



Appendix E-4

Nonroad 2008 Inventory Documentation

- Documentation of the EPA Region 7 NonRoad Emissions Modeling Protocol
- Documentation of the Commercial Marine Vessel Component of the National Emissions Inventory Methodology
- Documentation of the Locomotive Component of the National Emissions Inventory Methodology
- Documentation of the Aircraft Component of the National Emissions Inventory Methodology



**EPA Region 7 Off-Road Emissions Modeling Protocol
for 2008 and 2022 for the St. Louis, Missouri-Five
County Nonattainment Area**

**Ozone and PM2.5 Maintenance Plan Work Share
St. Louis, Missouri-Five County Area
Nonroad modeling for inventory development**

For this modeling exercise, the EPA Region 7 utilized the NONROAD2008a model to calculate an ozone and PM2.5 nonroad inventory in five counties in the St. Louis nonattainment area for the 1997 PM2.5 annual and 1997 Ozone NAAQS. The NONROAD2008a model provides the emissions for all nonroad source categories except aircraft, commercial marine vessel, and railroad locomotive.

In running the NONROAD model, the user must specify a modeling scenario by the inventory year, geographic area (nation, state, county), period (annual, seasonal, monthly, daily), and the equipment categories. For all other required variables, the NONROAD model provides default input values. For the following modeling exercises, fuel parameters (Reid Vapor Pressure (RVP), oxygen weight, sulfur content, ethanol volume and market percentage) and temperatures for each geographical area were provided by MDNR in lieu of the modeling default settings for more accurate results (see attachment).

Ozone Precursor Emissions

Ozone Methodology/Input Data

Nonroad mobile source emissions for the years of 2008 and 2022 are calculated using the EPA approved model, NONROAD2008a, and included Franklin County, Jefferson County, St. Charles County, St. Louis County and St. Louis City in St. Louis, Missouri.

For modeling ozone precursor pollutants, temperatures and fuel characteristics representative of each county during an ozone summer weekday, were entered into NONROAD2a and modeled to calculate an ozone season weekday emissions for nonroad sources. Minimum, maximum, and average temperatures for a typical summer season were provided by MDNR (see attachment). Modeling input parameters are as follows:

**Table B-38
NONROAD Model Temperature & Fuel Characteristic Input Values by County**

County	Oxygen Weight %	RVP psi	Gasoline Sulfur %	Diesel Sulfur	Marine Diesel Sulfur %	CNG / LPG Sulfur %	Temperatures		
							Min.	Max.	Avg.
Franklin	0.35	7	0.0049	0.0355	0.0402	0.003	61.8	90	75.96
Jefferson	0.35	7	0.0049	0.0355	0.0402	0.003	61	88.6	75.16
St. Charles	0.35	7	0.0049	0.0355	0.0402	0.003	62.2	89.2	76.15
St. Louis	0.35	7	0.0049	0.0355	0.0402	0.003	64.1	89.5	77.1
St. Louis City	0.35	7	0.0049	0.0355	0.0402	0.003	65.1	89.8	77.72

Direct PM_{2.5} / PM_{2.5} Precursor Emissions

Methodology/Input Data

Nonroad mobile source emissions for the years of 2008 and 2022 were calculated using the EPA approved model, NONROAD2008a, and included Franklin County, Jefferson County, St. Charles County, St. Louis County and St. Louis City in St. Louis, Missouri.

For modeling PM_{2.5} and PM_{2.5} precursor pollutants, temperatures and fuel characteristics representative of each county for each of the four seasons (winter, spring, summer, and fall) were entered into the NONROAD2008a model as input parameters. The highest temperature and lowest temperature from each three month period (December-February, March-May, June-August, and September-November) were averaged to create a seasonal average temperature.

Those seasonal average temperatures, seasonal minimum and seasonal maximum temperatures were then utilized in the model, including the fuel parameters, to calculate the total emissions for each county and season. Summing the emissions of all four seasons for each county gave the total annual emissions. The temperatures and fuel characteristics representative of each county were provided by MDNR. Modeling input parameters are as follows:

**Table B-39
NONROAD Model Temperature & Fuel Characteristic Input Values by County & Season**

County	Season	Oxygen Weight %	RVP psi	Gasoline Sulfur %	Diesel Sulfur	Marine Diesel Sulfur %	CNG / LPG Sulfur %	Temperatures		
								Min.	Max.	Avg.
Franklin	Winter	0.35	11.5	0.0043	0.0355	0.0402	0.003	19.7	47	33.4
Franklin	Spring	0.35	9	0.0046	0.0355	0.0402	0.003	33.5	76.9	55.2
Franklin	Summer	0.35	7	0.0049	0.0355	0.0402	0.003	61.8	90	75.9
Franklin	Autumn	0.35	9	0.0046	0.0355	0.0402	0.003	34.3	80.9	57.6
Jefferson	Winter	0.35	11.5	0.0043	0.0355	0.0402	0.003	18.6	45.6	32.1
Jefferson	Spring	0.35	9	0.0046	0.0355	0.0402	0.003	32.4	75.8	54.1
Jefferson	Summer	0.35	7	0.0049	0.0355	0.0402	0.003	61	88.6	74.8
Jefferson	Autumn	0.35	9	0.0046	0.0355	0.0402	0.003	33.6	79.8	56.7
St. Charles	Winter	0.35	11.5	0.0043	0.0355	0.0402	0.003	18.7	43.9	31.3
St. Charles	Spring	0.35	9	0.0046	0.0355	0.0402	0.003	32.3	75.8	54.1
St. Charles	Summer	0.35	7	0.0049	0.0355	0.0402	0.003	62.2	89.2	75.7
St. Charles	Autumn	0.35	9	0.0046	0.0355	0.0402	0.003	34.8	80.3	57.6
St. Louis	Winter	0.35	11.5	0.0043	0.0355	0.0402	0.003	19.8	44.2	32
St. Louis	Spring	0.35	9	0.0046	0.0355	0.0402	0.003	34.5	76.1	55.3
St. Louis	Summer	0.35	7	0.0049	0.0355	0.0402	0.003	64.1	89.5	76.8
St. Louis	Autumn	0.35	9	0.0046	0.0355	0.0402	0.003	35.5	80.2	57.9
St. Louis City	Winter	0.35	11.5	0.0043	0.0355	0.0402	0.003	20.7	45.5	32.6
St. Louis City	Spring	0.35	9	0.0046	0.0355	0.0402	0.003	35.7	76.4	56
St. Louis City	Summer	0.35	7	0.0049	0.0355	0.0402	0.003	65.1	89.8	77.5
St. Louis City	Autumn	0.35	9	0.0046	0.0355	0.0402	0.003	36.6	80.4	58.5

QA/QC

Quality control and quality assurance were conducted throughout this nonroad modeling process. Data collected from various data sources were verified and correctly entered or transcribed into the model. In some instances, input values, i.e., temperatures and fuel values were double and/or triple checked for accuracy to insure they corresponded to the data supplied by MDNR. In addition, a spot-checking of the modeling results, including rerunning the model for those results in question, was performed to insure reliability.

Nonroad Modeling Results Summary Tables

Table B-40

Ozone Typical Summer Day Emissions Tons / Day						
County	NO _x		VOC		CO	
	2008	2022	2008	2022	2008	2022
Franklin	2.93	1.81	3.59	1.55	23.56	19.76
Jefferson	2.89	1.27	3.64	2.06	38.72	34.77
St. Charles	7.61	3.33	7.49	3.95	85.2	73.93
St. Louis CO	20.55	9.08	27.22	17.85	424.3	388.64
St. Louis City	2.86	1.19	3.97	2.2	65.9	56.28
Total	36.84	16.68	45.91	27.61	637.7	573.38

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Direct PM _{2.5} and PM _{2.5} Precursor Pollutant County Totals (Tons per Year)										
County	PM _{2.5}		PM ₁₀		SO ₂		NO _x		VOC	
	2008	2022	2008	2022	2008	2022	2008	2022	2008	2022
Franklin	64.73	39.04	67.91	34.72	11.8	10.75	665.82	233.09	945.16	386.31
Jefferson	73.6	52.26	77.19	55.05	14.6	15.33	726.68	319.36	929.83	544.67
St. Charles	171.98	120.7	179.8	126.8	37.1	39.01	1893.6	827.95	1948.52	1031.57
St. Louis	530.64	444.8	558.1	471.3	99.3	106.99	5354.4	2323.2	6470.16	4457.23
St. Louis City	53.25	46.35	55.98	49.02	9.74	10.93	794.9	341.3	1066	628.57

Modeling File Naming Convention

Ozone: pollutant-county-year

PM_{2.5}: pollutant-county-year-season

OZONE Modeling Files Example: 03Frnk08 = (Ozone Franklin County 2008)

O3 = Ozone

08 = 2008

22 = 2022

Frnk = Franklin County

Jeff = Jefferson County

StCh = St. Charles County

StLC = St. Louis County

StCi = St. Louis City

PM2.5 Modeling Files Example: PMFr22wi = (PM2.5 Franklin County 2022 winter)

PM = PM2.5

08 = 2008

wi = winter

sp = spring

su = summer

au = autumn

Fr = Franklin County

Je = Jefferson County

Ch = St. Charles County

SL = St. Louis County

SC = St. Louis City

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**Documentation for Aircraft Component of the National Emissions
Inventory Methodology**

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1.0 INTRODUCTION

1.1 What is the National Emission Inventory?

The National Emission Inventory (NEI) is a comprehensive inventory covering all anthropogenic sources of criteria pollutants and hazardous air pollutants (HAPs) for all areas of the United States. The NEI was created by the U.S. Environmental Protection Agency's Emission Inventory and Analysis Group (EIAG) in Research Triangle Park, North Carolina. The NEI will be used to support air quality modeling and other activities. To this end, the EPA established a goal to compile comprehensive emissions data in the NEI for criteria and HAPs for mobile, point, and nonpoint sources. This report presents an overview of how emission estimates for the aircraft component of the NEI were compiled.

1.2 Why Did the EPA Create the NEI?

The Clean Air Act (CAA), as amended in 1990, includes mandates for the EPA related to criteria and hazardous air pollutants. The CAA defines criteria pollutants as being one of the following air pollutants:

- Carbon monoxide (CO);
- Sulfur oxides (SO_x);
- Nitrogen oxides (NO_x);
- Ozone; and
- Particulate matter (PM).

Hazardous air pollutants are also delineated in the CAA, see <http://www.epa.gov/ttn/atw/188polls.html> for a complete list of regulated pollutants and their chemical abstract service [CAS] numbers.

The CAA requires the EPA to identify emission sources of these pollutants, quantify emissions, develop regulations for the identified source categories, and assess the public health and environmental impacts after the regulations are put into effect. The NEI is a tool that EPA can use to meet the CAA mandates. In this report, criteria and HAP emission estimates are discussed for aircraft sources.

1.3 How is the EPA Going to Use This Version of the NEI?

It is anticipated that the emission inventory developed from this effort will have multiple end uses. The data have been formatted according to protocols established for the EPA's NEI submittals. The common data structure on which the NEI platform is based will allow the NEI emission data to be transferred to multiple end-users for a variety of purposes.

The criteria and HAP emission estimates developed for the NEI will be used to evaluate air pollution trends, air quality modeling analysis, and impacts of potential regulations.

1.4 Report Organization

Following this introduction, Section 2.0 provides information on how the national aircraft emission estimates were developed. This inventory effort was coordinated by the EPA's Office of Transportation and Air Quality (OTAQ) and EIAG. The appendixes were created to provide the supporting references from OTAQ.

2.0 DEVELOPMENT OF THE AIRCRAFT COMPONENT FOR THE NEI

2.1 How does this aircraft study fit into the NEI?

The NEI was developed to include all point, nonpoint (sometimes referenced as “area”), and mobile sources. The approaches used in the point and nonpoint source categories are documented in other reports. Table 2-1 summarizes the approaches used to estimate emissions from all nonroad sources included in the NEI program. Those source categories and years that are included in this report are noted in bold.

The scope of this inventory component of the NEI was to compile criteria and HAP emissions data for aircraft operating in United States air space. In this effort, national emission estimates were often developed as point sources for each airport. The methodologies used to estimate emissions are discussed in this report.

The target inventory area includes every state in the United States and every county within a state, including Washington, DC, Puerto Rico, and US Virgin Islands. There are no boundary limitations pertaining to traditional criteria pollutant nonattainment areas or to designated urban areas. The pollutants inventoried included all criteria pollutants (and the 188 HAPs identified in Section 112(b) of the CAA).

In addition to numerous specific chemical compounds, the list of 188 HAPs includes several compound groups [e.g., individual metals and their compounds, polycyclic organic matter (POM)]; the NEI includes emission estimates for the individual compounds wherever possible. Many of the uses of the NEI depend upon data (e.g., toxicity) for individual compounds within these groups rather than aggregated data on each group as a whole.

The intent in presenting the following emission inventory approach is to provide sufficient and transparent documentation such that states and local agencies can use these approaches, in conjunction with their specific local activity data to develop more accurate and comparable emission estimates in future submittals.

This documentation is not meant to provide an exhaustive analysis on the derivation of all the inputs. For example, an emission factor used for a national estimate may be given in the appendix, but the source test data that were evaluated to obtain this factor may not be presented or discussed. The goal of the documentation provided is to show in a brief and concise manner how a given estimate was derived.

Table 2-1a. Methods Used to Develop Emission Estimates for Onroad Vehicle Sources
(Years addressed in this report are noted in bold print)

Base Year(s)	Pollutant(s)	Geographic Area	Emission Estimation Method
2008	All Criteria, HAPs	US, Puerto Rico, Virgin Islands	Emission estimates for all pollutants were developed using EPA's National Mobile Inventory Model (NMIM), which uses MOBILE6 (specifically, M6203ChcOxFixNMIM.exe) to calculate onroad emission factors. Where States provided alternate onroad MOBILE6 inputs or VMT, these data replaced EPA default inputs. Default VMT is based on FHWA 2008 data and 2008 Census population estimates.
2005	All Criteria, HAPs	US, Puerto Rico, Virgin Islands	Emission estimates for all pollutants were developed using EPA's NMIM, which uses MOBILE6 to calculate onroad emission factors. Where States provided alternate onroad MOBILE6 inputs or VMT, these data replaced EPA default inputs. Default VMT is based on FHWA 2005 data and 2005 Census population estimates.
2002	All Criteria, HAPs	US, Puerto Rico, Virgin Islands	Emission estimates for all pollutants were developed using EPA's NMIM, which uses MOBILE6 to calculate onroad emission factors. Where States provided alternate onroad MOBILE6 inputs or VMT, these data replaced EPA default inputs. California-supplied emissions data which replaced default EPA emission estimates for this state. Default VMT is based on FHWA 2002 data and population data from 2000 Census.
2001	VOC, NO _x , CO, SO ₂ , PM ₁₀ , PM _{2.5}	California	Emissions and VMT provided by California at county/vehicle type level; State-provided emissions expanded to county/SCC level by EPA.
2001	NH ₃	California	Calculated at State/county/SCC level by month using MOBILE6 emission factors with State-provided VMT data.
2001	All Criteria	AL; CO; ME; MA; MS; OR; UT; VA; WV; Maricopa County, AZ; Hamilton County, TN	State-provided VMT grown to 2001; emissions calculated by EPA using MOBILE6 emission factors.
2001	All Criteria	Rest of US	Calculated at State/county/SCC level by month using MOBILE6 and FHWA-based VMT.
1999	All Criteria	AL; ME; MA; MS; UT; VA; WV; Maricopa County, AZ; Hamilton County, TN	Calculated at State/county/SCC level by month using MOBILE6; State-provided VMT data used.
1999	VOC, NO _x , CO, SO ₂ , PM ₁₀ , PM _{2.5}	California	Emissions and VMT provided by California at county/vehicle type level; State-provided emissions expanded to county/SCC level by EPA.
1999	NH ₃	California	Calculated at State/county/SCC level by month using MOBILE6 emission factors with State-provided VMT data.
1999	PM ₁₀ Exhaust	Colorado	PM ₁₀ emissions and VMT provided by State.

Table 2-1a. Methods Used to Develop Emission Estimates for Onroad Vehicle Sources
(Years addressed in this report are noted in bold print)

Base Year(s)	Pollutant(s)	Geographic Area	Emission Estimation Method
1999	VOC, NO _x , CO, SO ₂ , PM ₁₀ brake and tire wear, PM _{2.5} , NH ₃	Colorado	Calculated at State/county/SCC level by month using MOBILE6; State-provided VMT data used.
1999	All Criteria	Oregon	Emissions and VMT provided by Oregon at county/vehicle type level; State-provided emissions expanded to county/SCC level by EPA.
1999	All Criteria	Rest of US, Puerto Rico, and US Virgin Islands	Calculated at State/county/SCC level by month using MOBILE6 and FHWA-based VMT.
1999	HAPs	California	HAP emissions and VMT provided by California at county/vehicle type level; emissions allocated to SCC level by EPA.
1999	HAPs	Rest of US, Puerto Rico, and US Virgin Islands	MOBILE6 emission factors calculated at State/county/SCC level by season; applied to FHWA-based VMT.
1997-1998	All Criteria	US	2-step linear interpolation at State/count/SCC level based on 1996 and 1999 State/count/SCC level data.
1990, 1996	HAPs	US	MOBILE6 emission factors calculated at State/county/SCC level by season; applied to Federal Highway Administration (FHWA)-based vehicle miles traveled (VMT).
1991-1995	All Criteria	US	Linear interpolation at State/count/SCC level based on 1990 and 1996 State/count/SCC level data.
1988-1989	All Criteria	US	Linear interpolation at State/count/SCC level based on 1987 and 1990 State/count/SCC level data.
1979-1986	All Criteria	US	Linear interpolation at State/count/SCC level based on 1978 and 1987 State/count/SCC level data.
1978, 1987, 1990, 1996, 2000	All Criteria	US	Calculated at State/county/source classification code (SCC) level by month using MOBILE6, no State data incorporated.
1970, 1975	All Criteria	US	Linear extrapolation at national vehicle type level based on 1978 and 1987 national data.

**Table 2-1b. Methods Used to Develop Annual Emission Estimates for
Nonroad Mobile Sources**

(Categories included in this report are noted in bold print)

Category	Base Year	Pollutant(s)	Estimation Method*
<i>NONROAD Categories</i>			
Nonroad Gasoline, Diesel, LPG, CNG	2008	VOC, NO _x , CO, SO ₂ , PM ₁₀ , PM _{2.5} , NH ₃ , & HAPs	Emission estimates for NONROAD model engines were developed using EPA's National Mobile Inventory Model (NMIM), which incorporates NONROAD2008. Where states provided alternate NMIM nonroad inputs, these data replaced EPA default inputs.
	2005	VOC, NO _x , CO, SO ₂ , PM ₁₀ , PM _{2.5} , NH ₃ , & HAPs	Emission estimates for NONROAD model engines were developed using EPA's NMIM, which incorporates NONROAD2005. Where States provided alternate nonroad inputs, these data replaced EPA default inputs.
	2002	VOC, NO _x , CO, SO ₂ , PM ₁₀ , PM _{2.5} , NH ₃ , & HAPs	Emission estimates for NONROAD model engines were developed using EPA's NMIM, which incorporates NONROAD2004. Where states provided alternate nonroad inputs, these data replaced EPA default inputs. State-supplied emissions data also replaced default EPA emission estimates.
	1999	VOC, NO _x , CO, SO ₂ , PM ₁₀ , PM _{2.5}	Using emission estimates from two emission inventories including: 1) a 1996 county-level inventory, developed using EPA's October 2001 draft NONROAD model; and 2) an updated 1999 national inventory, based on EPA's draft Lockdown C NONROAD model (dated May 2002). Using the 1996 county-level emission estimates, seasonal and daily county-to-national ratios were then developed for application to updated national estimates per season estimated from the Lockdown C model. Replaced State-submitted data for California for all NONROAD model categories; Pennsylvania for recreational marine and aircraft ground support equipment, and Texas for select equipment categories.
	1996, 1997, 1998, 2000 & 2001	VOC, NO _x , CO, SO ₂ , PM ₁₀ , PM _{2.5}	Using emission estimates from two emission inventories including: 1) a 1996 county-level inventory, developed using EPA's October 2001 draft NONROAD model; and 2) updated year-specific national and California inventories, based on EPA's draft Lockdown C NONROAD model (dated May 2002). Using the 1996 county-level emission estimates, seasonal and daily county-to-national ratios and California county-to-state ratios were then developed for application to updated national estimates per season estimated from the Lockdown C model. California results replace the diesel equipment emissions generated from prior application of county-to-national ratios.

**Table 2-1b. Methods Used to Develop Annual Emission Estimates for
Nonroad Mobile Sources (Continued)**

(Categories included in this report are noted in bold print)

Category	Base Year	Pollutant(s)	Estimation Method*
Nonroad Gasoline, Diesel, LPG, and CNG (Continued)	1991-1995	VOC, NO _x , CO, SO ₂ , PM ₁₀ , PM _{2.5} , NH ₃	Using 1990 and 1996 county-level emissions inventories, estimated emissions using linear interpolation of national emissions between 1990 and 1996. From these emissions, calculated the average annual growth rate for each pollutant/SCC combination for each year, and then applied the growth factors to 1990 county-level emissions to estimate 1991-1995 emissions.
	1990	VOC, NO _x , CO, SO ₂ , PM ₁₀ , PM _{2.5}	Using emission estimates from two emission inventories including: 1) a 1996 county-level inventory, developed using EPA's October 2001 draft NONROAD model; and 2) updated 1990 national inventory, based on EPA's draft Lockdown C NONROAD model (dated May 2002). Using the 1996 county-level emission estimates, seasonal and daily county-to-national ratios were then developed for application to updated national estimates per season estimated from the Lockdown C model.
	1986, 1988, & 1989	VOC, NO _x , CO, SO ₂ , PM ₁₀ , PM _{2.5} , NH ₃	Using 1985 and 1990 county-level emissions inventories, estimated emissions using linear interpolation of national emissions between 1985 and 1990. From these emissions, calculated the average annual growth rate for each pollutant/SCC combination for each year, and then applied the growth factors to 1985 county-level emissions to estimate 1986-1989 emissions.
	1987	VOC, NO _x , CO, SO ₂ , PM ₁₀ , PM _{2.5}	Using EPA's draft Lockdown C NONROAD model (dated May 2002), developed updated national emissions for 1987 by running 4 seasonal NONROAD model runs to estimate annual criteria pollutant emissions. Also performed national NONROAD model runs to estimate typical summer weekday emissions.
	1985	VOC, NO _x , CO, SO ₂ , PM ₁₀ , PM _{2.5}	Using emission estimates from two emission inventories including: 1) a 1996 county-level inventory, developed using EPA's October 2001 draft NONROAD model; and 2) updated 1985 national inventory, based on EPA's draft Lockdown C NONROAD model (dated May 2002). Using the 1996 county-level emission estimates, seasonal and daily county-to-national ratios were then developed for application to updated national estimates per season estimated from the Lockdown C model.
	1970, 1975, 1978, & 1980	VOC, NO _x , CO, SO ₂ , PM ₁₀ , PM _{2.5}	Using EPA's draft Lockdown C NONROAD model (dated May 2002), developed updated national emissions for all years by running 4 seasonal NONROAD model runs to estimate annual criteria pollutant emissions. Also performed national NONROAD model runs to estimate typical summer weekday emissions.

**Table 2-1b. Methods Used to Develop Annual Emission Estimates for
Nonroad Mobile Sources (Continued)**

(Categories included in this report are noted in bold print)

Category	Base Year	Pollutant(s)	Estimation Method*
Nonroad Gasoline, Diesel, LPG, and CNG (Continued)	1996, 1997, 1998, 1999, 2000, & 2001	NH ₃	Obtaining national fuel consumption estimates from the Lockdown C NONROAD model, multiplying by NH ₃ emission factors, and distributing to counties using 1996 inventory, based on October 2001 draft NONROAD. NH ₃ emissions for California were also recalculated using updated diesel fuel consumption values generated for California-specific runs, and assuming the 1996 county-level distribution.
	1985 & 1990	NH ₃	Obtaining national fuel consumption estimates from the Lockdown C NONROAD model, multiplying by NH ₃ emission factors, and distributing to counties using 1996 inventory, based on October 2001 draft NONROAD.
	1987	NH ₃	Obtaining 1987 national fuel consumption estimates from Lockdown C NONROAD model and multiplying by NH ₃ emission factors.
	1970, 1975, 1978, & 1980	NH ₃	Obtaining national fuel consumption estimates from the Lockdown C NONROAD model and multiplying by NH ₃ emission factors.
	1990, 1996, & 1999	HAPs	Speciation profiles applied to county VOC and PM estimates. Metal HAPs were calculated using fuel and activity-based emission factors. Some state data were provided and replaced national estimates. (2003)
Aircraft			
Commercial Aircraft	2008	Criteria and HAPs	Federal Aviation Administration (FAA) Emissions and Dispersion Modeling System (EDMS) - Version 5.1.was run using BTS T-100 LTO data. (2009)
	2002 and 2005	Criteria and HAPs	Federal Aviation Administration (FAA) Emissions and Dispersion and Modeling System (EDMS) was run for criteria pollutants, VOC and PM emissions were speciated into HAP components. (2004)
	1990, 1996, 1999, 2000, 2001	VOC, NO _x , CO, SO _x	Input landing and take-off (LTO) data into FAA EDMS. National emissions were assigned to airports based on airport specific LTO data and BTS GIS data. State data replaced national estimates. (2003)
	1970-1998	VOC, NO _x , CO, SO _x	Estimated emissions for interim years using linear interpolation between available base years. (2003)
	1990, 1996, 1999	HAPs	Speciation profiles were applied to VOC estimates to get national HAP estimates. State data replaced national estimates. (2003)
General Aviation, Air Taxis	2008	Criteria and HAPs	Federal Aviation Administration (FAA) Emissions and Dispersion Modeling System (EDMS) - Version 5.1.was run using BTS T-100 LTO for aircraft identified as Air taxis. (2010) Used FAA LTO data from TAF and OTAQ provided activity data for smaller airports derived from FAA 5010 master plans. EPA approved generic emission factors for criteria estimates. Speciation profiles were applied to VOC and PM estimates to get national HAP estimates. (2010)

**Table 2-1b. Methods Used to Develop Annual Emission Estimates for
Nonroad Mobile Sources (Continued)**

(Categories included in this report are noted in bold print)

Category	Base Year	Pollutant(s)	Estimation Method*
General Aviation, Air Taxis (Continued)	2005	VOC, NO _x , CO, SO ₂ , PM ₁₀ , PM _{2.5}	2002 emissions for approximately 4,000 largest airports were calculated via EDMS and SIP guidance and included in the 2005 NEI as point sources. Only airports in FAA's T100 and TAF databases were included. State point source submittals were incorporated.
	1978, 1987, 1990, 1996, 1999, 2000, 2001, & 2002	VOC, NO _x , CO, SO ₂ , PM ₁₀ , PM _{2.5}	Used FAA LTO data and EPA approved emission factors for criteria estimates. Speciation profiles were applied to VOC estimates to get national HAP estimates. State data replaced national estimates. (2004)
	1970-1998	VOC, NO _x , CO, SO _x , PM ₁₀ , PM _{2.5}	Estimated emissions for interim years using linear interpolation between available base years. (2003)
	1990, 1996, 1999, & 2002	HAPs	Used FAA LTO data and EPA approved emission factors for criteria estimates. Speciation profiles were applied to VOC estimates to develop national HAP estimates. (2004)
	1990, 1996, 1999, & 2002	Pb	Used Department of Energy (DOE) aviation gasoline usage data with lead concentration of aviation gasoline. (2004)
	1996	NH ₃	Applied NH ₃ emissions factors to 1996 national jet fuel and aviation gasoline consumption estimates.
Military Aircraft	2008	VOC, NO_x, CO, SO₂, PM₁₀, PM_{2.5}	Used FAA LTO data as reported in TAF and EPA approved emission factors for criteria estimates. Representative HAP profiles were not readily available, therefore HAP estimates were not developed. (2010)
	2005	VOC, NO _x , CO, SO ₂ , PM ₁₀ , PM _{2.5}	2002 emissions were included in the 2005 NEI as point sources similar to other TAF reported data.
	1978, 1987, 1990, 1996, 1999, 2000, 2001, 2002, 2008	VOC, NO _x , CO, SO ₂ , PM ₁₀ , PM _{2.5}	Used FAA LTO data as reported in TAF and EPA approved emission factors for criteria estimates. Representative HAP profiles were not readily available, therefore HAP estimates were not developed.
	1970-1998	VOC, NO _x , CO, SO _x , PM ₁₀ , PM _{2.5}	Estimated emissions for interim years using linear interpolation between available base years. (2003)
Auxiliary Power Units and Ground Support Equipment	2008	VOC, NO_x, CO, SO₂, PM₁₀, PM_{2.5}, HAPs	Federal Aviation Administration (FAA) Emissions and Dispersion and Modeling System (EDMS) - Version 5.1 was run using BTS T-100 LTO data. (2009)
	2002 and 2005	VOC, NO _x , CO, SO ₂ , PM ₁₀ , PM _{2.5} , HAPs	Computed via NONROAD2005 model runs.
	1985-2001	VOC, NO _x , CO, SO ₂ , PM ₁₀ , PM _{2.5}	Grew 1996 emissions to each year using LTO operations data from the FAA. Estimation methods prior to 1996 reported in EPA, 1998.

**Table 2-1b. Methods Used to Develop Annual Emission Estimates for
Nonroad Mobile Sources (Continued)**
(Categories included in this report are noted in bold print)

Category	Base Year	Pollutant(s)	Estimation Method*
Unpaved Airstrips ¹	1985-2001	PM ₁₀ , PM _{2.5}	Grew 1996 emissions to each year using SIC 45-Air Transportation growth factors, consistent with the current draft version of EGAS. Estimation methods prior to 1996 reported in EPA, 1998.
Aircraft Refueling ¹	1985-2001	VOC	Grew 1996 emissions to each year using SIC 45-Air Transportation growth factors, consistent with the current draft version of EGAS. Estimation methods prior to 1996 reported in EPA, 1998.
Commercial Marine Vessel (CMV)			
All CMV Categories	2008	VOC, NO _x , CO, SO ₂ , PM ₁₀ , PM _{2.5}	OTAQ provided CAP emission estimates for all CMV categories. Note that the SCCs for this category have changed such that the Diesel category refers to smaller vessels (Category 1 and 2) using distillate fuels and the Residual category refers to larger (Category 3) vessels using a blend of residual fuels. Emissions were allocated to segments using GIS shapefiles and adjusted based on limited state data (2010)
	2008	HAPs	OTAQ's 2008 estimates were speciated into HAP components using SEPA profiles (2009)
CMV Diesel	2002 and 2005	VOC, NO _x , CO, SO ₂ , PM ₁₀ , PM _{2.5}	2001 Estimates carried over. Used state data when provided. (2004)
		HAPs	1999 Estimates carried over. Used state data when provided. (2004)
	1978, 1987, 1990, 1996, 1999, 2000, & 2001	VOC, NO _x , CO, SO _x , PM ₁₀ , & PM _{2.5}	Used criteria emission estimates in the background document for marine diesel regulations for 2000. Adjusted 2000 criteria emission estimates for other used based on fuel usage. Emissions were disaggregated into port traffic and underway activities. Port emissions were assigned to specific ports based on amount of cargo handled. Underway emissions were allocated based on Army Corp of Engineering waterway data. State data replaced national estimates. (2003)
	1970-1998	VOC, NO _x , CO, SO _x , PM ₁₀ , PM _{2.5}	Estimated emissions for interim years using linear interpolation between available base years. (2003)
	1990, 1996, 1999	HAPs	VOC and PM emission estimates were speciated into HAP components. State data replaced national estimates. (2003)
	1996	NH ₃	Applied NH ₃ emissions factors to 1996 distillate and residual fuel oil estimates (i.e., as reported in EIA, 1996).
	1990-1995	NH ₃	Estimation methods reported in EPA, 1998.

**Table 2-1b. Methods Used to Develop Annual Emission Estimates for
Nonroad Mobile Sources (Continued)**

(Categories included in this report are noted in bold print)

Category	Base Year	Pollutant(s)	Estimation Method*
CMV Steam Powered	2005	VOC, NO _x , CO, SO _x , PM ₁₀ , & PM _{2.5} , HAPs	2002 estimates grown to 2005 (2008).
	2002	VOC, NO _x , CO, SO _x , PM ₁₀ , & PM _{2.5} , HAPs	2002 based estimates were developed for port and underway category 3 (C3) vessels as part of a rulemaking effort. Emissions were developed separately for near port and underway emissions. For near port emissions, inventories for 2002 were developed for 89 deep water and 28 Great Lake ports in the U.S. The Waterway Network Ship Traffic, Energy, and Environmental Model (STEEM) was used to provide emissions from ships traveling in shipping lanes between and near individual ports (2008)
	1978, 1987, 1990, 1996, 1999, 2000, & 2001	VOC, NO _x , CO, SO _x , PM ₁₀ , & PM _{2.5}	Calculated criteria emissions based on EPA SIP guidance. Emissions were disaggregated into port traffic and under way activities. Port emissions were assigned to specific ports based on amount of cargo handled. Underway emissions were allocated based on Army Corp of Engineering waterway data. State data replaced national estimates. (2003)
	1970-1998	VOC, NO _x , CO, SO _x , PM ₁₀ , PM _{2.5}	Estimated emissions for interim years using linear interpolation between available base years. (2003)
	1990, 1996, & 1999	HAPs	VOC and PM emission estimates were speciated into HAP components. State data replaced national estimates. (2003)
Military Marine	1997-2001	VOC, NO _x , CO, SO ₂ , PM ₁₀ , PM _{2.5}	Applied EGAS growth factors to 1996 emissions estimates for this category.
CMV Coal, ² CMV, Steam powered, CMV Gasoline ²	1997-1998	VOC, NO _x , CO, SO ₂ , PM ₁₀ , PM _{2.5}	Applied EGAS growth factors to 1996 emissions estimates for this category.
CM Coal, CMV, Steam powered, CMV Gasoline, Military Marine	1991-1995	VOC, NO _x , CO, SO ₂ , PM ₁₀ , PM _{2.5}	Estimation methods reported in EPA, 1998.
Locomotives			
Class I, II, III and Yard operations	2008	VOC, NO _x , CO, PM ₁₀ , PM _{2.5} , SO _x & HAPs	Criteria emission estimates were provided to EPA by ERTAC. These data were assigned to individual railway segments using DOT shapefiles and guidance from ERTAC. HAP emissions were calculated by applying speciation profiles to VOC and PM estimates. (2010)

**Table 2-1b. Methods Used to Develop Annual Emission Estimates for
Nonroad Mobile Sources (Continued)**

(Categories included in this report are noted in bold print)

Category	Base Year	Pollutant(s)	Estimation Method*
Class I, Class II, Commuter, Passenger, and Yard Locomotives	1978, 1987, 1990, 1996, 1999, 2000, 2000, 2002, & 2005	VOC, NO _x , CO, PM ₁₀ , PM _{2.5}	Criteria pollutants were estimated by using locomotive fuel use data from DOE EIA and available emission factors. County-level estimates were obtained by scaling the national estimates with the rail GIS data from DOT. State data replaced national estimates. (2004)
	1978, 1987, 1990, 1996, 1999, 2000, 2001, 2002, & 2005	SO ₂	SO _x emissions were calculated by using locomotive fuel use and fuel sulfur concentration data from EIA. County-level estimates were obtained by scaling the national estimates with the county level rail activity data from DOT. State data replaced national estimates. (2004)
	1970-1998	VOC, NO _x , CO, SO _x , PM ₁₀ , PM _{2.5}	Estimated emissions for interim years using linear interpolation between available base years. (2003)
	1990, 1996, 1999, & 2002	HAPs	HAP emissions were calculated by applying speciation profiles to VOC and PM estimates. County-level estimates were obtained by scaling the national estimates with the county level rail activity from DOT. State data replaced national estimates. (2004)
	1997-1998	NH ₃	Grew 1996 base year emissions using EGAS growth indicators.
	1996	NH ₃	Applied NH ₃ emissions factors to diesel consumption estimates for 1996.
1990-1995	NH ₃	Estimation methods reported in EPA, 1998.	

