A National Methodology and Emission Inventory for Residential Fuel Combustion

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ABSTRACT

The 1999 National Emission Inventory (NEI) contains State-reported area source residential fuel combustion emission estimates. The approaches and methodologies used to develop residential fuel combustion emission inventories are not consistent among States. Therefore, the emissions reported to the NEI by States are not consistent or compatible. In response to this, an innovative methodology was developed and funded by the Emissions Inventory Improvement Program (EIIP) to calculate consistent residential fuel combustion criteria pollutant emissions on a national, state, and county level for the following fuels: natural gas, liquefied propane gas, kerosene, fuel oil, anthracite and bituminous coal. Once apportioned to the county level, emissions were calculated by multiplying the fuel consumption by the applicable emission factors. This approach provides for a consistent residential fuel combustion emission inventory. Furthermore, the methodology allows for easy future updates of fuel consumption and census data. In summary, this approach and methodology provides an efficient mechanism for calculating residential fuel combustion emissions on the State and county level for the United States and can be used for future NEI development efforts.

INTRODUCTION

This project, funded by the Emissions Inventory Improvement Program (EIIP) and administered by the United States' Environmental Protection Agency (EPA) Emission Factor Inventory Group (EFIG) had a two-fold goal: to analyze the reported residential fuel combustion emissions estimates in the 1999 NEI (version 2), and to develop a method for estimating residential fuel combustion emissions on a State and county level for the whole nation. State-level emissions comparisons were developed to show the differences between NEI reported emissions and emissions estimates developed for this project.

The draft 1999 National Emissions Inventory (NEI) contains area source emissions estimates for residential fuel combustion. These emission estimates are provided to the EPA by individual States. There is no comprehensive national methodology for calculating emissions from residential fuel combustion. Consequently, the methods used by States for calculating emissions from residential fuel combustion are inconsistent, as are their results.

The method developed for estimating residential fuel combustion emissions makes use of publicly available data sets. Separate data sets were obtained for fuel consumption, and for allocating fuel to States and individual counties. Emission factors were obtained from the EPA. Using the data and emission factors, emissions estimates were prepared for the following criteria pollutants:

- Carbon monoxide;
- Nitrogen oxides;
- Sulfur dioxide;
- Volatile organic compounds; and,
- Filterable particulate matter (both PM10 and PM2.5) and condensable PM.

Emissions estimates for all States and counties in the United States were developed in spreadsheets. Due to the size of the individual worksheets, it was not feasible to include copies in table format in this document. A number of screen shots have been included to provide pictures of the individual worksheets.

This paper documents the method and results of this project. It is arranged in a sequential order, beginning with a description and explanation of the various data sources. This is followed by a description of the methodology used to calculate emissions for residential fuel combustion. The results of applying the method are discussed, and conclusions are made regarding the use and validity of the emissions estimates generated by this project.

BODY

Data Sources

It was imperative that the methodology used for this project be based on publicly-available data. Therefore, one of our first milestones was to find publicly-available data sources. Fuel consumption data for 1999 were obtained from the US Department of Energy's (DOE) Energy Information Administration (EIA). Information on anthracite and bituminous coal consumption was obtained by contacting the DOE's EIA directly. The EIA made anthracite and bituminous coal consumption estimates available for 1999 but indicated that it would be discontinuing its reporting of anthracite coal in the future.

Data used to allocate EIA's fuel consumption data to the State and county level were obtained from the US Census Bureau's 1990 Detailed Housing Characteristics data set. The 1990 data set was the only one available during the duration of this project. Emission factors were selected from the EPA's Compilation of Stationary Emission Factors (commonly referred to as AP-42). Fuel oil sulfur data were obtained from the 1985 National Acid Precipitation Program (NAPAP) and the Federal Energy Commission's FERC-423 database. Coal sulfur data were obtained from the US Geological Survey's COALQUAL database. Finally, a copy of the draft 1999 version 2 NEI was obtained from the EPA, as were SCCs used to query the NEI database.

