February 24, 2020

# SPECIFICATION SHEET: ONROAD 2016v1 Platform

Description: Mobile onroad vehicle emissions developed with SMOKE-MOVES using the model, for simulating 2016 and future year U.S. air quality

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# 1. EXECUTIVE SUMMARY

This document details the approach and data sources used for developing gridded, hourly emissions for the mobile onroad vehicle sector that are suitable for input to an air quality model in terms of the format, grid resolution, and chemical species. Onroad mobile sources include all emissions from motor vehicles that operate on roadways such as passenger cars, motorcycles, minivans, sport-utility vehicles, light-duty trucks, heavy-duty trucks, and buses; this sector also includes emissions from vehicles while parked and refueling. Onroad mobile source emissions were processed for air quality modeling using emission factors output from the Motor Vehicle Emissions Simulator (MOVES). These factors were then combined with activity data to produce emissions within the Sparse Matrix Operator Kernel Emissions (SMOKE) modeling system. The collection of programs that compute the onroad mobile source emissions for air quality modeling are known as SMOKE-MOVES. SMOKE-MOVES uses a combination of vehicle activity data, emission factors from MOVES, meteorology data, and temporal allocation information needed to estimate hourly, gridded onroad emissions. California onroad mobile emissions were developed in collaboration with the California Air Resources Board (CARB). California onroad mobile source emissions were provided by CARB were temporally and spatially distributed in the same patterns as SMOKE-MOVES would produce.

SMOKE-MOVES processes onroad emissions for four different vehicle operating modes. Onroad emissions for future years incorporate projections of activity data and future-year-specific MOVES emission factors. The development of onroad mobile source emissions with SMOKE-MOVES is computationally intensive and takes several days to complete. Summaries showing pollutant totals from the onroad sector nationally and for key pollutants by state are provided. Some example maps of key pollutants are also provided.

# 2. INTRODUCTION

Onroad mobile source emissions result from motorized vehicles operating on public roadways. These include passenger cars, motorcycles, minivans, sport-utility vehicles, light-duty trucks, heavy-duty trucks, and buses. The sources are further divided by the fuel they use, including diesel, gasoline, E-85, and compressed natural gas (CNG) vehicles. The sector characterizes emissions from parked vehicle processes (e.g., starts, hot soak, and extended idle) as well as from on-network processes (i.e., from vehicles as they move along the roads). Except for California, all onroad emissions are generated using the SMOKE-MOVES emissions modeling framework that leverages MOVES-generated emission factors, county and SCC-specific activity data, and hourly meteorological data. The onroad source classification codes (SCCs) in the modeling platform are more finely resolved than those in the National Emissions Inventory (NEI). The NEI SCCs distinguish vehicles and fuels. The SCCs used in the model platform also distinguish between emissions process (i.e., off-network, on-network, and extended idle), and road types.

The emission rate (i.e., "lookup") tables input to SMOKE-MOVES are generated by MOVES. These tables differentiate emissions by process (i.e., running, start, vapor venting, etc.), fuel type, vehicle type, road type, temperature, speed, hour of day, and day of week. To generate the MOVES emission rates that could be applied across the U.S., MOVES was run to produce emission factors for a series of temperatures and speeds for a set of "representative counties," to which every other county in the country is mapped. Representative counties are used because it is impractical to generate a full set of emission factors for the more than 3,000 counties in the U.S. The representative counties for which emission factors are generated are selected according to their state, elevation, fuels used in the region, vehicle age distribution, ramp fraction, and inspection and maintenance programs. Every county in the country is then mapped to a representative county based on its similarity to the representative county with respect to those attributes. For vehicle age distributions and fuel types, rather than choose values specific to each representative county, a weighted average was computed for all counties represented by each representative county, and the mean of those averages was used. The representative counties were reanalyzed for the v1 platform according to each of the criteria. In addition, some states provided specific requests regarding representative counties. Following the reanalysis and state requests, 315 representative counties[1] were selected for 2016v1.

[1] See ftp://newftp.epa.gov/air/emismod/2016/v1/reports/onroad/2016-2017_Representative_Counties_Analysis_20190710.xlsx for details

Once representative counties were identified, emission factors were generated by running MOVES for each representative county for two "fuel months" – January to represent winter months and July to represent summer months – because in some parts of the country different types of fuels are used in each season. MOVES was run for the range of temperatures that occur in each representative county for each season. SMOKE selects the appropriate MOVES emissions rates for each county, hourly temperature, SCC, and speed bin and multiplies the emission rate by appropriate activity data: VMT (vehicle miles travelled), VPOP (vehicle population), or HOTELING (hours of extended idle) to produce emissions. These calculations are done for every county and grid cell in the continental U.S. for each hour of the year. SMOKE-MOVES accounts for the sensitivity of the on-road emissions counties to temperature and humidity by using the gridded hourly temperature information available from the meteorological model outputs used for air quality modeling.

