.	3.41E+04	8.36E+03	1.47E+04
M-V	7.81E+03	3.03E+03	9.37E+03

M-V represents the MANE-VU region average

Table 5.21 VOC Reduction Cost Effectiveness for the Replacement of an Existing Centralized Cordwood Heating System

State	VOC Reduction Cost Effectiveness ($/ton)		
	Pellet Furnaces and Boilers	Gas Furnaces and Boilers-Natural Gas	Gas Furnaces and Boilers-LPG
CT	1.86E+04	7.46E+03	2.34E+04
DE	6.91E+04	1.84E+04	3.49E+04
ME	1.56E+04	6.81E+03	2.27E+04
MD	4.33E+04	1.28E+04	2.90E+04
MA	1.63E+04	6.96E+03	2.29E+04
NH	1.48E+04	6.63E+03	2.26E+04
NJ	4.50E+04	1.32E+04	2.94E+04
NY	1.45E+04	6.56E+03	2.25E+04
PA	2.10E+04	7.98E+03	2.40E+04
RI	2.94E+04	9.81E+03	2.59E+04
VT	1.46E+04	6.58E+03	2.25E+04
D.C.	7.51E+04	1.97E+04	3.63E+04
M-V	1.72E+04	7.15E+03	2.31E+04

M-V represents the MANE-VU region average

Table 5.22 CO Reduction Cost Effectiveness for the Replacement of an Existing Centralized Cordwood Heating System

State	CO Reduction Cost Effectiveness ($/ton)		
	Pellet Furnaces and Boilers	Gas Furnaces and Boilers-Natural Gas	Gas Furnaces and Boilers-LPG
CT	1.25E+03	4.74E+02	1.42E+03
DE	4.65E+03	1.17E+03	2.12E+03
ME	1.05E+03	4.33E+02	1.38E+03
MD	2.91E+03	8.15E+02	1.76E+03
MA	1.10E+03	4.42E+02	1.39E+03
NH	9.97E+02	4.22E+02	1.37E+03
NJ	3.02E+03	8.39E+02	1.78E+03
NY	9.72E+02	4.17E+02	1.36E+03
PA	1.41E+03	5.07E+02	1.45E+03
RI	1.98E+03	6.24E+02	1.57E+03
VT	9.79E+02	4.18E+02	1.36E+03
D.C.	5.05E+03	1.26E+03	2.20E+03
M-V	1.16E+03	4.54E+02	1.40E+03

M-V represents the MANE-VU region average

Table 5.23 Pollutant Reduction Cost Effectiveness for the Addition of a Gas Log Set or Use of Wax/Fiber Firelogs in an Existing Fireplace without Insert Used for Aesthetics

Pollutant	Pollutant Reduction Cost Effectiveness ($/ton)				
	Vent-Free Gas Log Set-Natural Gas	Vented Gas Log Set-Natural Gas	Vent-Free Gas Log Set-LPG	Vented Gas Log Set-LPG	Wax/Fiber Firelog Fuel
PM	2.71E+04	2.99E+04	2.94E+04	3.41E+04	2.53E+03
VOC	4.39E+04	4.85E+04	4.83E+04	5.66E+04	5.11E+03
CO	5.55E+03	6.14E+03	6.01E+03	6.97E+03	5.16E+02

The cost effectiveness of the various mitigation options listed in Tables 5.11-5.23 are the central part of any realistic emission reductions program for RWC in the MANE-VU states. Wood resources are abundant and widely utilized as fuel, and heating is essential given the climate of the region. Some areas are economically depressed. The cost to households of any regulatory program mandating acceptable heating practices is a pivotal consideration. Likewise, the cost to households of any voluntary program is paramount for its success. The cost effectiveness of all reasonable scenarios for the replacement, modification or alternative fuel use for older existing, high emission wood-burning appliances is provided in this report for regulators and policy makers charged with the task of specifically lowering particulate, volatile organic compound and carbon monoxide emissions from residential wood combustion. The tables provided here allow for a direct comparison of the cost burden for each realistic mitigation option that would be shouldered by residential users. As an example, for an average resident in the MANE-VU region with an existing older technology centralized cordwood heating system, the best current option in terms of cost among the pellet, natural gas, and LPG options, is natural gas (assuming natural gas is available)(Table 5.22). Similarly, for wood-burning fireplaces used for aesthetics, manufactured wax/fiber firelogs offer the lowest cost per unit mass of air pollutant reduction (Table 5.23).

6. Summary

OMNI conducted *The Control Analysis and Documentation for Residential Wood Combustion in the MANE-VU Region* to re-evaluate previous RWC survey data, develop a new emissions inventory, and conduct emissions benefit and cost effectiveness analyses for RWC in the MANE-VU region. The resulting activity, emission, and cost effectiveness data resulted in an extensive look at MANE-VU RWC, and a basis for implementing various RWC control measures. This project was conducted in a manner that would produce the most current, relevant, and accurate RWC data for the MANE-VU region. Such data allows states and counties located within the region to assess the type and extent of RWC control measures that would be most effective for mitigating their RWC emissions.

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