Selection of Emission Factors

An extensive search and review was conducted to identify emission factors for the fuels and pollutants of concern to this project. The principal source of emission factors was the EPA's *Compilation of Stationary Source Emission Factors*, commonly referred to as AP-42. Wherever possible, the most recent release(s) of AP-42 were used. In many cases, residential-specific emission factors were not available for selected fuel types or heating unit size ranges. Emission factors were then selected based on the heating unit size and firing configuration that most closely matched residential heating units. Therefore, oftentimes commercial/institutional factors were selected. Heating unit size ranges were obtained from an earlier version of AP-42, Section 1.4 (1996). This section distinguishes among heating unit/boiler sizes in the following manner:

- Utility/Large Industrial Boilers: >100 MMBtu
- Small Industrial Boilers: 10 - 100 MMBtu
- Commercial Boilers: 0.3 - <10 MMBtu
- Residential Furnaces: <0.3 MMBtu.

The individual emission factors that were selected and used for this emission inventory are presented in the subsequent tables.

Natural Gas

Emission factors for residential natural gas combustion were obtained from AP-42, Section 1.4. Table 1 presents the selected emission factors for natural gas combustion.

Table 1. Emission Factors for Residential Natural Gas Combustion.

Pollutant	Emission Factor ($lb/10^6$ ft^3)	AP-42 Table	Publication Date
CO	40	1.4-1	07/98
NO_x	94	1.4-1	07/98
SO_2	0.6	1.4-2	07/98
VOC	5.5	1.4-2	07/98
PM10 (Filterable)	1.9	1.4-2	07/98
PM2.5 (Filterable)	1.9	1.4-2	07/98
PM Condensable	5.7	1.4-2	07/98

All emission factors are based on natural gas having a heat content of 1,020 Btu/ft^3. The CO and NO_x emission factors are specific for uncontrolled residential furnaces. The SO_2 and VOC emission factors are applicable to all units burning natural gas. The SO_2 emission factor assumes that the sulfur content of natural gas is 2,000 $grains/10^6$ ft^3. The filterable PM10 and PM2.5 emission factors are identical as all PM from natural gas combustion is assumed to be less than 1.0 micrometer in diameter.

Liquefied Petroleum Gas (LPG)

LPG emissions are considered to be similar to natural gas. Most of the emission factors were obtained from Section 1.5 in AP-42. PM10, PM2.5 (condensable and filterable) and VOC emission factors are the same as those for natural gas; NO_x emissions are approximately 50 percent higher than those for natural gas. The SO_2 emission factor is 0.10(S) $lb/10^3$ gallon of fuel combusted. Based on prior discussions with EPA, a national sulfur fuel content for LPG of 0.54 grains/100 ft^3 was assigned. Table 2 presents the selected emission factors for residential LPG combustion. Whenever natural gas emission factors were used it was necessary to convert them from $lb/ft^3 10^6$ to $lb/10^3$ gallons.

Table 2. Emission Factors for Residential LPG Combustion.

Pollutant	Emission Factor ($lb/10^3$ gallons)	AP-42 Table	Publication Date
CO	3.2	1.5-1	10/96
NO_x	13.0	1.4-2	07/98
SO_2	0.10	1.5-1	10/96
VOC	0.5	1.5-1	10/96
PM10 (Filterable)	0.17	1.4-2	07/98
PM2.5 (Filterable)	0.17	1.4-2	07/98
PM2.5 Condensable	0.51	1.4-2	07/98

Note: Emission factors have been converted from $lb/10^6 ft^3$ to $lb/10^3$ gallons.