Notes:

* Dates included at the end of Estimation Method represent the year that the section was revised.

1 Emission estimates for unpaved airstrips and aircraft refueling are included in the area source NEI, since they represent non-engine emissions.

2 National Emission estimates for CMV Coal and CMV Gasoline were not developed though states and local agencies may have submitted estimates for these source categories.

EPA, 1998. U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Emission Factors and Inventory Group, National Air Pollutant Emission Trends, Procedures Document, 1900–1996, EPA-454/R-98-008. May 1998.

2.2 What are Aircraft Sources?

The aircraft source category includes all aircraft types used for public, private, and military purposes. This includes four types of aircraft (EPA, 1992): 1) Commercial; 2) Air Taxis; 3) General Aviation; and 4) Military.

Commercial aircraft include those used for transporting passengers, freight, or both. Commercial aircraft tend to be larger aircraft powered with jet engines. Air Taxis (AT) carry passengers, freight, or both, but usually are smaller aircraft and operate on a more limited basis than the commercial carriers. General Aviation (GA) includes most other aircraft used for recreational flying and personal transportation. Aircraft that support business travel, usually on an unscheduled basis, are included in the category of general aviation.

The national AT and GA fleet includes both jet and piston-powered aircraft. Most of the AT and GA fleet are made up of piston powered aircraft, though smaller business jets can also be found in these categories. According to a 2008 Federal Aviation Administration GA and AT Activity Survey, 66% of all GA and AT activity are powered by piston-powered aircraft and 34% are jet (or turbine) driven. EPA has used this estimate as a national-scale default value in recently published studies investigating lead emissions from aviation sources (EPA, 2008). The piston powered aircraft tend to have higher VOC, PM, and CO emissions and lower NO_x emissions than larger jet-powered aircraft (EPA, 1992). Military aircraft cover a wide range of aircraft types such as training aircraft, fighter jets, helicopters, and jet- and a small number of piston powered planes of varying sizes.

It should be noted that this inventory effort also includes criteria and Hazardous Air Pollutants (HAP) emission estimates for aircraft Auxiliary Power Units (APU) and aircraft Ground Support Equipment (GSE) typically found at airports, such as aircraft refueling vehicles, baggage handling vehicles, and equipment, aircraft towing vehicles, and passenger buses.

2.3 What Pollutants are Included in the National Emission Estimates for Aircraft?

Emissions estimates were developed for all criteria pollutants including volatile organic compounds (VOC), nitrogen oxides (NO_x), carbon monoxide (CO), sulfur oxides (SO_x), particulate matter less than 10 microns (PM₁₀), particulate matter less than 2.5 microns (PM_{2.5}) and hazardous air pollutants (HAP) (Cook, 1997; Cook, 1998; EPA/FAA, 2009). The HAPs that are included in the national aircraft inventory are shown in Table 2-2 and are based on available test data and accepted emission estimation procedures.

Table 2-2. Aircraft Pollutant List

1,3-Butadiene	Carbon Dioxide	Naphthalene
1-Methylnaphthalene*	Carbon Monoxide	Nitrogen Oxides
2,2,4-Trimethylpentane	Chrysene*	O-xylene*
2-Methylnaphthalene*	Cumene*	Phenanthrene*
Acenaphthene*	Dibenzo[a,h]Anthracene*	Phenol
Acenaphthylene*	Ethyl Benzene	PM ₁₀ Primary
Acetaldehyde	Fluoranthene*	PM _{2.5} Primary
Acrolein	Fluorene*	Propionaldehyde
Anthracene*	Formaldehyde	Pyrene*
Benz[a]Anthracene*	Hexane*	Styrene
Benzene	Indeno[1,2,3-c,d]Pyrene*	Sulfur Dioxide
Benzo[a]Pyrene*	Lead	Toluene
Benzo[b]Fluoranthene*	Methane*	VOCs
Benzo[g,h,i,]Perylene*	Methanol*	Xylene
Benzo[k]Fluoranthene*	M-xylene*	

* Added to 2008 Inventory

2.4 How Were the Aircraft Emissions Estimated?

EPA has developed guidance for inventorying aircraft emissions associated with an aircraft's landing and takeoff (LTO) cycle. The cycle begins when the aircraft approaches the airport on its descent from cruising altitude, lands, taxis to the gate, and idles during passenger deplaning. It continues as the aircraft idles during passenger boarding, taxis back out onto the runway for subsequent takeoff, and ascent (climbout) to cruising altitude. Thus, the five specific operating modes in an LTO are (EPA, 1992): 1) Approach; 2) Taxi/idle-in; 3) Taxi/idle-out; 4) Takeoff; and 5) Climbout.

The LTO cycle provides a basis for calculating aircraft emissions. During each mode of operation, an aircraft engine operates at a fairly standard power setting for a given aircraft category. Emissions for one complete cycle are calculated using emission factors for each operating mode for each specific aircraft engine combined with the typical period of time the aircraft is in the operating mode.

On March 20, 2009, the EPA posted preliminary LTO data intended to be will use to calculate emissions for review prior to developing the aircraft inventory. State and local agencies were encouraged to review the materials posted at [ftp://ftp.epa.gov/EmisInventory/2008_nei/](http://ftp.epa.gov/EmisInventory/2008_nei/) and provide comments on any necessary corrections to:

- Airport names and locations for approximately 20,000 airports to be included in the Emission Inventory System (EIS) facility inventory;
- Landing and Takeoff (LTO) information that will be used to estimate emissions for each airport;
- Aircraft/engine combinations to link to FAA LTO data including default assumptions and AircraftEngineCodeTypes for EIS submittals; and
- Lead estimates and lead estimation methodology.

This preliminary review by state, local, and tribal groups provided information that EPA used to improve EPA's work. EPA received comments from four states (i.e., Minnesota Pollution Control Agency - Environmental Analysis and Outcomes Division; New Jersey Department of Environmental Protection; Bureau of Air Management, Connecticut Department of Environmental Protection; and Wisconsin Department of Natural Resources (specifically related to Volk Field Air National Guard Base (VOK) in Juneau County Wittman Regional Airport (OSH)) and three local agencies (i.e., Mecklenburg County North Carolina; Ventura County California Air Pollution Control District (Specifically related to Oxnard (OXR), Camarillo (CMA) and Santa Paula (SZP); and - Regional Air Pollution Control Agency (Dayton and Montgomery County Ohio)).

Criteria emission estimates are presented here for four different aircraft types: commercial air carrier, air taxis, general aviation, and military. HAP emission estimates were developed for all aircraft types.

Emissions for commercial air carriers for which detailed aircraft-specific activity data were available, were calculated differently than the other three aircraft categories (See Figure 2-1). Criteria and HAP emissions were estimated for commercial aircraft by applying aircraft make and model (e.g., Boeing 747-200 series) specific LTO activity data from *FAA's Form 41, Schedules T100 and T100(f) Air Carrier Data to the FAA's Emissions and Dispersion Modeling System (EDMS), Version 5.1* (DOT, 2008). It should be noted that due to the reporting requirements of T-100, only commercial activities are included in the dataset, and therefore does not include activity data for non-air carrier applications such as general aviation and military. This distinction led to a revision to EPA's original aircraft crosswalk table, also known as the aircraft engine type code, used to match aircraft to EDMS aircraft and to account for double counting between the T-100 data and the TAF data. In the revised crosswalk, aircraft that were previously considered general aviation and military based on aircraft model were changed to air taxi and commercial air carrier aircraft types based on the definition of air taxis (i.e., any aircraft that was not considered an air taxi was classified as an air carrier aircraft). The FAA reviewed the cross walk tables and made additional changes that moved some of the larger air taxis to the commercial air carrier category and some of the smaller commercial air carriers to the air taxi category. The revised crosswalk table is provided in an electronic file as supporting data for this study.

Emissions were calculated for each airport individually using airport specific mixing height. The national-scale default values for taxi in and out are seven and nineteen minutes, respectfully. It should be noted that EDMS incorporates the latest aircraft engine emission factors from the International Civil Aviation Organization Engine Exhaust Emissions Data Bank. The EDMS output includes organic HAPs, but not metals.

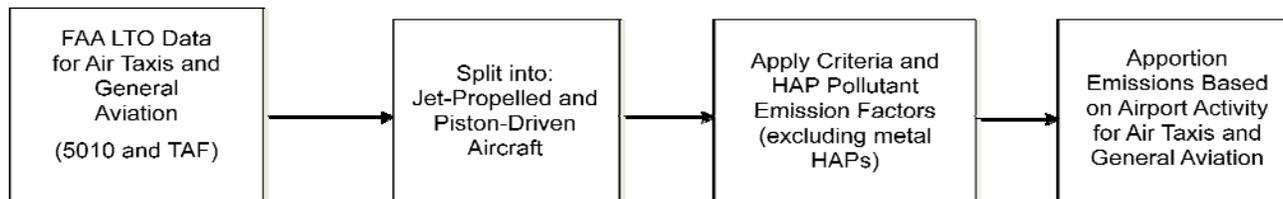


Figure 2-1. Procedures for Estimating Emissions from Commercial Air Carriers

Emissions for GSE and APU associated with commercial air carriers and air taxis for which T-100 data were available were estimated by EDMS, using the assumptions and defaults incorporated in the model. This is significant change from previous NEI year's emissions where GSE estimates came from the NONROAD model and APUs were not included in EPA's estimates. With EDMS, GSE that are assigned to an aircraft are given times (minutes per arrival, minutes per departure) based upon the type of service. For example, a fuel truck servicing a large commercial aircraft will have a different operating time than the same fuel truck servicing a commuter aircraft. All EDMS defaults for GSE duration and type (e.g., fuel truck, cabin service truck, baggage belt loader) were used. GSE emission factors used by EDMS are derived from EPA's NONROAD2005 model and are based on the following variables: fuel, brake horsepower and load factor. GSE engines burn gasoline, diesel, compressed natural gas (CNG), and liquefied petroleum gas (LPG). EPA has used a national-scale value to characterize engines type. The GSE engine distribution is shown below in Table 2-3. Like GSE, APU emissions are the product of operating time. The purpose of an aircraft APU is to provide power to start the main engines and run the heating, cooling, and ventilation systems prior to starting the main engines.

Table 2-3. National-Scale GSE Engine Distribution

GSE Engines Type	Percent of Total
Gasoline Fired, 4-Stroke	16.9
Liquefied Petroleum Gas (LPG) Fired	1.65
Compressed Natural Gas (CNG) Fired	1.25
Diesel Fired	80.2

Emissions of criteria pollutants for air taxis, general aviation, and military aircraft were calculated by combining aircraft operations data from FAA's *Terminal Area Forecasts (TAF) and 5010 Forms*. To avoid double counting between the T-100 data set and the TAF/5010 data,

LTOs by airport and aircraft type were summed in the T-100 data and compared with data in the TAF/5010 data. If the TAF/5010 LTO estimates were larger than the T-100 estimates for a specified aircraft type then the T-100 values were subtracted from the TAF/5010 values. If the T-100 values were larger than the TAF values, then the TAF values were set to zero. A data set of adjusted TAF/5010 LTOs were provided to OTAQ where additional adjustments were made to address older data in the TAF and 5010 datasets and to incorporate other insights provided by FAA reviewers.

The TAF/5010 LTO data were dividing into jet and piston powered fractions based on the national observation that 66 percent of all general aviation and air taxi activities are associated with piston powered aircraft and the remaining 34 percent of general aviation and air taxi activities are associated with jet powered aircraft. The adjusted and split TAF/5010 activity data were applied to emission factors as appropriate (See Figure 2-2). It should be noted that EDMS calculates organic HAP emissions in the model (metal HAPs are currently not included in the EDMS output). HAP emission estimates for air taxis, general aviation, and military aircraft were estimated by applying speciation profiles to VOC or PM₁₀ emissions estimates. The following equation was used (emission factor are included as Appendix A).

$$E_{ixj} = LTO_i \times FR_{pro-i} \times EF_{ij}$$

Where:

- E_{ixj} = Emission estimate for aircraft type i equipped with engine type x and pollutant j (lbs/year)
- LTO_i = Annual count of LTO cycles for aircraft type i
- FR_x = Fraction of LTOs equipped with engine type x
- EF_{ij} = Generic emission factor for aircraft type i equipped with engine type x and pollutant j (lbs/LTO)
- i = Aircraft type (i.e., air taxi, general aviation, and military)
- x = Engine type (i.e., jet or turboprop, and piston engine)
- j = Criteria pollutant j

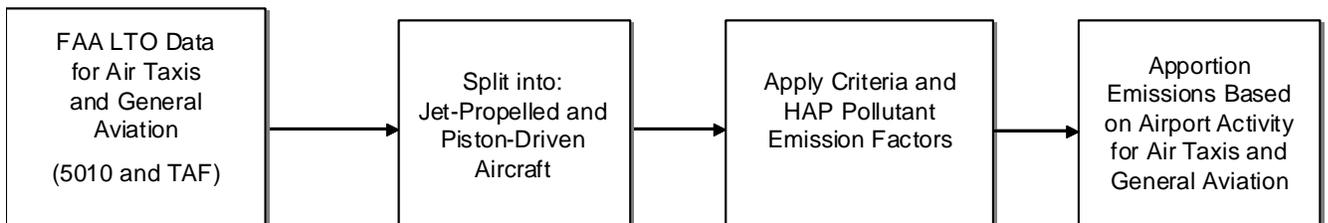


Figure 2-2. Procedures for Estimating Emissions from Commercial Air Taxis and General Aviation

Lead emission estimates were handled differently. Lead emissions are associated with leaded aviation fuel used in piston driven aircraft associated with general aviation. Lead emissions per LTO are calculated using the following equation:

$$\text{Pb(tons)} = (\text{piston-engine LTO}) (7.34 \text{ g Pb/LTO}) (0.95) / 907,180 \text{ (g/ton)}$$

Where the lead content of aviation gasoline is assumed to be 0.56 grams per liter or 2.12 grams per gallon.

In flight lead emissions were calculate based on national aviation gasoline consumption and similar assumptions noted above about lead fuel content and retention rates. Lead emissions associated with airport LTO activities were subtracted from the national fuel based lead emissions to approximate in flight lead emissions which were allocated to individual counties and noted with the code 777.

For additional details on EPA lead emission calculation procedures see Calculating Piston-Engine Aircraft Airport Inventories for Lead for the 2008 National Emissions Inventory (included in Appendix B).

HAP Emission Estimates

As noted earlier, EDMS calculates organic HAP emissions for aircraft activity reported in the T-100 dataset. Representative HAP speciation profiles were used to estimate the individual chemical species for each aircraft type included in the TAF/5010 dataset. Profiles are used to split (or speciate) organic gases, hydrocarbons, and particulate matter emissions estimates into more individual HAP compounds using the following equation:

$$E_{ixj} = LTO_{ix} \times SP_{ixj}$$

Where:

- E_{ixj} = Emission estimate for aircraft type i equipped with engine type x and pollutant j (tons/year)
- LTO_{ix} = Annual count of LTO cycles for aircraft type i and engine type x
- SP_{ixj} = Generic speciation profiles for aircraft type i equipped with engine type x and pollutant j (tons/LTO)
- i = Aircraft type (i.e., air taxi, general aviation, and military)
- x = Engine type (i.e., jet or turboprop, and piston engine)
- j = Pollutant j

Appendix A contains the HAP profiles converted to emissions factors used for this 2008 inventory. In this version of the NEI aircraft emissions inventory the following corrections to the HAP emission estimates were made:

- Acenpthylene was removed from this inventory for SCC 2275050012.

- To avoid double counting total xylene emissions were removed if speciated xylene factors were also available.

2.5 How Were Emissions Allocated?

For the 2008 inventory, emissions were individually estimated for each airport. A GIS database obtained from the Bureau of Transportation Statistics (BTS) contained airport level data with latitude and longitude coordinates.

2.6 QA/QC

Given the significant methodological changes over previous inventory efforts, several quality checks were implemented to ensure that these data were developed and allocated in a clear and reproducible manner. Some of the quality checks implemented include the following:

Emissions allocations and estimations

- All original data importations and transcriptions into the database were double-checked for errors.
- All calculation methods and approaches were evaluated for technical soundness.
- All unit conversions and equations used to generate results were double-checked for errors.
- All sources of original data are referenced in the spreadsheet.
- Emission factors were compiled from a variety of sources. Each emission factor development methodologies were evaluated to identify the most accurate emission factor for use in this inventory effort.
- Emission sums were evaluated across activity types (e.g., Aircraft, APU, and GSE) to ensure they consistently mirror LTO activity levels.
- 2008 pollutants and emissions were checked against the 2005 inventory to identify any missing pollutants or major changes compared to previous inventories. Discrepancies were investigated and revisions were made as needed.
- The validity of SCC codes, FIP county codes, and pollutant codes were confirmed.
- The validity of Airport and plane identification codes were confirmed.

2.7 What are the Results?

Table 2-4 summarizes the emission estimates for Aircraft, ground support equipment and APUs for criteria pollutants. Table 2-5 summarizes the emission estimates for individual HAPs. Both tables aggregate the data for all states, including the District of Columbia. Note that the 2008 estimates do not include state submitted emissions data.

Table 2-4. Aircraft Criteria Emission Estimates 2008 (tons per year)

Pollutant	2008										
	Military (2275001000)	Commercial (2275020000)	GA, Piston (2275050011)	GA, Turbine (2275050012)	AT, Piston (2275060011)	AT, Turbine (2275060012)	GSE, Gas (2265008005)	GSE, LPG (2267008005)	GSE, CNG (2268008005)	GSE, Diesel (2270008005)	APU (2275070000)
CO	33,161.20	75,463.61	192,510.69	56,532.07	19,116.38	10,180.90	18,005.13	1,768.69	1,398.67	85,607.61	4,072.84
NO _x	284.92	102,561.46	1,041.55	1,911.11	465.64	2,274.10	1,927.90	189.38	149.76	9,166.44	2,841.72
PM ₁₀ -PRI	709.12	1,782.43	3,792.85	1,397.21	242.12	797.03	55.87	5.49	4.34	265.62	457.11
PM _{2.5} -PRI	92.60	1,776.37	493.07	181.64	44.81	103.65	53.63	5.27	4.17	254.97	457.11
SO ₂	27.32	10,179.67	160.24	434.33	53.76	439.43	53.21	5.23	4.13	252.99	443.04
VOC	1,652.02	13,608.67	2,399.79	3,223.93	310.48	2,610.94	615.80	60.49	47.84	2,927.89	313.72

Table 2-5. Aircraft HAP Emission Estimates 2008 (tons per year)

Pollutant	2008										
	Military (2275001000)	Commercial (2275020000)	GA, Piston (2275050011)	GA, Turbine (2275050012)	AT, Piston (2275060011)	AT, Turbine (2275060012)	GSE, Gas (2265008005)	GSE, LPG (2267008005)	GSE, CNG (2268008005)	GSE, Diesel (2270008005)	APU (2275070000)
1,3-Butadiene	0.87	184.14	29.75	61.04	5.01	44.44					5.32
1-Methylnaphthalene	0.13	26.96		8.94	0.23	6.20					0.78
2,2,4-Trimethylpentane		0.69	1.09	1.55	0.03	0.51	8.95	0.88	0.69	42.54	
2-methylnaphthalene	0.11	22.48		7.45	0.20	5.17					0.65
Acenaphthene			0.36		0.17						
Acenaphthylene			2.03		0.93						
Acetaldehyde	2.21	466.29	18.82	154.57	11.97	113.00	2.43	0.24	0.19	11.57	13.47
Acrolein	0.02	37.70	1.82	88.61	0.04	32.72					
Anthracene			0.42	6.16E-04	0.19	3.52E-04					
Benz[a]Anthracene		6.09E-04	0.05	9.33E-05	0.02	5.32E-05					
Benzene	0.87	183.48	122.97	60.82	7.58	44.59	10.44	1.03	0.81	49.62	5.30
Benzo[a]Pyrene		4.52E-04	0.05	5.11E-05	0.02	2.91E-05					
Benzo[b]Fluoranthene		8.89E-04	0.06		0.03						
Benzo[g,h,i]Perylene		8.11E-06	0.13	8.47E-06	0.06	4.83E-06					
Benzo[k]Fluoranthene		8.89E-04	0.06		0.03						
Chrysene		6.17E-04	0.05	8.69E-05	0.02	4.96E-05					

Table 2-5. Aircraft HAP Emission Estimates 2008 (tons per year) (Continued)

Pollutant	2008										
	Military (2275001000)	Commercial (2275020000)	GA, Piston (2275050011)	GA, Turbine (2275050012)	AT, Piston (2275060011)	AT, Turbine (2275060012)	GSE, Gas (2265008005)	GSE, LPG (2267008005)	GSE, CNG (2268008005)	GSE, Diesel (2270008005)	APU (2275070000)
Cumene	2.68E-05	0.05		0.11		0.04					
Ethyl Benzene	1.55E-03	2.68	44.63	6.30	1.05	2.32					
Fluoranthene		1.17E-03	0.45	1.29E-03	0.21	7.35E-04					
Fluorene			0.74		0.34						
Formaldehyde	6.36	1,343.45	81.67	445.41	38.06	327.87	7.20	0.71	0.56	34.23	38.82
Hexane			21.25		0.50						
Indeno[1,2,3-c,d]Pyrene		0.00	0.04		0.02						
Lead **			245.48		8.97						
Methane	0.01				18.96	14.79	14.61	1.44	1.14	69.47	
Methanol	0.02	27.78		65.31		24.11					
m-Xylene	0.14	26.44	0.36	1.58E-04	0.88	3.66	11.09	1.09	0.86	52.74	0.89
Naphthalene	0.28	54.17	21.11	20.42	5.05	13.86					1.71
O-xylene	0.08	15.56	2.03	9.30E-05	1.40	2.19	5.43	0.53	0.42	25.80	0.52
Phenanthrene		0.01	1.25	0.01	0.58	3.27E-03					
Phenol	0.01	11.17		26.27		9.70					
Propionaldehyde	0.38	79.35	1.82	26.30	2.29	19.45	1.48	0.15	0.11	7.04	2.29
Pyrene		1.42E-03	0.61	1.58E-03	0.28	8.99E-04					
Styrene	0.16	33.73	10.32	11.18	1.18	8.25					0.97
Toluene	0.33	70.07	315.76	23.23	8.87	16.77	17.77	1.75	1.38	84.50	2.02
Xylenes (Mixed Isomers)		4.85	177.92	19.04	4.18	6.21					

** The lead estimated provided above represent emissions at individual airports, for 2008, there is an additional 296 tons of lead emitted associated with the combustion of leaded aviation gasoline during in flight operations which is not attributed to airports.

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Appendix A

Generic Aircraft Emission Factors/ Speciation Profiles

Commercial Aircraft Emission Factors			
Pollutant	CAS No.	CAA "187" or IRIS HAP?	Emission Factors (tons/LTO)
THC			2.680E-03
VOC			2.934E-03
TOG			3.276E-03
NO _x			9.288E-03
CO			1.119E-02
SO _x			8.910E-04
PM ₁₀			5.385E-04
PM _{2.5}			5.256E-04
Acetaldehyde	75070	CAA	1.400E-04
Acetone	67641		1.025E-05
Acetylene	74862		1.290E-04
Acrolein	107028	CAA	8.023E-05
Benzaldehyde	100527	IRIS	1.540E-05
Benzene	71432	CAA	5.507E-05
Benzo(a)anthracene	56553		1.297E-09
Benzo(a)pyrene	50328		9.621E-10
Benzo(b)fluoranthene	205992		1.892E-09
Benzo(ghi)perylene	191242		1.726E-11
Benzo(k)fluoranthene	207089		1.892E-09
1,3-Butadiene	101314	CAA	5.527E-05
1-Butene	101389		5.746E-05
Butyraldehyde	123728		3.899E-06
C14-Alkane	No CAS		6.094E-06
C15-Alkane	No CAS		5.799E-06
C16 Branched Alkane	No CAS		4.783E-06
C18-Alkane	No CAS		6.552E-08
C4-Benzene + C3-Aroald	No CAS		2.149E-05
C5-Benzene+C4-Aroald	No CAS		1.061E-05
Chrysene	218019		1.313E-09
Cis-2-Butene	514181		6.880E-06
Cis-2-Pentene	627203		9.042E-06
Crotonaldehyde	4170303		3.384E-05
1-Decene	872059		6.061E-06
Dibenzo(ah)anthracene	53703		2.551E-09
Dimethylnaphthalenes	28804888		2.949E-06
Ethane	74840		1.707E-05
Ethylbenzene	100414	CAA	5.701E-06
Ethylene	74851		5.065E-04
Fluoranthene	206440		2.492E-09

Commercial Aircraft Emission Factors			
Pollutant	CAS No.	CAA "187" or IRIS HAP?	Emission Factors (tons/LTO)
Formaldehyde	50000	CAA	4.033E-04
Glyoxal	107222		5.950E-05
Heptene	25339564		1.435E-05
Hexadecane	544763		1.605E-06
1-Hexene	592416		2.411E-05
Indeno(1,2,3-cd)pyrene	193395		2.050E-09
Isopropylbenzene	98828	CAA	9.829E-08
Isovaleraldehyde	514863		1.048E-06
Methacrolein	78853		1.405E-05
Methanol	67561	CAA	5.913E-05
Methyl Glyoxal	78988		4.924E-05
1-Methyl Naphthalene	14120		8.092E-06
2-Methyl Naphthalene	91576	IRIS	6.749E-06
3-Methyl-1-Butene	563451		3.669E-06
4-Methyl-1-Pentene	131372		4.259E-07
2-Methyl-1-Butene	563462		4.587E-06
2-Methyl-2-Butene	513359		6.061E-06
2-Methylpentane	107835		1.337E-05
2-Methyl-1-Pentene	763291		1.114E-06
M-Ethyltoluene	620144		5.045E-06
M-Tolualdehyde	620235		9.108E-06
Naphthalene (gas phase)	91203	CAA	6.084E-06
Naphthalene (solid phase)	91203	CAA	1.260E-06
Naphthalene	91203	CAA	1.772E-05
N-Decane	124185		1.048E-05
N-Dodecane	112403		1.514E-05
N-Heptadecane	629787		2.949E-07
N-Heptane	142825		2.097E-06
N-Nonane	111842		2.031E-06
N-Octane	111659		2.031E-06
1-Nonene	124118		8.059E-06
N-Pentadecane	629629		5.668E-06
N-Pentane	109660		6.487E-06
N-Propylbenzene	103651		1.736E-06
N-Tetradecane	629594		1.363E-05
N-Tridecane	629505		1.753E-05
N-Undecane	1120214		1.455E-05
Octene	111660		9.042E-06
O-Ethyltoluene	611143		2.130E-06

Commercial Aircraft Emission Factors			
Pollutant	CAS No.	CAA "187" or IRIS HAP?	Emission Factors (tons/LTO)
O-Tolualdehyde	529204		7.535E-06
1-Pentene	109671		2.542E-05
P-Ethyltoluene	622968		2.097E-06
Phenanthrene	85018		1.112E-08
Phenol	108952	CAA	2.378E-05
Propane	74986		2.555E-06
Propionaldehyde	123386	CAA	2.382E-05
Propylene	115071		1.485E-04
P-Tolualdehyde	104870		1.573E-06
Pyrene	121400		3.028E-09
Styrene	100425	CAA	1.012E-05
Toluene	108883	CAA	2.103E-05
Trans-2-Hexene	4050457		9.829E-07
Trans-2-Pentene	646048		1.176E-05
1,2,3-Trimethylbenzene	526738		3.473E-06
1,2,4-Trimethylbenzene	95636		1.147E-05
1,3,5-Trimethylbenzene	108678		1.769E-06
2,2,4-Trimethylpentane	540841	CAA	1.466E-06
Valeraldehyde	110623		8.027E-06
Xylene	1330207	CAA	1.032E-05

Air Taxi Emission Factors - Jet			
Pollutant	CAS No.	CAA "187" or IRIS HAP?	Emission Factors (tons/LTO)
THC			4.37E-04
VOC			5.03E-04
TOG			5.06E-04
NO _x			3.88E-04
CO			1.81E-03
SO _x			8.12E-05
PM ₁₀			3.017E-04
PM _{2.5}			3.922E-05
Acetaldehyde	75070	CAA	2.160E-05
Acetone	67641		1.583E-06
Acetylene	74862		1.992E-05
Acrolein	107028	CAA	1.238E-05
Anthracene	120127		1.331E-10
Benzaldehyde	100527	IRIS	2.377E-06
Benzene	71432	CAA	8.500E-06
Benzo(a)anthracene	56553		2.014E-11
Benzo(a)pyrene	50328		1.103E-11
Benzo(ghi)perylene	191242		1.829E-12
1,3-Butadiene	101314	CAA	8.531E-06
1-Butene	101389		8.869E-06
Butyraldehyde	123728		6.017E-07
C14-Alkane	No CAS		9.405E-07
C15-Alkane	No CAS		8.950E-07
C16 Branched Alkane	No CAS		7.383E-07
C18-Alkane	No CAS		1.011E-08
C4-Benzene + C3-Aroald	No CAS		3.317E-06
C5-Benzene+C4-Aroald	No CAS		1.638E-06
Chrysene	218019		1.876E-11
Cis-2-Butene	514181		1.062E-06
Cis-2-Pentene	627203		1.396E-06
Crotonaldehyde	4170303		5.224E-06
1-Decene	872059		9.355E-07
Dimethylnaphthalenes	28804888		4.551E-07
Ethane	74840		2.635E-06
Ethylbenzene	100414	CAA	8.799E-07
Ethylene	74851		7.818E-05
Fluoranthene	206440		2.784E-10
Formaldehyde	50000	CAA	6.225E-05
Glyoxal	107222		9.183E-06

Air Taxi Emission Factors - Jet			
Pollutant	CAS No.	CAA "187" or IRIS HAP?	Emission Factors (tons/LTO)
Heptene	25339564		2.215E-06
Hexadecane	544763		2.478E-07
1-Hexene	592416		3.722E-06
Isopropylbenzene	98828	CAA	1.517E-08
Isovaleraldehyde	514863		1.618E-07
Methacrolein	78853		2.169E-06
Methanol	67561	CAA	9.127E-06
Methyl Glyoxal	78988		7.600E-06
1-Methyl Naphthalene	14120		1.249E-06
2-Methyl Naphthalene	91576	IRIS	1.042E-06
3-Methyl-1-Butene	563451		5.663E-07
4-Methyl-1-Pentene	131372		6.574E-08
2-Methyl-1-Butene	563462		7.079E-07
2-Methyl-2-Butene	513359		9.355E-07
2-Methylpentane	107835		2.063E-06
2-Methyl-1-Pentene	763291		1.719E-07
M-Ethyltoluene	620144		7.787E-07
M-Tolualdehyde	620235		1.406E-06
Napthalene	91203	CAA	2.736E-06
N-Decane	124185		1.618E-06
N-Dodecane	112403		2.336E-06
N-Heptadecane	629787		4.551E-08
N-Heptane	142825		3.236E-07
N-Nonane	111842		3.135E-07
N-Octane	111659		3.135E-07
1-Nonene	124118		1.244E-06
N-Pentadecane	629629		8.748E-07
N-Pentane	109660		1.001E-06
N-Propylbenzene	103651		2.680E-07
N-Tetradecane	629594		2.104E-06
N-Tridecane	629505		2.705E-06
N-Undecane	1120214		2.245E-06
Octene	111660		1.396E-06
O-Ethyltoluene	611143		3.287E-07
O-Tolualdehyde	529204		1.163E-06
1-Pentene	109671		3.924E-06
P-Ethyltoluene	622968		3.236E-07
Phenanthrene	85018		1.238E-09
Phenol	108952	CAA	3.671E-06

Air Taxi Emission Factors - Jet			
Pollutant	CAS No.	CAA "187" or IRIS HAP?	Emission Factors (tons/LTO)
Propane	74986		3.944E-07
Propionaldehyde	123386	CAA	3.676E-06
Propylene	115071		2.293E-05
P-Tolualdehyde	104870		2.427E-07
Pyrene	121400		3.401E-10
Styrene	100425	CAA	1.563E-06
Toluene	108883	CAA	3.246E-06
Trans-2-Hexene	4050457		1.517E-07
Trans-2-Pentene	646048		1.815E-06
1,2,3-Trimethylbenzene	526738		5.360E-07
1,2,4-Trimethylbenzene	95636		1.770E-06
1,3,5-Trimethylbenzene	108678		2.731E-07
2,2,4-Trimethylpentane	540841	CAA	1.915E-07
Valeraldehyde	110623		1.239E-06
Xylene	1330207	CAA	2.352E-06

Air Taxi Emission Factors - Piston			
Pollutant	CAS No.	CAA "187" or IRIS HAP?	Emission Factors (tons/LTO)
THC			7.750E-05
VOC			8.484E-05
TOG			9.474E-05
NO _x			7.900E-05
CO			1.407E-02
SO _x			7.500E-06
PM ₁₀			3.015E-04
PM _{2.5}			3.920E-05
Acenaphthene	83329		2.201E-07
Acenaphthylene	208968		1.242E-06
Acetaldehyde	75070	CAA	5.874E-07
Acrolein	107028	CAA	5.684E-08
Anthracene	120127		2.563E-07
Benzene	71432	CAA	3.837E-06
Benzo(a)anthracene	56553		3.015E-08
Benzo(a)pyrene	50328		3.015E-08
Benzo(b)fluoranthene	205992		3.618E-08
Benzo(ghi)perylene	191242		7.839E-08
Benzo(k)fluoranthene	207089		3.618E-08
1,3-Butadiene	101314	CAA	9.285E-07
Chrysene	218019		3.015E-08
Ethylbenzene	100414	CAA	1.393E-06
Fluoranthene	206440		2.744E-07
Fluorene	86737		4.553E-07
Formaldehyde	50000	CAA	2.548E-06
Indeno(1,2,3-cd)pyrene	193395		2.412E-08
M-Xylene and P-Xylene	108383	CAA	2.201E-07
Naphthalene (gas phase)	91203	CAA	4.327E-07
Naphthalene (solid phase)	91203	CAA	4.432E-06
N-Hexane	110543		6.632E-07
O-Xylene	95476	CAA	1.242E-06
Phenanthrene	85018		7.658E-07
Propionaldehyde	123386	CAA	5.684E-08
Pyrene	121400		3.739E-07
Styrene	100425	CAA	3.221E-07
Toluene	108883	CAA	9.853E-06
2,2,4-Trimethylpentane	540841	CAA	3.394E-08

