Comparison of Nonroad Hazardous Air Pollutant Emissions Included in the National Emission Inventory

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ABSTRACT

The National Emission Inventory (NEI) includes criteria pollutants and hazardous air pollutants (HAPs) from all stationary and mobile sources. The mobile source emissions component of NEI contains estimates for onroad as well as nonroad source categories. Nonroad source categories include, aircraft, commercial marine vessel (CMV), locomotive, and "other" nonroad vehicle and engines[1]. The other nonroad source categories are the vehicles and engines included in U.S. Environmental Protection Agency's (EPA's) draft NONROAD model, such as construction and agricultural equipment, recreational engines, and portable commercial, institutional, and industrial equipment.

The nonroad emission estimates have been significantly improved in the 1999 NEI, both in terms of the quality of the emissions estimates which were developed and the refinement of the spatial allocation methods used. This paper discusses the methods used and improvements made to estimate emissions for the other nonroad emission sources. This paper also compares the emission estimates between each of the individual other nonroad categories, identifying the most significant sources of the HAPs included in the NEI. Spatial assessments are performed to evaluate emission differences between urban and rural counties.

BACKGROUND

Under Section 112 of the Clean Air Act (CAA), as amended in 1990 requires the EPA to identify emission sources of criteria pollutants and HAPs, 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 comprehensive inventory covering all criteria pollutants and HAPs for all areas of the United States. The NEI was created by the EPA's Emission Factor and Inventory Group (EFIG) in Research Triangle Park, North Carolina. The NEI is a tool that EPA can use to meet the CAA mandates.

The NEI 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 allow the NEI emission data to be transferred to multiple end-users for a variety of purposes. For example, the criteria and HAP

emission estimates developed for the NEI are incorporated into the annual EPA publication entitled *National Air Quality and Emissions Trends Report,* which is used to evaluate air pollution trends over time. The NEI is also a critical component of the EPA's national Air Toxics Program (as described in EPA's July 19, 1999 Federal Register notice, 64 FR 38706). The initial objective of the Air Toxics Program is to make the data available for air quality modeling and subsequent exposure and risk analyses use in the National Air Toxics Assessment (NATA).

The target inventory area of NEI 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 and the 188 HAPs identified in Section 112(b) of the CAA.

The mobile source component of the NEI is composed of onroad vehicles, aircraft, commercial marine vessels (CMVs), locomotive, and other nonroad engines and equipment. Emission estimates were developed for each mobile source category for each county in the U.S. Concurrent with the development of the national emission estimates, some state and local agencies developed and provided to the EPA emissions inventory data for their areas based on local knowledge and activity information. These state and local agency data replaced the national emission estimates when the pollutant, source category, and emission type matched with data in the NEI.

The other nonroad mobile source category includes vehicles and equipment that normally are not operated on public roads nor provide transportation and are not considered aircraft, CMVs or locomotives. Note, the individual source categories included in this group are the same source categories included in the NONROAD model. These include categories such as lawn and garden equipment, agricultural equipment, logging equipment, construction equipment, airport service vehicles, locomotive maintenance vehicles, and recreational equipment (including recreational marine engines). The other nonroad vehicles and equipment include both diesel-powered and gasoline-powered engines. Gasoline-powered engines can further be characterized into two engine categories, specifically 2- and 4-stroke engines.

Emission estimates for the other nonroad component of the NEI include all of the criteria pollutants and 22 HAPs (note that the polycyclic aromatic hydrocarbon (PAH) HAP group contains 16 individual compounds. The HAP estimates include the pollutants listed below. These pollutants were identified based on available test data and accepted emission estimating procedures.

1,3-Butadiene
2,2,4-Trimethylpentane
Acetaldehyde
Acrolein
Arsenic
Benzene
Chromium (Hexivalent)
Chromium (Trivalent)
Dioxins/Furans
Ethylbenzene
Formaldehyde
Lead
Manganese
Mercury
Methyl Tert-Butyl Ether
n-Hexane
Nickel
PAH
Propionaldehyde
Styrene
Toluene
Xylenes

METHODS USED TO ESTIMATE 1999 HAP EMISSIONS

The nonroad emission estimates provided in the NEI were derived using a mixture of “top down” and “bottom up” approaches. Figure 1 provides an overview of the approaches used to estimate emissions from this source sector. Data submitted by state and local agencies, for some areas, replaced EPA’s nationally-developed estimates.