Distillate (No. 2) Fuel Oil

Distillate fuel oil emission factors were obtained from Section 1.3 of AP-42. The emission factors are based on No. 2 fuel oil with a heating value of 140,000 Btu/gal. A sulfur content value of 0.30 percent by weight ($\%_w$) was assigned on a national basis for fuel oil. This value was obtained from the 1985 NAPAP. In addition to the number presented in NAPAP documentation, we analyzed the FERC-423 database. The FERC-423 database analysis indicated that the national distillate fuel oil sulfur content was 0.24%. Therefore, conservatively, it was decided to use $0.30\%_w$ from NAPAP. This was determined to be a conservative value for distillate fuel sulfur contents. The emission factors selected for residential distillate fuel oil combustion are presented in Table 3.

Table 3. Emission Factors for Residential Distillate Fuel Oil Combustion.

Pollutant	Emission Factor ($lb/10^3$ gallons)	AP-42 Table	Publication Date
CO	5.0	1.3-1	09/98
NO_x	18.0	1.3-1	09/98
SO_2	42.6	1.3-1	09/98
VOC as NMTOC[a]	0.7	1.3-3	09/98
PM10 (Filterable)	1.08	1.3-7	09/98
PM2.5 (Filterable)	0.83	1.3-7	09/98
PM Condensable	1.3	1.3-2	09/98

[a]NMTOC stands for non-methane total organic compounds.

The CO, NO_x, SO_2, and PM filterable emission factors are specific to residential furnaces. The PM 10 emission factor is for commercial boilers but is more consistent than the residential combustion-specific emission factor in AP-42. In addition, the residential fuel combustion-specific PM 10 emission factor is based on newer burner designs. In addition, AP-42 states that pre-1970's burner designs may have PM 10 emissions up to 3.0 $lb/10^3$ gal. Therefore, it was decided to use the 1.08 $lb/10^3$ gal emission factor. The emission factor for filterable PM2.5 is specific to commercial/institutional boilers having a design capacity <10 million Btu/hr. Based on capacity, this was determined to be the boiler size range most similar to those that may be found in residential settings.

Kerosene

AP-42 does not contain kerosene-specific emission factors. Therefore, distillate fuel oil factors were multiplied by the ratio of kerosene to distillate fuel oil heat contents (135,000 / 140,000). In addition, the same assumption regarding fuel oil sulfur contents was used ($0.30\%_w$). Table 4 contains the emission factors for residential kerosene combustion, which are approximately 4 percent lower than the emission factors for distillate fuel oil combustion.

Table 4. Emission Factors for Residential Kerosene Combustion.

Pollutant	Emission Factor ($lb/10^3$ gallons)	AP-42 Table	Publication Date
CO	4.8	1.3-1	09/98
NO_x	17.4	1.3-1	09/98
SO_2	41.1	1.3-1	09/98
VOC	0.7	1.3-3	09/98
PM10 (Filterable)	1.08	1.3-7	09/98
PM2.5 (Filterable)	0.83	1.3-7	09/98
PM Condensable	1.3	1.3-2	09/98

Anthracite Coal

Anthracite coal emission factors were obtained from Section 1.2 of AP-42. The SO_2 emission factor is dependent upon the sulfur content of coal. The particulate matter emission factor is dependent upon the ash content of the coal. To obtain sulfur and ash contents for anthracite coal, an analysis was performed of the USGS's COALQUAL database. The database was queried by State and it was determined that a representative ash percentage for anthracite coal was 13.38 percent. Furthermore, it was determined that on a national basis, anthracite coal contains 0.89 percent sulfur. These two values were used to calculate the PM10 and SO_2 emission factor.

The SO_2 and NO_x emission factors are for residential space heaters. The PM10 filterable emission factor was selected because it is for hand-fired units. It is assumed that most residential heating units are hand-fired and do not use more complicated firing mechanisms. The PM condensable emission factor is identical for both PM2.5 and PM10, as all condensable emissions are assumed to be less than 1.0 micrometer in diameter. The filterable PM2.5 emission factor is for uncontrolled commercial/institutional dry bottom boilers firing pulverized anthracite coal. This factor was selected because it is the only anthracite coal specific PM2.5 emission factor available in AP-42.