General Aviation Emission Factors - Jet			
Pollutant	CAS No.	CAA "187" or IRIS HAP?	Emission Factors (tons/LTO)
THC			3.00E-04
VOC			2.73E-04
TOG			3.06E-04
NO _x			1.62E-04
CO			4.79E-03
SO _x			3.68E-05
PM ₁₀			1.184E-04
PM _{2.5}			1.539E-05
Acetaldehyde	75070	CAA	1.309E-05
Acetone	67641		9.593E-07
Acetylene	74862		1.207E-05
Acrolein	107028	CAA	7.506E-06
Anthracene	120127		5.221E-11
Benzaldehyde	100527	IRIS	1.440E-06
Benzene	71432	CAA	5.152E-06
Benzo(a)anthracene	56553		7.903E-12
Benzo(a)pyrene	50328		4.327E-12
Benzo(ghi)perylene	191242		7.178E-13
1,3-Butadiene	101314	CAA	5.170E-06
1-Butene	101389		5.376E-06
Butyraldehyde	123728		3.647E-07
C14-Alkane	No CAS		5.700E-07
C15-Alkane	No CAS		5.425E-07
C16 Branched Alkane	No CAS		4.475E-07
C18-Alkane	No CAS		6.130E-09
C4-Benzene + C3-Aroald	No CAS		2.010E-06
C5-Benzene+C4-Aroald	No CAS		9.930E-07
Chrysene	218019		7.359E-12
Cis-2-Butene	514181		6.436E-07
Cis-2-Pentene	627203		8.459E-07
Crotonaldehyde	4170303		3.166E-06
1-Decene	872059		5.670E-07
Dimethylnaphthalenes	28804888		2.758E-07
Ethane	74840		1.597E-06
Ethylbenzene	100414	CAA	5.333E-07
Ethylene	74851		4.738E-05
Fluoranthene	206440		1.092E-10
Formaldehyde	50000	CAA	3.773E-05
Glyoxal	107222		5.566E-06

General Aviation Emission Factors - Jet			
Pollutant	CAS No.	CAA "187" or IRIS HAP?	Emission Factors (tons/LTO)
Heptene	25339564		1.342E-06
Hexadecane	544763		1.502E-07
1-Hexene	592416		2.256E-06
Isopropylbenzene	98828	CAA	9.194E-09
Isovaleraldehyde	514863		9.807E-08
Methacrolein	78853		1.315E-06
Methanol	67561	CAA	5.532E-06
Methyl Glyoxal	78988		4.606E-06
1-Methyl Naphthalene	14120		7.570E-07
2-Methyl Naphthalene	91576	IRIS	6.313E-07
3-Methyl-1-Butene	563451		3.433E-07
4-Methyl-1-Pentene	131372		3.984E-08
2-Methyl-1-Butene	563462		4.291E-07
2-Methyl-2-Butene	513359		5.670E-07
2-Methylpentane	107835		1.250E-06
2-Methyl-1-Pentene	763291		1.042E-07
M-Ethyltoluene	620144		4.720E-07
M-Tolualdehyde	620235		8.520E-07
Naphthalene (gas phase)	91203	CAA	1.674E-06
Naphthalene (solid phase)	91203	CAA	5.571E-08
Napthalene	91203	CAA	1.658E-06
N-Decane	124185		9.807E-07
N-Dodecane	112403		1.416E-06
N-Heptadecane	629787		2.758E-08
N-Heptane	142825		1.961E-07
N-Nonane	111842		1.900E-07
N-Octane	111659		1.900E-07
1-Nonene	124118		7.539E-07
N-Pentadecane	629629		5.302E-07
N-Pentane	109660		6.068E-07
N-Propylbenzene	103651		1.624E-07
N-Tetradecane	629594		1.275E-06
N-Tridecane	629505		1.640E-06
N-Undecane	1120214		1.361E-06
Octene	111660		8.459E-07
O-Ethyltoluene	611143		1.992E-07
O-Tolualdehyde	529204		7.049E-07
1-Pentene	109671		2.378E-06
P-Ethyltoluene	622968		1.961E-07
Phenanthrene	85018		4.858E-10

General Aviation Emission Factors - Jet			
Pollutant	CAS No.	CAA "187" or IRIS HAP?	Emission Factors (tons/LTO)
Phenol	108952	CAA	2.225E-06
Propane	74986		2.391E-07
Propionaldehyde	123386	CAA	2.228E-06
Propylene	115071		1.390E-05
P-Tolualdehyde	104870		1.471E-07
Pyrene	121400		1.334E-10
Styrene	100425	CAA	9.470E-07
Toluene	108883	CAA	1.968E-06
Trans-2-Hexene	4050457		9.194E-08
Trans-2-Pentene	646048		1.100E-06
1,2,3-Trimethylbenzene	526738		3.249E-07
1,2,4-Trimethylbenzene	95636		1.073E-06
1,3,5-Trimethylbenzene	108678		1.655E-07
2,2,4-Trimethylpentane	540841	CAA	1.313E-07
Valeraldehyde	110623		7.509E-07
Xylene	1330207	CAA	1.612E-06

General Aviation Emission Factors - Piston			
Pollutant	CAS No.	CAA "187" or IRIS HAP?	Emission Factors (tons/LTO)
THC			7.750E-05
VOC			7.524E-05
TOG			8.537E-05
NO _x			3.250E-05
CO			6.007E-03
SO _x			5.000E-06
PM ₁₀			1.184E-04
PM _{2.5}			1.539E-05
Acenaphthene	83329		1.123E-08
Acenaphthylene	208968		6.339E-08
Acetaldehyde	75070	CAA	5.874E-07
Acrolein	107028	CAA	5.684E-08
Anthracene	120127		1.308E-08
Benzene	71432	CAA	3.837E-06
Benzo(a)anthracene	56553		1.539E-09
Benzo(a)pyrene	50328		1.539E-09
Benzo(b)fluoranthene	205992		1.846E-09
Benzo(ghi)perylene	191242		4.000E-09
Benzo(k)fluoranthene	207089		1.846E-09
1,3-Butadiene	101314	CAA	9.285E-07
Chrysene	218019		1.539E-09
Ethylbenzene	100414	CAA	1.393E-06
Fluoranthene	206440		1.400E-08
Fluorene	86737		2.323E-08
Formaldehyde	50000	CAA	2.548E-06
Indeno(1,2,3-cd)pyrene	193395		1.231E-09
M-Xylene and P-Xylene	108383	CAA	1.123E-08
Naphthalene (gas phase)	91203	CAA	4.327E-07
Naphthalene (solid phase)	91203	CAA	2.262E-07
N-Hexane	110543		6.632E-07
O-Xylene	95476	CAA	6.339E-08
Phenanthrene	85018		3.908E-08
Propionaldehyde	123386	CAA	5.684E-08
Pyrene	121400		1.908E-08
Styrene	100425	CAA	3.221E-07
Toluene	108883	CAA	9.853E-06
2,2,4-Trimethylpentane	540841	CAA	3.394E-08

Military Emission Factor			
Pollutant	CAS No.	CAA "187" or IRIS HAP?	Emission Factors (tons/LTO)
THC			6.170E-04
VOC			6.815E-04
TOG			7.597E-04
NO _x			7.900E-05
CO			1.407E-02
SO _x			7.500E-06
PM ₁₀			3.017E-04
PM _{2.5}			3.922E-05
Acetaldehyde	75070	CAA	3.245E-05
Acetone	67641		2.378E-06
Acetylene	74862		2.993E-05
Acrolein	107028	CAA	1.861E-05
Benzaldehyde	100527	IRIS	3.571E-06
Benzene	71432	CAA	1.277E-05
1,3-Butadiene	101314	CAA	1.282E-05
1-Butene	101389		1.333E-05
Butyraldehyde	123728		9.041E-07
C14-Alkane	No CAS		1.413E-06
C15-Alkane	No CAS		1.345E-06
C16 Branched Alkane	No CAS		1.109E-06
C18-Alkane	No CAS		1.519E-08
C4-Benzene + C3-Aroald	No CAS		4.984E-06
C5-Benzene+C4-Aroald	No CAS		2.461E-06
Cis-2-Butene	514181		1.595E-06
Cis-2-Pentene	627203		2.097E-06
Crotonaldehyde	4170303		7.848E-06
1-Decene	872059		1.405E-06
Dimethylnapthalenes	28804888		6.837E-07
Ethane	74840		3.958E-06
Ethylbenzene	100414	CAA	1.322E-06
Ethylene	74851		1.175E-04
Formaldehyde	50000	CAA	9.352E-05
Glyoxal	107222		1.380E-05
Heptene	25339564		3.328E-06
Hexadecane	544763		3.723E-07
1-Hexene	592416		5.591E-06
Isopropylbenzene	98828	CAA	2.279E-08
Isovaleraldehyde	514863		2.431E-07
Methacrolein	78853		3.259E-06

Military Emission Factor			
Pollutant	CAS No.	CAA "187" or IRIS HAP?	Emission Factors (tons/LTO)
Methanol	67561	CAA	1.371E-05
Methyl Glyoxal	78988		1.142E-05
1-Methyl Naphthalene	14120		1.876E-06
2-Methyl Naphthalene	91576	IRIS	1.565E-06
3-Methyl-1-Butene	563451		8.509E-07
4-Methyl-1-Pentene	131372		9.876E-08
2-Methyl-1-Butene	563462		1.064E-06
2-Methyl-2-Butene	513359		1.405E-06
2-Methylpentane	107835		3.100E-06
2-Methyl-1-Pentene	763291		2.583E-07
M-Ethyltoluene	620144		1.170E-06
M-Tolualdehyde	620235		2.112E-06
Napthalene	91203	CAA	4.110E-06
N-Decane	124185		2.431E-06
N-Dodecane	112403		3.510E-06
N-Heptadecane	629787		6.837E-08
N-Heptane	142825		4.862E-07
N-Nonane	111842		4.710E-07
N-Octane	111659		4.710E-07
1-Nonene	124118		1.869E-06
N-Pentadecane	629629		1.314E-06
N-Pentane	109660		1.504E-06
N-Propylbenzene	103651		4.026E-07
N-Tetradecane	629594		3.160E-06
N-Tridecane	629505		4.064E-06
N-Undecane	1120214		3.373E-06
Octene	111660		2.097E-06
O-Ethyltoluene	611143		4.938E-07
O-Tolualdehyde	529204		1.747E-06
1-Pentene	109671		5.895E-06
P-Ethyltoluene	622968		4.862E-07
Phenol	108952	CAA	5.515E-06
Propane	74986		5.926E-07
Propionaldehyde	123386	CAA	5.523E-06
Propylene	115071		3.445E-05
P-Tolualdehyde	104870		3.647E-07
Styrene	100425	CAA	2.348E-06
Toluene	108883	CAA	4.877E-06
Trans-2-Hexene	4050457		2.279E-07
Trans-2-Pentene	646048		2.727E-06

Military Emission Factor			
Pollutant	CAS No.	CAA "187" or IRIS HAP?	Emission Factors (tons/LTO)
1,2,3-Trimethylbenzene	526738		8.053E-07
1,2,4-Trimethylbenzene	95636		2.659E-06
1,3,5-Trimethylbenzene	108678		4.102E-07
Valeraldehyde	110623		1.861E-06

Appendix B

Calculating Piston-Engine Aircraft Airport Inventories for Lead for the 2008 National Emissions Inventory

Calculating Piston-Engine Aircraft Airport Inventories for Lead for the 2008 National Emissions Inventory

December 2010

Section 1. Introduction

The main purpose of this document is to describe the methods the Environmental Protection Agency (EPA) used to calculate airport lead (Pb) inventories for the 2008 National Emissions Inventory (NEI).¹ These methods focus on the development of approaches to estimate piston-engine aircraft activity at airports in the U.S. since the activity of this fleet is reported to the Federal Aviation Administration (FAA) as general aviation (GA) or air taxi (AT) activity – categories that also include jet-engine aircraft activity. The methods described here reflect improvements to the methods used in developing the airport-specific piston-engine aircraft inventories in the 2002 NEI and the 2005 NEI.

Background information regarding the use of leaded aviation gasoline (avgas) in piston-engine powered aircraft is available in other documents.^{2,3} Briefly, most piston-engine aircraft operations fall into the categories of either GA or AT. Aircraft used in GA and AT activities include a diverse set of aircraft types and engine models and are used in a wide variety of applications.⁴ Lead emissions associated with GA and AT aircraft stem from the use of one hundred octane low lead (100LL) avgas. The lead is added to the fuel in the form of tetraethyl lead (TEL). This lead additive helps boost fuel octane, prevent engine knock, and prevent valve seat recession and subsequent loss of compression for engines without hardened valves. Today, 100LL is the most commonly available type of aviation gasoline in the United States.⁵ Lead is not added to jet fuel that is used in commercial aircraft, most military aircraft, or other turbine-engine powered aircraft. Lead emissions from the use of leaded avgas comprised 45% of the national inventory for emissions of lead in 2002.⁶

¹ In this document '2008 NEI' refers to 2008 NEI version 1 (January 2011), available at <http://www.epa.gov/ttn/chief/net/2008inventory.html>

² EPA (2007) Review of the National Ambient Air Quality Standards for Lead: Policy Assessment of Scientific and Technical Information. OAQPS Staff Paper. EPA-452/R-07-013 November 2007. pp 2-8 and 2-9.

³ FAA William J. Hughes Technical Center
http://www.tc.faa.gov/act4/insidethefence/2006/0609_06_AvFuels.htm

⁴ Commercial aircraft include those used for scheduled service transporting passengers, freight, or both. Air taxis fly scheduled and for-hire service carrying passengers, freight or both, but they usually are smaller aircraft than those operated by commercial air carriers. General aviation includes most other aircraft (fixed and rotary wing) used for personal transportation, business, instructional flying, and aerial application.

⁵ ChevronTexaco (2005) Aviation Fuels Technical Review. FTR-3.
http://www.chevronglobalaviation.com/docs/aviation_tech_review.pdf

⁶ U.S. Environmental Protection Agency (2008) EPA's Report on the Environment EPA/600/R-07/045F. Available at: <http://www.epa.gov/roe>

This document is organized into eight sections. Section 2 describes the data we use to calculate the national inventory for the amount of lead released to the air from the combustion of leaded avgas. Section 3 describes the landing and takeoff data we use to calculate airport-specific inventories for lead. Section 4 describes how we estimate landing and takeoff data for the airport facilities that do not report it to the FAA. Section 5 describes the estimate of landing and takeoff activity occurring at heliports in the U.S. Section 6 describes the methods used to calculate the airport-specific inventories for lead. Section 7 describes data that would be needed to improve the estimates of airport-specific inventories for lead and Section 8 describes the estimates of the amount of lead emitted in-flight that are in the 2008 NEI.

In this document, units of tons (i.e., U.S. short tons) are used when discussing the national and airport-specific lead inventory in order to be consistent with the manner in which the NEI reports inventories for lead and other pollutants. The unit of grams is used in describing the concentration of lead in avgas and in describing emission factors. Conversion factors are provided for clarity.

Section 2. Calculating the National Avgas Lead Inventory

Because lead is a persistent pollutant and accumulates in the environment, we include all lead emissions from piston-engine aircraft in the NEI – emissions occurring during the landing and take-off cycle at airports as well as emissions occurring at altitude.⁷ To calculate the national avgas lead inventory, we use information provided by the U.S. Department of Transportation's (DOT's) Federal Aviation Administration (FAA) regarding the volume of leaded avgas consumed in the U.S. in 2008.⁸ The U.S. Department of Energy's (DOE's) Energy Information Administration (EIA) provides information regarding the volume of leaded avgas produced in a given year. EPA has historically used the DOE EIA avgas fuel volume produced to calculate national lead inventories from the consumption of leaded avgas. However, since EPA uses DOT airport activity and aircraft data, we are using the DOT fuel volume data in the 2008 NEI to calculate the national lead inventory in order to use a consistent data source. In this document, when we refer to avgas fuel volume data it is data supplied by DOT, except where noted.

As demonstrated in the equation below, to calculate the annual emission of lead from the consumption of leaded avgas, we multiply the volume of avgas used by the concentration of lead in the avgas, minus the small amount of lead that is retained in the engine, engine oil and/or exhaust system. The volume of avgas used in the U.S. in 2008

⁷ U.S. EPA, 2006. Air Quality: Criteria for Lead: 2006; EPA/600/R-5/144aF; U.S. Government Printing Office, Washington, DC, October, 2006.

⁸ U.S. Department of Transportation Federal Aviation Administration Aviation Policy and Plans. FAA Aerospace Forecast Fiscal Years 2010-2030. p.99. Available at: http://www.faa.gov/data_research/aviation/aerospace_forecasts/2010-2030/media/2010%20Forecast%20Doc.pdf This document provides historical data for 2000-2008 as well as forecast data.

was 248,100,000 gallons.⁹ The concentration of lead in avgas ([Pb] in the equation below) can be one of four levels (ranging from 0.14 to 1.12 grams of lead per liter) as specified by the American Society for Testing and Materials (ASTM). By far the most common avgas supplied is “100 Low Lead” or 100LL.^{10,11} The maximum lead concentration specified by ASTM for 100LL is 0.56 grams per liter or 2.12 grams per gallon.¹² A fraction of lead is retained in the engine, engine oil and/or exhaust system which we currently estimate at 5%.¹³

For the 2008 NEI, the national estimate of lead emissions from the consumption of avgas was 551 tons (see equation below).

$$\frac{(248,100,000 \text{ gal})(2.12 \text{ g Pb/gal})(0.95)}{907,180 \text{ g/ton}} = 551 \text{ tons Pb}$$

As described above, DOE’s EIA also provides estimates of the annual volume of leaded avgas produced in a given year. For 2008, the volume of avgas produced in the U.S. was 5,603 thousand barrels or 235,326,000 gallons.¹⁴ Consumption of this volume of avgas equates to a national lead emissions estimate for this source of 522 short tons.

Section 3. Landing and Takeoff Data Sources and Uses

Airport-specific inventories require information regarding landing and takeoff (LTO) activity by aircraft type.¹⁵ According to FAA records, there are approximately 20,000 airport facilities in the U.S., the vast majority of which are expected to have activity by piston-engine aircraft that operate on leaded avgas. Of these facilities, EPA’s NEI has in the past, reported emissions of lead (and other criteria pollutants and

⁹ U.S. Department of Transportation Federal Aviation Administration Aviation Policy and Plans. FAA Aerospace Forecast Fiscal Years 2010-2030. p.99. Available at: http://www.faa.gov/data_research/aviation/aerospace_forecasts/2010-2030/media/2010%20Forecast%20Doc.pdf This document provides historical data for 2000-2008 as well as forecast data.

¹⁰ ChevronTexaco (2005) Aviation Fuels Technical Review. FTR-3.

¹¹ The 2008 General Aviation Statistical Databook & Industry Outlook report by General Aviation Manufacturers Association (GAMA) found that over 90% of avgas is 100LL.

¹² ASTM International (2005) Annual Book of ASTM Standards Section 5: Petroleum Products, Lubricants, and Fossil Fuels Volume 05.01 Petroleum Products and Lubricants (I): D 56 – D 3230.

¹³ The information used to develop this estimate is from the following references: (a) Todd L. Petersen, Petersen Aviation, Inc, *Aviation Oil Lead Content Analysis*, Report # EPA 1-2008, January 2, 2008, available at William J. Hughes Technical Center Technical Reference and Research Library at <http://actlibrary.tc.faa.gov/> and (b) E-mail from Theo Rindlisbacher of Switzerland Federal Office of Civil Aviation to Bryan Manning of U.S. EPA, regarding lead retained in engine, September 28, 2007.

¹⁴ DOE Energy Information Administration. Fuel production volume data obtained from <http://tonto.eia.doe.gov/dnav/pet/hist/mgaupus1A.htm> accessed November 2006.

¹⁵ An aircraft operation is defined as any landing or takeoff event, therefore, to calculate LTOs, operations are divided by two. Most data sources from FAA report aircraft activity in numbers of operations which, for the purposes of calculating lead emissions using the method described in this document, need to be converted to LTO events.

hazardous air pollutants) at 3,410 airports.¹⁶ While the 3,410 airport facilities are among the most active in the U.S., they comprise only a small fraction of the total airport facilities where leaded avgas is used.

FAA's Office of Air Traffic provides a complete listing of operational airport facilities in the National Airspace System Resources (NASR) database. The electronic NASR data report, referred to here as the 5010 airport data report, can be generated from the NASR database and is available for download from the FAA website.¹⁷ This report is updated every 56 days. EPA obtains airport information (including operations) for a subset of the facilities in the NASR database from FAA's Terminal Area Forecast (TAF) database that is prepared by FAA's Office of Aviation Policy and Plans.¹⁸ The TAF database currently includes information for airports in FAA's National Plan of Integrated Airport Systems (NPIAS), which identifies airports that are significant to national air transportation. Approximately 500 of the airports that are in the TAF database have either an FAA air traffic control tower or an FAA contract tower where controllers count operations. The operations data from the control towers is reported to The Operations Network (OPSNET)¹⁹ which is publically available in the Air Traffic Activity System (ATADS) database.²⁰ The operations data for the towered airports that is reported in OPSNET and ATADS is then reported to the TAF database. The operations data for the airports in the TAF database that do not have control towers represent estimates.²¹ The operations supplied in the 5010 airport data report for facilities not reported in the TAF may be self-reported by airport operators through data collection accomplished by airport inspectors who work for the State Aviation Agency, or operations data can be obtained through other means.²²

The 5010 airport data report supplies the date that the associated operations data represents.²³ Because airports that are not in the TAF database submit data voluntarily to FAA for the 5010 data report, many of the airports have operations data that represent data for years earlier than 2008. Nationally, GA and AT piston-engine operations have decreased in recent years,²⁴ therefore EPA did not use operations data from years prior to 2008 as it is reported. Instead, EPA multiplied the older GA and AT piston-engine data (Section 6 describes the method EPA used to calculate the number of piston-engine

¹⁶ These 3,410 facilities are the facilities for which the FAA's Terminal Area Forecast (TAF) database provides information regarding aircraft activity. The TAF database is prepared by FAA's Office of Aviation Policy and Plans and includes information for the airports in FAA's National Plan of Integrated Airport Systems (NPIAS). One of the goals of the NPIAS is to identify airports that are significant to national air transportation.

¹⁷ http://www.faa.gov/airports_airtraffic/airports/airport_safety/airportdata_5010/

¹⁸ <http://aspm.faa.gov/main/taf.asp>

¹⁹ <http://aspm.faa.gov/opsnet/sys/>

²⁰ <http://aspm.faa.gov/opsnet/sys/Airport.asp>

²¹ FAA's Terminal Area Forecast Summary (Fiscal Years 2009 – 2030), Appendix A (page 28)
http://www.faa.gov/data_research/aviation/taf_reports/media/TAF%20Summary%20Report%20FY%202009%20-%202030.pdf

²² In the absence of updated information from States, local authorities or Tribes, we are using the LTO data provided in the FAA database.

²³ The 12-month ending date on which annual operations data in the report is based.

²⁴ http://www.faa.gov/data_research/aviation_data_statistics/general_aviation/

operations from total GA and AT activity data) by scaling factors that were calculated by dividing the 2008 national amount of avgas produced by the national amount of avgas produced in the year the operations data represents.²⁵ A table with the scaling factors is provided in Appendix A. The national volume of avgas produced data comes from the DOE, EIA website and is available for 1981 – 2009.²⁶ For operations data older than 1981, EPA divided the 2008 national amount of avgas produced by the average of the national amount of avgas produced from 1981 – 1989. Jet engines do not use avgas, therefore EPA did not apply scaling factors to the turbine operations for data from years prior to 2008.

EPA also obtains operations data from the T-100 segment data from the Bureau of Transportation Statistics (BTS). The aircraft in the T-100 data are matched to aircraft in the FAA's Emission and Dispersion Modeling System (EDMS) using the crosswalk table developed for earlier versions of the NEI. Generally the T-100 data covers commercial air carrier operations, but some AT activities are included in the data set that would double count with the TAF data at the same airport. To correct for possible double counting, first the AT LTOs included in the T-100 data were compiled using the aircraft type data included in the aircraft make/models crosswalk.²⁷ The resulting aggregated LTOs were compared with the reported TAF LTOs for airports where there were overlaps. The T-100 AT LTOs were then subtracted from the TAF AT data to ensure that double counting was minimized. Note that if the T-100 AT value was larger than the TAF value, the TAF value was set to zero to eliminate the possibility of negative LTOs in the dataset.

The 2008 draft NEI was developed using the January 15, 2009 version of the 5010 airport data report. In that version of the report there were 19,925 airport facilities in the U.S. that had submitted data to the FAA. Among these 19,925 facilities, 99 facilities were not relevant for the purposes of estimating lead emissions because they were either listed as closed (85) or they were balloonports (14).²⁸ Therefore, lead inventories were needed for 19,826 facilities. In the January 15, 2009 version of the 5010 airport data report there were 5,654 airport facilities for which operations data were provided (many of which are facilities in FAA's TAF database).²⁹ There were 14,172 facilities in the 5010 airport data report for which there were no operations data.³⁰ As a

²⁵ The FAA General Aviation and Air Taxi (Part 135) Activity Surveys (source of national level piston-engine operations data) are only available annually, starting in 1999. Because there are airports with operations data older than 1999, EPA used avgas product supplied data as a surrogate for piston-engine operations to estimate the change in piston-engine activity over the last three decades.

²⁶ <http://tonto.eia.doe.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=mgaupus1&f=A>. DOT recently changed the way they estimate fuel consumption data, so while EPA used DOT data to determine the 2008 national avgas lead inventory, for the purpose of calculating these scaling factors EPA used DOE's data in order to have historical fuel data that is calculated in a consistent manner.

²⁷ The T-100 data does not specify that the operations data is air taxi in nature; however, in discussions with FAA, EPA determined that these flights are air taxi in nature and has assigned them in the 2008 NEI as such.

²⁸ Balloon craft do not use avgas

²⁹ Either Commuter, GA Itinerant, GA Local, or Air Taxi operations data, as these operations can be performed by piston-engine aircraft.

³⁰ No Commuter, GA Itinerant, GA Local, or Air Taxi operations data.

part of the review process for the draft 2008 NEI, EPA received updated airport data from states and also looked at more recent versions of the 5010 airport data report to update the status of airports, so the number of airports for which EPA estimated activity is slightly lower in the 2008 NEI than in the draft 2008 NEI. The following section of this document describes the method EPA used to estimate operations for the 14,132 airport facilities in the 2008 NEI that do not have reported activity data.

As described in Section 1, most piston-engine aircraft fall into the categories of either GA or AT. Some GA and AT activity is conducted by turboprop and turbojet aircraft which do not use leaded avgas. There are no national databases that provide airport-specific LTO activity data for piston-engine aircraft separately from turbojet and turboprop aircraft. The databases described above report total GA and AT activity conducted by both piston-engine and jet-engine aircraft. Part (a) in Section 6 describes how we estimate piston-engine LTOs at airports in the 2008 NEI.

Section 4. Estimating LTOs at the 14,132 Airport Facilities with No LTO Data

FAA has used regression models to estimate operations at facilities where operations data are not available.^{31,32} In this work and other work, FAA identified characteristics of small towered airports for which there were statistically significant relationships with operations at these airports.³³ Regression models based on the airport characteristics were then used to estimate general aviation operations for a set of non-towered airports. The airport characteristics identified by FAA and used to estimate general aviation operations at small airports include: the number of aircraft based at a facility (termed ‘based aircraft’), population in the vicinity of the airport, airport regional prominence, per capita income, region, and the presence of certificated flight schools.

In the 2000 report titled ‘Model for Estimating General Aviation Operations at Non-towered Airports,’ a model of GA annual activity was developed using information from small towered airports to explain GA activity at towered and non-towered airports. The model explained GA activity at the towered airports well (R^2 of 0.75) but produced higher estimates than state-supplied estimates for non-towered airports.³⁴

The relevant data available in the 5010 airport data report for the purposes of estimating airport operations include: facility type (airport, balloonport, seaplane base, gliderport, heliport, stolport,³⁵ ultralight); number of GA aircraft based at each airport by

³¹ Federal Aviation Administration, Office of Aviation Policy and Plans, Statistics and Forecast Branch. July 2001. Model for Estimating General Aviation Operations at Non-towered Airports Using Towered and Non-towered Airport Data. Prepared by GRA, Inc.

³² Mark Hoekstra, “Model for Estimating General Aviation Operations at Non-Towered Airports” prepared for FAA Office of Aviation Policy and Plans, April 2000.

³³ GRA, Inc. “Review of TAF Methods,” Final Report, prepared for FAA Office of Aviation Policy and Plans under Work Order 45, Contract No. DTFA01-93-C-00066, February 25, 1998.

³⁴ The mean absolute difference between the model operations estimate and the state operations estimate was 16,940 operations.

³⁵ Stolport is an airport designed with STOL (Short Take-Off and Landing) operations in mind, normally having a short single runway.

type (glider, helicopter, jet engine, military, multi-engine, single engine, ultralight); operations data (air taxi, commercial, commuter, GA itinerant, GA local, military)³⁶; and operations date (12-month ending date on which annual operations data is based). Census data was also merged with the 5010 airport data report to give population data for each airport's county.

Using the FAA work referenced above, we explored relationships among the airport data variables that best predicted aircraft activity (LTOs). We found that based aircraft was a highly significant and positive regressor to LTOs. Table 1 shows that for facilities that did not have LTO data in the January 15, 2009 version of the 5010 airport data report, 7,856 had based aircraft data while 6,316 did not have based aircraft data.^{37, 38} Therefore, as described below, LTO estimates were derived using different methods depending on data availability.

Table 1: Contingency table describing the numbers of airport facilities that have or do not have LTO data and/or based aircraft data for airport facilities in the January 15, 2009 version of the 5010 airport data report

		HAVE LTO DATA		
		YES	NO	
HAVE BASED AIRCRAFT DATA	YES	4,872	7,856	12,728
	NO	782	6,316	7,098
		5,654	14,172	19,826

³⁶ As explained in footnote 15, an aircraft operation is defined as any landing or takeoff event, therefore, to calculate LTOs, operations are divided by two. The 5010 airport data report from FAA reports aircraft activity in numbers of operations which, for the purposes of calculating Pb emissions using the method described in the TSD, are converted to LTO events.

³⁷ As described in Section 3, the number of facilities with no LTO data changed slightly from the draft 2008 NEI to the 2008 NEI. In the 2008 NEI, of the facilities that did not have reported activity data, 7,837 facilities reported based aircraft data and 6,295 did not report based aircraft data.

³⁸ These numbers include data for the following types of facilities: airports, balloonports, seaplane bases, gliderports, heliports, stolports, and ultralights.

(a) Estimating LTOs at Facilities with Based Aircraft Data, but No LTO Data:

There are 6,414 facilities in the 2008 NEI (not including heliports) for which the 5010 airport data report supplies the number of based aircraft³⁹ but not activity data to which the regression equation (based aircraft vs. LTOs) could be applied. Using the 4,872 airports for which both LTO and aircraft data is known, the initial relationship found between based aircraft and LTOs was:

Equation 1:

$$\text{LTOs} = 2494 + 208 * \text{aircraft} \quad R^2 = 0.55$$

The FAA models found population to be another significant regressor. We used the population of the county in which the airport is located as the population variable. Adding county population to the model gave the following relationship:

Equation 2:

$$\text{LTOs} = 2204 + 194 * \text{aircraft} + 0.0038 * \text{county population} \quad R^2 = 0.56$$

EPA received numerous comments to the docket on its Advance Notice of Proposed Rulemaking on Lead Emissions from Piston-Engine Aircraft Using Leaded Aviation Gasoline⁴⁰ indicating that aviation in Alaska is different than it is in the continental U.S. Commenters pointed out that in Alaska, 82% of communities are not accessible by road and rely on air transport for life sustaining goods and services.⁴¹ Commenters also noted that Alaskans travel by air eight times more often per capita than those in the continental U.S. For those reasons, we added a dummy variable in equation 3 to identify whether or not an airport is located in Alaska. Because the relationship between based aircraft and LTOs is likely different for Alaskan airports than it is for airports that aren't in Alaska, we also added an interaction term to equation 3 (interaction of an airport being in Alaska and its sum of based aircraft).

Equation 3:

$$\text{LTOs} = 1937 + 205 * \text{aircraft} + 0.0038 * \text{county population} + 566 * \text{Alaska} - 108 * (\text{Alaska} * \text{aircraft}) \quad R^2 = 0.58$$

After analyzing the data and plot for the data underlying equation 3, we found many airport facilities identified as commercial airports for which based aircraft was extremely low (i.e., less than 10), yet LTOs were quite high (i.e., anywhere from 100,000

³⁹ Based aircraft for this purpose was limited to single- and multi-engine aircraft, helicopters, and ultralights since these aircraft types can use leaded avgas.

⁴⁰ U.S. Environmental Protection Agency (2010) Advance Notice of Proposed Rulemaking on Lead Emissions From Piston-Engine Aircraft Using Leaded Aviation Gasoline. 75 FR 22440 (April 28, 2010).

⁴¹ Comments to the docket on EPA's Advance Notice of Proposed Rulemaking on Lead Emissions from Piston-Engine Aircraft Using Leaded Aviation Gasoline from the Alaska Air Carriers Association (dated 18 June 2010; comment number OAR-2007-0294-0323.1) and Alaska Governor Parnell (dated 25 August 2010; comment number OAR-2007-0294-0403.1).

to more than 200,000 LTOs/year).⁴² These facilities were removed from the regression analysis. Additionally, for reasons described below, heliports were also removed from the regression. The resulting relationship was:

Equation 4:

$$\text{LTOs} = 1293 + 203 * \text{aircraft} + 0.0019 * \text{county population} - 473 * \text{Alaska} - 144 * (\text{Alaska} * \text{aircraft}) \quad R_2 = 0.65$$

When equation 4 was applied to the 6,414 airport facilities that report based aircraft data but not LTO activity, the resulting sum of LTOs was almost 15 million. EPA estimates that the number of LTOs at the airports that do not report activity data should approximate the number of LTOs from the bottom of the distribution of the set of airports that report activity data to the 5010 airport data report but that are not in the TAF database. The average number of LTOs per year from airports in the bottom 30% of the set of airports that report activity data to the 5010 airport data report but that are not in the TAF database is ~63 LTOs/year. Multiplying 63 by the number of airports that do not report activity data equals 549,050 LTOs.⁴³ Therefore, EPA used equation 4 to generate the distribution of LTOs at the individual airports that report based aircraft data but not activity data and then applied a scaling factor of 0.0356 to those LTOs to obtain the LTOs that are reported in the 2008 NEI.⁴⁴ The sum of the LTOs from this set of airports plus the sum of the LTOs at the airports that do not report either based aircraft or activity data (described below in section (b)) sum to 549,050 LTOs. These LTOs are all assigned to the GA, piston-engine category since they are assigned to smaller general aviation airports that are assumed to have little to no air taxi or jet aircraft activity.