The emission estimates for organic HAPs were developed by applying HAP speciation profiles to county-level volatile organic compounds (VOC) estimates. A number of different fuels are used in

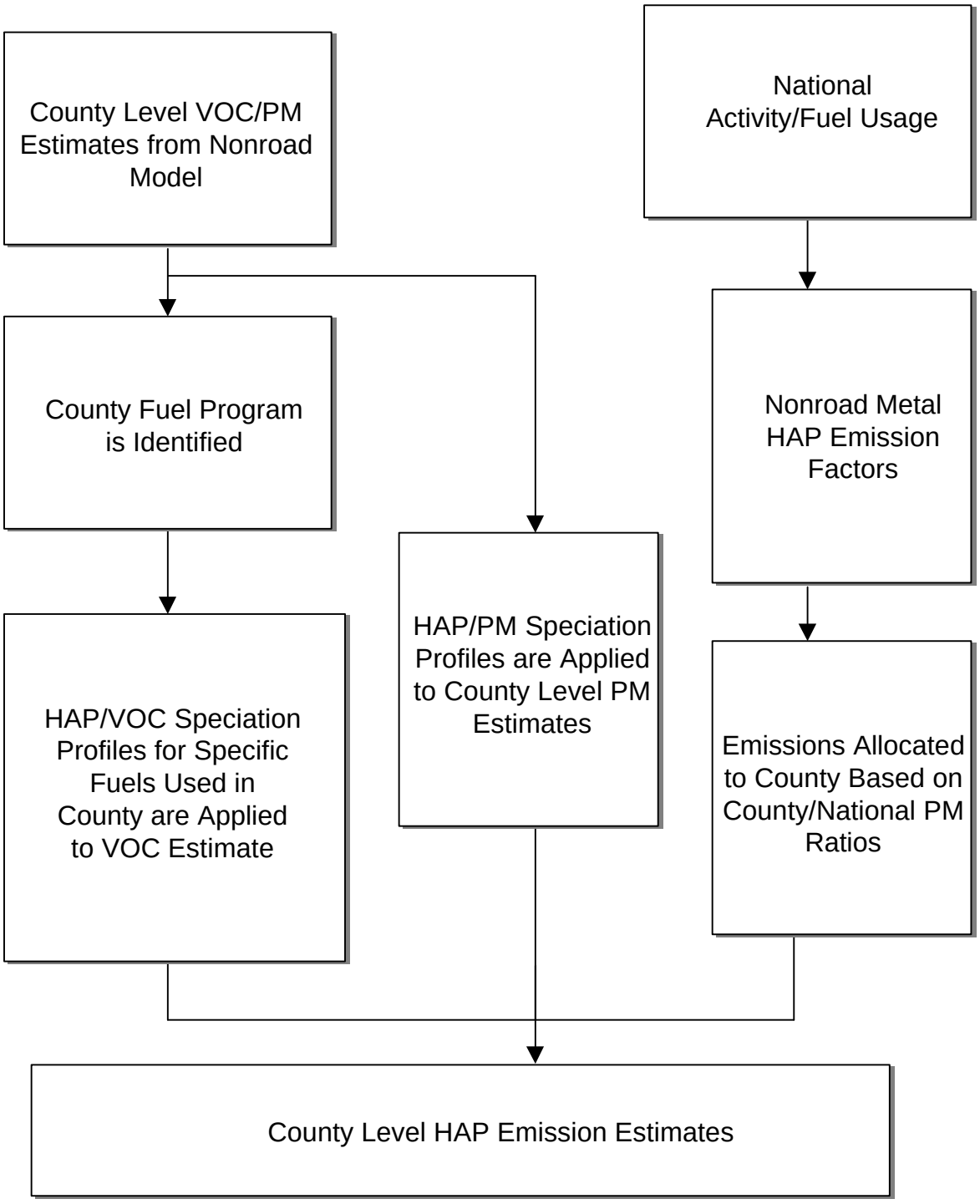

Figure 1. Procedures for Estimating County Level HAP Emission from Nonroad Mobile Sources

onroad vehicles. EPA assumed that these same fuels were used in other nonroad applications. These nonroad fuels included:

- Baseline gasoline, conventional lead-free fuel;
- Winter oxygenated gasoline with methyl tertiary butyl ether (MTBE) or tertiary amyl methyl ether (TAME);
- Winter oxygenated gasoline with ethanol;
- Reformulated fuels with MTBE or TAME;
- Reformulated fuels with ethanol; and
- Diesel.