In summary, the SMOKE-MOVES process for creating the air quality model-ready onroad mobile emissions consists of the following steps:

1) Select the representative counties to use in the MOVES runs.
2) Determine which months will be used to represent other month's fuel characteristics.
3) Create inputs needed only by MOVES. MOVES requires county-specific information on vehicle populations, age distributions, speed distribution, temporal profiles, and inspection-maintenance programs for each of the representative counties.
4) Create inputs needed both by MOVES and by SMOKE, including temperatures and activity data.
5) Run MOVES to create emission factor tables for the temperatures and speeds that exist in each county during the modeled period.
6) Run SMOKE to apply the emission factors to activity data (VMT, VPOP, and HOTELING) to calculate emissions based on the gridded hourly temperatures in the meteorological data.
7) Aggregate the results to the county-SCC level for summaries and QA.

The onroad emissions are processed as four components that are merged together into the final onroad sector emissions:

- rate-per-distance (RPD) uses VMT as the activity data plus speed and speed profile information to compute on-network emissions from exhaust, evaporative, permeation, refueling, and brake and tire wear processes;
- rate-per-vehicle (RPV) uses VPOP activity data to compute off-network emissions from exhaust, evaporative, permeation, and refueling processes;

- rate-per-profile (RPP) uses VPOP activity data to compute off-network emissions from evaporative fuel vapor venting, including hot soak (immediately after a trip) and diurnal (vehicle parked for a long period) emissions; and
- rate-per-hour (RPH) uses hoteling hours activity data to compute off-network emissions for idling of long-haul trucks from extended idling and auxiliary power unit process.

California is the only state agency that submitted their own onroad emissions for use in the 2016v1 modeling platform. California uses their own EPA-approved onroad mobile emission model, EMFAC, which uses emission inventory codes (EICs) to characterize the emission processes instead of SCCs. EPA and CARB worked together to develop a code mapping to better match EMFAC's EICs to EPA MOVES' detailed set of SCCs that distinguish between off-network and on-network and brake and tire wear emissions. This code mapping is provided in "2014v1_EICtoEPA_SCCmapping.xlsx." which is found in the supporting data for the 2014 NEI v2 TSD[2]. CARB provided their criteria and hazardous air pollutant (CAP and HAP) emissions by county using EPA SCCs after applying the mapping. This allows the unique motor vehicle rules in California to be reflected in the emissions estimates, while leveraging the more detailed SCCs and the highly resolved spatial patterns, temporal patterns, and speciation from SMOKE-MOVES. California emissions are run through SMOKE-MOVES as a separate sector called "onroad_ca_adj", as opposed to the "onroad" sector which includes contiguous US states except California.

Further details on how SMOKE-MOVES was run to match California's emissions data are provided in the Emissions Processing Requirements section below. The "onroad_nonconus" sector was used for the areas of Alaska, Hawaii, Puerto Rico, and the U.S. Virgin Islands. For the purposes of summaries, emissions from all onroad sectors are referred to as the "onroad" sector.

# 3. INVENTORY DEVELOPMENT METHODS

Onroad emissions were computed with SMOKE-MOVES by multiplying specific types of vehicle activity data by the appropriate emission factors. This section includes discussions of the activity data and the emission factor development. The vehicles (aka source types) for which MOVES computes emissions are shown in Table 1. SMOKE-MOVES was run for specific modeling grids. Emissions for the contiguous U.S. states and Washington, D.C., were computed for a grid covering those areas, while emissions for Alaska, Hawaii, Puerto Rico, and the U.S.

[2] ftp://newftp.epa.gov/air/nei/2014/doc/2014v2_supportingdata/onroad/

Virgin Islands were computed by running SMOKE-MOVES for distinct grids covering each of those regions.