Equation 4 and the scaling factor were used to estimate LTO activity for the 2008 NEI at airport facilities that report based aircraft data but not activity data.

(b) Estimating LTOs at Facilities with Neither Based-Aircraft Data nor LTO Data:

There are 2,260 facilities (not including heliports) for which the 5010 airport data report supplies neither the number of based aircraft nor activity data. In the absence of data to establish a relationship to airport activity, we assign a default value of LTOs to the GA, piston-engine category for each of these facilities.

⁴² From FAA's website, "Addresses for Commercial Service Airports", available at: http://www.faa.gov/airports_airtraffic/airports/planning_capacity/passenger_allcargo_stats/addresses/media/commercial_service_airports_addresses.xls

⁴³ This rounded number is calculated by multiplying 63.298 LTOs/year by 8,674, which is the number of airports that don't report activity data (6,414 don't report activity data and 2,260 facilities don't report activity or based aircraft data).

⁴⁴ The scaling factor was calculated by dividing 528,710 LTOs by 14,862,767 LTOs; the 528,710 LTOs are equal to 549,050 LTOs minus 20,340 LTOs (20,340 LTOs represent the sum of LTOs assigned to the 2,260 facilities that don't report either activity data or based aircraft data - the derivation of LTO estimates for these facilities is described in Section 4 (b)). The 14,862,767 LTOs are the sum of LTOs that result from applying equation 4 to the 6,414 facilities with based aircraft data but no activity data.

The default value was determined by evaluating GA LTOs that are reported at the set of 2,471 facilities that report activity data to the 5010 airport data report but that are not in the TAF set of airports. The average number of LTOs reported to the bottom ten percent of these facilities (when sorted by total GA LTOs) was 9. These facilities are assumed to most closely approximate the set of 2,260 facilities that do not report any based aircraft or LTO data; therefore, we assigned 9 LTOs to the GA, piston-engine category for these airport facilities for purposes of developing inventory estimates.

Section 5. Calculating LTOs at Heliports:

There were 5,559 heliport facilities in the January 15, 2009 FAA 5010 data report that were operational. Of those, only 92 (or 2%) reported LTO data, and of those, only 31 reported both based aircraft and LTO data. Because of the limited information regarding activity at heliports, some municipalities have hired contractors to survey activity in their local area.^{45, 46}

The summary statistics for LTO data provided at the 92 operational heliports is presented in Table 2. These facilities report a wide range in activity from 3 LTOs/year to more than 18,000 LTOs/year. Some facilities clearly have significant helicopter traffic (i.e., thousands of LTOs/year) which is supported by the contractor summaries of heliport activity in the Washington Metropolitan area. The little data available to us suggests that the median helicopter activity is less than 200 LTOs/year. In the absence of more information on which to base estimates of LTO activity, we assigned 141 LTOs (the median of the reported heliport LTOs) to the GA category at all of the heliports which do not report LTO data. The piston-engine fraction developed in Section 6 is applied to the 141 LTOs resulting in 51 LTOs assigned to the GA, piston-engine category and 90 assigned to the GA, turbine-engine category. This is an area of significant uncertainty in the inventory and one for which EPA is seeking information from local agencies.

Table 2: Heliport LTO Data for those Reporting LTO Data in the January 15, 2009 Version of the 5010 Airport Data Report

18,250	Maximum LTOs
3	Minimum LTOs
1,123	Average LTOs
141	Median LTOs
50	Mode LTOs

⁴⁵ Executive Summary: Regional Helicopter System Plan, Metropolitan Washington Area, prepared by Edwards and Kelcey for the Metropolitan Washington Council of Governments, 2005.

⁴⁶ Alaska Aviation Emission Inventory, prepared by Sierra Research, Inc. for Western Regional Air Partnership, 2005.

Section 6. Methodology for Estimating Airport-Specific Lead Emissions

In 2008, EPA developed a method to calculate lead emissions at airports where piston-engine powered aircraft operate.⁴⁷ This method brings lead inventories into alignment with the manner in which other criteria pollutants emitted by aircraft are calculated. This method is described here with changes that were made from previous methods (i.e., the method used to develop the 2002 inventory) and applied in developing airport lead inventories for the 2008 NEI. In this section we first present the equation used to calculate lead emitted during the LTO cycle then we describe each of the components of the input data: we describe how we calculate piston-engine LTOs from data available in FAA databases, we describe the derivation of the emission factor for the amount of lead emitted during the LTO cycle, and we describe the estimate of the amount of lead retained in the engine and oil that we do not include in the amount of lead released to the air.

Historically, where aircraft specific activity data are available (such as T-100), aircraft gaseous and particulate matter (PM) emissions have been calculated through the FAA's EDMS.⁴⁸ This modeling system was designed to develop emission inventories for the purpose of assessing potential air quality impacts of airport operations and proposed airport development projects. However, EDMS has a limited number of piston-engine aircraft in its aircraft data and is currently not set up to calculate metal emissions and thus, it is not a readily available tool for determining airport lead inventories related to aircraft operations. In developing this approach to determine piston-engine aircraft lead emissions, EPA relied upon the basic methodology employed in EDMS. This requires as input the activity of piston-engine aircraft at a facility, fuel consumption rates by these aircraft during the various modes of the LTO cycle and time in each mode (taxi/idle-out, takeoff, climb-out, approach, and taxi/idle-in), the concentration of lead in the fuel and the retention of lead in the engine and oil. The equation used to calculate airport-specific lead emissions during the LTO cycle is below, followed by a description of each of the input parameters.

$$\text{LTO Pb (tons)} = \frac{(\text{piston-engine LTO})(\text{avgas Pb g/LTO})(1-\text{Pb retention})}{907,180 \text{ g/ton}}$$

(a) Calculating Piston-engine LTO:

Piston-engine LTOs are used to calculate emissions of lead that are assigned to the airport facility where the aircraft operations occur. An aircraft operation is defined as any landing or takeoff event, therefore, to calculate LTOs, operations are divided by two. Most data sources from FAA report aircraft activity in numbers of operations which, for the purposes of calculating lead emissions, need to be converted to LTO events. We

⁴⁷ U.S. EPA (2008) Lead Emissions from the Use of Leaded Aviation Gasoline in the United States, Technical Support Document. EPA420-R-08-020. Available at: www.epa.gov/otaq/aviation.htm.

⁴⁸ EDMS available from http://www.faa.gov/about/office_org/headquarters_offices/aep/models/edms_model/

describe here the method used to estimate the fraction of GA and AT LTOs at an airport that are conducted by piston-engine aircraft. These fractions are calculated separately (one fraction for GA and one for AT). These fractions are multiplied by total LTOs reported separately for GA and AT and then summed to arrive at the total LTOs conducted by piston-engine aircraft at an airport.

One use of the 2008 NEI is to identify sources of lead, including airports, that have inventories of 0.50 tons per year or more for the purposes of identifying locations where lead monitoring may be required to evaluate compliance with the National Ambient Air Quality Standard for Lead. To calculate the most airport-specific inventories for airports that may potentially exceed this inventory threshold, we used a more airport-specific surrogate for this subset of airports than the remainder of the airports where we applied national default averages described below.

We used the fraction of based aircraft at an airport that are single- or multi-engine to calculate the number of GA LTOs at an airport that were conducted by piston-engine aircraft. The data regarding the population of based aircraft at an airport is available for a subset of airports in the FAA 5010 master records data report described in Section 3. For example, if an airport reports 150 single-engine aircraft, 20 multi-engine aircraft and a total of 180 aircraft based at that facility, then the fraction of based aircraft we would use as a surrogate for piston-engine aircraft is 94% $((150+20)/180)$. We then multiply the total GA LTOs for that facility by 0.94 to calculate piston-engine LTOs.

We evaluated this surrogate by comparing the results of using it with piston-engine aircraft operations reported for airports that supply this information in master plans, airport layout plans, noise abatement studies and/or land use compatibility plans. We could rarely find data from the same year for comparison purposes; however, for the majority of airports, based aircraft and actual observed piston-engine aircraft activity agreed within ten percent.⁴⁹

For the majority of airports in the 2008 NEI we used national average fractions of GA and AT LTOs conducted by piston-engine aircraft that were derived using FAA's General Aviation and Part 135⁵⁰ Activity Surveys – CY 2008 (GAATA).⁵¹ Table 2.4 in the 2008 GAATA Survey reports that approximately sixty-six percent (66%) of all GA and AT LTOs are from piston-engine aircraft which use avgas, and about thirty-four

⁴⁹ Documents used to evaluate the use of based aircraft include the following:

Airport Master Plan Update Prescott Municipal Airport (Ernest A Love Field) (2009) Available at: www.cityofprescott.net/d/amp_tablecontents.pdf

Gillespie field Airport Layout Plan Update Narrative Report (2005) Available at: www.co.san-diego.ca.us/dpw/airports/powerpoints/pdalp.pdf

Land Use Compatibility Plan for the Grand Forks International Airport (2006) Available at: www.gfkairport.com/authority/pdf/land_use.pdf

McClellan-Palomar Land Use Compatibility Plan (Amended March 4, 2010) Available at: www.ci.oceanside.ca.us/.../McClellan-Palomar_ALUCP_03-4-10_amendment.pdf

⁵⁰ On-demand (air taxi) and commuter operations not covered by Part 121

⁵¹ The FAA GAATA is a database collected from surveys of pilots flying aircraft used for general aviation and air taxi activity. For more information on the 2008 GAATA, see Appendix A at http://www.faa.gov/data_research/aviation_data_statistics/general_aviation/CY2008/

percent (34%) are turboprop and turbojet powered which use jet fuel, such as Jet A. The LTO data in Table 2.4 in the 2008 GAATA Survey does not distinguish LTOs as GA or AT, and thus does not allow us derive separate piston activity fractions for GA and AT.

We are using the number of hours flown by piston versus turboprop or turbojet aircraft (reported in Table 1.4 in the 2008 GAATA Survey) to allow us to make separate estimates of the fraction of GA activity conducted by piston aircraft and the fraction of AT activity conducted by piston aircraft. We chose to use the fraction of hours flown by piston-engine aircraft as a surrogate to calculate the fraction of LTOs flown by piston aircraft since the overall (i.e., for GA and AT combined) piston percent of hours flown (66.4%) is very close to the percent of LTOs that are piston (65.7%). Table 1.4 of the 2008 GAATA presents the total hours flown by aircraft type and separates GA from AT. Seventy-three percent (73%) of all GA hours flown are by piston-engine aircraft while twenty-eight percent (28%) of all GA hours flown are by turboprop and turbojet powered aircraft.⁵² Twenty-three percent (23%) of all AT hours flown are by piston-engine aircraft while seventy-seven percent (77%) of all AT hours flown are by turboprop and turbojet powered aircraft. Approximately 5,000 of the total 20,000 airport facilities in the U.S. are heliports at which only helicopters (rotocraft) operate. Therefore, EPA also calculated the percent of rotocraft hours flown that are conducted by piston-engine aircraft. Thirty-six percent (36%) of all GA rotocraft hours flown are by piston-engine rotocraft while sixty-four percent (64%) of all GA rotocraft hours flown are by turboprop and turbojet powered rotocraft. Two percent (2%) of all AT rotocraft hours flown are by piston-engine rotocraft while ninety-eight percent (98%) of all AT rotocraft hours flown are by turboprop and turbojet powered rotocraft. Table 3 identifies the piston and turbine fractions that were used in the absence of airport-specific information to calculate piston-engine operations at airports and heliports in the 2008 NEI.

Table 3: Piston and Turbine Activity Fractions used in the 2008 NEI

	Airports		Heliports	
	GA	AT	GA	AT
Piston Powered	72.5%	23.1%	36.1%	2%
Turbine Powered	27.5%	76.9%	63.9%	98%

⁵² Numbers in the text may not add to 100% due to rounding; the percentages in Table 3 are the values we used to calculate the 2008 NEI.

(b) Calculating the Piston-engine Aircraft Emission Factor: Grams of Lead Emitted per LTO:

Piston-engine aircraft can have either one or two engines. EDMS version 5.0.2 contains information on the amount of avgas used per LTO for some single and twin-engine aircraft. The proportion of piston-engine LTOs conducted by single- versus twin-engine aircraft was taken from the FAA's GAATA Survey for 2008 (90% of LTOs are conducted by aircraft having one engine and 10% of LTOs by aircraft having two engines).⁵³ Since twin-engine aircraft have higher fuel consumption rates than those with single engines, a weighted-average LTO fuel usage rate was calculated to apply to the population of piston-engine aircraft as a whole. For the single-engine aircraft, the average amount of fuel consumed per LTO was determined from the six types of single piston-engine aircraft within EDMS.⁵⁴ This was calculated by averaging the single-engine EDMS outputs for fuel consumed per LTO using the EDMS scenario property of ICAO/USEPA Default - Times in Mode (TIM), with a 16 minute taxi-in/taxi-out time according to EPA's *Procedures for Emission Inventory Preparation, Volume IV: Mobile Sources*, 1992.⁵⁵ This gives a value of 16.96 pounds of fuel per LTO (lbs/LTO). The average single-engine fuel consumption rate was divided by the average density of 100LL avgas, 6 pounds per gallon (lbs/gal), producing an average fuel usage rate for single-engine piston aircraft of 2.83 gallons per LTO (gal/LTO). This same calculation was performed for the two twin-engine piston aircraft within EDMS, producing an average LTO fuel usage rate for twin-engine piston aircraft of 9.12 gal/LTO.

Using these single- and twin-engine piston aircraft fuel consumption rates, a weighted average fuel usage rate per LTO was computed by multiplying the average fuel usage rate for single-engine aircraft (2.83 gal/LTO) by the fleet percentage of single-engine aircraft LTOs (90%). Next, the twin-engine piston aircraft average fuel usage rate (9.12 gal/LTO) was multiplied by the fleet percentage of twin-engine aircraft LTOs (10%). By summing the results of the single- and twin-engine aircraft usage rates, the overall weighted-average fuel usage rate per LTO of 3.46 gal/LTO was obtained.

To calculate the emission factor, the concentration of lead in fuel is multiplied by the fuel consumption per LTO. The maximum lead concentration specified by ASTM for 100LL is 0.56 grams per liter or 2.12 grams per gallon. This amount of lead is normally added to assure that the required lean and rich mixture knock values are achieved. Multiplying this lead concentration in avgas by the weighted average fuel usage rate produces an overall average value of 7.34 grams of lead per LTO (g Pb/LTO) for piston-engines: 3.46 gal/LTO x 2.12 g Pb/gal = 7.34 g Pb/LTO.

⁵³ The LTOs from the categories of 1-engine fixed wing piston, piston rotocraft, experimental total, and light sport were summed to determine the total number of single-engine piston aircraft LTOs.

⁵⁴ EPA understands that EDMS 5.0.2 has a limited list of piston-engines, but these are currently the best data available.

⁵⁵ U.S. EPA, *Procedures for Emission Inventory Preparation, Volume IV: Mobile Sources*, EPA-450/4-81026d (Revised), 1992.

(c) Retention of Lead in Engine and Oil (1-Pb Retention):

Data collected from aircraft piston-engines operating on leaded avgas suggests that about 5% of the lead from the fuel is retained in the engine and engine oil.⁵⁶ Thus the emitted fraction is 0.95. This information is used in calculating airport-specific lead inventories and will be used to develop future national estimates of lead emitted from the consumption of leaded avgas.

Applying these parameters in the equation above yields the following equation:

$$\text{Pb(tons)} = \frac{(\text{piston-engine LTO}) (7.34 \text{ g Pb/LTO}) (0.95)}{907,180 \text{ g/ton}}$$

which simplifies to:

$$\text{Pb(tons)} = (\text{piston-engine LTO}) (7.7 \times 10^{-6})$$

$$\text{Where piston-engine LTO}^{57} = (\text{GA LTO} \times 0.725) + (\text{AT LTO} \times 0.231)$$

(d) Estimating Lead Emissions from Piston-Engine Helicopters:

The emission factor for helicopters (g Pb/LTO) was determined in the same manner as described above for piston-engine fixed-wing aircraft. The concentration of lead in avgas (2.12 g/gal) was multiplied by the weighted average fuel usage rate for four types of Robinson helicopter engines.⁵⁸ This produced an overall average emission factor of 6.60 grams of lead per LTO (g Pb/LTO) for piston-engine powered helicopters.

There are no national databases that provide heliport-specific LTO activity data for piston-engine powered helicopters separately from turbine-engine powered helicopters. The 2008 FAA GA and Part 135 Activity (GAATA) Survey reports that approximately 36% of all GA helicopter hours flown are by piston-engine aircraft which use avgas, and about 64% are by turbine-engine powered which use jet fuel (which does

⁵⁶ The information used to develop this estimate is from the following references: (a) Todd L. Petersen, Petersen Aviation, Inc, *Aviation Oil Lead Content Analysis*, Report # EPA 1-2008, January 2, 2008, available at William J. Hughes Technical Center Technical Reference and Research Library at <http://actlibrary.tc.faa.gov/> and (b) E-mail from Theo Rindlisbacher of Switzerland Federal Office of Civil Aviation to Bryan Manning of U.S. EPA, regarding lead retained in engine, September 28, 2007.

⁵⁷ This equation for piston-engine LTOs only applies to non-heliport facilities. See the text immediately below for equations for calculating piston-engine LTOs and Pb emissions at heliports.

⁵⁸ This was done using the following 4 engine types in EDMS 5.1: Robinson R22 IO-320-D1AD; Robinson R22 IO-360-B; Robinson R22 O-320; Robinson R22 TSIO-360C. The fuel consumption rates were: Robinson R22 IO-320-D1AD – 5.546 g Pb/LTO; Robinson R22 IO-360-B – 5.973 g Pb/LTO; Robinson R22 O-320 – 6.276 g Pb/LTO; Robinson R22 TSIO-360C – 8.604 g Pb/LTO.

not contain lead).⁵⁹ The 2008 FAA GAATA Survey reports that approximately 2% of all AT helicopter hours flown are by piston-engine aircraft which use avgas, and about 98% are by turbine-engine powered rotocraft. We expect the fraction of helicopter activity conducted by piston-engines to vary by heliport with some facilities having no piston-engine powered helicopter activity and some hosting mainly or only piston-engine powered helicopters. However, in the absence of heliport-specific data, the national default estimates of 36% for GA and 2% for AT from the GAATA Survey were used. Therefore, to calculate piston-engine aircraft LTO as input for this equation, the helicopter GA LTOs were multiplied by 0.36 and helicopter AT LTOs were multiplied by 0.02.

Lead emitted at the heliport facility was calculated for the 2008 NEI using either the LTO data provided in FAA databases or the estimate LTO activity in the following equation (i.e., 141 LTOs):

$$\text{Pb(tons)} = (\text{piston-engine helicopter LTO}) (6.60 \text{ g Pb/LTO}) (0.95)$$

$$907,180 \text{ g/ton}$$

which simplifies to:

$$\text{Pb(tons)} = (\text{piston-engine helicopter LTO}) (6.9 \times 10^{-6})$$

Where piston-engine helicopter LTO = (Helicopter GA LTO x 0.36) + (Helicopter AT LTO x 0.02)

Section 7. Improving Airport-specific Lead Emissions Estimates

There are refinements to the methods described here that would improve airport-specific inventories, most of which involve acquiring airport- and aircraft-specific input data. The following information describes data inputs that could be used to generate airport lead inventories tailored to specific airports or otherwise improve the estimates using currently available data. State and local authorities might have, or be able to collect, better information for some of these key data inputs.

State and local agencies might have access to airport-specific data that would improve the national estimates of lead emissions per LTO. These improvements largely involve replacing national average or default values with airport-specific data on the activity of piston-engine aircraft. Three key data inputs are:

⁵⁹ The FAA GAATA is a database collected from surveys of pilots flying aircraft used for general aviation and air taxi activity. For more information on the GAATA, see Appendix A at http://www.faa.gov/data_statistics/aviation_data_statistics/general_aviation/

- 1) Airport-specific LTO activity for piston-powered aircraft, including the fraction of piston-engine activity conducted by single- versus twin-engine aircraft. Some airport facilities collect this information and states may use these data to calculate airport-specific lead inventories. The activity data should be current and updated on a regular schedule so that the data represents the inventory year as closely as possible.
- 2) The time spent in each mode of the LTO cycle. EPA uses the EDMS scenario property of ICAO/USEPA Default - Times in Mode, with a 16 minute taxi-in/taxi-out time according to EPA's Procedures for Emission Inventory Preparation, Volume IV: Mobile Sources, 1992. While some local authorities have confirmed that these are the relevant times in mode at their airports for piston aircraft, the applicability of these times in mode will vary by airport. EPA has learned that one of the important factors in piston aircraft operation that is currently not included in the time in mode or emissions estimates is the time and fuel consumption during the pre-flight run-up checks conducted by piston-engine aircraft prior to takeoff.
- 3) Other data inputs for the airport-specific lead inventory calculation for which states or local authorities may provide airport-specific information include the concentration of lead in the avgas supplied at an airport, and the fraction of lead in fuel that is retained in the engine and oil, and aircraft-specific fuel consumption rates by the piston-engine aircraft in specific modes of operation.

The accuracy of the based aircraft data on which equation 4 is modeled can be improved. FAA recognizes the need to improve the integrity of the 5010 data report based-aircraft counts for all of the GA airports and reliever airports in the NPIAS and is currently in the process of improving the data collection and submission methods to accomplish this task.⁶⁰

Section 8. Lead emitted in flight (i.e., outside the LTO cycle):

Lead emissions, especially those at altitude, undergo dispersion and eventually deposit to surfaces, and lead deposited to soil and water can remain available for uptake by plants, animals and humans for long periods of time. Because lead is a persistent pollutant, we are including all lead emissions – at airports and in-flight – in the NEI.⁶¹

For inventory purposes, lead emitted outside the LTO cycle occurs during aircraft cruise mode and portions of the climb-out and approach modes above the mixing height (typically 3,000 ft⁶²). This part of an aircraft operation emits lead at various altitudes as well as close to and away from airports. Because the precise area of lead emission and deposition is not known for these flights, EPA is using a simplistic approach to allocate

⁶⁰ National Based Aircraft Inventory Program:

<http://www.basedaircraft.com/public/FrequentlyAskedQuestions.aspx>, accessed 2/17/2009

⁶¹ U.S. EPA, 2006. Air Quality: Criteria for Lead: 2006; EPA/600/R-5/144aF; U.S. Government Printing Office, Washington, DC, October, 2006.

⁶² According to EPA's *Procedures for Emission Inventory Preparation, Volume IV: Mobile Sources, 1992*.

these emissions for the purposes of the 2008 NEI. A brief explanation of the nature of GA flights is provided here for context regarding emissions of lead in-flight.

FAA categorizes GA flights as either local area or itinerant operations and this distinction plays a role in the area over which lead is emitted. Local operations are those activities performed by aircraft operating in the local traffic pattern or within sight of the airport, aircraft executing simulated instrument approaches or low passes at the airport, and/or aircraft operating to or from the airport in a designated practice area located within a 20-mile radius of the airport. Local operations are common for GA aircraft. This includes applications such as recreational, proficiency and instructional flying as well as many common general aerial support tasks. Emissions during local flying are more likely to influence air and soil concentrations of lead in the vicinity of the airport because they occur near the airport, often at altitudes below the mixing height.

Itinerant operations are all operations other than those described above as local operations. An itinerant aircraft operation usually is one in which the aircraft departs from one airport and lands at a different airport. Depending on air time and distance, an itinerant flight is much more likely to involve departing the local flying area of the originating airport and climbing to altitudes above the mixing height. It is reasonable then, to generally expect that lead emitted outside the LTO cycle during itinerant operations, in contrast with local operations, will be more widely dispersed and at greater distances from the airport.

The portion of the national avgas lead emitted in flight (i.e., outside the LTO cycle) is calculated by subtracting the sum of airport facility lead inventories from the national avgas lead inventory. Even though FAA collects and reports information regarding the fraction of GA operations that are local and itinerant, there is no practical method to assign in-flight lead emissions to small geographic areas such as airports or census tracts. And similar data is not available for AT operations, a portion of which are conducted by piston-engine aircraft. Since the average duration of a piston-engine aircraft flight is approximately an hour, an itinerant flight can traverse county lines. Therefore, given the current data available, the best approach is to assign the out-of-LTO cycle lead to the state where the flight originated.

In the 2008 NEI EPA allocated lead emissions that are calculated as being outside the LTO cycle to states based on the state-specific fraction of national GA and AT piston-engine LTO activity. The state-specific fractions were calculated by multiplying the percent of GA and AT piston-engine LTO activity in each state by 296 tons, which is the amount of lead we currently estimate is emitted outside of the LTO cycle nationwide. Table 4 presents the total GA and AT piston-engine LTOs by state, the state-specific fraction of national GA and AT piston-engine LTO activity, and the out-of-LTO lead emissions assigned to each state.

Table 4: Out-of-LTO Lead Emissions by State

STATE	Total GA and AT Piston LTOs	Percent of National GA and AT Piston LTOs (by state)	Out of LTO Pb emissions (tons)
AK	660,133	2.0%	5.86
AL	671,026	2.0%	5.96
AR	638,875	1.9%	5.68
AZ	1,430,302	4.3%	12.71
CA	3,881,357	11.6%	34.48
CO	780,426	2.3%	6.93
CT	226,807	0.7%	2.01
DC	28,833	0.1%	0.26
DE	84,617	0.3%	0.75
FL	2,751,015	8.3%	24.44
GA	750,876	2.3%	6.67
HI	138,432	0.4%	1.23
IA	281,961	0.8%	2.50
ID	430,812	1.3%	3.83
IL	920,908	2.8%	8.18
IN	566,583	1.7%	5.03
KS	459,720	1.4%	4.08
KY	280,378	0.8%	2.49
LA	622,011	1.9%	5.53
MA	714,159	2.1%	6.34
MD	436,861	1.3%	3.88
ME	228,302	0.7%	2.03
MI	880,818	2.6%	7.82
MN	647,876	1.9%	5.76
MO	389,551	1.2%	3.46
MS	461,383	1.4%	4.10
MT	270,311	0.8%	2.40
NC	743,004	2.2%	6.60
ND	214,139	0.6%	1.90
NE	221,681	0.7%	1.97
NH	173,355	0.5%	1.54
NJ	466,961	1.4%	4.15
NM	309,657	0.9%	2.75
NV	298,712	0.9%	2.65
NY	999,738	3.0%	8.88
OH	1,180,583	3.5%	10.49
OK	575,402	1.7%	5.11
OR	596,730	1.8%	5.30
PA	954,839	2.9%	8.48

PR	80,728	0.2%	0.72
RI	45,348	0.1%	0.40
SC	506,650	1.5%	4.50
SD	228,198	0.7%	2.03
TN	535,913	1.6%	4.76
TX	2,422,722	7.3%	21.52
UT	299,471	0.9%	2.66
VA	502,559	1.5%	4.46
VI	25,763	0.1%	0.23
VT	88,318	0.3%	0.78
WA	1,189,142	3.6%	10.56
WI	778,320	2.3%	6.91
WV	143,393	0.4%	1.27
WY	106,190	0.3%	0.94

For additional information or if you have questions regarding the methods described in this document, please contact Meredith Pedde (pedde.meredith@epa.gov) or Marion Hoyer (hoyer.marion@epa.gov).

Supplemental Table 1

Table A-1: Scaling factors

Year	U.S. Product Supplied of Aviation Gasoline (Thousand Barrels)⁶³	Ratio of 2008 to Year X
Before 1981 ⁶⁴		0.57
1981	11,147	0.50
1982	9,307	0.60
1983	9,444	0.59
1984	8,692	0.64
1985	9,969	0.56
1986	11,673	0.48
1987	9,041	0.62
1988	9,705	0.58
1989	9,427	0.59
1990	8,910	0.63
1991	8,265	0.68
1992	8,133	0.69
1993	7,606	0.74
1994	7,555	0.74
1995	7,841	0.71
1996	7,400	0.76
1997	7,864	0.71
1998	7,032	0.80
1999	7,760	0.72
2000	7,188	0.78
2001	6,921	0.81
2002	6,682	0.84
2003	5,987	0.94
2004	6,189	0.91
2005	7,006	0.80
2006	6,626	0.85
2007	6,258	0.90
2008	5,603	1.00

⁶³ Data from the Energy Information Administration's (EIA's) table, "U.S. Product Supplied of Aviation Gasoline (Thousand Barrels)." Available at:

<http://tonto.eia.doe.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=mgaupus1&f=A> Accessed August 25, 2010.

⁶⁴ EIA does not have data for volumes of avgas product supplied for years earlier than 1981. To calculate the scaling factor to use for activity data from years before 1981, we used the ratio of 2008 avgas volume product supplied to the average avgas volume supplied from 1981 to 1989.

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**Documentation for the Commercial Marine Vessel Component
of the National Emissions Inventory**

Methodology

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1.0 INTRODUCTION

1.1 What is the National Emission Inventory?

The National Emission Inventory (NEI) is a comprehensive inventory covering all anthropogenic sources of criteria pollutants and hazardous air pollutants (HAPs) for all areas of the United States. The NEI was created by the U.S. Environmental Protection Agency's Emission Inventory and Analysis Group (EIAG) in Research Triangle Park, North Carolina. The NEI will be used to support air quality modeling and other activities. To this end, the EPA established a goal to compile comprehensive emissions data in the NEI for criteria and HAPs for mobile, point, and nonpoint sources. This report presents an overview of how emission estimates for the commercial marine vessel (CMV) component of the 2008 NEI was compiled.

1.2 Why Did the EPA Create the NEI?

The Clean Air Act (CAA), as amended in 1990, includes mandates for the EPA related to criteria and hazardous air pollutants. The CAA defines criteria pollutants as being one of the following air pollutants:

- Carbon monoxide (CO);
- Sulfur oxides (SO_x);
- Nitrogen oxides (NO_x);
- Ozone; and
- Particulate matter (PM).

Where emission factors and activity data permit, ammonia (NH₃) estimates are also included as an important precursor to PM. Hazardous air pollutants are also delineated in the CAA, see <http://www.epa.gov/ttn/atw/188polls.html> for a complete list of regulated pollutants and their chemical abstract service [CAS] numbers.

The CAA requires the EPA to identify emission sources of these pollutants, quantify emissions, develop regulations for the identified source categories, and assess the public health and environmental impacts after the regulations are put into effect. The NEI is a tool that EPA can use to meet the CAA mandates. In this report, criteria and HAP emission estimates are discussed for CMV sources.

1.3 How is the EPA Going to Use This Version of the NEI?

It is anticipated that the emission inventory developed from this effort will have multiple end uses. The data have been formatted according to protocols established for the EPA's NEI submittals. The common data structure on which the NEI platform is based will allow the NEI emission data to be transferred to multiple end-users for a variety of purposes.

The criteria and HAP emission estimates developed for the NEI will be used to evaluate air pollution trends, air quality modeling analysis and impacts of potential regulations.

1.4 Report Organization

Following this introduction, Section 2.0 provides information on how the national CMV, emission estimates were developed. This inventory effort was coordinated by the EPA's Office of Transportation and Air Quality (OTAQ) and EIAG.

The appendix were created to provide technical details on how the national emissions were developed and how state and local inventory data (when provided) were incorporated into the national estimates. Appendix A provides a copy of the report documenting how the 2002 data were adjusted to reflect marine vessel activity and emissions for 2008.

2.0 DEVELOPMENT OF THE COMMERCIAL MARINE VESSEL COMPONENT FOR THE NEI

2.1 How Does This CMV Study Fit into the NEI?

The NEI was developed to include all point, nonpoint (sometimes referenced as “area”), and mobile sources. The approaches used in the point and nonpoint source categories are documented in other reports. Table 1 summarizes the approaches used to estimate emissions from all nonroad sources included in the NEI program. Those source categories and years that are included in this report are noted in bold.

The scope of this inventory component of the NEI was to compile criteria and HAP emissions data for CMVs operating in United States waters and federal waters extending 200 nautical miles from the United States’ coastline. In this effort, national emission estimates were often developed and allocated to counties based on available Geographic Information System (GIS) data. The methodologies used to estimate emissions and the procedures used to spatially allocate them to the county-level are discussed in this report.

Table 2-1. Methods Used to Develop Annual Emission Estimates for Nonroad Mobile Sources

(Categories included in this report are noted in bold print)

Category	Base Year	Pollutant(s)	Estimation Method*
NONROAD Categories			
Nonroad Gasoline, Diesel, LPG, CNG	2002	VOC, NO _x , CO, SO ₂ , PM ₁₀ , PM _{2.5} , NH ₃ , & HAPs	Emission estimates for NONROAD model engines were developed using EPA’s National Mobile Inventory Model (NMIM), which incorporates NONROAD2004. Where states provided alternate nonroad inputs, these data replaced EPA default inputs. State-supplied emissions data also replaced default EPA emission estimates.

**Table 2-1. Methods Used to Develop Annual Emission Estimates for
Nonroad Mobile Sources (Continued)**

(Categories included in this report are noted in bold print)

Category	Base Year	Pollutant(s)	Estimation Method*
	1999	VOC, NO _x , CO, SO ₂ , PM ₁₀ , PM _{2.5}	Using emission estimates from two emission inventories including: 1) a 1996 county-level inventory, developed using EPA's October 2001 draft NONROAD model; and 2) an updated 1999 national inventory, based on EPA's draft Lockdown C NONROAD model (dated May 2002). Using the 1996 county-level emission estimates, seasonal and daily county-to-national ratios were then developed for application to updated national estimates per season estimated from the Lockdown C model. Replaced State-submitted data for California for all NONROAD model categories; Pennsylvania for recreational marine and aircraft ground support equipment, and Texas for select equipment categories.
	1996, 1997, 1998, 2000 & 2001	VOC, NO _x , CO, SO ₂ , PM ₁₀ , PM _{2.5}	Using emission estimates from two emission inventories including: 1) a 1996 county-level inventory, developed using EPA's October 2001 draft NONROAD model; and 2) updated year-specific national and California inventories, based on EPA's draft Lockdown C NONROAD model (dated May 2002). Using the 1996 county-level emission estimates, seasonal and daily county-to-national ratios and California county-to-state ratios were then developed for application to updated national estimates per season estimated from the Lockdown C model. California results replace the diesel equipment emissions generated from prior application of county-to-national ratios.