In the NEI, the use of these different fuels was considered in calculating emission. Information was obtained from Office of Transportation and Air Quality (OTAQ) that indicated the percentage of the year each gasoline fuel type was used in each county. These data were based on individual county participation in the Federal Reformulated Gasoline Program and State Oxygenated Fuel Programs. The fuel usage data were considered in assigning appropriate speciation profiles to each county. These profiles matched engine type (i.e., diesel, 2-stroke gasoline, 4-stroke gasoline), fuel type, and emission type (i.e., exhaust or evaporative), and were applied to the other nonroad VOC estimates for each county to calculate the county-specific HAP emissions. The county-level VOC estimates were derived from 1999 NONROAD model runs using the "lockdown C (May 2002)" version. It was assumed that diesel fuels have negligible evaporative emissions.

In some cases it was possible to obtain engine-specific HAP/VOC speciation profiles for certain pollutants. When specific HAP/VOC speciation profiles could not be obtained, average speciation profiles for each nonroad engine type (i.e., 2-stoke, 4-stroke, and diesel) were developed and used. These profiles were based on recent test studies published in peer-reviewed journals, as well as profiles compiled in the EPA's SPECIATE database.

It should be noted that different HAP/VOC speciation profiles for acetaldehyde, acrolein, formaldehyde, propionaldehyde, and 2, 2, 4-trimethylpentane were used to estimate other nonroad diesel emissions in California to account for the reformulated diesel fuel used in that state.

The approach used to develop HAP speciation profiles for diesel-powered nonroad equipment is similar to the approach used to develop speciation profiles for gasoline-powered equipment, except in the cases for polycyclic aromatic hydrocarbons (PAH) and aldehydes. These profiles were developed by OTAQ as follows. In the case of diesel PAH profiles, additional data on highway diesel fuel usage in nonroad diesel fuel operations were available. Therefore, the nonroad diesel PAH speciation profiles were derived by the ratio of the percent of highway fuel usage and onroad diesel PAH data profiles with nonroad fuel consumption and nonroad diesel PAH data.

The emission estimates for dioxin/furans and metal HAPs, excluding lead, were estimated by applying emission factors to vehicle activity or fuel consumption data. For these metal HAP estimates, it was necessary to combine the 2- and 4-stroke engine-type categories into one category, called gasoline engines. Thus, dioxin/furans and metal HAP emissions for all gasoline engines, regardless of type, were based on the same metal emission factor. A national estimate of other nonroad lead emissions was obtained by multiplying the average lead content of mobile fuel with the amount of fuel used nationally in nonroad applications. Note, the lead content of fuel is relatively small and represents trace compounds in the extracted crude oil.

In contrast to earlier versions of the NEI, the current version includes several significant

improvements to the other nonroad component. For this version, EPA

- Developed 2,2,4-trimethylpentane estimates. Previously emission inventories did not include this pollutant for the other nonroad sources.

- Adjusted the PAH emission estimates to accounted for spillover usage of highway diesel fuel in nonroad applications. In earlier version of the inventory this spillover effect was not considered in estimating emissions.

- Revised metal HAP calculations using activity or fuel consumption. Previously metal HAP emissions were estimated by speciating the PM estimates.

- Revised mercury and arsenic emission estimates based on half of the detection limit to more accurately represent expected emission levels. The emission factors used in previously inventories were considerably higher and based on test data which may not be representative.

- Speciated chromium emission estimates into trivalent and hexivalent chromium. These two pollutants have significantly different toxicities, such that disaggregating these estimates will improve the NATA risk assessments that are based on the NEI emission inventories.

- Dioxin emissions estimates were developed using vehicle miles traveled (VMT)-based emission factors for gasoline and diesel powered equipment. Previously, dioxin was not one of the pollutants considered in estimating emissions for the other nonroad source categories.

COMPARISON OF EMISSION ESTIMATES

To easily compare the national HAP emissions, emission summaries are provided below in a variety of ways including: state, county, SCC tier II, SCC, and SCC by engine type. Not surprisingly, total HAP emissions are largest in the larger states (see Table 1), California being the top emitter. However it is unfair to say that the whole state is responsible for the high emissions. As Figure 2 notes, nonroad emissions vary from county to county.