A conservative emission factor for CO was selected because AP-42 states that emissions from improperly operated or maintained coal-burning units may be "one or two orders of magnitude higher" than the listed factors. We assumed that many residential coal-burning units would be improperly operated or maintained. In addition, a 1986 version of AP-42 states emission factors of anthracite and bituminous coal are interchangeable, "based on the similarity of anthracite and bituminous coal." The NEI was also queried to ascertain which emission factors were being used to estimate CO emissions from anthracite coal burning boilers. The factor listed in Table 5 for CO was found in the NEI to be used for both coal types, further bolstering the argument for using this factor for estimating CO emissions from both types of coal.

Table 5. Emission Factors for Residential Anthracite Coal Combustion.

Pollutant	Emission Factor (lb/ton)	AP-42 Table	Publication Date
CO	275	1.1-3	09/98
NO_x	3.0	1.2-1	10/96
SO_2	39S	1.2-1	10/96
VOC	10	1.1-19	09/98
PM10 (Filterable)	10.0	1.2-3	10/96
PM2.5 (Filterable)	0.6A	1.2-4	10/96
PM Condensable	0.08A	1.2-3	10/96

Bituminous Coal

Emission factors for bituminous coal combustion are from Section 1.1 of AP-42. As was the case for anthracite coal, the SO_2 emission factor requires a sulfur percentage. This percentage was obtained from the USGS's COALQUAL database. As it was determined that bituminous coal is combusted in States that do not contain local deposits of coal, it was necessary to perform a proximity analysis. The assumption was made that the bituminous coal used for residential fuel combustion originates in the nearest State. Therefore, States not having coal but reporting its usage were assigned sulfur percentages based on proximity. In this way, for example, California was assigned Arizona's sulfur contents, and North Carolina was assigned Tennessee's sulfur percentage value. The individual sulfur percentage values were entered into the spreadsheets and used to calculate SO_2 emissions.

AP-42 does not contain any residential-specific emission factors for bituminous coal combustion. Therefore, emission factors were selected based on boiler firing configuration and size. The SO_2 emission factor selected is for commercial/institutional hand-fed units, and therefore potentially similar to residential units. The CO emission factor selected was chosen for hand-fed units and it provides a conservative emission estimate. The emission factor used for VOC is for commercial/institutional hand-fed units and based on total non-methane organic compounds (TNMOC). The filterable PM10 emission factor chosen is for hand-fed commercial/institutional units. The filterable PM2.5 and condensable PM emission factor are for uncontrolled commercial/institutional underfeed stoker boilers. AP-42 states that in the absence of data for hand-fed units, the underfeed stoker emission factor can be used. In addition, it is the only factor for uncontrolled coal combustion.

Table 6. Emission Factors for Residential Bituminous Coal Combustion.

Pollutant	Emission Factor (lb/ton)	AP-42 Table	Publication Date
CO	275	1.1-3	09/98
NO_x	9.1	1.1-3	09/98
SO_2	31S	1.1-3	09/98
VOC	10	1.1-19	09/98
PM10 (Filterable)	6.2	1.1-4	09/98
PM2.5 (Filterable)	3.8	1.1-10	09/98
PM Condensable	0.04	1.1-5	09/98

Selection of SCCs

SCCs were selected that matched the criteria for residential fuel combustion. These SCCs were used to query the 1999 NEI v.2 to obtain emission estimates for States. Provided in Table 7 is a summary of the SCCs that were used to query the NEI.

Table 7. SCCs used for Querying the 1999 NEI v.2.