**Table 2-1. Methods Used to Develop Annual Emission Estimates for
Nonroad Mobile Sources (Continued)**

(Categories included in this report are noted in bold print)

Category	Base Year	Pollutant(s)	Estimation Method*
Nonroad Gasoline, Diesel, LPG, and CNG (Continued)	1991-1995	VOC, NO _x , CO, SO ₂ , PM ₁₀ , PM _{2.5} , NH ₃	Using 1990 and 1996 county-level emissions inventories, estimated emissions using linear interpolation of national emissions between 1990 and 1996. From these emissions, calculated the average annual growth rate for each pollutant/SCC combination for each year, and then applied the growth factors to 1990 county-level emissions to estimate 1991-1995 emissions.
	1990	VOC, NO _x , CO, SO ₂ , PM ₁₀ , PM _{2.5}	Using emission estimates from two emission inventories including: 1) a 1996 county-level inventory, developed using EPA's October 2001 draft NONROAD model; and 2) updated 1990 national inventory, based on EPA's draft Lockdown C NONROAD model (dated May 2002). Using the 1996 county-level emission estimates, seasonal and daily county-to-national ratios were then developed for application to updated national estimates per season estimated from the Lockdown C model.
	1986, 1988, & 1989	VOC, NO _x , CO, SO ₂ , PM ₁₀ , PM _{2.5} , NH ₃	Using 1985 and 1990 county-level emissions inventories, estimated emissions using linear interpolation of national emissions between 1985 and 1990. From these emissions, calculated the average annual growth rate for each pollutant/SCC combination for each year, and then applied the growth factors to 1985 county-level emissions to estimate 1986-1989 emissions.
	1987	VOC, NO _x , CO, SO ₂ , PM ₁₀ , PM _{2.5}	Using EPA's draft Lockdown C NONROAD model (dated May 2002), developed updated national emissions for 1987 by running 4 seasonal NONROAD model runs to estimate annual criteria pollutant emissions. Also performed national NONROAD model runs to estimate typical summer weekday emissions.

**Table 2-1. Methods Used to Develop Annual Emission Estimates for
Nonroad Mobile Sources (Continued)**

(Categories included in this report are noted in bold print)

Category	Base Year	Pollutant(s)	Estimation Method*
Nonroad Gasoline, Diesel, LPG, and CNG (Continued)	1985	VOC, NO _x , CO, SO ₂ , PM ₁₀ , PM _{2.5}	Using emission estimates from two emission inventories including: 1) a 1996 county-level inventory, developed using EPA's October 2001 draft NONROAD model; and 2) updated 1985 national inventory, based on EPA's draft Lockdown C NONROAD model (dated May 2002). Using the 1996 county-level emission estimates, seasonal and daily county-to-national ratios were then developed for application to updated national estimates per season estimated from the Lockdown C model.
	1970, 1975, 1978, & 1980	VOC, NO _x , CO, SO ₂ , PM ₁₀ , PM _{2.5}	Using EPA's draft Lockdown C NONROAD model (dated May 2002), developed updated national emissions for all years by running 4 seasonal NONROAD model runs to estimate annual criteria pollutant emissions. Also performed national NONROAD model runs to estimate typical summer weekday emissions.
	1996, 1997, 1998, 1999, 2000, & 2001	NH ₃	Obtaining national fuel consumption estimates from the Lockdown C NONROAD model, multiplying by NH ₃ emission factors, and distributing to counties using 1996 inventory, based on October 2001 draft NONROAD. NH ₃ emissions for California were also recalculated using updated diesel fuel consumption values generated for California-specific runs, and assuming the 1996 county-level distribution.
	1985 & 1990	NH ₃	Obtaining national fuel consumption estimates from the Lockdown C NONROAD model, multiplying by NH ₃ emission factors, and distributing to counties using 1996 inventory, based on October 2001 draft NONROAD.
	1987	NH ₃	Obtaining 1987 national fuel consumption estimates from Lockdown C NONROAD model and multiplying by NH ₃ emission factors.

**Table 2-1. Methods Used to Develop Annual Emission Estimates for
Nonroad Mobile Sources (Continued)**

(Categories included in this report are noted in bold print)

Category	Base Year	Pollutant(s)	Estimation Method*
Nonroad Gasoline, Diesel, LPG, and CNG (Continued)	1970, 1975, 1978, & 1980	NH ₃	Obtaining national fuel consumption estimates from the Lockdown C NONROAD model and multiplying by NH ₃ emission factors.
	1990, 1996, & 1999	HAPs	Speciation profiles applied to county VOC and PM estimates. Metal HAPs were calculated using fuel and activity-based emission factors. Some state data were provided and replaced national estimates. (2003)
<i>Aircraft</i>			
Commercial Aircraft	2008	Criteria and HAPs	Federal Aviation Administration (FAA) Emissions and Dispersion and Modeling System (EDMS) - Version 5.1.was run using BTS T-100 LTO data. (2009)
	2002	Criteria and HAPs	Federal Aviation Administration (FAA) Emissions and Dispersion and Modeling System (EDMS) was run for criteria pollutants, VOC and PM emissions were speciated into HAP components. (2004)
	1990, 1996, 1999, 2000, 2001	VOC, NO _x , CO, SO _x	Input landing and take-off (LTO) data into FAA EDMS. National emissions were assigned to airports based on airport specific LTO data and BTS GIS data. State data replaced national estimates. (2003)
	1970-1998	VOC, NO _x , CO, SO _x	Estimated emissions for interim years using linear interpolation between available base years. (2003)
	1990, 1996, 1999	HAPs	Speciation profiles were applied to VOC estimates to get national HAP estimates. State data replaced national estimates. (2003)
General Aviation, Air Taxis	2008	Criteria and HAPs	Used FAA LTO data from TAF and OTAQ provided activity data for smaller airports derived from FAA 5010 master plans. EPA approved generic emission factors for criteria estimates. Speciation profiles were applied to VOC and PM estimates to get national HAP estimates. (2009)

**Table 2-1. Methods Used to Develop Annual Emission Estimates for
Nonroad Mobile Sources (Continued)**

(Categories included in this report are noted in bold print)

Category	Base Year	Pollutant(s)	Estimation Method*
General Aviation, Air Taxis (Continued)	1978, 1987, 1990, 1996, 1999, 2000, 2001, & 2002	VOC, NO _x , CO, SO ₂ , PM ₁₀ , PM _{2.5}	Used FAA LTO data and EPA approved emission factors for criteria estimates. Speciation profiles were applied to VOC estimates to get national HAP estimates. State data replaced national estimates. (2004)
	1970-1998	VOC, NO _x , CO, SO _x , PM ₁₀ , PM _{2.5}	Estimated emissions for interim years using linear interpolation between available base years. (2003)
	1990, 1996, 1999, & 2002	HAPs	Used FAA LTO data and EPA approved emission factors for criteria estimates. Speciation profiles were applied to VOC estimates to develop national HAP estimates. (2004)
	1990, 1996, 1999, & 2002	Pb	Used Department of Energy (DOE) aviation gasoline usage data with lead concentration of aviation gasoline. (2004)
	1996	NH ₃	Applied NH ₃ emissions factors to 1996 national jet fuel and aviation gasoline consumption estimates.
Military Aircraft	1978, 1987, 1990, 1996, 1999, 2000, 2001, 2002, 2008	VOC, NO _x , CO, SO ₂ , PM ₁₀ , PM _{2.5}	Used FAA LTO data as reported in TAF and EPA approved emission factors for criteria estimates. Representative HAP profiles were not readily available, therefore HAP estimates were not developed. (2009)
	1970-1998	VOC, NO _x , CO, SO _x , PM ₁₀ , PM _{2.5}	Estimated emissions for interim years using linear interpolation between available base years. (2003)
Auxiliary Power Units	2008	VOC, NO _x , CO, SO ₂ , PM ₁₀ , PM _{2.5}	Federal Aviation Administration (FAA) Emissions and Dispersion and Modeling System (EDMS) - Version 5.1.was run using BTS T-100 LTO data. (2009)
	1985-2001	VOC, NO _x , CO, SO ₂ , PM ₁₀ , PM _{2.5}	Grew 1996 emissions to each year using LTO operations data from the FAA. Estimation methods prior to 1996 reported in EPA, 1998.

**Table 2-1. Methods Used to Develop Annual Emission Estimates for
Nonroad Mobile Sources (Continued)**

(Categories included in this report are noted in bold print)

Category	Base Year	Pollutant(s)	Estimation Method*
Unpaved Airstrips ¹	1985-2001	PM ₁₀ , PM _{2.5}	Grew 1996 emissions to each year using SIC 45-Air Transportation growth factors, consistent with the current draft version of EGAS. Estimation methods prior to 1996 reported in EPA, 1998.
Aircraft Refueling ¹	1985-2001	VOC	Grew 1996 emissions to each year using SIC 45-Air Transportation growth factors, consistent with the current draft version of EGAS. Estimation methods prior to 1996 reported in EPA, 1998.
Commercial Marine Vessel (CMV)			
All CMV Categories	2008	VOC, NO_x, CO, SO₂, PM₁₀, PM_{2.5}	2002 estimates were adjusted by OTAQ to reflect 2008 activity levels., note that the SCCs for this category have changed such that the Diesel category refers to smaller vessels (Category 1 and 2) using distillate fuels and the Residual category refers to larger (Category 3) vessel using a blend of residual fuels (2009)
	2008	HAPs	OTAQ's 2008 estimates were speciated into HAP components using SEPA profiles
	2002	VOC, NO _x , CO, SO ₂ , PM ₁₀ , PM _{2.5}	2001 Estimates carried over. Used state data when provided. (2004)
		HAPs	1999 Estimates carried over. Used state data when provided. (2004)
CMV Diesel	1978, 1987, 1990, 1996, 1999, 2000, & 2001	VOC, NO _x , CO, SO _x , PM ₁₀ , & PM _{2.5}	Used criteria emission estimates in the background document for marine diesel regulations for 2000. Adjusted 2000 criteria emission estimates for other used based on fuel usage. Emissions were disaggregated into port traffic and underway activities. Port emissions were assigned to specific ports based on amount of cargo handled. Underway emissions were allocated based on Army Corp of Engineering waterway data. State data replaced national estimates. (2003)
	1970-1998	VOC, NO _x , CO, SO _x , PM ₁₀ , PM _{2.5}	Estimated emissions for interim years using linear interpolation between available base years. (2003)
	1990, 1996, 1999	HAPs	VOC and PM emission estimates were speciated into HAP components. State data replaced national estimates. (2003)

**Table 2-1. Methods Used to Develop Annual Emission Estimates for
Nonroad Mobile Sources (Continued)**

(Categories included in this report are noted in bold print)

Category	Base Year	Pollutant(s)	Estimation Method*
	1996	NH ₃	Applied NH ₃ emissions factors to 1996 distillate and residual fuel oil estimates (i.e., as reported in EIA, 1996).
	1990-1995	NH ₃	Estimation methods reported in EPA, 1998.
CMV Steam Powered	1978, 1987, 1990, 1996, 1999, 2000, & 2001	VOC, NO _x , CO, SO _x , PM ₁₀ , & PM _{2.5}	Calculated criteria emissions based on EPA SIP guidance. Emissions were disaggregated into port traffic and under way activities. Port emissions were assigned to specific ports based on amount of cargo handled. Underway emissions were allocated based on Army Corp of Engineering waterway data. State data replaced national estimates. (2003)
	1970-1998	VOC, NO _x , CO, SO _x , PM ₁₀ , PM _{2.5}	Estimated emissions for interim years using linear interpolation between available base years. (2003)
	1990, 1996, & 1999	HAPs	VOC and PM emission estimates were speciated into HAP components. State data replaced national estimates. (2003)
Military Marine	1997-2001	VOC, NO _x , CO, SO ₂ , PM ₁₀ , PM _{2.5}	Applied EGAS growth factors to 1996 emissions estimates for this category.
CMV Coal, ² CMV, Steam powered, CMV Gasoline ²	1997-1998	VOC, NO _x , CO, SO ₂ , PM ₁₀ , PM _{2.5}	Applied EGAS growth factors to 1996 emissions estimates for this category.
CM Coal, CMV, Steam powered, CMV Gasoline, Military Marine	1991-1995	VOC, NO _x , CO, SO ₂ , PM ₁₀ , PM _{2.5}	Estimation methods reported in EPA, 1998.
Locomotives			
Class I, Class II, Commuter, Passenger, and Yard Locomotives	1978, 1987, 1990, 1996, 1999, 2000, 2000, & 2002	VOC, NO _x , CO, PM ₁₀ , PM _{2.5}	Criteria pollutants were estimated by using locomotive fuel use data from DOE EIA and available emission factors. County-level estimates were obtained by scaling the national estimates with the rail GIS data from DOT. State data replaced national estimates. (2004)

**Table 2-1. Methods Used to Develop Annual Emission Estimates for
Nonroad Mobile Sources (Continued)**

(Categories included in this report are noted in bold print)

Category	Base Year	Pollutant(s)	Estimation Method*
Class I, Class II, Commuter, Passenger, and Yard Locomotives (Continued)	1978, 1987, 1990, 1996, 1999, 2000, 2001, & 2002	SO ₂	SO _x emissions were calculated by using locomotive fuel use and fuel sulfur concentration data from EIA. County-level estimates were obtained by scaling the national estimates with the county level rail activity data from DOT. State data replaced national estimates. (2004)
	1970-1998	VOC, NO _x , CO, SO _x , PM ₁₀ , PM _{2.5}	Estimated emissions for interim years using linear interpolation between available base years. (2003)
	1990, 1996, 1999, & 2002	HAPs	HAP emissions were calculated by applying speciation profiles to VOC and PM estimates. County-level estimates were obtained by scaling the national estimates with the county level rail activity from DOT. State data replaced national estimates. (2004)
	1997-1998	NH ₃	Grew 1996 base year emissions using EGAS growth indicators.
	1996	NH ₃	Applied NH ₃ emissions factors to diesel consumption estimates for 1996.
	1990-1995	NH ₃	Estimation methods reported in EPA, 1998.

Notes:

- * Dates included at the end of Estimation Method represent the year that the section was revised.
 - 1 Emission estimates for unpaved airstrips and aircraft refueling are included in the area source NEI, since they represent non-engine emissions.
 - 2 National Emission estimates for CMV Coal and CMV Gasoline were not developed though states and local agencies may have submitted estimates for these source categories.
- EPA, 1998. U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Emission Factors and Inventory Group, National Air Pollutant Emission Trends, Procedures Document, 1900–1996, EPA-454/R-98-008. May 1998.

The target inventory area includes every state in the United States and every county within a state. There are no boundary limitations pertaining to traditional criteria pollutant nonattainment areas or to designated urban areas. The pollutants inventoried included all criteria pollutants (except for the other nonroad source category which addressed only HAPs in this report) and the 188 HAPs identified in Section 112(b) of the CAA. Some state or local agencies provided emissions information on more HAPs than those delineated in the CAA, only the federally regulated HAPs are included in the NEI.

In addition to numerous specific chemical compounds, the list of 188 HAPs includes several compound groups [e.g., individual metals and their compounds, polycyclic organic matter (POM)]; the NEI includes emission estimates for the individual compounds wherever possible. Many of the uses of the NEI depend upon data (e.g., toxicity) for individual compounds within these groups rather than aggregated data on each group as a whole.

The intent in presenting the following emission inventory approach is to provide sufficient and transparent documentation such that states and local agencies can use these approaches, in conjunction with their specific local activity data to develop more accurate and comparable emission estimates in future submittals.

2.2 What are Commercial Marine Vessels?

The CMV source category includes all boats and ships used either directly or indirectly in the conduct of commerce or military activity. These vessels range from 20-foot charter boats to large tankers which can exceed 1,000 feet in length (EPA, 1989). In spite of the broad range of vessels represented by this category, a number of common characteristics allow for the use of simple emission estimation methods. The majority of vessels in this category are powered by diesel engines that are either fueled with distillate or residual fuel oil blends. For the purpose of this inventory it is assumed that Category 3 vessels primarily use residual blends while Category 1 and 2 vessels typically used distillate fuels.

The Category 3 (C3) inventory developed by OTAQ includes vessels which use C3 engines for propulsion. C3 engines are defined as having displacement above 30 liters per cylinder (U.S. EPA, 2003). The resulting inventory includes emissions from both propulsion and auxiliary engines used on these vessels, as well as those on gas and steam turbine vessels. Geographically, the inventories include port and interport emissions that occur within the area that extends 200 nautical miles (nm) from the official U.S. baseline, which is roughly equivalent to the border of the U.S. Exclusive Economic Zone (EEZ).

Category 1 and 2 vessels tend to be smaller ships that operate closer to shore, and along inland and intercoastal waterways. Naval vessels are not included in this inventory, though Coast Guard vessels are included as Category 1 and 2 vessels.

The CMV source category does not include recreational marine vessels, which are generally less than 100 feet in length, most being less than 30 feet, and powered by either inboard or outboard engines (EPA, 1989). Emissions from recreational marine vessels are included in the nonroad source category.

2.3 What Pollutants are Included in the National Emission Estimates for CMVs?

The EPA's Office of Transportation and Air Quality (OTAQ) provided estimates for all criteria pollutants including volatile organic compounds (VOC), nitrogen oxides (NO_x), carbon monoxide (CO), sulfur oxides (SO_x), particulate matter less than 10 microns (PM₁₀), particulate matter less than 2.5 microns (PM_{2.5}) and carbon dioxide (CO₂). Criteria emissions were provided for Category 1 and 2 vessels (Carey, 2009b); Category 3 port, reduced speed zone, and cruising activities (Carey, 2009a and Carey, 2009c); and Category 3 interport activities (Carey, 2009d).

The VOC and PM estimates were speciated into hazardous air pollutants (HAP) components based on available data sources. The Swedish Environmental Protection Agency (SEPA) document *Methodology for Calculating Emissions from Ships: 1. Update of emission factors* served as the primary source of HAP emission factors which were converted into speciation profiles (Cooper and Gustafsson, 2004). Ammonia emission factors were also obtained from the SEPA, but as these factors require activity data, and such data were not available for Category 3 vessels operating in Federal waters, ammonia was estimated as a ratio of PM₁₀ using the SEPA emission factors. Similar ratios were developed for Category 1 and 2 vessels, assuming that this fleet primarily operates on marine diesel fuel with 80.5 percent of the fleet equipped with medium speed engines and the remaining 19.5 percent were high speed engines. This provided a weighted NH₃ emission factor of 4.61E-03 g/kw-hr for operations at-sea and in-port. The PM₁₀ factors vary for at-sea (0.2 g/kw-hr) and in-port (0.4 g/kw-hr), so our NH₃ / PM₁₀ ratios were different for at-sea (2.31E-02) and in-port (1.15E-02).

While the SEPA document was used as the primary speciation source, other resources were investigated for potential inclusion in this effort. Recent BTEX data from Moldanova et al. were examined, but it included inconsistent benzene factors, some over 20% of hydrocarbon (HC) factors, were much higher than others found in recent publications and, as a result, were not included (Cook, 2009). CE-CERT metals data was also reviewed as it pertained to slow speed residual fuel engines (Cook, 2009). The CE-CERT emission factors were in line with the Swedish factors for nickel and lead, but they were an order of magnitude different for chromium, cadmium, and selenium. As a result, the Swedish factors were retained over the CE-CERT data based on the larger study sample size, while CE-CERT's manganese emission factors were added as these factors were not included in the Swedish study (Cook, 2009).

The complete pollutant list for CMVs is shown in Table 2-2.

2.4 How Were the CMV Emissions Estimated?

As noted above, the CMV criteria and CO₂ emission estimates were provided for this inventory by OTAQ. Category 3 commercial marine inventories were developed for a base year of 2002 then projected to 2008 applying regional adjustment factors to account for growth. In addition, NO_x adjustment factors were applied to account for implementation of the NO_x Tier 1 standard. Details about adjustments and growth factors can be found in the Category 3 documentation (Appendix A). For Category 1 and 2 marine diesel engines, the emission estimates were consistent with the 2008 Locomotive and Marine federal rule making (Carey, 2009b).

Table 2-2. Commercial Marine Vessel Pollutant List

2,2,4 Trimethylpentane	Carbon Monoxide*	Naphthalene
Acenaphthene	Chromium(VI)	Nickel
Acenaphthylene	Chromium (III)	Nitrogen Oxides*
Acetaldehyde	Chrysene	PAH, total
Acrolein	Cobalt	Phenanthrene
Ammonia	Dibenzo[a,h]Anthracene	Phosphorus
Anthracene	Dioxins/Furans	PM10 Primary*
Arsenic	Ethyl benzene	PM2.5 Primary ⁺
Benz(a)anthracene	Fluoranthene	Polychlorinated Biphenyls
Benzene	Fluorene	Propionaldehyde
Benzo(a)pyrene	Formaldehyde	Pyrene
Benzo(b)fluoranthene	Hexachlorobenzene	Selenium
Benzo(g,h,i)perylene	Hexane	Styrene
Benzo(k)fluoranthene	Indeno(1,2,3-cd)pyrene	Sulfur Dioxide*
Beryllium	Lead	Toluene
Cadmium	Manganese	VOCs*
Carbon Dioxide*	Mercury	Xylene

* Provided by OTAQ

⁺ PM_{2.5} was provided by OTAQ for all vessels and modes except for Category 3 Interport, where it was calculated using OTAQ guidance.

OTAQ's emissions were then allocated to individual GIS polygons using appropriate methods that varied by operating mode (i.e., hotelling, maneuvering, reduced speed zone, and underway). HAP emissions were estimated by applying speciation profiles to each polygon's VOC and PM estimates. Figure 2-1 provides an overview of the approach used to estimate and spatially allocate CMV emissions.

Speciation profiles were applied to the VOC, PM₁₀, and PM_{2.5} emission estimates to calculate the associated HAP emissions using the following equation.

$$VOC-PM_{10/2.5} * speciation\ profile_i = HAP\ emission\ estimate:$$

Where:

HAP emission estimate = HAP Emission estimate (tons/year)
for pollutant:

VOC-PM_{10/2.5} = VOC or PM emission estimate
(tons/year)

Speciation Profile_i = VOC or PM speciation fraction for
HAP i

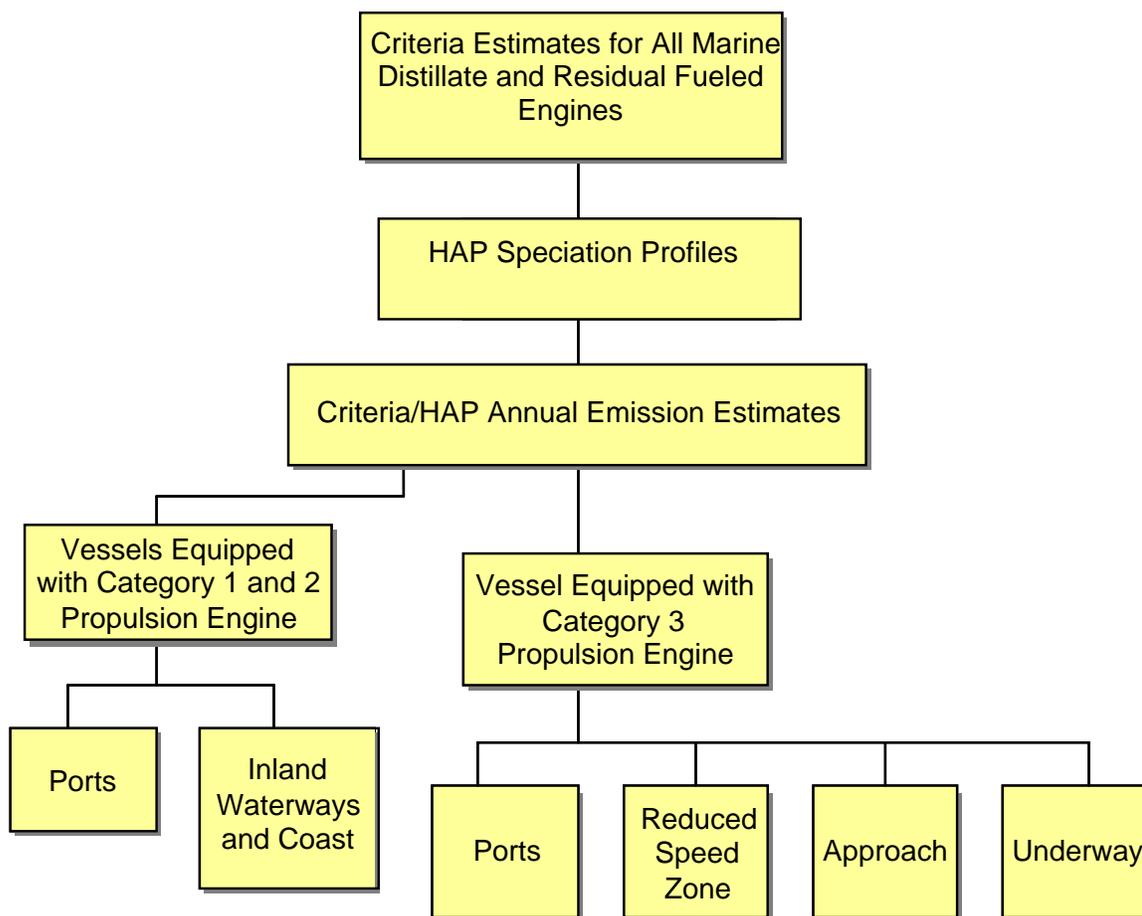


Figure 2-1. General Approach Used to Develop Marine Vessel Component of the 2008 National Emission Inventory

For Category I diesel-powered vessels, the speciation profiles were based on high-speed diesel vehicle (HSDV) factors obtained from information in the SEPA's *Methodology for Calculating Emissions from Ships: 1. Update of emission factors* (Cooper and Gustafsson, 2004). For Category 2 diesel-powered vessels, the speciation profiles were developed from medium-speed diesel vehicles (MSDV). Since emissions and activity data were provided as a combined value for all Category 1 and 2 vessels, the Category 1 and Category 2 emission factors were averaged to obtain a single emission factor for all diesel vessels. All port activities for Category 1 and 2 vessels were assumed to be maneuvering.

For Category 3 vessels, speciation profiles were developed using data from *Methodology for Calculating Emissions from Ships: 1. Update of emission factors* and assuming 80.5% of Category 3 vessels were equipped with slow-speed engines and 19.5% of vessels were equipped with medium speed engines based on vessel census data reported in the International Maritime Organization's (IMO) recent greenhouse gas (GHG) study (IMO 2009). Separate speciation profiles were created for Category 3 vessels for underway, maneuvering, and hotelling activities. Chromium emissions were split into hexavalent and trivalent chromium based on an assumption that 34% of total chromium was hexavalent and the remaining 66% was trivalent.

2.5 How Were Emissions Allocated?

Previous emissions allocations were based on waterway length and port county assignment. In this effort, spatial accuracy was greatly enhanced via the creation of GIS polygons representing port and waterway boundaries. GIS polygons allowed the estimation/allocation of emissions to defined port, waterway, and coastal areas, leading to improved spatial resolution compared to 2002's county-level emissions. Methodologies for both port and underway emissions are described in detail in the sections that follow.

2.6 How Were Port Emissions Allocated?

Port boundaries were developed using a variety of resources to identify the most accurate port boundaries. First, GIS data or maps provided directly from the port were used. Next, maps or port descriptions from local port authorities, port districts, etc. were used in combination with existing GIS data to identify port boundaries. Finally, satellite imagery from tools such as Google Earth and street layers from StreetMap USA were used to delineate port areas. Emphasis was placed on mapping the 117 ports with Category 3 vessel activity using available shape files of the port area. The Port of Huntington was developed differently given its large extent and limited available map data. The state of West Virginia provided a revised file of US Army Corps of Engineers *port terminals* reported to be part of the Port of Huntington-Tristate area. A 200 meter buffer of the water features near these port terminals was created to identify port area.

In all cases, polygons were created on land, bordering waterways and coastal areas, and were split by county boundary. Each polygon was identified by the port name and state and county FIPS in addition to a unique ShapeID. Smaller ports with Category 1 and 2 activities were mapped as small circles. Note that no Category 3 emissions were mapped to small circles. The final shapefile contained 159 ports and 196 polygons.

OTAQ provided Category 1 and 2 criteria emissions and activity as a single national number. These emissions and activity were allocated to ports based on total commodity tonnage

data obtained from the U.S. Army Corps of Engineers (USACE) Principal Ports file for 2007 (U.S. ACE, 2009). Emissions were then assigned to polygons within a port based on port area.

OTAQ developed port-level emissions for 117 of the largest U.S. ports with Category 3 activity. Activity in megawatt hours (MWh) and resulting criteria and CO₂ emissions were provided by port for maneuvering and hotelling modes. Emissions were then assigned to polygons within a port based on port area. HAP emissions were then speciated from VOC and PM estimates for each polygon using the methodology described in Section 3.0.

2.7 How Were Underway Emissions Allocated?

For this inventory, a GIS polygon layer was created to more accurately represent the location of CMV-related activity and emissions. Inland waterway polygons were obtained from the Bureau of Transportation Statistics' National Transportation Atlas Database hydro polygon layer (U.S. DOT, 2007). These polygons were further divided by county boundary and waterway ID. Coastal waters were drawn using Mineral Management Service state-federal boundary files and were also divided to indicate county boundaries. Federal waters were included as large area blocks outlined by the Exclusive Economic Zone (EEZ) boundary provided by EPA, which extends to approximately 200 nautical miles from the coastline. The final product is a polygon layer that includes all inland and coastal state waters and federal waters along with FIP, polygon area, and a unique ShapeID. Underway emissions were allocated differently by vessel category and mode, as outlined below.

2.7.1 Category 1 and 2 Underway

OTAQ provided Category 1 and 2 criteria emissions and activity as a single national number. These emissions and activity were allocated to underway polygons in state waters based on total commodity movements (in tons) data obtained from USACE (U.S. ACE, 2001). These data were waterway-specific, so waterways that crossed into multiple FIPs had emissions assigned by waterway length in each polygon. HAP emissions were then speciated from VOC and PM estimates using the methodology described in Section 3.0 for each polygon.

2.7.2 Category 3 Reduced Speed Zones (RSZ)

OTAQ provided polyline shapefiles indicating location of RSZ activities along with port-specific RSZ emissions and activity. These polylines were intersected with existing shipping lane polygons, and emissions were allocated to polygons based on the approach segment length on a per-port basis. HAP emissions were then speciated from VOC and PM estimates using the methodology described in Section 3.0 for each polygon.

2.7.3 Category 3 Approach

OTAQ provided polyline shapefiles indicating location of cruising activities along with port-specific cruising emissions and activity. These polylines were intersected with our existing polygons, and emissions were allocated to polygons based on the approach segment length on a per-port basis. HAP emissions were then speciated from VOC and PM estimates using the methodology described in Section 3.0 for each polygon.

2.7.4 Category 3 Interport

OTAQ provided 4km grids for interport-only emissions for CO, CO₂, HC, NO_x, SO_x, and PM₁₀. These grids were provided in a customized projection which, without a custom geographic transformation, could not be converted to match the polygon layer's projection. Furthermore, the emission estimates provided by OTAQ were developed using EEZs which were in the GCS Arc Sphere projection. Per OTAQ's direction, the interport polygons were converted from North American Equidistant Conic to GCS Arc Sphere by using the data frame projections tool as the transformation method. This approach was recommended by OTAQ in order to mirror previous methodology and provide emission estimates consistent with the recent Category 3 Commercial Marine Inventory. Zonal statistics tools were used to sum the gridded emissions within each underway polygon. HAP emissions were then speciated from VOC and PM estimates using the methodology described in Section 3.0 for each polygon.

2.8 QA/QC

Given the significant methodological changes over previous inventory efforts, several quality checks were implemented to ensure that these data were developed and allocated in a clear and reproducible manner. Some of the quality checks implemented include the following:

GIS shapefiles

- Topology was created and validated through several rounds or revisions to remove gaps or overlapping features both within and between polygon layers.
- Boundaries derived from Google Earth imagery were validated against Street Map network, port-provided map images, USACE ports points, and other online mapping resources to improve boundary accuracy.
- All final shapefiles and polygon characteristics (such as area, etc.) were managed and evaluated in a single projection to ensure quality area and distance measurements, consistent results across CMV activity types, and maximum accuracy across the study area. The only exception to this was in the case of the interport criteria emissions, as described in Section 4.2.4.

Emissions allocations and estimations

- Emission factors were compiled from a variety of sources, and emission factor development methodologies evaluated to identify the most accurate emission factor for use in this inventory effort.
- National emission sums were checked both before and after allocation to ensure no emissions were dropped or grown.
- HAP speciation profiles were checked for accuracy, and speciated emissions were checked on both the polygon and national level to ensure accuracy.
- All unit conversions were double-checked for errors.
- Emission sums were evaluated across activity types (i.e., hotelling, maneuvering, cruising, reduced speed zones, and interport) to ensure they consistently mirror activity levels.
- Port and underway emissions were examined across SCCs to ensure consistency with activity levels and vessel populations.

- 2008 pollutants and emissions were checked against the 2005 inventory to identify any missing pollutants or major changes compared to previous inventories. Discrepancies were investigated and revisions were made as needed.

2.9 What are the Results?

Table 2-3 summarizes the emission estimates for CMVs for criteria pollutants. Table 2-4 summarizes the emission estimates for individual HAPs. Note that for the purposes of this inventory vessels equipped with category 1 and 2 propulsion engines are assumed to operate on Distillate diesel, while vessels equipped with Category 3 propulsion engines are assumed to use a residual blend. Both tables provide data for all states; these 2008 estimates do not include state submitted data.

Table 2-3. Commercial Marine Vessel Criteria and Greenhouse Gas Emission Estimates 2008 (TPY)

Pollutant	Diesel Port	Diesel Underway	Diesel Total	Residual Port	Residual Underway	Residual Total	CMV Total
CO	113,452	37,817	151,269	5,871	68,588	74,459	225,728
CO ₂	39,221,848	13,073,950	52,295,798	3,703,169	30,986,332	34,689,501	86,985,299
NH ₃	210	140	350	64	323	387	737
NO _x	588,844	196,281	785,125	70,044	813,908	883,952	1,669,077
PM10-PRI	20,954	6,985	27,939	6,730	67,702	74,432	102,371
PM25-PRI	20,325	6,775	27,100	6,081	62,318	68,399	95,499
SO ₂	34,803	11,601	46,404	52,512	522,327	574,839	621,243
VOC	12,752	4,251	17,003	2,412	28,711	31,123	48,126

* Note that for the purposes of this inventory vessels equipped with category 1 and 2 propulsion engines are assumed to operate on Distillate diesel, while vessels equipped with Category 3 propulsion engines are assumed to use a residual blend.