When the emissions are normalized for county surface area, the top ten states still have some of the highest emissions, but it also becomes apparent that emissions are concentrated in the eastern half of the United States and the west coast. It should be noted that there are a few very high emission density locations that appear as small black dots in California, Virginia, and New England states (see Figure 3). These are an artifact of the normalization calculations. These dots tend to be municipalities with small surface area such that a relative small nonroad emission source could make the municipality a high density emission center.

When the emissions are compared between the rural and urban counties by individual pollutants, the emissions are always higher in the urban counties than in the rural counties. However, it is interesting to note that the actual ranking of the pollutants differ slightly between the rural counties and the urban counties. For example, the top ten pollutants in both rural and urban counties are the same though their order may be different (see Table 2).

When the total emissions are ranked according to SCC tier II, pleasure craft, lawn and garden

equipment, and recreational equipment are the leading contributors and represent 82 percent of total HAP emissions(see Table 3). When the emissions are ranked by the individual SCC codes, the top ten consist of three pleasure craft SCC codes, three recreational equipment SCC codes, and four lawn and garden equipment SCC codes (see Table 4), which is consistent with the tier II ranking.

Emissions are also ranked according to the three different engine types: 2-stroke, 4-stroke, and diesel. For 2-stroke ranking the top ten source categories consist of recreational vessels and equipment and lawn and garden equipment. The largest contributor, 2-stroke outboard pleasure crafts, emitted 142,540.76 tons (see Table 5). The top ten ranked emissions for 4-stroke SCC codes are somewhat different, including a lot of lawn and garden equipment and some pleasure crafts. The top 4-stroke contributor, commercial lawn and garden equipment, emitted 18,218.11 tons, a magnitude smaller than the top 2-stroke contributors (see Table 6). Finally, the top ten ranked emissions for diesel SCC codes consists of industrial equipment, agricultural equipment, and a large number of construction and mining equipment. The top contributor, agricultural tractors, emitted 14,213.72 tons, again a magnitude smaller than the top 2-stroke contributor (see Table 7).

CONCLUSIONS

The major sources of nonroad emissions are from 2-stroke equipment, accounting for most of the HAP emissions. Specifically, recreational vessels and equipment and lawn and garden equipment account for over 80 percent of HAP emissions. Urban emissions are consistently higher than the rural emissions, which is not surprising. This is most apparent for counties in the Southeast, Southwest and Northeast. When pollutant emissions are ranked, metals and PAHs are on the lower side compared to the other organic HAPs.

Improvements can still be made to the other nonroad emission estimates, particularly in incorporating into the emission estimating methods new, more representative emission factors and speciation profiles. The inclusion of more state and local agency data into the NEI's other nonroad component should also lead to more accurate emission estimates. In addition, resources can be better focused on specific counties or states that have higher emissions for better accuracy. More attention toward developing improved emission estimation methodology for the higher emitted pollutants seems warranted.

REFERENCES

1. U.S. EPA/Emission Factor and Inventory Group, *Documentation for Aircraft, Commercial Marine Vessel, Locomotive, and Other Nonroad Components of the National Emission Inventory: Volume I - Methodology.* Research Triangle Park, NC, November 11, 2002.

TABLES

Table 1. Top ten state ranked total HAP emissions.

State	State FIP	Emissions (TPY)
CA	06	68,302.46
FL	12	54,707.30
TX	48	45,920.72
MI	26	41,188.90
NY	36	40,246.91
MN	27	28,125.03
OH	39	27,075.43
IL	17	24,766.03
PA	42	24,301.44
WI	55	23,712.81

Table 2. Ranked pollutant emissions by rural and urban counties.

Pollutant	Rural Emissions (TPY)
Toluene	93,179.204
Xylenes	63,804.998
2,2,4-Trimethylpentane	42,884.146
Benzene	20,529.909
Ethyl Benzene	14,606.160
Formaldehyde	12,245.131
Hexane	10,069.139
Acetaldehyde	5,089.205
Methyl Tert-Butyl Ether	2,345.957
1,3-Butadiene	2,300.444
Propionaldehyde	1,148.137
Styrene	977.436
Acrolein	555.604
Methanol	177.353
Naphthalene	139.964
Chlorine	45.979
Methyl Ethyl Ketone	44.507
Phenanthrene	24.064
Fluorene	13.709
Cumene	13.022
Acenaphthylene	10.813
Pyrene	9.251
Fluoranthene	8.593
Acenaphthene	7.204
Benzo[g,h,i,]Perylene	3.155
Arsenic & Compounds	2.513
Anthracene	2.440
Mercury & Compounds	1.960
Benz[a]Anthracene	0.987
Indeno[1,2,3-c,d]Pyrene	0.955
Benzo[a]Pyrene	0.838
Manganese & Compounds	0.802
Chrysene	0.739
Chromium & Compounds	0.735
Benzo[b]Fluoranthene	0.537
Nickel & Compounds	0.494
Benzo[k]Fluoranthene	0.477
Lead & Compounds	0.471
Nickel	0.342
Cobalt	0.332
16-PAH	0.324
7-PAH	0.163
Antimony	0.136
Phosphorus	0.121
Cadmium	0.066
Dibenzo[a,h]Anthracene	0.025
Selenium	0.005
2,3,7,8-TCDD TEQ	0.0001