**Table 1. MOVES vehicle (source) types**

| MOVES vehicle type | description | HPMS vehicle type |
|---|---|---|
| **11** | Motorcycle | 10 |
| **21** | Passenger Car | 25 |
| **31** | Passenger Truck | 25 |
| **32** | Light Commercial Truck | 25 |
| **41** | Intercity Bus | 40 |
| **42** | Transit Bus | 40 |
| **43** | School Bus | 40 |
| **51** | Refuse Truck | 50 |
| **52** | Single Unit Short-haul Truck | 50 |
| **53** | Single Unit Long-haul Truck | 50 |
| **54** | Motor Home | 50 |
| **61** | Combination Short-haul Truck | 60 |
| **62** | Combination Long-haul Truck | 60 |

**Activity data development**

SMOKE-MOVES uses vehicle miles traveled (VMT), vehicle population (VPOP), and hours of hoteling, to calculate emissions. These datasets are collectively known as “activity data”. For each of these activity datasets, first a national dataset was developed; this national dataset is called the “EPA default” dataset. Second, data submitted by state agencies were incorporated where available, in place of the EPA default data. EPA default activity were used for California, but the emissions were scaled to California-supplied values during the emissions processing. The agencies for which submitted VMT and VPOP data were used for 2016 platforms are shown in Table 2 along with the timing of the submission: 2014v1 or 2016 beta or 2016 v1. Data submitted for the 2014 NEI were adjusted before they were used for 2016 platforms.

**Table 2. Factors applied to project VMT from 2014 to 2016 to prepare default activity data**

| Agency | 2016 VMT | 2016 VPOP |
|---|---|---|
| Alaska | yes (2014v1) | yes (2014v1) |
| Arizona - Maricopa | yes (2014v1) | yes (2014v1) |
| Arizona - Pima | yes (v1) | yes (v1) |
| Colorado | yes (beta) | yes (v1) |
| Connecticut | yes (beta) | yes (2014v1) |
| Delaware | yes (2014v1) | yes (2014v1) |
| District of Columbia | yes (2014v1) | yes (2014v1) |
| Georgia | yes (beta) | yes (beta) |

| **Agency** | **2016 VMT** | **2016 VPOP** |
|---|---|---|
| Idaho | yes (2014v1) | yes (2014v1) |
| Illinois - Chicago area | yes (v1) | yes (v1) |
| Illinois - rest of state | yes (beta) | yes (2014v1) |
| Indiana - Louisville area | yes (v1) | |
| Kentucky - Jefferson | yes (v1) | yes (2014v1) |
| Kentucky - Louisville exurbs | yes (v1) | |
| Maine | yes (2014v2) | yes (2014v2) |
| Maryland | yes (beta) | yes (beta) |
| Massachusetts | yes (v1) | yes (v1) |
| Michigan - Detroit area | yes (beta) | yes (2014v1) |
| Michigan - rest of state | yes (beta) | yes (2014v1) |
| Minnesota | yes (beta) | yes (2014v1) |
| Missouri | yes (2014v1) | yes (2014v1) |
| Nevada - Clark | yes (beta) | yes (beta) |
| Nevada - Washoe | yes (2014v1) | yes (2014v1) |
| New Hampshire | yes (beta) | yes (beta) |
| New Jersey | yes (beta) | yes (v1) |
| New Mexico - Bernalillo | yes (2014v1) | yes (2014v1) |
| New York | yes (2014v1) | yes (2014v1) |
| North Carolina | yes (beta) | yes (beta) |
| Ohio | yes (2014v1) | yes (2014v1) |
| Oregon | yes (2014v1) | yes (2014v1) |
| Pennsylvania | yes (beta) | yes (beta) |
| Rhode Island | yes (2014v1) | yes (2014v1) |
| South Carolina | yes (beta) | yes (beta) |
| Tennessee - Davidson | yes (2014v1) | yes (2014v1) |
| Tennessee - Knox | yes (2014v1) | yes (2014v1) |
| Tennessee - rest of state | yes (2014v2) | yes (2014v2) |
| Texas | yes (2014v1) | yes (2014v1) |
| Vermont | yes (2014v2) | yes (2014v2) |
| Virginia | yes (beta) | yes (2014v2) |
| Washington | yes (2014v2) | yes (2014v2) |
| West Virginia | yes (beta) | yes (beta) |
| Wisconsin | yes (beta) | yes (beta) |

Vehicle Miles Traveled (VMT)