Table 2-4. Commercial Marine Vessel HAP Emission Estimates 2008 (TPY)

Pollutant	Diesel Port	Residual Port	Diesel Underway	Residual Underway
2,2,4-Trimethylpentane	3.825675	NA	1.062688	NA
Acenaphthene	0.36585	0.002068	0.101625	0.021188
Acenaphthylene	0.564019	0.003193	0.156672	0.032717
Acetaldehyde	710.6	0.552315	197.388896	6.574751
Acrolein	33.47466	NA	9.298516	NA
Anthracene	0.564019	0.003193	0.156672	0.032717
Arsenic	0.366686	2.358644	0.209535	11.836005
Benz[a]Anthracene	0.60975	0.003448	0.169375	0.035334
Benzene	194.5738	0.023636	54.048288	0.281365
Benzo[a]Pyrene	0.052384	0.011793	0.034923	0.059180
Benzo[b]Fluoranthene	0.104768	0.023586	0.069845	0.118360
Benzo[g,h,i,]Perylene	0.137194	0.000778	0.038109	0.007977
Benzo[k]Fluoranthene	0.052384	0.011793	0.034923	0.059180
Beryllium	NA	0.003674	NA	0.036965
Cadmium	0.059298	0.057506	0.035970	1.530064
Chromium (VI)	0.178105	1.224973	0.118737	4.419583
Chromium III	0.345733	2.377888	0.230489	8.579191
Chrysene	0.106706	0.000604	0.029641	0.006188
Cobalt	NA	1.717108	NA	10.426100
Dioxins/Furans as 2,3,7,8-TCDD TEQs	1.57E-06	1.18E-06	0.000001	0.000006
Ethyl Benzene	19.12838	NA	5.313438	NA
Fluoranthene	0.335363	0.001897	0.093156	0.019443
Fluorene	0.746944	0.004227	0.207484	0.043311
Formaldehyde	1430.802	3.786611	397.445137	45.075801
Hexachlorobenzene	0.000419	9.43E-05	0.000279	0.000473
Hexane	52.60303	NA	14.611954	NA
Indeno[1,2,3-c,d]Pyrene	0.104768	0.023586	0.069845	0.118360
Lead	1.571513	0.354705	1.047675	1.773791
Manganese	0.032059	0.385606	0.008905	3.879322
Mercury	0.000524	0.008218	0.000349	0.035508
Naphthalene	21.35649	0.121021	5.932360	1.240126
Nickel	10.47675	90.68502	6.984500	398.764466
PAH, total	26.5488	0.154501	7.496895	1.584859
Phenanthrene	0.85365	0.004829	0.237125	0.049480
Phosphorus		26.71489	NA	387.932155
Polychlorinated Biphenyls	0.005238	0.001179	0.003492	0.005918
Propionaldehyde	58.34154	NA	16.205985	NA
Pyrene	0.594506	0.003363	0.165141	0.034462
Selenium	0.000593	0.053465	0.000360	0.235603
Styrene	20.08479	NA	5.579110	NA
Toluene	30.6054	NA	8.501500	NA
Xylenes (Mixed Isomers)	45.9081	NA	12.752250	NA

* Note that for the purposes of this inventory vessels equipped with category 1 and 2 propulsion engines are assumed to operate on Distillate diesel, while vessels equipped with Category 3 propulsion engines are assumed to used a residual blend.

NA – Not Applicable.

2.10 Commercial Marine Vessel References

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Appendix A
2008 Category 3 Commercial Marine Vessel Inventory Methodology

Citation: U.S. Environmental Protection Agency. *Development of 2008CY Category 3 Commercial Marine Inventory*. Office of Transportation and Air Quality, Ann Arbor, MI. 2009.

Development of 2008CY Category 3 Commercial Marine Inventory

The Category 3 (C3) inventory includes vessels which use C3 engines for propulsion. C3 engines are defined as having displacement above 30 liters per cylinder. The resulting inventory includes emissions from both propulsion and auxiliary engines used on these vessels, as well as those on gas and steam turbine vessels.

Geographically, the inventories include port and interport emissions that occur within the area that extends 200 nautical miles (nm) from the official U.S. baseline, which is roughly equivalent to the border of the U.S. Exclusive Economic Zone (EEZ). The U.S. region was clipped to the boundaries of the U.S. EEZ in areas where the 200nm boundary extended beyond the EEZ.

Category 3 commercial marine inventories were developed for a base year of 2002. [1] These were then projected to 2008. Regional adjustment factors were applied to account for growth. In addition, NO_x adjustment factors were applied to account for implementation of the NO_x Tier 1 standard. The methodology for each type of adjustment is described below.

Growth Factors by Geographic Region

The emissions inventory is calculated for nine geographic regions: Alaska East, Alaska West, East Coast, Gulf Coast, Hawaii East, Hawaii West, North Pacific, South Pacific, and the Great Lakes. Average annual growth rates from 2002-2020 were calculated for five regions: East Coast, Gulf Coast, North Pacific, South Pacific, and the Great Lakes. The Alaska regions were assigned the growth factor for the North Pacific region, while the Hawaii regions were assigned the growth factor for the South Pacific region. Each regional growth rate was then compounded over the inventory projection time period for 2008 (i.e., 6 years). The average annual growth rates and resulting multiplicative growth factors for each emission inventory region is presented in Table 1 below.

Table 1. Regional Emission Inventory Growth Factors for 2008

Emission Inventory Region	2002-2020 Average Annualized Growth Rate (%)	Multiplicative Growth Factor for 2008 Relative to 2002
Alaska East (AE)	3.3	1.2151
Alaska West (AW)	3.3	1.2151
East Coast (EC)	4.5	1.3023
Gulf Coast (GC)	2.9	1.1871
Hawaii East (HE)	5.0	1.3401
Hawaii West (HW)	5.0	1.3401
North Pacific (NP)	3.3	1.2151
South Pacific (SP)	5.0	1.3401
Great Lakes (GL)	1.7	1.1064

NO_x Adjustment Factors

The 2008 calendar year baseline inventory includes pre-control (Tier 0) engines and those subject to the NO_x Tier 1 standard that became effective in 2000. The NO_x emission factors (EFs) by tier and engine/ship type are given in Table 2.

Table 2. NO_x Emission Factors by Tier

Engine/Ship Type	NO _x EF (g/kW-hr)	
	Tier 0	Tier 1
Main		
Slow-Speed Diesel (SSD)	18.1	16.1
Medium-Speed Diesel (MSD)	14	12.5
Steam Turbine (ST)	2.1	n/a
Gas Turbine	6.1	n/a
Auxiliary		
Passenger Ship	14.6	13.0
Other Ships	14.5	12.9

The NO_x EFs by tier were then used with age distributions to generate calendar year NO_x EFs by engine/ship type for 2008. For 2002, Tier 0 EFs were used for simplicity. These calendar year NO_x EFs are provided in Table 3. Since the age distributions are different for vessels in the Great Lakes, NO_x EFs were determined separately for the Great Lakes.

Table 3. NO_x Emission Factors by Calendar Year

Engine/Ship Type	CY NO _x EF (g/kW-hr)		
	2002	2008	
		DSP ^a	GL ^b
Main			
Slow-Speed Diesel (SSD)	18.1	17.07	17.50
Medium-Speed Diesel (MSD)	14	13.01	13.74
Steam Turbine (ST)	2.1	2.1	2.1
Gas Turbine	6.1	6.1	n/a
Auxiliary			
Passenger Ship	14.6	13.76	14.32
Other Ships	14.5	13.60	14.16

^aDSP = Deep sea ports and areas other than the Great Lakes

^bGL = Great Lakes

Emission adjustment factors for NO_x were then calculated. Adjustment factors are ratios of the 2008 calendar year EFs to the 2002 calendar year EFs. The adjustment factors by engine/ship type are provided in Table 4.

Table 4. NO_x EF Adjustment Factors for 2008CY

Engine/Ship Type	2008 NO _x Adj (unitless)	
	DSP ^a	GL ^b
Main		
Slow-Speed Diesel (SSD)	0.9433	0.9670
Medium-Speed Diesel (MSD)	0.9293	0.9815
Steam Turbine (ST)	1.0000	1.0000
Gas Turbine	1.0000	n/a
Auxiliary		
Passenger Ship	0.9403	0.9784
Other Ships	0.9403	0.9784

Methodology for Development of 2008CY Port Inventories

For the non-California ports, 2002 emissions for each port are summed by engine/ship type. Propulsion and auxiliary emissions are summed separately, since the EF adjustment factors differ. The appropriate regional growth factor, as provided in Table 1, is then applied, along with the NO_x EF adjustment factors by engine/ship type in Table 4 to calculate the 2008 port inventories.

For the California ports, 2002 emissions for each port are summed by ship type. Propulsion and auxiliary emissions are summed separately, since the EF adjustment factors differ. The EF adjustment factors by engine/ship type in Table 4 are consolidated by ship type, using the CARB assumption that engines on all ships except passenger ships are 95 percent slow speed diesel (SSD) engines and 5 percent medium speed diesel engines (MSD) based upon a 2005 CARB survey. All passenger ships were assumed to be MSD engines. Steam turbines (ST) and gas turbines (GT) are not included in the CARB inventory. The NO_x EF adjustment factors by ship type are then applied, along with ship-specific growth factors used by CARB, to calculate the 2008 California port inventories. The ship-specific growth factors for 2008 relative to 2002 are provided in Table 5 below.

Table 5. Growth Factors by Ship Type for California Ports

Ship Type	Calendar Year	
	2002	2008
Auto	1.0000	1.1525
Bulk	1.0000	0.7412
Container	1.0000	1.4023
General	1.0000	0.9071
Passenger	1.0000	1.9823
Reefer	1.0000	1.0112
RoRo	1.0000	1.1525
Tanker	1.0000	1.3005

Methodology for Development of 2008CY Interport Inventories

The interport portion of the inventory is not segregated by engine or ship type. As a result, regional NO_x EF adjustment factors were developed based on the assumed mix of main (propulsion) engine types in each region. The mix of main engine types by region was developed using the ship call and power data and is presented in Table 6. Main engines are considered a good surrogate for interport emissions, since the majority of emissions while underway are due to the main engines. The NO_x EF adjustment factors by main engine type in Table 4 were used together with the mix of main engine types by region in Table 6 to develop the regional adjustment factors. The resulting NO_x EF regional adjustment factors are provided in Table 7. These NO_x EF regional adjustment factors, together with the regional growth factors in Table 1, were applied to calculate the 2008 interport inventories.

Table 6. Installed Power by Main Engine Type

Region	2008 Installed Power (%)			
	MSD	SSD	GT	ST
Alaska East (AE)	19.1%	18.4%	0.3%	62.2%
Alaska West (AW)	19.1%	18.4%	0.3%	62.2%
East Coast (EC)	25.6%	72.5%	0.9%	1.0%
Gulf Coast (GC)	13.7%	85.5%	0.0%	0.8%
Hawaii East (HE)	66.2%	18.5%	7.4%	8.0%
Hawaii West (HW)	66.2%	18.5%	7.4%	8.0%
North Pacific (NP)	5.1%	83.5%	1.6%	9.7%
South Pacific (SP)	17.8%	82.2%	0.0%	0.0%
Great Lakes (GL)	47.9%	43.7%	0.0%	8.4%

Table 7. NO_x EF Regional Adjustment Factors

Region	2002	2008
Alaska East (AE)	1.0000	0.9761
Alaska West (AW)	1.0000	0.9761
East Coast (EC)	1.0000	0.9408
Gulf Coast (GC)	1.0000	0.9419
Hawaii East (HE)	1.0000	0.9428
Hawaii West (HW)	1.0000	0.9428
North Pacific (NP)	1.0000	0.9490
South Pacific (SP)	1.0000	0.9408
Great Lakes (GL)	1.0000	0.9767

The resulting 2008 Category 3 emission inventories are shown in Table 8 for each of the nine geographic regions and the nation.

Table 8. 2008 Regional and National Emissions from Category 3 Vessel Main and Auxiliary Engines

Region	Metric Tonnes						
	NO _x	PM ₁₀	PM _{2.5} ^a	HC	CO	SO ₂	CO ₂
Alaska East (AE)	21,590	1,749	1,609	733	1,730	13,032	807,159
Alaska West (AW)	71,901	5,755	5,294	2,441	5,750	42,694	2,631,081
East Coast (EC)	271,707	23,021	21,180	9,573	22,665	190,767	10,696,360
Gulf Coast (GC)	195,240	16,839	15,492	6,903	16,990	125,728	7,604,870
Hawaii East (HE)	28,837	2,403	2,211	1,013	2,390	17,843	1,108,047
Hawaii West (HW)	40,573	3,381	3,110	1,426	3,362	25,105	1,559,016
North Pacific (NP)	30,248	2,647	2,435	1,153	2,568	18,790	1,216,723
South Pacific (SP)	132,669	10,982	10,103	4,692	11,368	81,896	5,145,632
Great Lakes (GL)	16,395	1,318	1,212	557	1,312	9,797	605,001
Total Metric Tonnes	809,160	68,094	62,646	28,492	68,136	525,651	31,373,889
<i>Total Short Tons^b</i>	891,946	75,061	69,056	31,407	75,107	579,431	34,583,792

^a Estimated from PM₁₀ using a multiplicative adjustment factor of 0.92.

Reference (for 2002 inventory development)

- 1) U.S. Environmental Protection Agency, “Draft Regulatory Impact Analysis: Control of Emissions of Air Pollution from Category 3 Marine Diesel Engines,” Office of Transportation and Air Quality, EPA-420-D-09-002, June 2009.

Appendix B

2008 Commercial Marine Vessel Hazardous Air Pollutant Speciation Profiles

Table 1. Category 1 and 2 Hazardous Air Pollutant Speciation Profile for Port Activities

Pollutant Code	Pollutant	Speciation Basis	2008 Emission Factor
540841	2,2,4-trimethylpentane	VOC	3.00E-04
83329	Acenaphthene	PM _{2.5}	1.80E-05
208968	Acenaphthylene	PM _{2.5}	2.78E-05
75070	Acetaldehyde	VOC	5.57E-02
107028	Acrolein	VOC	2.63E-03
NH3	Ammonia	PM ₁₀	1.15E-02
120127	Anthracene	PM _{2.5}	2.78E-05
7440382	Arsenic	PM ₁₀	1.75E-05
56553	Benz[a]Anthracene	PM _{2.5}	3.00E-05
71432	Benzene	VOC	1.53E-02
50328	Benzo[a]Pyrene	PM ₁₀	2.50E-06
205992	Benzo[b]Fluoranthene	PM ₁₀	5.00E-06
191242	Benzo[g,h,i,l]Perylene	PM _{2.5}	6.75E-06
207089	Benzo[k]Fluoranthene	PM ₁₀	2.50E-06
7440439	Cadmium	PM ₁₀	2.83E-06
16065831	Chromium III	PM ₁₀	1.65E-05
18540299	Chromium VI	PM ₁₀	8.50E-06
218019	Chrysene	PM _{2.5}	5.25E-06
600	Dioxin	PM ₁₀	2.50E-09
100414	Ethylbenzene	VOC	1.50E-03
206440	Fluoranthene	PM _{2.5}	1.65E-05
86737	Fluorene	PM _{2.5}	3.68E-05
50000	Formaldehyde	VOC	1.12E-01
118741	Hexachlorobenzene	PM ₁₀	2.00E-08
193395	Indeno[1,2,3-c,d]Pyrene	PM ₁₀	5.00E-06
439921	Lead	PM ₁₀	7.50E-05
7439965	Manganese	PM ₁₀	1.53E-06
7439976	Mercury	PM ₁₀	2.50E-08
91203	Naphthalene	PM _{2.5}	1.05E-03
110543	n-Hexane	VOC	4.13E-03
7440020	Nickel	PM ₁₀	5.00E-04
1336363	Polychlorinated Biphenyls	PM ₁₀	2.50E-07
85018	Phenanthrene	PM _{2.5}	4.20E-05
123386	Propionaldehyde	VOC	4.58E-03
129000	Pyrene	PM _{2.5}	2.93E-05
7782492	Selenium	PM ₁₀	2.83E-08
100425	Styrene	VOC	1.58E-03
108883	Toluene	VOC	2.40E-03

Table 2. Category 1 and 2 Hazardous Air Pollutant Speciation Profile for Underway Activities

Pollutant Code	Pollutant	Speciation Basis	2008 Emission Factor
1330207	Xylene	VOC	3.60E-03
540841	2,2,4-trimethylpentane	VOC	2.50E-04
83329	Acenaphthene	PM _{2.5}	1.50E-05
208968	Acenaphthylene	PM _{2.5}	2.31E-05
75070	Acetaldehyde	VOC	4.64E-02
107028	Acrolein	VOC	2.19E-03
NH3	Ammonia	PM ₁₀	2.31E-02
120127	Anthracene	PM _{2.5}	2.31E-05
7440382	Arsenic	PM ₁₀	3.00E-05
56553	Benz[a]Anthracene	PM _{2.5}	2.50E-05
71432	Benzene	VOC	1.27E-02
50328	Benzo[a]Pyrene	PM ₁₀	5.00E-06
205992	Benzo[b]Fluoranthene	PM ₁₀	1.00E-05
191242	Benzo[g,h,i,l]Perylene	PM _{2.5}	5.63E-06
207089	Benzo[k]Fluoranthene	PM ₁₀	5.00E-06
7440439	Cadmium	PM ₁₀	5.15E-06
16065831	Chromium III	PM ₁₀	3.30E-05
18540299	Chromium VI	PM ₁₀	1.70E-05
218019	Chrysene	PM _{2.5}	4.38E-06
600	Dioxin	PM ₁₀	5.00E-09
100414	Ethylbenzene	VOC	1.25E-03
206440	Fluoranthene	PM _{2.5}	1.38E-05
86737	Fluorene	PM _{2.5}	3.06E-05
50000	Formaldehyde	VOC	9.35E-02
118741	Hexachlorobenzene	PM ₁₀	4.00E-08
193395	Indeno[1,2,3-c,d]Pyrene	PM ₁₀	1.00E-05
7439921	Lead	PM ₁₀	1.50E-04
7439965	Manganese	PM ₁₀	1.28E-06
7439976	Mercury	PM ₁₀	5.00E-08
91203	Naphthalene	PM _{2.5}	8.76E-04
110543	n-Hexane	VOC	3.44E-03
7440020	Nickel	PM ₁₀	1.00E-03
1336363	Polychlorinated Biphenyls	PM ₁₀	5.00E-07

Table 2. Category 1 and 2 Hazardous Air Pollutant Speciation Profile for Underway Activities (Continued)

Pollutant Code	Pollutant	Speciation Basis	2008 Emission Factor
85018	Phenanthrene	PM _{2.5}	3.50E-05
123386	Propionaldehyde	VOC	3.81E-03
129000	Pyrene	PM _{2.5}	2.44E-05
7782492	Selenium	PM ₁₀	5.15E-08
100425	Styrene	VOC	1.31E-03
108883	Toluene	VOC	2.00E-03
1330207	Xylene	VOC	3.00E-03

Table 3. Category 3 Hazardous Air Pollutant Speciation Profile for Hotelling Activities

Pollutant Code	Pollutant	Speciation Basis	2008 Emission Factor
83329	Acenaphthene	PM _{2.5}	3.40E-07
208968	Acenaphthylene	PM _{2.5}	5.25E-07
75070	Acetaldehyde	VOC	2.29E-04
NH3	Ammonia	PM ₁₀	1.08E-02
120127	Anthracene	PM _{2.5}	5.25E-07
7440382	Arsenic	PM ₁₀	4.00E-04
56553	Benz[a]Anthracene	PM _{2.5}	5.67E-07
71432	Benzene	VOC	9.80E-06
50328	Benzo[a]Pyrene	PM ₁₀	2.00E-06
205992	Benzo[b]Fluoranthene	PM ₁₀	4.00E-06
191242	Benzo[g,h,I,]Perylene	PM _{2.5}	1.28E-07
207089	Benzo[k]Fluoranthene	PM ₁₀	2.00E-06
7440417	Beryllium	PM ₁₀	5.46E-07
7440439	Cadmium	PM ₁₀	5.90E-06
16065831	Chromium III	PM ₁₀	3.96E-04
18540299	Chromium VI	PM ₁₀	2.04E-04
218019	Chrysene	PM _{2.5}	9.93E-08
7440484	Cobalt	PM ₁₀	2.92E-04
53703	Dibenzo[a,h]Anthracene	PM _{2.5}	0.00E+00
600	Dioxin	PM ₁₀	2.00E-09

**Table 3. Category 3 Hazardous Air Pollutant Speciation Profile for
Hotelling Activities (Continued)**

Pollutant Code	Pollutant	Speciation Basis	2008 Emission Factor
206440	Fluoranthene	PM _{2.5}	3.12E-07
86737	Fluorene	PM _{2.5}	6.95E-07
50000	Formaldehyde	VOC	1.57E-03
118741	Hexachlorobenzene	PM ₁₀	1.60E-08
193395	Indeno[1,2,3-c,d]Pyrene	PM ₁₀	4.00E-06
7439921	Lead	PM ₁₀	6.00E-05
7439965	Manganese	PM ₁₀	5.73E-05
7439976	Mercury	PM ₁₀	1.40E-06
91203	Naphthalene	PM _{2.5}	1.99E-05
7440020	Nickel	PM ₁₀	1.54E-02
1336363	Polychlorinated Biphenyls	PM ₁₀	2.00E-07
85018	Phenanthrene	PM _{2.5}	7.94E-07
7723140	Phosphorous	PM ₁₀	4.38E-03
130498292	POM as 16-PAH	PM _{2.5}	2.49E-05
130498292	POM as 7-PAH	PM ₁₀	4.50E-07
129000	Pyrene	PM _{2.5}	5.53E-07
7782492	Selenium	PM ₁₀	9.08E-06

**Table 4. Category 3 Hazardous Air Pollutant Speciation Profile for
Maneuvering Activities**

Pollutant Code	Pollutant	Speciation Basis	2008 Emission Factor
83329	Acenaphthene	PM _{2.5}	3.40E-07
208968	Acenaphthylene	PM _{2.5}	5.25E-07
75070	Acetaldehyde	VOC	2.29E-04
NH3	Ammonia	PM ₁₀	2.38E-03
120127	Anthracene	PM _{2.5}	5.25E-07
7440382	Arsenic	PM ₁₀	8.74E-05
56553	Benz[a]Anthracene	PM _{2.5}	5.67E-07
71432	Benzene	VOC	9.80E-06
50328	Benzo[a]Pyrene	PM ₁₀	4.37E-07
205992	Benzo[b]Fluoranthene	PM ₁₀	8.74E-07

Table 4. Category 3 Hazardous Air Pollutant Speciation Profile for Maneuvering Activities (Continued)

Pollutant Code	Pollutant	Speciation Basis	2008 Emission Factor
191242	Benzo[g,h,i,l]Perylene	PM _{2.5}	1.28E-07
207089	Benzo[k]Fluoranthene	PM ₁₀	4.37E-07
7440417	Beryllium	PM ₁₀	5.46E-07
7440439	Cadmium	PM ₁₀	2.26E-05
16065831	Chromium III	PM ₁₀	1.27E-04
18540299	Chromium VI	PM ₁₀	6.53E-05
218019	Chrysene	PM _{2.5}	9.93E-08
7440484	Cobalt	PM ₁₀	5.94E-05
53703	Dibenzo[a,h]Anthracene	PM _{2.5}	0.00E+00
600	Dioxin	PM ₁₀	4.37E-10
206440	Fluoranthene	PM _{2.5}	3.12E-07
86737	Fluorene	PM _{2.5}	6.95E-07
50000	Formaldehyde	VOC	1.57E-03
118741	Hexachlorobenzene	PM ₁₀	3.50E-09
193395	Indeno[1,2,3-c,d]Pyrene	PM ₁₀	8.74E-07
7439921	Lead	PM ₁₀	1.40E-05
7439965	Manganese	PM ₁₀	5.73E-05
7439976	Mercury	PM ₁₀	2.71E-07
91203	Naphthalene	PM _{2.5}	1.99E-05
7440020	Nickel	PM ₁₀	3.25E-03
1336363	Polychlorinated Biphenyls	PM ₁₀	4.37E-08
85018	Phenanthrene	PM _{2.5}	7.94E-07
7723140	Phosphorous	PM ₁₀	1.79E-03
130498292	POM as 16-PAH	PM _{2.5}	2.49E-05
130498292	POM as 7-PAH	PM ₁₀	4.90E-07
129000	Pyrene	PM _{2.5}	5.53E-07
7782492	Selenium	PM ₁₀	1.91E-06

Table 5. Category 3 Hazardous Air Pollutant Speciation Profile for Underway Activities

Pollutant Code	Pollutant	Speciation Basis	2008 Emission Factor
83329	Acenaphthene	PM _{2.5}	3.40E-07
208968	Acenaphthylene	PM _{2.5}	5.25E-07

Table 5. Category 3 Hazardous Air Pollutant Speciation Profile for Underway Activities (Continued)

Pollutant Code	Pollutant	Speciation Basis	2008 Emission Factor
75070	Acetaldehyde	VOC	2.29E-04
NH3	Ammonia	PM ₁₀	4.77E-03
120127	Anthracene	PM _{2.5}	5.25E-07
7440382	Arsenic	PM ₁₀	1.75E-04
56553	Benz[a]Anthracene	PM _{2.5}	5.67E-07
71432	Benzene	VOC	9.80E-06
50328	Benzo[a]Pyrene	PM ₁₀	8.74E-07
205992	Benzo[b]Fluoranthene	PM ₁₀	1.75E-06
191242	Benzo[g,h,I]Perylene	PM _{2.5}	1.28E-07
207089	Benzo[k]Fluoranthene	PM ₁₀	8.74E-07
7440417	Beryllium	PM ₁₀	5.46E-07
7440439	Cadmium	PM ₁₀	2.26E-05
7440473	Chromium	PM ₁₀	1.92E-04
16065831	Chromium III	PM ₁₀	1.27E-04
18540299	Chromium VI	PM ₁₀	6.53E-05
218019	Chrysene	PM _{2.5}	9.93E-08
7440484	Cobalt	PM ₁₀	1.54E-04
53703	Dibenzo[a,h]Anthracene	PM _{2.5}	0.00E+00
600	Dioxin	PM ₁₀	8.74E-10
206440	Fluoranthene	PM _{2.5}	3.12E-07
86737	Fluorene	PM _{2.5}	6.95E-07
50000	Formaldehyde	VOC	1.57E-03
118741	Hexachlorobenzene	PM ₁₀	6.99E-09
193395	Indeno[1,2,3-c,d]Pyrene	PM ₁₀	1.75E-06
7439921	Lead	PM ₁₀	2.62E-05
7439965	Manganese	PM ₁₀	5.73E-05
7439976	Mercury	PM ₁₀	5.24E-07
91203	Naphthalene	PM _{2.5}	1.99E-05
7440020	Nickel	PM ₁₀	5.89E-03
1336363	Polychlorinated Biphenyls	PM ₁₀	8.74E-08
85018	Phenanthrene	PM _{2.5}	7.94E-07
7723140	Phosphorus	PM ₁₀	5.73E-03
130498292	POM as 16-PAH	PM _{2.5}	2.49E-05
130498292	POM as 7-PAH	PM ₁₀	4.90E-07
129000	Pyrene	PM _{2.5}	5.53E-07
7782492	Selenium	PM ₁₀	3.48E-06

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**Documentation for Locomotive Component of the National Emissions
Inventory Methodology**

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1.0 INTRODUCTION

1.1 What are Locomotive Sources?

The locomotive source category includes railroad locomotives powered by diesel-electric engines. A diesel-electric locomotive uses 2-stroke or 4-stroke diesel engines and an alternator or a generator to produce the electricity required to power its traction motors. The locomotive source category does not include locomotives powered by electricity or steam. Emissions associated with the operation of electric locomotives would be included in the point source utility emission estimate. It is believed that the number of wood or coal driven steam locomotives is currently very small; therefore, these types of locomotives are not included in this inventory.

The locomotive source category is further divided up into three categories: Class I line haul, Class II/III line haul, and Class I yard. The national rail estimates were developed by the Eastern Regional Technical Advisory Committee hereafter referenced as ERTAC Rail. This group is comprised of eastern states' regulatory agencies in collaboration with the rail industry. ERTAC Rail developed emissions estimates based on fuel data obtained from the American Association of Railroads for each subcategory. California locomotive emission estimates were handled separately from the rest of the United States because of their use of low sulfur locomotive diesel fuels.

2.0 DEVELOPMENT OF THE LOCOMOTIVE COMPONENT FOR THE NEI

2.1 What Pollutants are Included in the National Emission Estimates for Locomotives?

All of the criteria pollutants, VOC, CO, NO_x, SO_x, PM, and PM_{2.5}, are included in the locomotive component of the NEI. OTAQ identified the HAPs for which data were available to develop inventory estimates (Scarbro, 2001). The hazardous air pollutants (HAPs), listed below, were identified based on available test data and accepted emission estimation procedures. Emission estimation methods have changed over the history of the NEI, as outlined briefly in Table 2-2 for nonroad sources.

Table 2-1. Locomotive Pollutant List

1,3-Butadiene	Beryllium	Napthalene
2,2,4-Trimethylpentane	Cadmium	n-Hexane
Acenaphthene	Chromium (Hexavalent)	Nickel
Acenaphthylene	Chromium (Trivalent)	Phenanthrene
Acetaldehyde	Chrysene	PAH Propionaldehyde
Acrolein	Dibenz(a,h) anthracene	Pyrene
Anthracene	Ethyl Benzene	Styrene
Arsenic	Fluoranthene	Toluene
Benzene	Fluorene	Xylene
Benzo(a)anthracene	Formaldehyde	
Benzo[a]pyrene	Indeno(1,2,3-cd) pyrene	
Benzo[b]fluoranthene	Lead	
Benzo[g,h,i,]perylene	Manganese	
Benzo[k]fluoranthene	Mercury	

**Table 2-2. Methods Used to Develop Annual Emission Estimates for
Nonroad Mobile Sources**

(Categories included in this report are noted in bold print)

Category	Base Year	Pollutant(s)	Estimation Method*
<i>NONROAD Categories</i>			
Nonroad Gasoline, Diesel, LPG, CNG	2008	VOC, NO _x , CO, SO ₂ , PM ₁₀ , PM _{2.5} , NH ₃ , & HAPs	Emission estimates for NONROAD model engines were developed using EPA's National Mobile Inventory Model (NMIM), which incorporates NONROAD2008. Where states provided alternate NMIM nonroad inputs, these data replaced EPA default inputs.
	2005	VOC, NO _x , CO, SO ₂ , PM ₁₀ , PM _{2.5} , NH ₃ , & HAPs	Emission estimates for NONROAD model engines were developed using EPA's NMIM, which incorporates NONROAD2005. Where States provided alternate nonroad inputs, these data replaced EPA default inputs.
	2002	VOC, NO _x , CO, SO ₂ , PM ₁₀ , PM _{2.5} , NH ₃ , & HAPs	Emission estimates for NONROAD model engines were developed using EPA's NMIM, which incorporates NONROAD2004. Where states provided alternate nonroad inputs, these data replaced EPA default inputs. State-supplied emissions data also replaced default EPA emission estimates.
	1999	VOC, NO _x , CO, SO ₂ , PM ₁₀ , PM _{2.5}	Using emission estimates from two emission inventories including: 1) a 1996 county-level inventory, developed using EPA's October 2001 draft NONROAD model; and 2) an updated 1999 national inventory, based on EPA's draft Lockdown C NONROAD model (dated May 2002). Using the 1996 county-level emission estimates, seasonal and daily county-to-national ratios were then developed for application to updated national estimates per season estimated from the Lockdown C model. Replaced State-submitted data for California for all NONROAD model categories; Pennsylvania for recreational marine and aircraft ground support equipment, and Texas for select equipment categories.
	1996, 1997, 1998, 2000 & 2001	VOC, NO _x , CO, SO ₂ , PM ₁₀ , PM _{2.5}	Using emission estimates from two emission inventories including: 1) a 1996 county-level inventory, developed using EPA's October 2001 draft NONROAD model; and 2) updated year-specific national and California inventories, based on EPA's draft Lockdown C NONROAD model (dated May 2002). Using the 1996 county-level emission estimates, seasonal and daily county-to-national ratios and California county-to-state ratios were then developed for application to updated national estimates per season estimated from the Lockdown C model. California results replace the diesel equipment emissions generated from prior application of county-to-national ratios.

**Table 2-2. Methods Used to Develop Annual Emission Estimates for
Nonroad Mobile Sources (Continued)**
(Categories included in this report are noted in bold print)

Category	Base Year	Pollutant(s)	Estimation Method*
Nonroad Gasoline, Diesel, LPG, and CNG (Continued)	1991-1995	VOC, NO _x , CO, SO ₂ , PM ₁₀ , PM _{2.5} , NH ₃	Using 1990 and 1996 county-level emissions inventories, estimated emissions using linear interpolation of national emissions between 1990 and 1996. From these emissions, calculated the average annual growth rate for each pollutant/SCC combination for each year, and then applied the growth factors to 1990 county-level emissions to estimate 1991-1995 emissions.
	1990	VOC, NO _x , CO, SO ₂ , PM ₁₀ , PM _{2.5}	Using emission estimates from two emission inventories including: 1) a 1996 county-level inventory, developed using EPA's October 2001 draft NONROAD model; and 2) updated 1990 national inventory, based on EPA's draft Lockdown C NONROAD model (dated May 2002). Using the 1996 county-level emission estimates, seasonal and daily county-to-national ratios were then developed for application to updated national estimates per season estimated from the Lockdown C model.
	1986, 1988, & 1989	VOC, NO _x , CO, SO ₂ , PM ₁₀ , PM _{2.5} , NH ₃	Using 1985 and 1990 county-level emissions inventories, estimated emissions using linear interpolation of national emissions between 1985 and 1990. From these emissions, calculated the average annual growth rate for each pollutant/SCC combination for each year, and then applied the growth factors to 1985 county-level emissions to estimate 1986-1989 emissions.
	1987	VOC, NO _x , CO, SO ₂ , PM ₁₀ , PM _{2.5}	Using EPA's draft Lockdown C NONROAD model (dated May 2002), developed updated national emissions for 1987 by running 4 seasonal NONROAD model runs to estimate annual criteria pollutant emissions. Also performed national NONROAD model runs to estimate typical summer weekday emissions.
	1985	VOC, NO _x , CO, SO ₂ , PM ₁₀ , PM _{2.5}	Using emission estimates from two emission inventories including: 1) a 1996 county-level inventory, developed using EPA's October 2001 draft NONROAD model; and 2) updated 1985 national inventory, based on EPA's draft Lockdown C NONROAD model (dated May 2002). Using the 1996 county-level emission estimates, seasonal and daily county-to-national ratios were then developed for application to updated national estimates per season estimated from the Lockdown C model.
	1970, 1975, 1978, & 1980	VOC, NO _x , CO, SO ₂ , PM ₁₀ , PM _{2.5}	Using EPA's draft Lockdown C NONROAD model (dated May 2002), developed updated national emissions for all years by running 4 seasonal NONROAD model runs to estimate annual criteria pollutant emissions. Also performed national NONROAD model runs to estimate typical summer weekday emissions.