Pollutant	Urban Emissions (TPY)
Xylenes	126,777.333
Toluene	112,455.342
2,2,4-Trimethylpentane	50,064.851
Benzene	44,376.047
Formaldehyde	30,332.876
Ethyl Benzene	27,330.040
Methyl Tert-Butyl Ether	25,111.911
Hexane	17,869.317
Acetaldehyde	12,558.070
1,3-Butadiene	6,119.609
Styrene	2,941.842
Propionaldehyde	2,733.345
Acrolein	1,339.023
Methanol	709.972
Naphthalene	519.980
Methyl Ethyl Ketone	443.303
Chlorine	239.828
Cumene	55.335
Phenanthrene	49.654
Acenaphthylene	29.909
Fluorene	27.458
Pyrene	17.797
Fluoranthene	16.160
Acenaphthene	15.282
Anthracene	6.139
Benzo[g,h,i,]Perylene	5.602
Arsenic & Compounds	5.070
Mercury & Compounds	4.061
Manganese	3.606
Chromium & Compounds	3.471
Nickel	1.898
Antimony	1.826
Benz[a]Anthracene	1.818
Cobalt	1.766
Indeno[1,2,3-c,d]Pyrene	1.699
Phosphorus	1.616
Benzo[a]Pyrene	1.580
16-PAH	1.524
Chrysene	1.461
Nickel & Compounds	1.408
Benzo[b]Fluoranthene	1.173
Lead & Compounds	1.142
Benzo[k]Fluoranthene	1.078
Cadmium	0.880
7-PAH	0.768
Selenium	0.066
Dibenzo[a,h]Anthracene	0.0393
2,3,7,8-TCDD TEQ	0.0002

Table 3. Total HAP emissions by tier II.

Emissions (TPY)	Tier II
260,740.73	Pleasure Craft
195,976.63	Lawn and Garden Equipment
145,470.08	Recreational Equipment
47,399.31	Commercial Equipment
40,011.26	Construction and Mining Equipment
23,387.38	Agricultural Equipment
14,702.29	Industrial Equipment
3,775.25	Logging Equipment
425.48	Airport Ground Support Equipment
367.16	Railroad Equipment
176.94	Underground Mining Equipment

Table 4. Top ten ranked total HAP emissions for all SCC codes.

SCC	Emissions (TPY)	SCC Description 3	SCC Description 6	SCC Description 8
2282005010	142,540.76	Pleasure Craft	Gasoline 2-Stroke	Outboard
2282005015	80,472.23	Pleasure Craft	Gasoline 2-Stroke	Personal Water Craft
2260001020	66,670.94	Off-highway Vehicle Gasoline, 2-Stroke	Recreational Equipment	Snowmobiles
2260001010	39,378.84	Off-highway Vehicle Gasoline, 2-Stroke	Recreational Equipment	Motorcycles: Off-road
2260004021	22,579.99	Off-highway Vehicle Gasoline, 2-Stroke	Lawn and Garden Equipment	Chain Saws < 6 HP (Commercial)
2260004026	20,640.94	Off-highway Vehicle Gasoline, 2-Stroke	Lawn and Garden Equipment	Trimmers/Edgers/Brush Cutters (Commercial)
2282005000	20,603.13	Pleasure Craft	Gasoline 2-Stroke	Total
2260004031	20,450.96	Off-highway Vehicle Gasoline, 2-Stroke	Lawn and Garden Equipment	Leafblowers/Vacuums (Commercial)
2265004071	18,218.11	Off-highway Vehicle Gasoline, 4-Stroke	Lawn and Garden Equipment	Turf Equipment (Commercial)
2260001030	16,884.75	Off-highway Vehicle Gasoline, 2-Stroke	Recreational Equipment	Offroad Motorcycles/ATVs

Table 5. Top ten ranked total HAP emissions for 2-stroke SCC codes.