EPA calculated default 2016 state VMT by projecting the 2014NEIv2 platform VMT to 2016. The 2014NEIv2 Technical Support Document has details on the development of those VMT (https://www.epa.gov/air-emissions-inventories/2014-national-emissions-inventory-nei-technical-support-document-tsd). The data projected to 2016 were used for states that did not submit 2016 VMT data. Projection factors to grow state VMT from 2014 to 2016 were based on state-level VMT data from the FHWA VM-2 reports (https://www.fhwa.dot.gov/policyinformation/statistics/2014/vm2.cfm and https://www.fhwa.dot.gov/policyinformation/statistics/2016/vm2.cfm). For most states, separate factors were calculated for urban VMT and rural VMT. Some states have a very different distribution of urban activity versus rural activity between 2014NEIv2 and the FHWA data, due to inconsistencies in the definition of urban versus rural. For those states, a single state-wide projection factor based on total FHWA VMT across all road types was applied to all VMT independent of road type. The following states used a single state-wide projection factor to adjust the VMT to 2016 levels: AK, GA, IN, ME, MA, NE, NM, NY, ND, TN, and WV. Also, state-wide projection factors in Texas and Utah were developed from alternative VMT datasets provided by their respective Departments of Transportation. The VMT projection factors for all states are provided in Table 3.

**Table 3. Factors applied to project VMT from 2014 to 2016 to prepare default activity data**

| State | Rural roads | Urban roads | Projection Factor Source |
|---|---|---|---|
| Alabama | 5.36% | 5.47% | FHWA VM-2 urban/rural |
| Alaska | 8.27% | 8.27% | FHWA VM-2 total |
| Arizona | 1.07% | 6.35% | FHWA VM-2 urban/rural |
| Arkansas | 4.80% | 5.36% | FHWA VM-2 urban/rural |
| California | 1.06% | 2.39% | FHWA VM-2 urban/rural |
| Colorado | 5.97% | 6.67% | FHWA VM-2 urban/rural |
| Connecticut | 1.33% | 1.45% | FHWA VM-2 urban/rural |
| Delaware | 4.42% | 6.75% | FHWA VM-2 urban/rural |
| District of Columbia | 0.00% | 2.68% | FHWA VM-2 urban/rural |
| Florida | 10.27% | 6.64% | FHWA VM-2 urban/rural |
| Georgia | 10.10% | 10.10% | FHWA VM-2 total |
| Hawaii | 6.14% | 4.21% | FHWA VM-2 urban/rural |
| Idaho | 5.51% | 7.80% | FHWA VM-2 urban/rural |
| Illinois | 3.40% | 1.96% | FHWA VM-2 urban/rural |
| Indiana | 5.02% | 5.02% | FHWA VM-2 total |
| Iowa | 6.17% | 6.05% | FHWA VM-2 urban/rural |
| Kansas | 2.42% | 6.52% | FHWA VM-2 urban/rural |
| Kentucky | 2.52% | 3.26% | FHWA VM-2 urban/rural |
| Louisiana | -5.49% | 7.10% | FHWA VM-2 urban/rural |
| Maine | 3.75% | 3.75% | FHWA VM-2 total |
| Maryland | 4.98% | 4.75% | FHWA VM-2 urban/rural |
| Massachusetts | 7.42% | 7.42% | FHWA VM-2 total |
| Michigan | 5.62% | 0.66% | FHWA VM-2 urban/rural |
| Minnesota | 2.66% | 2.97% | FHWA VM-2 urban/rural |
| Mississippi | 1.83% | 4.96% | FHWA VM-2 urban/rural |
| Missouri | 4.70% | 4.17% | FHWA VM-2 urban/rural |
| Montana | 3.32% | 4.34% | FHWA VM-2 urban/rural |
| Nebraska | 5.54% | 5.54% | FHWA VM-2 total |
| Nevada | 8.30% | 5.30% | FHWA VM-2 urban/rural |

| State | Rural roads | Urban roads | Projection Factor Source |
|---|---|---|---|
| New Hampshire | 5.00% | 3.65% | FHWA VM-2 urban/rural |
| New Jersey | 5.41% | 2.83% | FHWA VM-2 urban/rural |
| New Mexico | 10.01% | 10.01% | FHWA VM-2 total |
| New York | -4.90% | -4.90% | FHWA VM-2 total |
| North Carolina | 7.47% | 8.41% | FHWA VM-2 urban/rural |
| North Dakota | -7.35% | -7.35% | FHWA VM-2 total |
| Ohio | 4.61% | 5.42% | FHWA VM-2 urban/rural |
| Oklahoma | 4.72% | 1.23% | FHWA VM-2 urban/rural |
| Oregon | 8.05% | 4.84% | FHWA VM-2 urban/rural |
| Pennsylvania | -4.30% | 4.73% | FHWA VM-2 urban/rural |
| Rhode Island | 3.26% | 3.26% | FHWA VM-2 urban/rural |
| South Carolina | 9.70% | 8.89% | FHWA VM-2 urban/rural |
| South Dakota | 3.23% | 2.64% | FHWA VM-2 urban/rural |
| Tennessee | 6.29% | 6.29% | FHWA VM-2 total |
| Texas | 7.82% | 7.82% | TxDOT[3] |
| Utah | 11.62% | 11.62% | UDOT[4] |
| Vermont | 5.55% | 2.24% | FHWA VM-2 urban/rural |
| Virginia | -4.93% | 9.78% | FHWA VM-2 urban/rural |
| Washington | 6.86% | 4.43% | FHWA VM-2 urban/rural |
| West Virginia | 2.21% | 2.21% | FHWA VM-2 total |
| Wisconsin | 4.15% | 9.32% | FHWA VM-2 urban/rural |
| Wyoming | -1.38% | -1.53% | FHWA VM-2 urban/rural |
| Puerto Rico | 0.00% | 0.00% | No FHWA VM-2 data |
| Virgin Islands | 0.00% | 0.00% | No FHWA VM-2 data |