**Table 2-2. Methods Used to Develop Annual Emission Estimates for
Nonroad Mobile Sources (Continued)**
(Categories included in this report are noted in bold print)

Category	Base Year	Pollutant(s)	Estimation Method*
Nonroad Gasoline, Diesel, LPG, and CNG (Continued)	1996, 1997, 1998, 1999, 2000, & 2001	NH ₃	Obtaining national fuel consumption estimates from the Lockdown C NONROAD model, multiplying by NH ₃ emission factors, and distributing to counties using 1996 inventory, based on October 2001 draft NONROAD. NH ₃ emissions for California were also recalculated using updated diesel fuel consumption values generated for California-specific runs, and assuming the 1996 county-level distribution.
	1985 & 1990	NH ₃	Obtaining national fuel consumption estimates from the Lockdown C NONROAD model, multiplying by NH ₃ emission factors, and distributing to counties using 1996 inventory, based on October 2001 draft NONROAD.
	1987	NH ₃	Obtaining 1987 national fuel consumption estimates from Lockdown C NONROAD model and multiplying by NH ₃ emission factors.
	1970, 1975, 1978, & 1980	NH ₃	Obtaining national fuel consumption estimates from the Lockdown C NONROAD model and multiplying by NH ₃ emission factors.
	1990, 1996, & 1999	HAPs	Speciation profiles applied to county VOC and PM estimates. Metal HAPs were calculated using fuel and activity-based emission factors. Some state data were provided and replaced national estimates. (2003)
Aircraft			
Commercial Aircraft	2008	Criteria and HAPs	Federal Aviation Administration (FAA) Emissions and Dispersion Modeling System (EDMS) - Version 5.1.was run using BTS T-100 LTO data. (2009)
	2002 and 2005	Criteria and HAPs	Federal Aviation Administration (FAA) Emissions and Dispersion and Modeling System (EDMS) was run for criteria pollutants, VOC and PM emissions were speciated into HAP components. (2004)
	1990, 1996, 1999, 2000, 2001	VOC, NO _x , CO, SO _x	Input landing and take-off (LTO) data into FAA EDMS. National emissions were assigned to airports based on airport specific LTO data and BTS GIS data. State data replaced national estimates. (2003)
	1970-1998	VOC, NO _x , CO, SO _x	Estimated emissions for interim years using linear interpolation between available base years. (2003)
	1990, 1996, 1999	HAPs	Speciation profiles were applied to VOC estimates to get national HAP estimates. State data replaced national estimates. (2003)
General Aviation, Air Taxis	2008	Criteria and HAPs	Federal Aviation Administration (FAA) Emissions and Dispersion Modeling System (EDMS) - Version 5.1.was run using BTS T-100 LTO for aircraft identified as Air taxis. (2010) Used FAA LTO data from TAF and OTAQ provided activity data for smaller airports derived from FAA 5010 master plans. EPA approved generic emission factors for criteria estimates. Speciation profiles were applied to VOC and PM estimates to get national HAP estimates. (2010)

**Table 2-2. Methods Used to Develop Annual Emission Estimates for
Nonroad Mobile Sources (Continued)**
(Categories included in this report are noted in bold print)

Category	Base Year	Pollutant(s)	Estimation Method*
General Aviation, Air Taxis (Continued)	2005	VOC, NO _x , CO, SO ₂ , PM ₁₀ , PM _{2.5}	2002 emissions for approximately 4,000 largest airports were calculated via EDMS and SIP guidance and included in the 2005 NEI as point sources. Only airports in FAA's T100 and TAF databases were included. State point source submittals were incorporated.
	1978, 1987, 1990, 1996, 1999, 2000, 2001, & 2002	VOC, NO _x , CO, SO ₂ , PM ₁₀ , PM _{2.5}	Used FAA LTO data and EPA approved emission factors for criteria estimates. Speciation profiles were applied to VOC estimates to get national HAP estimates. State data replaced national estimates. (2004)
	1970-1998	VOC, NO _x , CO, SO _x , PM ₁₀ , PM _{2.5}	Estimated emissions for interim years using linear interpolation between available base years. (2003)
	1990, 1996, 1999, & 2002	HAPs	Used FAA LTO data and EPA approved emission factors for criteria estimates. Speciation profiles were applied to VOC estimates to develop national HAP estimates. (2004)
	1990, 1996, 1999, & 2002	Pb	Used Department of Energy (DOE) aviation gasoline usage data with lead concentration of aviation gasoline. (2004)
	1996	NH ₃	Applied NH ₃ emissions factors to 1996 national jet fuel and aviation gasoline consumption estimates.
Military Aircraft	2008	VOC, NO _x , CO, SO ₂ , PM ₁₀ , PM _{2.5}	Used FAA LTO data as reported in TAF and EPA approved emission factors for criteria estimates. Representative HAP profiles were not readily available, therefore HAP estimates were not developed. (2010)
	2005	VOC, NO _x , CO, SO ₂ , PM ₁₀ , PM _{2.5}	2002 emissions were included in the 2005 NEI as point sources similar to other TAF reported data.
	1978, 1987, 1990, 1996, 1999, 2000, 2001, 2002, 2008	VOC, NO _x , CO, SO ₂ , PM ₁₀ , PM _{2.5}	Used FAA LTO data as reported in TAF and EPA approved emission factors for criteria estimates. Representative HAP profiles were not readily available, therefore HAP estimates were not developed.
	1970-1998	VOC, NO _x , CO, SO _x , PM ₁₀ , PM _{2.5}	Estimated emissions for interim years using linear interpolation between available base years. (2003)
Auxiliary Power Units and Ground Support Equipment	2008	VOC, NO _x , CO, SO ₂ , PM ₁₀ , PM _{2.5} , HAPs	Federal Aviation Administration (FAA) Emissions and Dispersion and Modeling System (EDMS) - Version 5.1.was run using BTS T-100 LTO data. (2009)
	2002 and 2005	VOC, NO _x , CO, SO ₂ , PM ₁₀ , PM _{2.5} , HAPs	Computed via NONROAD2005 model runs
	1985-2001	VOC, NO _x , CO, SO ₂ , PM ₁₀ , PM _{2.5}	Grew 1996 emissions to each year using LTO operations data from the FAA. Estimation methods prior to 1996 reported in EPA, 1998.

**Table 2-2. Methods Used to Develop Annual Emission Estimates for
Nonroad Mobile Sources (Continued)**
(Categories included in this report are noted in bold print)

Category	Base Year	Pollutant(s)	Estimation Method*
Unpaved Airstrips ¹	1985-2001	PM ₁₀ , PM _{2.5}	Grew 1996 emissions to each year using SIC 45-Air Transportation growth factors, consistent with the current draft version of EGAS. Estimation methods prior to 1996 reported in EPA, 1998.
Aircraft Refueling ¹	1985-2001	VOC	Grew 1996 emissions to each year using SIC 45-Air Transportation growth factors, consistent with the current draft version of EGAS. Estimation methods prior to 1996 reported in EPA, 1998.
Commercial Marine Vessel (CMV)			
All CMV Categories	2008	VOC, NO _x , CO, SO ₂ , PM ₁₀ , PM _{2.5}	OTAQ provided CAP emission estimates for all CMV categories. Note that the SCCs for this category have changed such that the Diesel category refers to smaller vessels (Category 1 and 2) using distillate fuels and the Residual category refers to larger (Category 3) vessels using a blend of residual fuels. Emissions were allocated to segments using GIS shapefiles and adjusted based on limited state data (2010)
	2008	HAPs	OTAQ's 2008 estimates were speciated into HAP components using SEPA profiles (2009)
CMV Diesel	2002 and 2005	VOC, NO _x , CO, SO ₂ , PM ₁₀ , PM _{2.5}	2001 Estimates carried over. Used state data when provided. (2004)
		HAPs	1999 Estimates carried over. Used state data when provided. (2004)
	1978, 1987, 1990, 1996, 1999, 2000, & 2001	VOC, NO _x , CO, SO _x , PM ₁₀ , & PM _{2.5}	Used criteria emission estimates in the background document for marine diesel regulations for 2000. Adjusted 2000 criteria emission estimates for other used based on fuel usage. Emissions were disaggregated into port traffic and underway activities. Port emissions were assigned to specific ports based on amount of cargo handled. Underway emissions were allocated based on Army Corp of Engineering waterway data. State data replaced national estimates. (2003)
	1970-1998	VOC, NO _x , CO, SO _x , PM ₁₀ , PM _{2.5}	Estimated emissions for interim years using linear interpolation between available base years. (2003)
	1990, 1996, 1999	HAPs	VOC and PM emission estimates were speciated into HAP components. State data replaced national estimates. (2003)
	1996	NH ₃	Applied NH ₃ emissions factors to 1996 distillate and residual fuel oil estimates (i.e., as reported in EIA, 1996).
	1990-1995	NH ₃	Estimation methods reported in EPA, 1998.

**Table 2-2. Methods Used to Develop Annual Emission Estimates for
Nonroad Mobile Sources (Continued)**
(Categories included in this report are noted in bold print)

Category	Base Year	Pollutant(s)	Estimation Method*
CMV Steam Powered	2005	VOC, NO _x , CO, SO _x , PM ₁₀ , & PM _{2.5} , HAPs	2002 estimates grown to 2005 (2008).
	2002	VOC, NO _x , CO, SO _x , PM ₁₀ , & PM _{2.5} , HAPs	2002 based estimates were developed for port and underway category 3 (C3) vessels as part of a rulemaking effort. Emissions were developed separately for near port and underway emissions. For near port emissions, inventories for 2002 were developed for 89 deep water and 28 Great Lake ports in the U.S. The Waterway Network Ship Traffic, Energy, and Environmental Model (STEEM) was used to provide emissions from ships traveling in shipping lanes between and near individual ports (2008)
	1978, 1987, 1990, 1996, 1999, 2000, & 2001	VOC, NO _x , CO, SO _x , PM ₁₀ , & PM _{2.5}	Calculated criteria emissions based on EPA SIP guidance. Emissions were disaggregated into port traffic and under way activities. Port emissions were assigned to specific ports based on amount of cargo handled. Underway emissions were allocated based on Army Corp of Engineering waterway data. State data replaced national estimates. (2003)
	1970-1998	VOC, NO _x , CO, SO _x , PM ₁₀ , PM _{2.5}	Estimated emissions for interim years using linear interpolation between available base years. (2003)
	1990, 1996, & 1999	HAPs	VOC and PM emission estimates were speciated into HAP components. State data replaced national estimates. (2003)
Military Marine	1997-2001	VOC, NO _x , CO, SO ₂ , PM ₁₀ , PM _{2.5}	Applied EGAS growth factors to 1996 emissions estimates for this category.
CMV Coal, ² CMV, Steam powered, CMV Gasoline ²	1997-1998	VOC, NO _x , CO, SO ₂ , PM ₁₀ , PM _{2.5}	Applied EGAS growth factors to 1996 emissions estimates for this category.
CM Coal, CMV, Steam powered, CMV Gasoline, Military Marine	1991-1995	VOC, NO _x , CO, SO ₂ , PM ₁₀ , PM _{2.5}	Estimation methods reported in EPA, 1998.
Locomotives			
Class I, II, III and Yard operations	2008	VOC, NO_x, CO, PM₁₀, PM_{2.5}, SO_x & HAPs	Criteria emission estimates were provided to EPA by ERTAC. These data were assigned to individual railway segments using DOT shapefiles and guidance from ERTAC. HAP emissions were calculated by applying speciation profiles to VOC and PM estimates. (2010)

**Table 2-2. Methods Used to Develop Annual Emission Estimates for
Nonroad Mobile Sources (Continued)**

(Categories included in this report are noted in bold print)

Category	Base Year	Pollutant(s)	Estimation Method*
Class I, Class II, Commuter, Passenger, and Yard Locomotives	1978, 1987, 1990, 1996, 1999, 2000, 2000, 2002, & 2005	VOC, NO _x , CO, PM ₁₀ , PM _{2.5}	Criteria pollutants were estimated by using locomotive fuel use data from DOE EIA and available emission factors. County-level estimates were obtained by scaling the national estimates with the rail GIS data from DOT. State data replaced national estimates. (2004)
	1978, 1987, 1990, 1996, 1999, 2000, 2001, 2002, & 2005	SO ₂	SO _x emissions were calculated by using locomotive fuel use and fuel sulfur concentration data from EIA. County-level estimates were obtained by scaling the national estimates with the county level rail activity data from DOT. State data replaced national estimates. (2004)
	1970-1998	VOC, NO _x , CO, SO _x , PM ₁₀ , PM _{2.5}	Estimated emissions for interim years using linear interpolation between available base years. (2003)
	1990, 1996, 1999, & 2002	HAPs	HAP emissions were calculated by applying speciation profiles to VOC and PM estimates. County-level estimates were obtained by scaling the national estimates with the county level rail activity from DOT. State data replaced national estimates. (2004)
	1997-1998	NH ₃	Grew 1996 base year emissions using EGAS growth indicators.
	1996	NH ₃	Applied NH ₃ emissions factors to diesel consumption estimates for 1996.
	1990-1995	NH ₃	Estimation methods reported in EPA, 1998.

Notes:

* Dates included at the end of Estimation Method represent the year that the section was revised.

1 Emission estimates for unpaved airstrips and aircraft refueling are included in the area source NEI, since they represent non-engine emissions.

2 National Emission estimates for CMV Coal and CMV Gasoline were not developed though states and local agencies may have submitted estimates for these source categories.

EPA, 1998. U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Emission Factors and Inventory Group, National Air Pollutant Emission Trends, Procedures Document, 1900–1996, EPA-454/R-98-008. May 1998.

3.0 HOW WERE LOCOMOTIVE EMISSIONS ESTIMATED?

ERTAC Rail used confidential railroad-provided data to generate railroad-specific criteria emission estimates for line haul and rail yards at the rail segment and rail yard level, respectively. Appendices A-C provide more detail on how emissions were developed and includes critical data used in calculating these estimates. This section of the report describes the emission estimating methods used in general terms as well as the approach for reallocating the emissions to protect confidential data. The data and documentation provided with respect to ERTAC Rail's emission estimates pertain to the version that was incorporated into the NEI and does not reflect recent revisions.

3.1 Line Haul Criteria Emissions Estimates

Criteria pollutant emissions were estimated by applying emission factors to the total amount of distillate fuel oil used by line haul locomotives. Fuel usage was obtained from publically available Class I Railroad Annual Reports (Form R-1). The R-1 reports are submitted to the Surface Transportation Board annually and include financial and operations data to be used in monitoring rail industry health and identifying changes that may affect national transportation policy. Additionally, each railroad provided fleet mix information that allowed ERTAC Rail to calculate railroad-specific emission factors. Weighted Emission Factors (EF) per pollutant for each gallon of fuel used (gm/gal or lbs/gal) were calculated for each Class I railroad fleet based on its fraction of line haul locomotives at each regulated Tier level. EPA emission factors were used for PM_{2.5}, SO₂, and NH₃.

The weighted emission factors were then applied to the link-specific fuel consumption to obtain emissions for each rail segment. Given the confidentiality of the activity data, emissions for criteria pollutants were provided to EPA by ERTAC Rail by county for Class I line haul. Class II/III rail was provided by railroad company and county. Appendices A and B provide more detail on the Class I and Class II/III line haul emission development, respectively.

3.2 Rail Yard Criteria Emissions Estimates

Rail yard locations were identified using a database from the Federal Railroad Administration. Criteria pollutant emissions were estimated by applying emission factors to the total amount of distillate fuel used by locomotives. Each railroad provided fleet mix information that allowed ERTAC to calculate railroad-specific emission factors. The company-specific, system wide fleet mix was used to calculate weighted average emissions factors for switchers operated by each Class I railroad. EPA emission factors were used for PM_{2.5}, SO₂, and NH₃.

R-1 report-derived fuel use was allocated to rail yards using an approximation of line haul activity data within the yard; see Appendix C for more details. These fuel consumption values were further revised by direct input from the Class I railroads. The weighted emission factors were then applied to the yard-specific fuel consumption to obtain emissions for each yard. Since the rail yard inventory was based on publically-available data, the final criteria emission estimates were provided per rail yard.

3.3 Hazardous Air Pollutant Emissions Estimates

HAP emissions were estimated by applying speciation profiles to the VOC or PM estimates. The speciation profiles were derived from *Evaluation of Factors that Affect Diesel Exhaust Toxicity* (Truex and Norbeck, 1998), and data provided by OTAQ (Scarbro, 2001 and 2002). It should be noted that since California uses low sulfur diesel fuel and emission factors specific for California railroad fuels were available, calculations of the state's emissions were done separately from the other states. The HAP speciation profile used in this effort is shown in Table 3-1. HAP estimates were calculated at the yard and link level, after the criteria emissions had been allocated.

Table 3-1. Hazardous Air Pollutant Speciation Profile for 2008 Locomotive Emission Estimation

Pollutant Name	California	All Other States	Speciation Base
1,3 Butadiene	0.0000615	0.0047735	PM ₁₀
2-2-4 Trimethylpentane	0.0022425	0.0022425	VOC
Acenaphthene	0.0000080	0.0000306	PM ₁₀
Acenaphthylene	0.0002182	0.0004275	PM ₁₀
Acetaldehyde	0.0004492	0.0276274	PM ₁₀
Acrolein	0.0000855	0.0045943	PM ₁₀
Anthracene	0.0000535	0.0001009	PM ₁₀
Arsenic	0.0000004	0.0000004	PM ₁₀
Benzene	0.0000517	0.0038020	PM ₁₀
Benzo(a)anthracene	0.0000121	0.0000160	PM ₁₀
Benzo(a)pyrene	0.0000044	0.0000027	PM ₁₀
Benzo(b)fluoranthene	0.0000044	0.0000064	PM ₁₀
Benzo(ghi)perylene	0.0000044	0.0000031	PM ₁₀
Benzo(k)fluoranthene	0.0000044	0.0000052	PM ₁₀
Beryllium	0.0000280	0.0000280	PM ₁₀
Cadium	0.0000280	0.0000280	PM ₁₀
Chromium (III)	0.0000001	0.0000040	PM ₁₀
Chromium (VI)	0.0000000	0.0000021	PM ₁₀
Chrysene	0.0000092	0.0000119	PM ₁₀
Dibenz(a,h)anthracene	0.0000000	0.0000000	PM ₁₀
Ethylbenzene	0.0020000	0.0020000	VOC
Fluoranthene	0.0000601	0.0000746	PM ₁₀
Fluorene	0.0000619	0.0001407	PM ₁₀
Formaldehyde	0.0009451	0.0636582	PM ₁₀
Indeno(1,2,3-cd)pyrene	0.0000033	0.0000027	PM ₁₀
Lead	0.0000840	0.0000840	PM ₁₀
Manganese	0.0000020	0.0000020	PM ₁₀
Mercury	0.0000280	0.0000280	PM ₁₀
Napthalene	0.0018505	0.0025756	PM ₁₀
n-Hexane	0.0055000	0.0055000	VOC

Table 3-1. Hazardous Air Pollutant Speciation Profile for 2008 Locomotive Emission Estimation (Cont.)

Pollutant Name	California	All Other States	Speciation Base
Nickel	0.0000066	0.0000066	PM ₁₀
Phenanthrene	0.0002822	0.0005671	PM ₁₀
Propionaldehyde	0.0061000	0.0061000	VOC
Pyrene	0.0000771	0.0001054	PM ₁₀
Styrene	0.0021000	0.0021000	VOC
Toluene	0.0032000	0.0032000	VOC
Xylene	0.0048000	0.0048000	VOC

4.0 HOW WERE COUNTY LINE HAUL EMISSIONS REALLOCATED TO INDIVIDUAL RAIL SEGMENTS?

4.1 Class I Line Haul Emissions Allocation

Class I line haul emissions were allocated to rail segments based on segment-specific railroad traffic data (ton miles) obtained from the Department of Transportation (BTS, 2009). This dataset categorizes the segments' level of activity into ranges of MGTM and is populated by FRA. Emissions were divided between all mainline segments using these activity ranges as a proxy to allocate more emissions to segments with higher activity.

Since the activity data were provided as ranges, a single "allocation value", typically the midpoint of the range, was selected for use in the emissions allocation. The exception to this was the "0" activity category, which by definition had "unknown" activity. As a result, most mainline segments with the "0" activity category were not included in the emissions calculation/allocation. However, there was a small subset of segments that did have known activity values in the confidential data set but were labeled as "unknown" in the publically available data set. Those segment IDs were provided by ERTAC Rail for inclusion in the emission allocation; however, the activity of these segments was averaged to protect confidential data. Table 4-1 lists the activity categories along with their ranges in MGTM/mi and the allocation value used in the emissions spatial allocation.

Table 4-1. Line Haul Segment Activity (MGTM/Mi) Categories

Category	Range Minimum	Range Maximum	Allocation Value Used
0*	0.0003	0.09	0.01233
1	0.1	4.9	2.5
2	5	9.9	7.45
3	10	19.9	14.95
4	20	39.9	29.95
5	40	59.9	49.95
6	60	99.9	79.95
7	100	1000000	100

* The "0" category has "unknown" activity in the publically available segment data. As a result, this table lists the minimum, maximum, and average of the confidential activity data greater than zero that were categorized as "unknown" in the public data.

The county emission sums were reallocated to the segments by multiplying the county emissions by the segment's allocation value divided by the sum of the allocation values for all links within the county.

$$E_{iL} = E_{iC} * \frac{A_L}{\sum_{C=1}^N A_{LC}}$$

Where:

- E_{iL} = Emissions of pollutant i per link L (tons/year).
- E_{iC} = Emissions of pollutant i per county C (tons/year).
- A_L = Allocation value for link L per activity category from public BTS dataset
- A_{LC} = Sum of allocation values for all links in county C from public BTS dataset

Note that rail line data for Puerto Rico, U.S. Virgin Islands, and Hawaii data were not included in ERTAC Rail’s shapefile and were developed separately; however, since these areas have exclusively Class II/III railroads present, these efforts are discussed in the following section.

4.2 Class II/III Line Haul Emissions Allocation

ERTAC Rail created a shapefile of Class II/III mainline rail segments from their FRA-provided proprietary shapefile as described in Appendix B for the contiguous 48 states and Alaska. Raw rail line data for Puerto Rico were obtained from USGS (Scanlon and Briere, 2000), and rail line data for Hawaii was obtained from ESRI’s Digital Chart of the World (ESRI 2010). The U.S. Virgin Islands have no rail lines. Because Class II/III railroads are less likely to use rail segments that are heavily traveled by Class I railroads, the activity-based approach used for Class I lines was not appropriate. Instead, Class II/III line haul emissions were allocated to rail segments using segment length as a proxy.

The county emission sums were reallocated to the segments by multiplying the county emissions by the segment’s length divided by the sum of the length for all links within the county.

$$E_{iL} = E_{iC} * \frac{l_L}{\sum_{C=1}^N l_{LC}}$$

Where:

- E_{iL} = Emissions of pollutant i per link L (tons/year).
- E_{iC} = Emissions of pollutant i per county C (tons/year).
- l_L = Allocation value for link L per activity category from public BTS dataset
- l_{LC} = Sum of allocation values for all links in county C from public BTS dataset

Since ERTAC Rail used proprietary data to develop the shapefile, some segment IDs were not found in the EIS data set. These segments were manually identified, and their emissions were allocated to the nearest segment within the EIS data set.

4.3 Rail Yard Emissions Allocation

Rail yard emissions were developed based on yard name and ownership properties. As a result, unique yards needed to be identified and emissions summed. Unfortunately, the yard data lacked detail necessary for confident duplicate checks and yard matching such as address, detailed yard name, etc. As a result, a GIS was used to find the centroid of the yards based on the latest public BTS rail network, using the yard name and FIPS. The list of unique yards was further examined against ERTAC's data and within Google Earth to identify any yards that required further revision. A crosswalk of original ERTAC data to new, consolidated yard IDs facilitated the summing of activity and emissions. 753 unique yards were identified nationwide. This underestimate of the total number of yards is most likely due to using line-haul-focused data to identify locations and develop rail yard emissions.

Once the unique yards were identified and criteria emissions were summed at the yard, the PM and VOC-based HAP speciation profile was applied to estimate HAP emissions at each yard.

4.4 State Provided Data

In this version of NEI, state and local agencies were invited to provide locomotive data that replaced the estimates based on national fuel consumption. However, only a small rail yard dataset was received from Kentucky. Their rail yard list was compared with the ERTAC/ERG yard list, and 2 yards were found in both sets. These yards were merged so as to avoid duplication in activity or emissions.

4.5 What are the Results?

Table 3 summarizes the 2008 locomotive mobile source emission estimates.

Table 3. 2008 Locomotive Emissions Data

2008 Locomotive Criteria Emissions				
Pollutant Name	Class I Line Haul	Class II/III Line Haul	Rail Yard	TOTAL
CO	110,969	5,055	9,152	125,176
NH ₃	347	16	27	390
NO _x	754,433	51,342	73,741	879,516
PM ₁₀ -PRI	25,477	1,264	2,086	28,827
PM ₂₅ -PRI	23,439	1,163	2,024	26,626
SO ₂	7,836	357	619	8,811
VOC	37,941	1,896	4,824	44,661
2008 Locomotive Hazardous Air Pollutant Emissions				
Pollutant Name	Class I Line Haul	Class II/III Line Haul	Rail Yard	TOTAL
1,3 Butadiene	116.7941	5.7969	9.3296	131.9206
2-2-4 Trimethylpentane	85.0832	4.2511	10.8178	100.1521
Acenaphthene	0.7569	0.0376	0.0609	0.8554

Table 3. 2008 Locomotive Emissions Data (Cont.)

2008 Locomotive Hazardous Air Pollutant Emissions				
Pollutant Name	Class I Line Haul	Class II/III Line Haul	Rail Yard	TOTAL
Acenaphthylene	10.6772	0.5298	0.8639	12.0709
Acetaldehyde	676.0572	33.5552	54.0089	763.6213
Acrolein	112.4351	5.5806	8.9828	126.9985
Anthracene	2.5231	0.1252	0.2042	2.8525
Arsenic	0.0091	0.0005	0.0007	0.0103
Benzene	93.0272	4.6173	7.4312	105.0757
Benzo(a)anthracene	0.4047	0.0201	0.0329	0.4577
Benzo(a)pyrene	0.0717	0.0036	0.0059	0.0812
Benzo(b)fluoranthene	0.1607	0.0079	0.0131	0.1817
Benzo(ghi)perylene	0.0798	0.0040	0.0066	0.0904
Benzo(k)fluoranthene	0.1312	0.0065	0.0107	0.1484
Beryllium	0.7138	0.0354	0.0584	0.8076
Cadium	0.7138	0.0354	0.0584	0.8076
Chromium (III)	0.0985	0.0049	0.0079	0.1113
Chromium (VI)	0.0508	0.0025	0.0041	0.0574
Chrysene	0.2998	0.0149	0.0244	0.3391
Ethylbenzene	75.8814	3.7914	9.6479	89.3207
Fluoranthene	1.8868	0.0936	0.1538	2.1342
Fluorene	3.5039	0.1739	0.2830	3.9608
Formaldehyde	1,557.66	77.3124	124.4335	1759.4059
Indeno(1,2,3-cd)pyrene	0.0684	0.0034	0.0056	0.0774
Lead	2.1413	0.1062	0.1753	2.4228
Manganese	0.0520	0.0026	0.0043	0.0589
Mercury	0.7138	0.0354	0.0584	0.8076
Napthalene	64.8766	3.2187	5.2765	73.3718
n-Hexane	208.6739	10.4263	26.5317	245.6319
Nickel	0.1669	0.00983	0.0137	0.19043
Phenanthrene	14.1555	0.7024	1.1450	16.0029
Propionaldehyde	231.4383	11.5637	29.4261	272.4281
Pyrene	2.6566	0.1318	0.2161	3.0045
Styrene	79.6755	3.9809	10.1303	93.7867
Toluene	121.4103	6.0662	15.4366	142.9131
Xylene	182.1154	9.0993	23.1549	214.3696

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Appendix A

ERTAC Class I Line Haul Documentation

DRAFT
ERTAC Rail Emissions Inventory
Part 1: Class I Line-Haul Locomotives

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Introduction

Air protection agencies from twenty-seven states, coordinated through the Eastern Regional Technical Advisory Committee (ERTAC) and headed by the Lake Michigan Air Directors Consortium (LADCO), identified a need to better quantify and characterize rail-related emissions inventories. Traditional locomotives largely utilize diesel engines, resulting in emissions of NO_x, diesel PM, hydrocarbons, greenhouse gases, and other pollutants. These emissions are sometimes concentrated in areas exceeding National Ambient Air Quality Standards. No cohesive nationwide railroad emission estimates based on local operations are known to have been made previously. Inventory development methods for locomotive emissions estimates vary from state to state and, in general, lack the spatial or temporal resolution needed to support air quality modeling and planning¹⁻⁵.

The ERTAC Rail Subcommittee (ERTAC Rail) was established with active representatives from twelve member states, three regional planning offices, and the US EPA. The subcommittee's goals are to (1) standardize agencies' inventory development methods through a collaborative effort, (2) improve the quality of data received and the resulting emission inventories, and (3) reduce the administrative burden on railroad companies of providing data.

With support from the Rail industry and assistance from the ERTAC Rail Data Workgroup (Appendix A), ERTAC Rail has developed 3 inventories of locomotive emissions (Table 1); from Class I line-haul, Shortline and Regional Railroads (Class II and III operations), and Class I railyard switchers. Because of the difficulty in obtaining data and differences in states' needs for inventory years, sources from both 2007 and 2008 were utilized (Appendix B.) Due to the variability and uncertainty in much of the data, the results are considered applicable for either 2007 or 2008.

The Surface Transportation Board (STB) defines Class I Railroads as having had minimum carrier operating revenues of \$401.4 million (USD) in 2008. There are 8 Class I Railroads operating in the United States (Table 2), about 12 Regional Railroads (Class II), and approximately 530 Class III Railroads (Shortlines). While categorized as a Class I Railroad, Amtrak was excluded from these inventories because of significant differences in equipment and operation characteristics. Line-haul locomotives travel long distances (e.g. between cities) while switcher locomotives largely operate in railyards, splitting and joining rail cars with varying destinations. Passenger and Commuter Rail (including Amtrak), industrial locomotives, and associated non-locomotive equipment are not included in these inventories.

This paper documents the data sources and methodologies used for calculating the Class I line-haul emissions inventory. Class I line-haul activities are the largest source of rail-related emissions, with estimates of Class I line-haul fuel consumption totals to be from 74 to 84% of all rail sources combined^{4, 5}. For this reason, characterizing Class I line-haul emissions were a focal point of ERTAC Rail’s inventory development efforts. Information on ERTAC Rail, Railroad participation, the Rail industry, and effects of rail on air quality are available elsewhere⁶.

Table 1. Summary of ERTAC Rail Inventories: U.S. Locomotive Emissions and Fuel Use for either 2007 or 2008*.

	Fuel Use** (gal/yr)	Emissions (tons/yr)					
		NO _x	PM _{2.5}	HC	SO ₂	CO	NH ₃
Class I*** line-haul	3,770,914,002	754,443	23,439	37,941	7,836	110,969	347
Class I switcher	300,492,223	73,741	2,024	4,824	619	9,152	27
Class II and III	157,800,000	51,367	1,163	1,897	357	5,058	16

*See Appendix B for a description of the year and source of data utilized for each inventory.

**Locomotive grade diesel

***Excluding Amtrak and including work train fuel use

Table 2. Class I Railroads, Reported Locomotive Fuel Use, and Railroad Fuel Consumption Index (RFCI)⁷.

Class I Railroads*	R-1 Reported Locomotive Fuel Use (gal/yr)		RFCI (ton-miles/gal)
	Line-Haul (2007)**	Switcher (2008)	
BNSF	1,393,874,954	52,497,057	883.14
Canadian National	93,830,751	12,290,022	1190.79
Canadian Pacific***	50,320,233	4,594,067	1096.28
CSX	514,687,186	53,717,674	963.81
Kansas City Southern	69,787,071	1,816,759	785.89
Norfolk Southern	463,267,278	32,317,375	865.75
Union Pacific	1,185,146,529	143,470,336	974.64
Total	3,770,914,002	300,492,223	929.47

* Excluding Amtrak

** Includes work trains

*** CP's line-haul fuel use values include 2008 data (rather than 2007) for their Delaware and Hudson subsidiary.

Method

Earlier efforts to characterize line-haul railroad emissions relied on highly aggregated activity data (Figure 1), and generally apportioned annual system-wide fuel use equally across all route miles of track operated by a Class I railroad. However, the majority of freight tonnage carried by Class I railroads is concentrated on a disproportionately small number of route miles. In addition, emissions calculations were previously based on an estimate of annual nationwide-average locomotive fleet mix to create one set of emissions factors.

For this inventory, the Class I Railroads allowed ERTAC Rail access under a confidentiality agreement to a link-level (single lengths of track) line-haul GIS layer activity dataset managed by the Federal Railroad Administration⁹. Each railroad also provided fleet mix information that allowed ERTAC Rail to calculate weighted emission factors based on the fraction of their line-haul fleet meeting each Tier level category. The use of this data, largely following a line-haul inventory methodology recommended by Sierra Research^{2,3}, resulted in a link-level line-haul locomotive emission inventory using railroad-specific emission factors. This segment-level inventory is nationwide, aggregated to state and county level files, and will be released as gridded emissions files for use in photochemical and dispersion modeling. Link-level emissions may be provided for special study requests pending approval of any Class I railroads operating in the study domain. The calculations are described below as a two-part process, calculating railroad-specific factors and emissions per rail link.

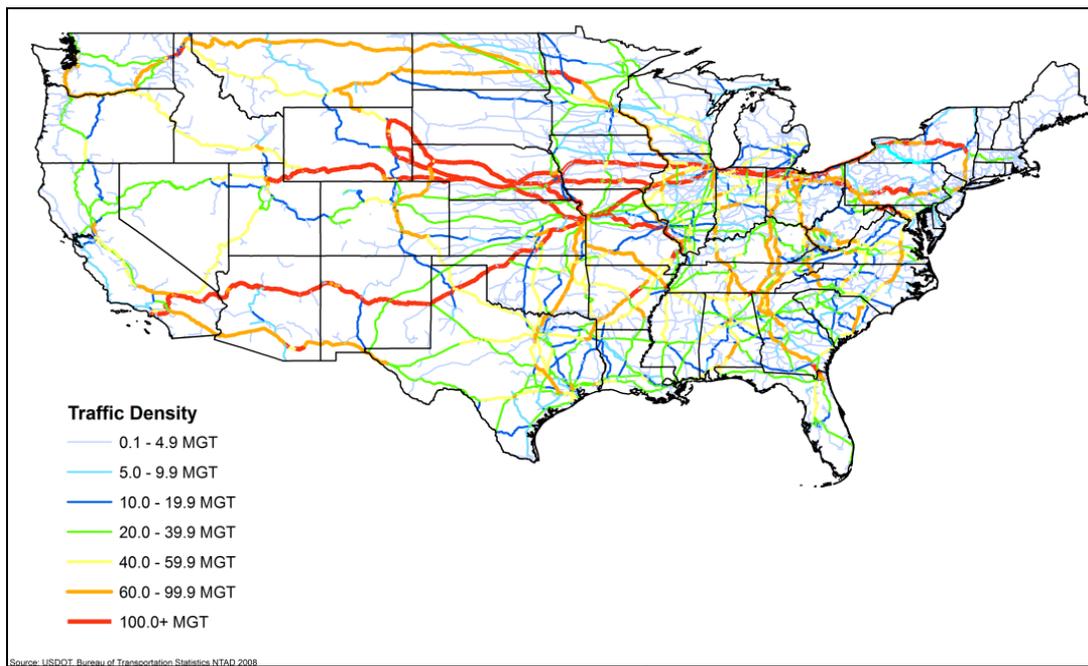


Figure 1. US Railroad Traffic Density in 2006.⁸ MGT is million gross tons.

1. Calculate Railroad-Specific Factors.

The EPA provides annual default Emission Factors for locomotives based on characteristic operating cycles ('duty cycles') and the estimated nationwide fleet mixes for both switcher and line-haul locomotives. However, fleet mixes vary from railroad to railroad and, as can be seen in Figure 2, Class I railroad activity is highly regionalized in nature and subject to issues of local terrain such as operation on plains vs. mountainous areas, which can have a significant impact on fuel consumption and emissions.