SCC	Emissions (TPY)	SCC Description 3	SCC Description 6	SCC Description 8
2282005010	142,540.76	Pleasure Craft	Gasoline 2-Stroke	Outboard
2282005015	80,472.23	Pleasure Craft	Gasoline 2-Stroke	Personal Water Craft
2260001020	66,670.94	Off-highway Vehicle Gasoline, 2-Stroke	Recreational Equipment	Snowmobiles
2260001010	39,378.84	Off-highway Vehicle Gasoline, 2-Stroke	Recreational Equipment	Motorcycles: Off-road
2260004021	22,579.99	Off-highway Vehicle Gasoline, 2-Stroke	Lawn and Garden Equipment	Chain Saws < 6 HP (Commercial)
2260004026	20,640.94	Off-highway Vehicle Gasoline, 2-Stroke	Lawn and Garden Equipment	Trimmers/Edgers/Brush Cutters (Commercial)
2282005000	20,603.13	Pleasure Craft	Gasoline 2-Stroke	Total
2260004031	20,450.96	Off-highway Vehicle Gasoline, 2-Stroke	Lawn and Garden Equipment	Leafblowers/Vacuums (Commercial)
2260001030	16,884.75	Off-highway Vehicle Gasoline, 2-Stroke	Recreational Equipment	Offroad Motorcycles/ATVs
2260004025	10,048.19	Off-highway Vehicle Gasoline, 2-Stroke	Lawn and Garden Equipment	Trimmers/Edgers/Brush Cutters (Residential)

Table 6. Top ten ranked total HAP emissions for 4-stroke SCC codes.

SCC	Emissions (TPY)	SCC Description 3	SCC Description 6	SCC Description 8
2265004071	18,218.11	Off-highway Vehicle Gasoline, 4-Stroke	Lawn and Garden Equipment	Turf Equipment (Commercial)
2265004010	15,147.11	Off-highway Vehicle Gasoline, 4-Stroke	Lawn and Garden Equipment	Lawn Mowers (Residential)
2265004055	14,052.29	Off-highway Vehicle Gasoline, 4-Stroke	Lawn and Garden Equipment	Lawn and Garden Tractors (Residential)
2265006005	13,280.16	Off-highway Vehicle Gasoline, 4-Stroke	Commercial Equipment	Generator Sets
2265004000	9,554.97	Off-highway Vehicle Gasoline, 4-Stroke	Lawn and Garden Equipment	All
2282010005	8,919.11	Pleasure Craft	Gasoline 4-Stroke	Inboard/Sterndrive
2265004011	8,310.53	Off-highway Vehicle Gasoline, 4-Stroke	Lawn and Garden Equipment	Lawn Mowers (Commercial)
2282010000	7,909.13	Pleasure Craft	Gasoline 4-Stroke	Total
2265006030	7,461.20	Off-highway Vehicle Gasoline, 4-Stroke	Commercial Equipment	Pressure Washers
2265001030	5,304.72	Off-highway Vehicle Gasoline, 4-Stroke	Recreational Equipment	Offroad Motorcycles/ATVs

Table 7. Top ten ranked total HAP emissions for diesel SCC codes.

SCC	Emissions (TPY)	SCC Description 3	SCC Description 6	SCC Description 8
2270005015	14,213.72	Off-highway Vehicle Diesel	Agricultural Equipment	Agricultural Tractors
2270002000	6,317.43	Off-highway Vehicle Diesel	Construction and Mining Equipment	Total
2270005000	4,008.83	Off-highway Vehicle Diesel	Agricultural Equipment	Total
2270002066	3,454.93	Off-highway Vehicle Diesel	Construction and Mining Equipment	Tractors/Loaders/Backhoes
2270002072	2,770.45	Off-highway Vehicle Diesel	Construction and Mining Equipment	Skid Steer Loaders
2270002069	2,541.82	Off-highway Vehicle Diesel	Construction and Mining Equipment	Crawler Tractor/Dozers
2270002060	2,309.53	Off-highway Vehicle Diesel	Construction and Mining Equipment	Rubber Tire Loaders
2270002051	1,693.14	Off-highway Vehicle Diesel	Construction and Mining Equipment	Off-highway Trucks
2270002036	1,633.78	Off-highway Vehicle Diesel	Construction and Mining Equipment	Excavators
2270003060	1,335.27	Off-highway Vehicle Diesel	Industrial Equipment	AC\Refrigeration

Figure 2. Nonroad total annual HAP emission at the county level.