For the 2016v1 platform, VMT data submitted by state and local agencies were incorporated and used in place of EPA defaults, as described below. Note that VMT data need to be provided to SMOKE for each county and SCC. The onroad SCCs characterize vehicles by MOVES fuel type, vehicle (aka source) type, emissions process, and road type. Any VMT provided at a different resolution than this were converted to a full county-SCC resolution to prepare the data for processing by SMOKE.

Air agencies from CO, CT, GA, IL, MD, NJ, NC, VA, WI, and Pima County (AZ) provided 2016 VMT data by county and Highway Performance Monitoring Systems (HPMS) vehicle type to be used for the 2016beta and 2016v1 platforms. That level of detail is sufficient for MOVES, but SMOKE also needs VMT broken out by MOVES vehicle type (which is more detailed than HPMS vehicle

[3] 2014: https://ftp.dot.state.tx.us/pub/txdot-info/trf/crash_statistics/2014/01.pdf
2016: https://ftp.dot.state.tx.us/pub/txdot-info/trf/crash_statistics/2016/01.pdf
[4] 2014: https://www.udot.utah.gov/main/uconowner.gf?n=27035817009129993
2016: https://www.udot.utah.gov/main/uconowner.gf?n=36418522778889648

type as shown in Table 1), and by fuel type and road type. To get VMT at the resolution needed by SMOKE, the county-HPMS VMT data provided by the states were loaded into the county databases (CDBs) that are used to run MOVES. MOVES CDBs include fuel type splits, road type splits, and VPOP by MOVES vehicle type. Using those tables, county-HPMS VMT data were converted into the county-SCC VMT data that are needed by SMOKE. One exception to the use of local data in these states was for North Carolina, where EPA default VMT for buses were used along with state-submitted VMT for other vehicle types.

South Carolina and Massachusetts submitted VMT by county-HPMS using the same HPMS splits in every county in the state. Unlike Massachusetts, South Carolina did not provide county-specific road type splits. Instead, a new set of county-specific HPMS splits was developed from the EPA default VMT. For all HPMS types except 25 (light cars and trucks), county-HPMS ratios were calculated from the EPA default VMT, and then scaled up or down so that the overall state-HPMS ratio would match South Carolina's state-HPMS ratio. For HPMS type 25, the county-HPMS ratios were set equal to the remainder within each county so that all ratios within each county sum to 1.0. The new VMT by county-HPMS varies by county while respecting the state-wide HPMS splits in South Carolina's original VMT dataset. The VMT was then split to full SCC level using a similar procedure as other states that submitted VMT at the county-HPMS level.

Pennsylvania and New Hampshire submitted VMT for the 2016beta platform at the full county-SCC level, already in the FF10 format needed by SMOKE. These data were used directly for the 2016v1 platform, except for the redistribution of light duty VMT (see last item in this subsection).

Michigan and Minnesota submitted 2016 VMT by county and by road type for the 2016beta platform. Fuel type and vehicle type distributions from the EPA default VMT were used to convert these data to full SCC.

West Virginia submitted county total VMT only for the 2016beta platform. Fuel, vehicle, and road type distributions from the EPA default VMT were used to convert their data to full SCC.

For the 2016beta platform, Clark County, NV, submitted VMT by county and MOVES vehicle type, which is more detailed than HPMS vehicle type, but nevertheless cannot be imported into MOVES CDBs as easily to facilitate the creation of VMT at the full SCC detail. Fuel type and road type distributions from the EPA default VMT were used to convert these data to full SCC.