SCC	Fuel	Description
2104001000	Anthracite Coal	All Combustor Types
2104002000	Bituminous/Subbituminous Coal	All Combustor Types
2104004000	Distillate Oil	All Combustor Types
2104005000	Residual Oil	All Combustor Types
2104006000	Natural Gas	All Combustor Types
2104006010	Natural Gas	Residential Furnaces
2104007000	Liquefied Petroleum Gas	All Combustor Types
2104011000	Kerosene	Total: All Heater Types

Methodology

Various data sources (discussed under Data Sources section) were used to develop one spreadsheet with numerous worksheets in MS Excel®. Worksheets were developed by fuel type for the following fuels:

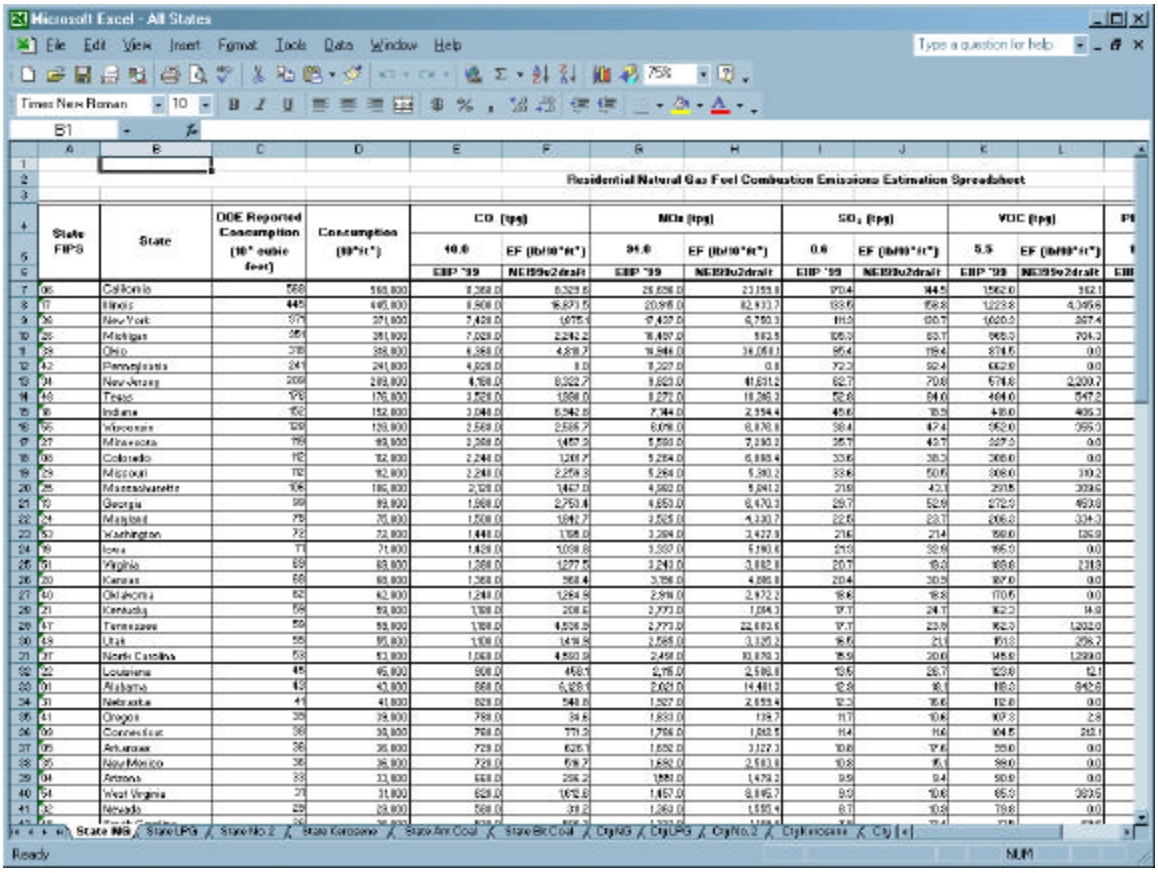
1. Natural gas,
2. Liquefied propane gas,
3. Distillate fuel oil,
4. Kerosene
5. Anthracite coal, and,
6. Bituminous coal.

The fuel specific spreadsheets contained the following information in separate columns:

1. State FIPS code,
2. State name,
3. DOE reported fuel consumption for the fuel type,
4. DOE reported fuel consumption in a format compatible with emission factors,
5. Pollutant-specific emission factors linked to fuel usage to calculate emissions.