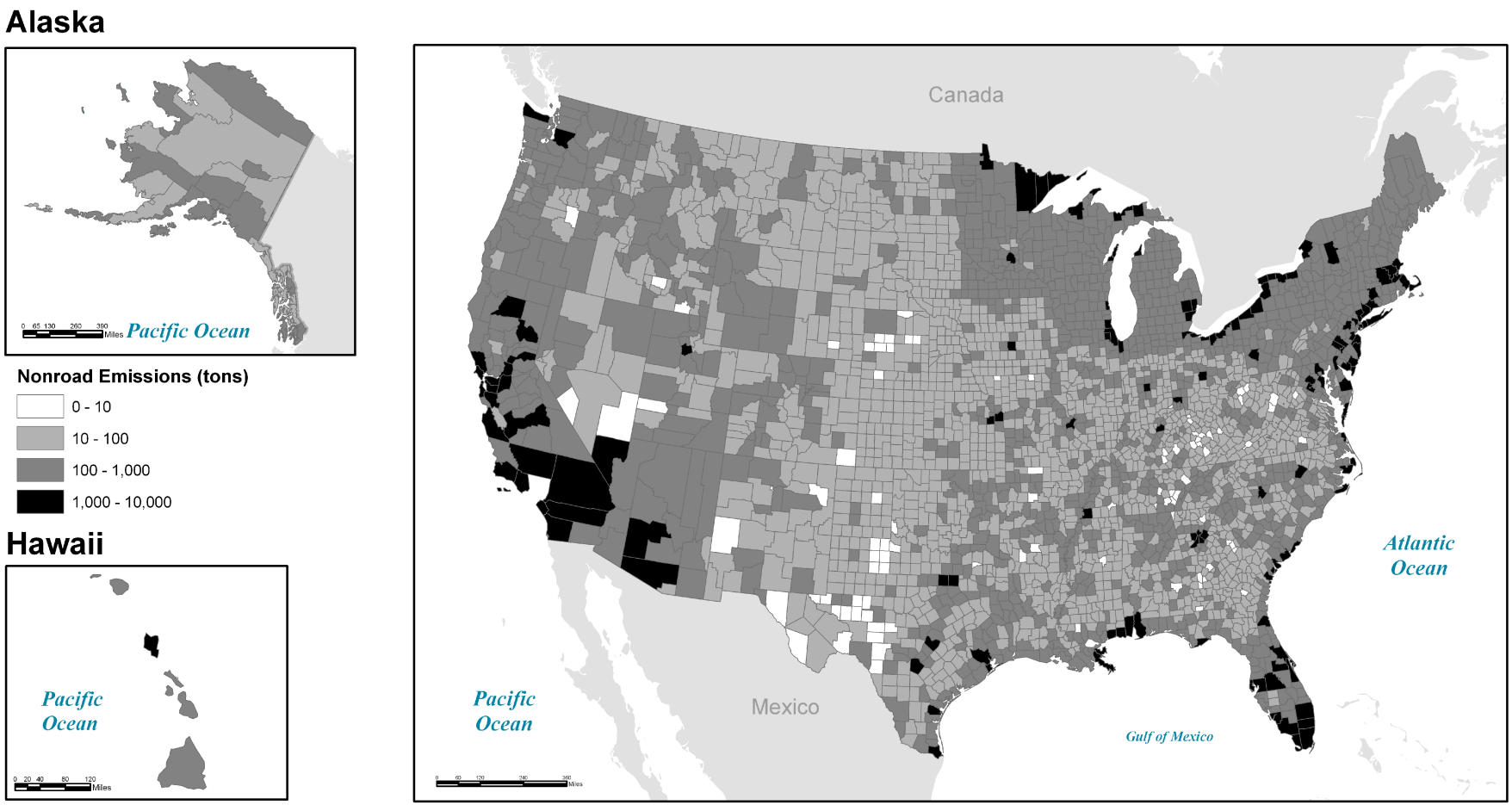

Figure 3. Nonroad total annual HAP emission normalized by county area at the county level.