For the 2016v1 platform, VMT was provided by:

- Massachusetts (by HPMS, to override what was provided for beta)
- Chicago area (8 counties, by HPMS/road; excluded motorcycles)
- Louisville area (5 counties, county totals restricted/unrestricted)
- Pima County AZ (by HPMS)

Some of the provided data were adjusted following quality assurance, as described below in the VPOP section.

A final step was performed on all state-submitted VMT. The distinction between a “passenger car” (MOVES vehicle type 21) versus a “passenger truck” (MOVES vehicle type 31) versus a “light commercial truck” (MOVES vehicle type 32) is not always consistent between different datasets. This distinction can have a noticeable effect on the resulting emissions, since MOVES emission factors for passenger cars are quite different than those for passenger trucks and light commercial trucks.

To ensure consistency in the 21/31/32 splits across the country, all state-submitted VMT for MOVES vehicle types 21, 31, and 32 (all of which are part of HPMS vehicle type 25) was summed, and then re-split using the 21/31/32 splits from the EPA default VMT. VMT for each source type as a percentage of total 21/31/32 VMT was calculated by county from the EPA default VMT. Then, state-submitted VMT for 21/31/32 was summed and then resplit according to those percentages.

This was done for all states and counties listed above which submitted VMT for 2016. Most of the states listed above did not provide VMT down to the source type, so splitting the light-duty vehicle VMT does not create an inconsistency with state-provided data in those states. Exceptions are New Hampshire and Pennsylvania: those two states provided SCC-level VMT, but these were reallocated to 21/31/32 so that the splits are performed in a consistent way across the country. The 21/31/32 splits in the EPA default VMT can be traced back to the 2014NEIv2 VPOP data obtained from IHS-Polk.

<u>Speed activity (SPEED / SPDIST)</u>

In SMOKE 4.7, SMOKE-MOVES was updated to use speed distributions similarly to how they are used when running MOVES in inventory mode. This new speed distribution file, called the SPDIST file, specifies the amount of time spent in each MOVES speed bin for each county, vehicle (aka source) type, road type, weekday/weekend, and hour of day. This file contains the same information at the same resolution as the Speed Distribution table used by MOVES but is reformatted for SMOKE. Using the SPDIST file results in a SMOKE emissions calculation that is more consistent with MOVES than the old hourly speed profile (SPDPRO) approach, because emission factors from all speed bins can be used, rather than interpolating between the two bins surrounding the single average speed value for each hour as is done with the SPDPRO approach.

As was the case with the previous SPDPRO approach, the SPEED inventory that includes a single overall average speed for each county, SCC, and month, must still be read in by the SMOKE program Smkinven. SMOKE requires the SPEED dataset to exist even when speed distribution data are available, even though only the speed distribution data affects the selection of emission factors. The SPEED dataset is carried over from 2014NEIv2, while the SPDIST dataset is new for the 2016v1 platform. Both are based on a combination of the Coordinating Research Council (CRC) A-100[5] data and MOVES CDBs.

Vehicle population (VPOP)

The EPA default VPOP dataset was based on the EPA default VMT dataset described above. For each county, fuel type, and vehicle type, a VMT/VPOP ratio (miles per vehicle per year) was calculated based on the 2014NEIv2 VMT and VPOP datasets. That ratio was applied to the 2016 EPA default VMT, to produce an EPA default VPOP projection.

As with VMT, several state and local agencies submitted VPOP data for the beta and v1 platforms, and those data were used in place of the EPA default VPOP. The VPOP SCCs used by SMOKE are similar to the VMT SCCs, except the emissions process is represented as "00" because it is not relevant to vehicle population data.

For the 2016 beta platform, GA, MD, MA, NJ, NC, WI, and Pima County AZ provided VPOP data for the year 2016 by county and MOVES vehicle type. That level of detail is sufficient for MOVES, but SMOKE also needs VPOP broken out by fuel type. To get VPOP by full SCC, the county-vehicle VPOP data provided by the states were loaded into the MOVES CDBs. Using fuel type tables in the CDBs, it is possible to take county-vehicle VPOP data and create county-SCC VPOP data at the resolution needed by SMOKE. For Massachusetts, based on quality assurance checks, modifications to their VPOP like those done for their VMT were not needed. Wisconsin provided VPOP for 2016 by county and HPMS vehicle type instead of by MOVES vehicle type, but the same procedure was applied as for other states in this group. For North Carolina, EPA default VPOP data were used for buses along with the state-submitted VPOP for other vehicle types, consistent with the VMT.