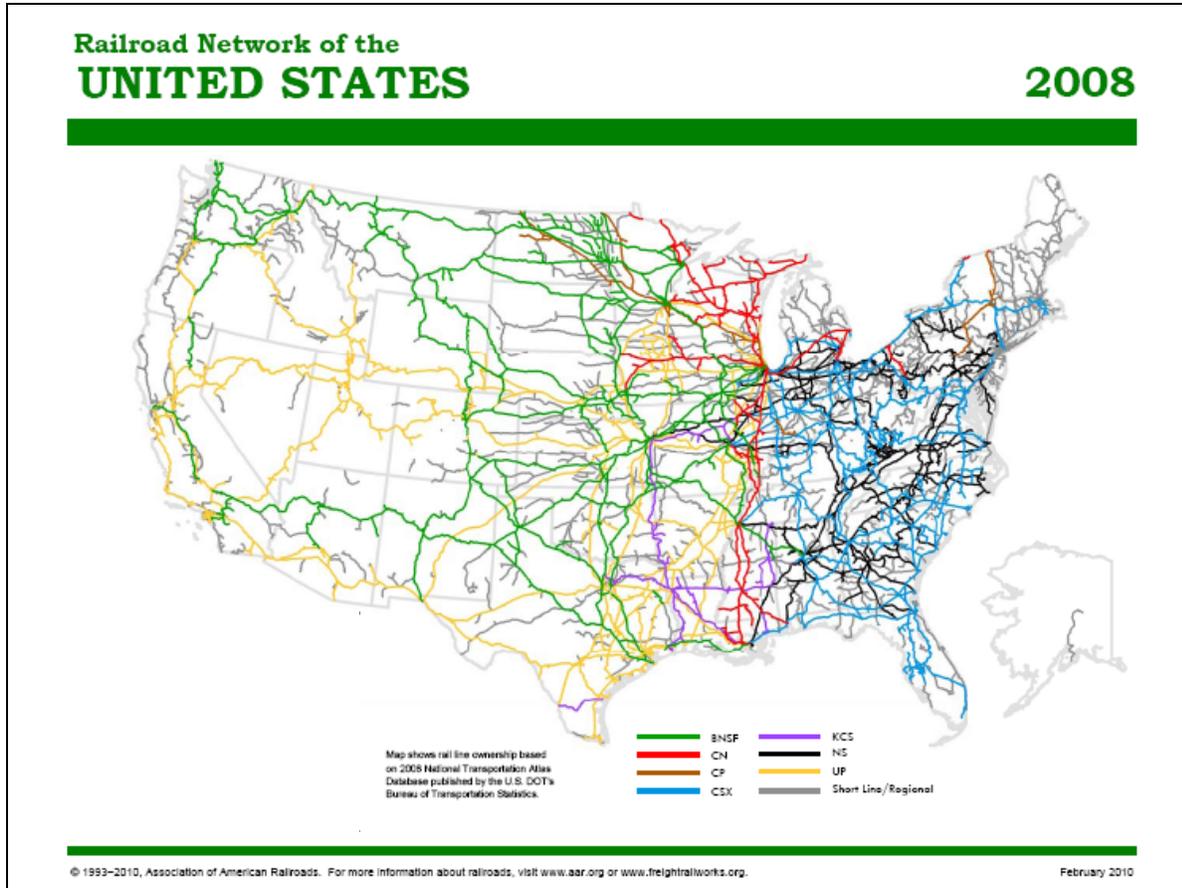


Figure 2. Class I Railroad Territories in the United States¹⁰.

As an alternative approach to using a single nationwide set of emission factors, ERTAC Rail requested each Class I company to provide a description of their line-haul fleet mix based on Tier rating, which each company provided under a confidentiality agreement. An engine's Tier level is based on the year the engine was built and determines allowable emission limits (Table 3).

Table 3. EPA line-haul locomotive Emission Factors by Tier, 1997 standards (grams/gal). Note that the new standards released in 2008 did not apply to fleets in the year 2008. ¹¹

	PM₁₀	HC	NO_x	CO
Uncontrolled (pre-1973)	6.656	9.984	270.4	26.624
Tier 0 (1973-2001)	6.656	9.984	178.88	26.624
Tier 1 (2002-2004)	6.656	9.776	139.36	26.624
Tier 2 (2005 +)	3.744	5.408	102.96	26.624

Based on values in EPA Technical Highlights: Emission Factors for Locomotives, EPA Office of Transportation and Air Quality, EPA-420-F-09-025, April 2009.

Weighted Emission Factors (EF) per pollutant for each gallon of fuel used (gm/gal or lbs/gal) were calculated for each Class I railroad fleet based on its fraction of line-haul locomotives at each regulated Tier level (Eqn 1; Table 3).

$$EF_{iRR} = \sum_{T=1}^4 (EF_{iT} * f_{TRR}) \quad \text{Equation 1}$$

- EF_{iRR} = Weighted Emission Factor for pollutant i for Class I railroad RR (gm/gal).
- EF_{iT} = Emission Factor for pollutant i for locomotives in Tier T (gm/gal) (Table 3).
There were 4 Tiers of locomotives in the 2008 fleets.
- f_{TRR} = Fraction of railroad RR fleet in Tier T.

While engine emissions are variable within Tier categories, this approach likely provides better regional estimates than uniformly applying the nationwide average emission factors. This approach likely provides conservative emission estimates as locomotive engines are certified to meet or exceed the emissions standard for each Tier, although emission levels may increase after certification.

Other emission factors are not engine specific. For locomotives, PM_{2.5} is assumed to be 97% of PM₁₀ ¹¹, and emission factors applied for SO₂ and NH₃ are 1.88 g/gal ¹¹ and 83.3 mg/gal ¹² respectively. Greenhouse gases are estimated using emission factors shown in Table 4.

Table 4. EPA greenhouse gas emission factors for locomotive diesel fuel (grams/gal). ¹³

	CO₂	N₂O	CH₄
Locomotive diesel	1.015E4	0.26	0.80

A Railroad Fuel Consumption Index (RFCI) was also calculated for each Class I railroad using their system-wide line-haul fuel consumption (FC) and gross ton-mile (GTM) data reported in their annual R-1 reports submitted to the Surface Transportation Board⁷ (Eqn 2). This value represents the average number of GTM produced per gallon of diesel fuel used over their system in a year, and varies between railroad carriers depending on factors such as fleet mix, system

terrain, speeds, loading/weight of cargo, train type (e.g., intermodal, unit, and manifest), and operating practices. (Table 2).

$$RFCI_{RR} = \frac{GTM_{RR}}{FC_{RR}} \quad \text{Equation 2}$$

$RFCI_{RR}$ = Railroad Fuel Consumption Index (gross ton-miles/gal) per Class I railroad (RR).
 GTM_{RR} = Gross Ton-Miles (GTM), annual system-wide gross ton miles of freight transported per RR. (R-1 Report Schedule 755, Line 104)
 FC_{RR} = Annual system-wide fuel consumption by line-haul and work trains per RR (gal) (R-1 Report Schedule 750, Lines 1 and 6).

2. Calculate Emissions per Link.

Emissions of pollutant *i* per link *L* (E_{iL}) are then calculated by multiplying the gallons of diesel fuel consumed by each Class I railroad on the link by that railroad's weighted Emission Factor for the pollutant, and summed over all railroads operating on the link (Eqn 3). This approach splits the activity on each link (represented by MGT) evenly between all railroads operating on the link. Note that the weighted Emission Factors are converted to tons/gal for these calculations, and that variables with units in tons may represent tons of freight hauled (MGT, RFCI) or tons of pollutants (EF, E).

$$E_{iL} = \sum_{RR=1}^N \left(\frac{MGT_L * 10^6}{N} \right) * I_L * EF_{iRR} \quad \text{Equation 3}$$

E_{iL} = Emissions of pollutant *i* per link *L* (tons/year).
 N = Number of Class I railroads operating on link *L*.
 MGT_L = Millions of Gross Tons hauled per link per year from the FRA database (10^6 tons/yr)⁹.
 l_L = Link length from the FRA database (miles).
 EF_{iRR} = Weighted Emission Factor for pollutant *i* per railroad *RR* (Eqn 1; tons/gal).
 $RFCI_{RR}$ = Railroad Fuel Consumption Index per railroad *RR* (Eqn 2; gross ton-miles/gal).

Note that approximately 36% of Class I route miles in the United States are shared by more than one Class I carrier, a fraction that drops to 26% when neglecting track only shared between one Class I freight railroad and Amtrak. Accurately apportioning the specific fractions of tonnage (MGT) per carrier per link was considered, but after comparing likely worst-case areas, the difficulty of merging carrier-specific MGT with the aggregated FRA MGT dataset was considered too great considering the potential gain in accuracy. Where warranted, MGT data may be apportioned more accurately in the future.

Limitations, Conclusions, and Future Work

Rail-related emissions can be important components of emissions inventories used to support effective air quality management practices, at local, state, regional, and national levels. This line-haul inventory, as well as the companion Class I railyard inventory and Class II/III inventory, greatly improve our estimates of rail-related emissions. However, a systematic study of variability and uncertainty in line-haul locomotive emissions and activity, by fleets, locations, and through time, would give valuable information for identifying how to best improve this inventory as well provide an indication of how representative the inventory may be. An uncertainty study on the data used for this inventory, including the R-1 reported fuel use and the confidential link-level tonnage data, would also help in evaluating the quality of this inventory. Localized studies should also examine how shared tracks are apportioned between multiple carriers.

Early ERTAC Rail discussions concluded that link-level tonnage was the most important data to obtain, while other variables such as track grade and track speed could not be addressed at this time. ERTAC Rail calculated railroad-specific fleet-averaged emission factors rather than applying the estimated national average; however, it is recognized that emissions from individual engines are highly variable even within Tier categories depending on variables such as the specific locomotive model, operation cycle, and conditions of operation. Future evaluation of emission variability within Tiers and between certain types of operation and locations would also be valuable.

Emissions inventory preparation guidance from the U.S. EPA describes locomotive activity as relatively constant throughout the year (e.g. no daily, weekly, or seasonal variability); however, actual activity levels do vary seasonally and annual averaging may dilute or exaggerate concentrations during pollution episodes. ERTAC Rail and the Class I railroad community had some discussions addressing if incorporating more specific fleet mix or monthly or seasonal variation may be worthwhile, and these topics should be looked into further.

Finally, it is important to reiterate that the link-level MGT data maintained by the FRA is proprietary and can only be released to agencies/groups outside the FRA with the express permission of each Class I railroad. It is possible that one or more Class I railroads could withhold permission for access, but data for specialized studies may be provided if requested. This database can also be improved by better distinguishing between haulage and trackage rights, and by apportioning tonnage hauled on links to specific carriers.

We would like to thank the Class I Railroads and their representatives for their assistance and support in the development of this inventory.

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Appendix A: ERTAC Rail Data Workgroup

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Joanne Maxwell	Amtrak

Appendix B: Source and Year of Data Utilized for Each Inventory

Data	Year	Source
Class I Line-Haul		
Annual Line-Haul Fuel Use and Gross Ton-Miles	2007	STB R-1 Reports (CP data for D&H is for 2008.)
Line-haul fleet mix for emission factors	2008	Each Class I railroad
Link-level tonnage	2007	FRA confidential database
Class I Railyards (Switcher Locomotives)		
Annual Switcher Fuel Use	2008	R-1 Reports
Switcher fleet mix for emission factors	2008	Each Class I railroad
Link-level tonnage or Density Code (for activity estimate)	2007	FRA confidential database
Class II and III Locomotives		
Annual Total Fuel Use	2008	ASLRRRA Annual Report (2008)
Track length and railroad	2008	ASLRRRA Annual Report (2008)
Estimated fleet mix for emission factors		Discussions with ASLRRRA and Class II and III representatives.

Appendix B

ERTAC Class II/III Line Haul Documentation

DRAFT

ERTAC – Class 2/3 Shapefile Documentation

13 Jul 2009

Introduction

This document outlines the methods and procedures used to compile a shapefile representing the links in the FRA 1:100,000 railroad dataset that are owned or operated by Class II and III railroad companies. It is important to note that there is a considerable amount of overlap between the Class II's and III's and the Class I and passenger railroads. Class II's and III's can operate on Class I or passenger rail links and vice versa. Although the final shapefile specifically represents Class II and III links, there are many Class I and passenger railroads represented as well.

Procedure

1. Started with all proprietary FRA links where “NET = ‘M’ and “STCNTYFIPS” <> ‘ ‘ (this definition query selects all active mainline links located within the United States).
2. Ran 12 queries, one for each ownership and trackage rights field, to select all links not associated with a Class I freight railroad or Amtrak and not containing a null value (e.g., "RROWNER1" <> 'AMTK' AND "RROWNER1" <> 'BNSF' AND "RROWNER1" <> 'CN' AND "RROWNER1" <> 'CPRS' AND "RROWNER1" <> 'CSXT' AND "RROWNER1" <> 'KCS' AND "RROWNER1" <> 'NS' AND "RROWNER1" <> 'UP' AND "RROWNER1" <> '). The first query was setup as a new selection. Each of the 11 subsequent queries were setup to add records to initial set of records. 26,261 links were selected and exported to a new shapefile.
3. Due to the multitude of railroad codes used to represent commuter rail operations across the country, additional processing was required to remove any links that were not operated by a Class II or III freight railroad. Each commuter railroad was queried out of the new shapefile and the links analyzed to eliminate all links where no Class II or III operations were occurring. The following commuter rail operations were evaluated: NJT (New Jersey Transit), MNCW (Metro-North Commuter Railroad), LI (Long Island Railroad), CDOT (Connecticut DOT), MBTA (Massachusetts Bay Transportation Authority), SEPA (Southeastern Pennsylvania Transportation Authority), MARC (Maryland Area Rail Commuter), VRE (Virginia Railway Express), MTRA (Northeastern Illinois Regional Commuter Railroad), CSS (Northern Indiana Commuter Transportation District), DART (Dallas Area Rapid Transit), SCRA (Southern California Regional Rail Authority – including also SCAX, LACM, LAPT, and LATC), TCRA (South Florida Regional Transportation Authority), PJPB (Caltrain), and ACE (Altamont Commuter Express).

Approximately 1581 links were identified with no Class II or III operations and were deleted from the Class 2/3 shapefile.

4. The remaining Class II and III links were then compared to the regional maps contained in the July-August issue of The Official Railway Guide to assess the completeness of the Class 2/3 shapefile. Six specific edits were made to the shapefile to correct the most glaring errors: 1) BMLP links deleted (Black Mesa & Lake Powell, an electric coal hauling railway in Arizona); 2) DSNG links deleted (Durango & Silverton steam tourist railroad in Colorado); 3) CIC haulage rights links on CN from Chicago to Omaha deleted; 4) DMIR links deleted (Duluth, Missabe & Iron Range, now owned and operated by CN in Minnesota); 5) EVWR's ex-CSXT links coded from Evansville, IN to Okawville, IL (Evansville Western Railroad); 6) INRD ex-CP links coded from Chicago, IL to Louisville, IN (Indiana Rail Road).
5. During the course of reviewing the FRA dataset, 555 "active" links were found to have no ownership or trackage rights codes. 1005 links have no codes listed in the 3 ownership fields. In most cases these links are very short and scattered across the country. Only the links representing the EVWR and INRD spanned large distances and were fixed. The other problem links were deemed to be insignificant. A listing of these links will be provided back to the FRA to assist with their coding in 1:100K railway shapefile.

Appendix C

ERTAC Rail Yard Documentation

DRAFT
ERTAC Rail Emissions Inventory
Part 2: Class I Railyard Switcher Locomotives

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Introduction

Air protection agencies from twenty-seven states, coordinated through the Eastern Regional Technical Advisory Committee (ERTAC) and headed by the Lake Michigan Air Directors Consortium (LADCO), identified a need to better quantify and characterize rail-related emissions inventories. Traditional locomotives largely utilize diesel engines, resulting in emissions of NO_x, diesel PM, hydrocarbons, greenhouse gases, and other pollutants. These emissions are sometimes concentrated in areas exceeding National Ambient Air Quality Standards. No cohesive nationwide railroad emission estimates are known to have been made previously. Inventory development methods for locomotive emissions estimates vary from state to state and, in general, lack the spatial or temporal resolution needed to support air quality modeling and planning¹⁻⁵.

The ERTAC Rail Subcommittee (ERTAC Rail) was established with active representatives from twelve member states, three regional planning offices, and the US EPA. The subcommittee's goals are to (1) standardize agencies' inventory development methods through a collaborative effort, (2) improve the quality of data received and the resulting emission inventories, and (3) reduce the administrative burden on railroad companies of providing data. With support from the Rail industry and assistance from the ERTAC Rail Data Workgroup (Appendix), ERTAC Rail has developed 3 inventories of locomotive emissions; from Class I line-haul, Shortline and Regional Railroads, and Class I railyard switchers, for the year 2008 (Table 1).

The Surface Transportation Board (STB) defines Class I Railroads as having had minimum carrier operating revenues of \$401.4 million (USD) in 2008. There are 8 Class I Railroads operating in the United States (Table 2), about 12 Regional Railroads (Class II), and approximately 530 Class III Railroads (Shortlines). While categorized as a Class I Railroad, Amtrak was excluded from these inventories because of significant differences in equipment and operation characteristics. Line-haul locomotives travel long distances (e.g. between cities) while switcher locomotives largely operate in railyards, splitting and joining rail cars with varying destinations. Passenger and Commuter Rail (including Amtrak), industrial locomotives, and associated non-locomotive equipment are not included in these inventories.

Table 1. Summary of ERTAC Rail Inventories: U.S. Locomotive Emissions and Fuel Use for either 2007 or 2008*.

	Fuel Use** (gal/yr)	Emissions (tons/yr)					
		NO _x	PM _{2.5}	HC	SO ₂	CO	NH ₃
Class I*** line-haul	3,770,914,002	754,443	23,439	37,941	7,836	110,969	347
Class I switcher	300,492,223	73,741	2,024	4,824	619	9,152	27
Class II and III	157,800,000	51,367	1,163	1,897	357	5,058	16

*See Appendix B for a description of the year and source of data utilized for each inventory.

**Locomotive grade diesel

***Excluding Amtrak and including work train fuel use

Table 2. Class I Railroads and Reported Locomotive Fuel Use⁷.

Class I Railroads*	R-1 Reported Locomotive Fuel Use (gal/yr)	
	Line-Haul (2007)**	Switcher (2008)
BNSF	1,393,874,954	52,497,057
Canadian National	93,830,751	12,290,022
Canadian Pacific***	50,320,233	4,594,067
CSX	514,687,186	53,717,674
Kansas City Southern	69,787,071	1,816,759
Norfolk Southern	463,267,278	32,317,375
Union Pacific	1,185,146,529	143,470,336
Total	3,770,914,002	300,492,223

* Excluding Amtrak

** Includes work trains

*** CP's line-haul fuel use values include 2008 data (rather than 2007) for their Delaware and Hudson subsidiary.

This paper documents the data sources and methodologies used for calculating the Class I switcher (“Railyard”) inventory. Information on ERTAC Rail, Railroad participation, the Rail industry, and effects of rail on air quality are available elsewhere⁶.

Method

Switcher locomotives are expected to be the single largest source of air emissions in railyards. Therefore, as a starting point for a comprehensive railyard inventory, a Class I switcher emission inventory was developed. It is assumed that estimates for yards of interest, associated equipment and activity, and smaller railroads could be refined later.

While ERTAC Rail represents states east of the Mississippi River, the railroad companies specified they wanted this effort to result in a consistent nationwide inventory. ERTAC Rail agreed to calculate emissions for all states when the data was available and when additional

significant effort was not required. Because both the dataset of railyards and switcher fuel use was nationwide in scope, the resulting initial railyard inventory is a nationwide, ‘top-down’ derivation. However, railroad companies may have different levels and quality of data available, and may have interpreted some data requests differently. Also, states are requested to update yards they have detailed information on when possible, and a few states (i.e. California) have unique railroad operations and equipment. Therefore, data for some areas will be more accurate than for others, and locally-derived inventories may be more accurate.

This documentation describes development of the initial top-down inventory, which consisted of three main activities:

1. Locate Class I Railyards
2. Select/Calculate Emission Factors
3. Estimate Locomotive Activity
4. Improve Estimates

1. Locate Class I Railyards.

Identification and correct placement of railyards was an important first step, requiring a comprehensive electronic dataset. A confidential database was obtained from the Federal Railroad Administration (FRA) with permission from the Class I Railroads (FRA database). A similar public database compiled by the Bureau of Transportation Statistics is also available⁷. Data from this source will not match the confidential data exactly, but will be very similar. The FRA database has rail links (track lengths) individually identified as parts of specific railyards. While there may be discrepancies in how each railroad defined railyard links, this dataset appears to identify most Class I railyards in the U.S., and shows a high density of yards in the eastern states (Figure 1). The database gives length, up to 3 owners and 3 operators, and a Federal Density Code (explained below) for each railyard link.

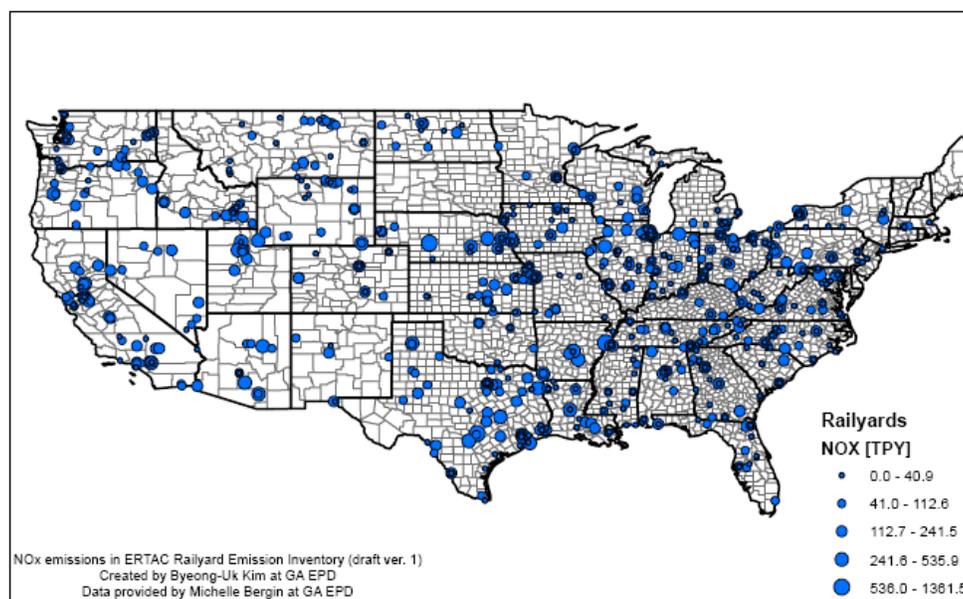


Figure 1. Class I Railyards in the United States and estimates of Annual NOx emissions from switcher locomotives (tons/yr in 2008).

2. Select/Calculate Emission Factors.

The EPA provides annual default emission factors based on characteristic operating cycles ('duty cycles') and the estimated nationwide fleet mix for both switcher and line-haul locomotives. However, switcher fleet mix is not uniform from company to company and, as can be seen in Figure 2, Class I railroad activity is highly regional.

As an alternative approach, ERTAC Rail requested each Class I rail company to provide a description of their switcher fleet mix based on Tier rating, which each company provided under a confidentiality agreement. An engine's Tier determines allowable emission limits based on the year the engine was built (Table 3). While engine emissions are variable within Tier categories, this estimate likely provides a better regional estimate than the nationwide average. The company-specific systemwide fleet mix was used to calculate weighted average emissions factors for switchers operated by each Class I railroad.

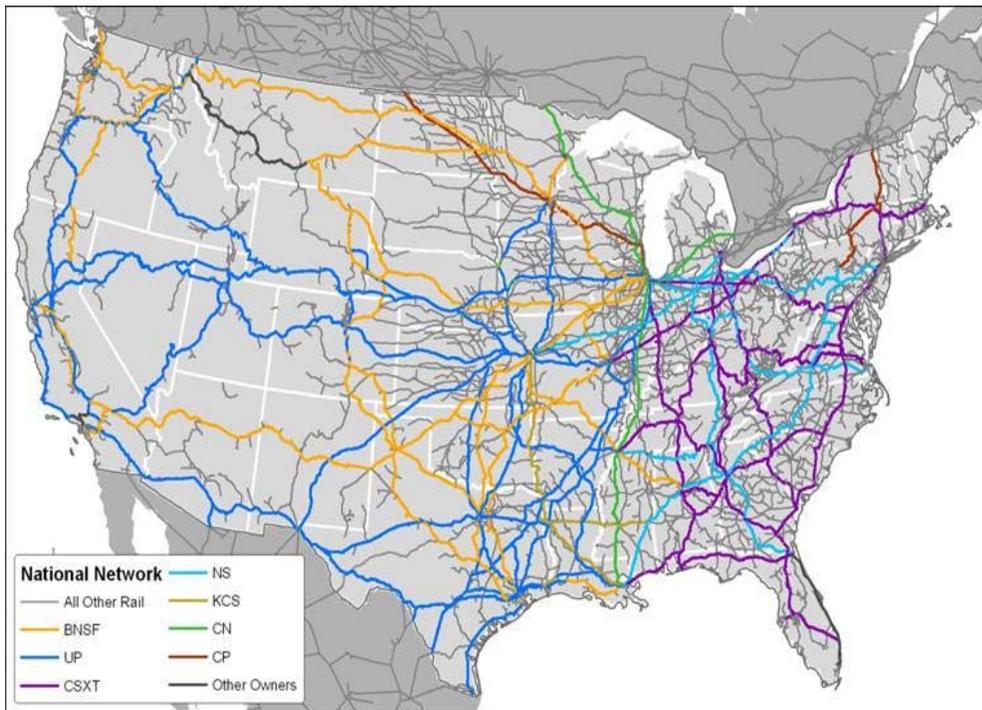


Figure 2. Class I Railroad Territories in the United States.

Table 3. EPA switcher locomotive emission factors by Tier, 1997 standards (grams/gal).

	PM₁₀	HC	NO_x	CO
Uncontrolled (pre-1973)	6.688	15.352	264.48	27.816
Tier 0 (1973-2001)	6.688	15.352	191.52	27.816
Tier 1 (2002-2004)	6.536	15.352	150.48	27.816
Tier 2 (2005 +)	2.888	7.752	110.96	27.816

Listed years apply to the year the engine was built. Table based on values from⁸. Note that the new standards released in 2008 did not apply to existing fleets in the year 2008.

For locomotives, PM_{2.5} is assumed to be 97% of PM₁₀⁸, and emission factors for SO₂ and NH₃ are 1.88 g/gal and 83.3 mg/gal respectively (add cites). Greenhouse gases are also estimated using emission factors shown in Table 4.

Table 4. EPA greenhouse gas emission factors for locomotive diesel fuel (grams/gal).

	CO ₂	N ₂ O	CH ₄
Locomotive diesel	1.015E4	0.26	0.80

Source: U.S. Environmental Protection Agency. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2005, EPA 430-R-07-002, Annex 3.2, (April 2007), web site: <http://www.epa.gov/climatechange/emissions/usinventoryreport.html>

These emission factors are based on a characteristic duty cycle for switchers which assumes operation over 24-hour per day 365 days per year. An evaluation of the effect of variability in railyards and switching duties on emissions would be useful for future inventories.

3. Estimate Locomotive Activity.

Class I railroads report total annual switcher locomotive fuel use to the STB, which is reported in publicly available ‘R-1’ reports (Table 2). There may be inconsistencies between railroads in how fuel use is estimated to be apportioned between line-haul and switcher locomotive use, and possibly in the total locomotive fuel use, so these values may be adjusted in the future.

However, the use of these values provides a starting point for estimating total U.S. Class I locomotive-related emissions segregated by Class I carrier. The R-1 report was used by ERTAC for both the line-haul and switcher locomotive emissions inventories.

The next step for inventory development is to allocate switcher fuel use to each railyard. Two methods were applied, one that relies on publicly available line-haul activity (the ‘Decode’ method), and the other using confidential line-haul activity (the ‘MGT’ method.) At this time, Norfolk Southern and Kansas City Southern have provided input for use of the MGT method and the Decode method is applied for the other five railroads.

The Decode Method – Publicly available data

Each link in both the publicly available BTS database and the confidential FRA database has a ‘Federal Density Code’ (Decode) ranging from 1 to 7 assigned based on the cumulative annual freight tonnage hauled on the link (track). Total Switcher Fuel Use in each railyard Y (SFU_Y) is estimated as follows:

First the Switcher Activity Indicator per yard (SAI_Y) is estimated by multiplying the average decode of the links identified as part of the same railyard by the sum of the length of the links for that railyard (Eqn 1).

$$SAI_Y = \sum (l_{nY} * FDC_{nY}) \quad \text{Equation 1}$$

SAI_Y = Switcher Activity Indicator in Railyard Y

n_Y = number of links identified as part of railyard Y
 l_{nY} = length of link n in miles
 FDC_n = Federal Density Code (1 to 7) of link n

Next, this value is then weighted (SAI_Y') based on an ownership factor (OF) set between 0 and 1. The OF depends on the number of owners listed for each railyard: if there is one owner the OF is set to 1, if there are two owners the primary owner is set to 0.8 and the secondary is 0.2, and if there are 3 owners the primary is 0.6, the secondary is 0.2, and the tertiary is 0.1.

$$SAI_Y' = OF_Y * SAI_Y \quad \text{Equation 2}$$

Next, the SAI_Y' of all railyards belonging to a Class I railroad (RR) were summed, and the fraction of the railroads total SAI associated with each railyard was multiplied by the railroads total annual switcher fuel use reported in the R-1 (TFU_{RR}), resulting in the total Switcher Fuel Use for each railyard Y (Eqn 2).

$$SFU_Y = \frac{SAI_Y'}{\sum_{RR} SAI_Y'} * TFU_{RR} \quad \text{Equation 3}$$

SFU_Y = Switcher Fuel Use at railyard Y

Finally, the SFU_Y is multiplied by the emission factors described in the previous section to obtain annual switcher emissions at each railyard.

The MGT Method – Confidential data

Two railroads, Norfolk Southern and Kansas City Southern, provided confidential link-level tonnage information and weighting factors to correct skewed estimates to improve estimated switcher activity at important yards. Other railroads may also allow the use of this technique for their inventories in the future.

The MGT Method also uses the FRA database for railyard identification and link lengths. However, rather than using the average dencode per link, confidential annual gross tonnage (MGT) hauled per link in the railyard was used to calculate the railyard switcher activity (SAI_Y). This is calculated by replacing FDC_n in Equation 2 with link-specific tonnage MGT_n (Equation 4).

$$SAI_Y = \sum (l_{nY} * MGT_{nY}) \quad \text{Equation 4}$$

SAI_Y = Switcher Activity Indicator in Railyard Y
 n_Y = number of links identified as part of railyard Y

l_{nY} = length of link n in miles
 MGT_{nY} = million gross tons on link n

This method provides a more refined comparison between railyards than the use of the 7-category dencodes; however, is more susceptible to errors for yards where tonnage is not correlated to switching activity. For example, a yard with large coal trains pulling through used for crews to change over would be assigned an overly high level of emissions for switching activity. To account for this, a discretionary Switching Activity Factor (SAF) was introduced to allow railroads to roughly weight yards with clearly higher or lower levels of switching activity than what results from the mathematical allocation. Therefore, SAI_Y is weighted based on both the ownership factor (OF) as well as the SAF (Equation 5). For example, a yard used for crew changes and not switching may have an SAF of 0, while a yard at a major interchange between cities may have an SAF of 3.

$$SAI_Y' = OF_Y * SAF_Y * SAI_Y \quad \text{Equation 5}$$

Again, the SAI_Y' of all railyards belonging to a Class I railroad (RR) are summed, and the fraction of the railroads total SAI associated with each railyard was multiplied by the railroads total annual switcher fuel use reported in the R-1 (TFU_{RR}), resulting in the total Switcher Fuel Use for each railyard Y (Eqn 6).

$$SFU_Y = \frac{SAI_Y'}{\sum_{RR} SAI_Y'} * TFU_{RR} \quad \text{Equation 6}$$

While the SAF allows estimates of yard-specific emissions to be adjusted, the total level of emissions for each railroad, which is based on systemwide fuel use and systemwide emission factors, remains unchanged. The MGT method SFU_Y is also later multiplied by the emission factors described in the previous section to obtain annual switcher emissions at each railyard.

4. Improve estimates.

In addition to the Switching Activity Factor described above, direct input was also used to improve emission estimates for important railyards. Each Class I railroad provided an estimate of annual average switcher fuel use (generally much lower than the EPA default of 82,490 gal/yr) as well as the name, location, and number of operating switchers for railyards with 8 or more switchers operating in ozone or PM2.5 nonattainment areas. This data was used to overwrite the dencode or MGT derived emissions estimates for those railyards.

The difference in estimated fuel use for those railyards was re-allocated (added or removed) between the remaining railyards belonging to that Class I railroad. It is important to note that there are some discrepancies in how this data was reported for the large railyards by each railroad. For example, some railroads reported all switchers located at a railyard while others reported 'full time equivalent' switchers, meaning the number of switchers normalized to a full working cycle (24-hours per day year-round.) This process should be standardized for future inventory versions.

States also have the option of updating specific railyard emissions estimates. Because this inventory is derived ‘top-down’, local studies and familiarity with specific railyards is expected to provide better estimates, which can be used to adjust this inventory. Care must be taken to ensure the other railyard estimates are adjusted to account for increases or decreases in estimated fuel use per yard.

Limitations, Conclusions, and Future Work

What this ERTAC Rail railyard inventory does well is provide a comprehensive overview of where railyards are, who owns them, and gives a geographical allocation of switcher emissions bounded by what is reported as nationwide switcher fuel usage by the Class I railroads. These sources can be important for air quality management in nonattainment areas, as well as in regional analysis and for future transportation planning. This inventory will be useful for regional and some local modeling, helps identify where railyards need to be better characterized, and provides a strong foundation for future development of a meaningful nationwide Class I switcher emissions inventory.

There are important uncertainties associated with estimates from this method, including, but not limited to, the use of tonnage hauled as an indicator of the amount of switching activity, and, for a few of the railroads, how the amount of switcher fuel use was determined to be reported in the R-1. The R-1 reported values are currently under examination.

There is also likely significant variability in actual switching duty-cycles and, potentially, in the number of switchers operating at some railyards at different times of the year. ‘Road-switching’, or the use of what are considered switching locomotives to move between nearby yards, should be addressed in either this or the ERTAC line-haul inventory.

It must be noted that freight-related rail activity is not always routine and no annual emissions inventory will ever be able to capture the innate variability of the source. However, as other large emission sources are reduced, and if rail activity increases as expected, it is important to include our best estimates of these sources in air quality analysis. In the future, on-line data loggers and other tracking technologies, combined with ambient studies and detailed modeling, will hopefully provide more insight to the emissions of locomotives and other railyard sources.

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Appendix: ERTAC Rail Data Workgroup

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