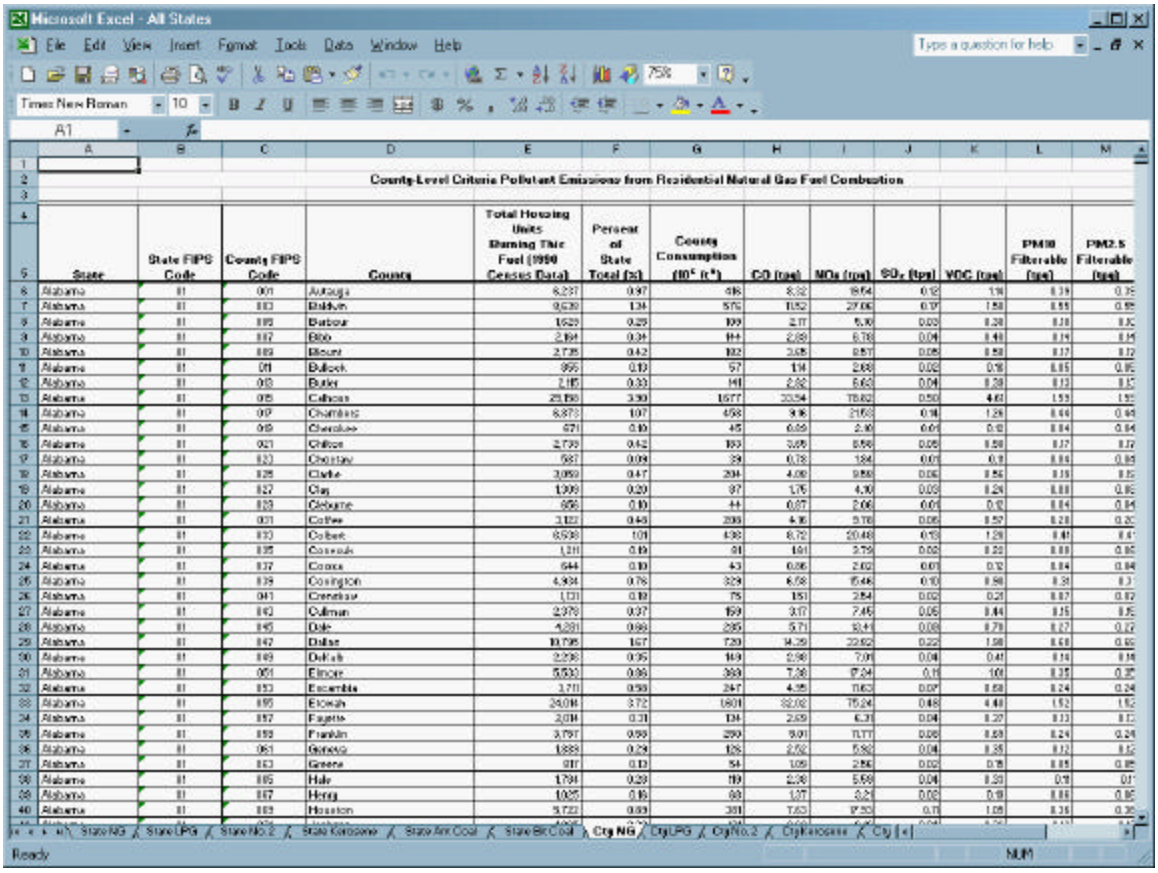
These spreadsheets (see **Figures 1** and **2** for details) were used to calculate fuel consumption by State. DOE fuel consumption estimates were entered manually into the spreadsheets. The DOE numbers were presented in units of billions of cubic feet for natural gas; thousands of barrels for propane, distillate fuel oil and kerosene; and tons for coal. The DOE numbers were converted to numbers compatible with the emission factors.

Figure 1. Excel worksheet detailing the State EIIP and NEI emission totals for Natural Gas.