[5] http://crcsite.wpengine.com/wp-content/uploads/2019/05/ERG_FinalReport_CRCA100_28Feb2017.pdf

West Virginia and Clark County, Nevada also provided VPOP for the 2016 beta platform by county and MOVES vehicle type. Because they did not provide VMT by county-HPMS, these data were not put into MOVES databases for splitting. Instead, the VPOP data were split to full SCC using county-vehicle to county-SCC ratios calculated from the 2016 beta VMT - not the EPA default VMT, but the final VMT incorporating state data and split to full SCC within MOVES CDBs. So effectively, MOVES CDBs were used to split their VPOP to full SCC, but only indirectly. West Virginia's VPOP dataset did not include any intercity buses (MOVES vehicle type 41), thus intercity bus VPOP data were taken from the EPA default VPOP.

The FF10-formatted county-SCC VPOP data provided by Pennsylvania and New Hampshire for the 2016 beta platform were used for the 2016v1 platform.

EPA default VPOP data were used for the states that submitted VMT but did not submit VPOP (CT, IL, MI, MN, and VA). The new VMT that South Carolina provided, in addition to the recalculation of HPMS splits between counties, introduced some issues with VMT/VPOP ratios when comparing the 2016beta VMT with EPA default beta VPOP. The largest VMT/VPOP ratio issues were for HD vehicles. Because the light-duty (LD) VPOP data are based on the IHS-Polk registration data, only the heavy-duty (HD) VPOP data were modified for South Carolina using the EPA defaults. For HD VPOP in South Carolina: new VPOP = EPA default VPOP * (SC-submitted VMT / EPA default VMT). In other words, the same changes that were made to the VMT as a result of the new state data were also made to the VPOP on a percentage basis. This preserves VMT/VPOP ratios for HD vehicles in South Carolina compared to the EPA default data. This procedure resulted in some changes to the overall HD VPOP total in South Carolina, both at the county level and state level.

VPOP by source type was not re-split among the LD types 21/31/32. This is consistent with the 2016beta platform, in which all state-submitted VMT was re-split, but state-submitted VPOP at the source type level or better was not.

For 2016v1, VPOP data were provided for:

- Massachusetts (by HPMS)
- Chicago area (8 counties, by source type)
- Colorado (by source type)
- New Jersey (by source type)
- Pima County, AZ (by source type)

The state-submitted VMT and VPOP data underwent several modifications based on quality assurance:

**Colorado:**

1. There was a lot of inconsistency between the VMT and VPOP when it was broken down into individual vehicle types. Colorado indicated that we shouldn't put too much stock into the HPMS->vehicle breakdowns in their VPOP data. So, we summed their VPOP to HPMS type and re-split to vehicle type based on splits from beta VPOP.
2. Due to concerns about VMT/VPOP ratios for long haul source types (41, 53, 62), we recalculated the VPOP from VMT using average national VMT/VPOP ratios from 2014v2: 53,000 for 41s; 18,600 for 53s, and 68,000 for 62s. We also recalculated the 52 VPOP as old 52+53 VPOP minus new 53 VPOP. In one county (08019), 52 VPOP ended up negative, so we increased the 53 VMT/VPOP ratio (which decreased the VPOP) for that county only.
3. There were also some VMT/VPOP ratios at the county level for HPMS vehicle types 42, 43, and 61 that were greater than 150,000 miles/year. For these, we increased the VPOP for these county-vehicle combinations so that the VMT/VPOP ratio would never exceed 150,000. This affected 6 county-vehicle combinations, mostly with small VPOP.

**Chicago area:**

1. Chicago provided separate VMT for HPMS vehicle types 20 and 30, which were summed and re-split based on 2016beta platform VMT to keep LD vehicle type distributions consistent.
2. Motorcycles VMT and VPOP were taken from the 2016beta platform.
3. Based on email communication and number comparison, we have reason to believe the Chicago area bus VMT (submitted as total buses) includes 41/42 only and not 43 (school). So, the bus VMT were allocated to 41/42 only and 43 VMT were carried forward from 2016beta.
4. For bus VPOP, Chicago did not provide intercity buses, so those were carried forward from 2016beta, but their transit and school bus VPOP values were retained.
5. The provided 50/60 VPOP appeared to be much too low, so we recalculated it based on their VMT combined with average VMT/VPOP ratios: 24,000 for 51s; 10,000 for 52s; 18,600 for 53s; 4,000 for 54s; 57,000 for 61s and 68,000 for 62s.
6. Counties 17063/17093 had VPOP for 41/42 but no VMT. We added VMT from the 2016beta platform for these county-vehicle combinations. The VMT for 41 was carried forward from 2016beta to 2016v1. For 42, the 2016v1 VMT = beta VMT * (v1 VPOP / beta VPOP).