Once the calculations had been performed, the individual fuel-specific worksheets were sorted in order of decreasing emissions. In addition, these initial 6 worksheets contained emission estimates from the 1999 NEI as comparisons. Therefore, for each pollutant and State, the NEI emission estimate was presented in conjunction with the calculated number. This enabled a quick and easy comparison of emission estimates.

Figure 2. Excel worksheet detailing emission totals by county for natural gas.



Following the fuel-specific worksheets, State and county specific worksheets were developed for each fuel type. States were ordered alphabetically, and each State's counties were included in a separate column adjacent to the State. These spreadsheets were linked to the fuel-specific State worksheets to obtain fuel consumption and emission factor data. Therefore, fuel and emission factors were only entered once for each fuel type.

Results

Criteria pollutant emissions were calculated for 50 States and the District of Columbia. For some pollutants, the calculated emissions were similar to those reported by States in the NEI. Table 8 contains a comparison of national totals calculated for this project and those obtained by querying the NEI.

Great care was taken to ensure that the State totals matched the sum of all county emission for each State. This was performed by importing the spreadsheet (and its associated worksheets) into

FoxPro and conducting specific queries that looked at State totals and the total emissions from all counties for a specific State on a pollutant basis.

As is apparent from Table 8, there is no real consistency among the State-reported data. In some cases the estimates calculated for this project (EIIP) are higher than the NEI, and the reverse is also common. This is most likely attributable to States using different methodologies for calculating emissions from residential fuel combustion.

Emissions factors were carefully selected and scrutinized for inclusion in this project. The emission factors presented in the tables included in this paper offer perhaps the most comprehensive and reliable set of factors that can be used to calculate emissions from residential fuel combustion. It is not known if a more comprehensive and in-depth analysis of emission factors has been performed for the estimation of emissions from residential fuel combustion.

CONCLUSION

The methodology developed for this project and described in this paper enables a simple and consistent approach to calculating emissions from residential fuel combustion. In addition, the spreadsheets that have been developed are easy to maintain and update. For example, it should take very little effort to replace the 1990 Census Housing Data with the new 2000 Census data once it becomes available. Similarly, it should be easy and straightforward to replace the DOE consumption estimates with more current data. The worksheets within the spreadsheet can also be modified to calculate HAP emissions.

The emissions calculations and corresponding results are more consistent than those reported to the NEI by individual States. State reported NEI residential fuel combustion estimates could be substituted with the emissions estimates developed by this project. This should create a more robust and consistent data set in the NEI. Therefore, EPA may propose to replace existing State-reported residential fuel combustion emission estimates with those developed using the methodology described in this project.

Table 8. Comparison of 1999 Project Calculated Emissions and 1999NEI v2 Reported Emissions for all States.

Pollutant	Fuel Type											
	Natural Gas		LPG		Distillate Fuel Oil		Kerosene		Anthracite Coal		Bituminous Coal	
	EIIP	NEI	EIIP	NEI	EIIP	NEI	EIIP	NEI	EIIP	NEI	EIIP	NEI
CO	94,580	97,747	9,906	2,718	14,476	39,626	1,976	670	47,685	10,503	207,034	100,604
NO_x	222,263	362,287	40,241	9,908	52,638	161,703	7,148	2,447	520	4,963	6,851	102,503
SO_2	1,419	1,662	310	61	124,578	130,290	16,914	3,762	6,013	5,015	46,043	19,065
VOC	13,005	16,645	1,517	591	2,076	7,699	284	171	1,734	720	7,529	6,349
PM10 Filterable	4,493	9,215	526	50	3,158	5,505	445	14	1,734	4,275	4,668	3,372
PM 2.5 Filterable	4,493	9,215	526	17	2,427	4,209	342	11	1,392	0	2,861	518
PM Condensable	13,478	0	1,579	0	3,802	0	535	0	185	0	30	0

Key Words: residential fuel combustion, emission inventory, EIIP, emission factors.

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