**Pima County:** The provided 50/60 VPOP was not based on vehicle registrations, so we recalculated based on their VMT combined with average VMT/VPOP ratios (as was done for Chicago).

Hoteling hours (HOTELING)

Hoteling hours activity is used to calculate emissions from extended idling and auxiliary power units (APUs) for heavy duty diesel vehicles. Many states have commented that EPA estimates of hoteling hours, and therefore emissions resulting from hoteling are higher than they could realistically be in reality given the available parking spaces. Therefore, recent hoteling activity datasets, including the 2014NEIv2, 2016 beta, and 2016v1 platforms, incorporate reductions to hoteling activity data based on the availability of truck stop parking spaces in each county, as described below. For 2016v1, hoteling hours were recomputed using a new factor identified by EPA's Office of Transportation and Air Quality as more appropriate based on recent studies[6].

The method used in 2016v1 is the following:

- Start with 2016v1 VMT for 62 on restricted roads, by county.
- Multiply that by 0.007248 hours/mile (Sonntag, 2018). This results in about 73.5% less hoteling hours as compared to the 2014v2 approach.
- Apply parking space reductions as has been done for 2016beta, except for states that requested we not do that (CO, ME, NJ, NY).

Hoteling hours were adjusted down in counties for which there were more hoteling hours assigned to the county than could be supported by the known parking spaces. To compute the adjustment, we started with the hoteling hours for the county as computed by the above method, and then we applied reductions directly to the 2016 hoteling hours based on known parking space availability so that there were not more hours assigned to the county than the available parking spaces could support if they were full every hour of every day.

A dataset of truck stop parking space availability with the total number of parking spaces per county was used in the computation of the adjustment factors. This same dataset is used to develop the spatial surrogate for hoteling emissions. For the 2016v1 platform, the parking space dataset includes several updates compared to 2016beta platform, based on information

[6] Sonntag, D., J. Brakora, C. Fulper, D. Brzezinski, A. Verma, S. Ballare, A. Kotz, K. Kelly, K. Boriboonsomsin, G. Scora, K. Johnson, T. Durbin. Updating MOVES with Instrumented Heavy-duty Truck Activity Data. March 11, 2019. 29th CRC Real World Emissions Workshop.

provided by some state (e.g., MD). Since there are 8,784 hours in the year 2016; the maximum number of possible hoteling hours in a particular county is equal to 8,784 * the number of parking spaces in that county. Hoteling hours for each county were capped at that theoretical maximum value for 2016 in that county, with some exceptions as outlined below.

Because the truck stop parking space dataset may be incomplete in some areas, and trucks may sometimes idle in areas other than designated spaces, it was assumed that every county has at least 12 parking spaces, even if fewer parking spaces are found in the parking space dataset. Therefore, hoteling hours are never reduced below 105,408 hours for the year in any county. If the unreduced hoteling hours were already below that maximum, the hours were left unchanged; in other words, hoteling activity are never increased as a result of this analysis.

A handful of high activity counties that would otherwise be subject to a large reduction were analyzed individually to see if their parking space count seemed unreasonably low. In the following counties, the parking space count and/or the reduction factor was manually adjusted:

- 17043 / DuPage IL (instead of reducing hoteling by 89%, applied no adjustment)
- 39061 / Hamilton OH (parking spot count increased to 20 instead of the minimum 12)
- 47147 / Robertson TN (parking spot count increased to 52 instead of just 26)
- 51015 / Augusta VA (parking space count increased to 48 instead of the minimum 12)
- 51059 / Fairfax VA (parking spot count increased to 20 instead of the minimum 12)

Georgia and New Jersey submitted hoteling activity for the 2016v1 platform. For these states, the EPA default projection was replaced with their state data. New Jersey provided their hoteling activity in a series of HotellingHours MOVES-formatted tables, which include separate activity for weekdays and weekends and for each month and which have units of hours-per-week. These data first needed to be converted to annual totals by county.

For Georgia we were going to bring forward their beta HOTELING but found it was now much too large compared to other states once the new hoteling factor was implemented. After discussion with Georgia Department of Natural Resources staff, we agreed to recalculate from VMT for all counties except for those where parking > 0 and restricted VMT = 0. In those counties, Georgia's 2016beta hoteling were reduced by 73.5% (the same reduction factor applied to the rest of the country).

Alaska Department of Natural Resources staff requested that we zero out hoteling activity in several counties due to the nature of driving patterns in their region.  In addition, there are no hoteling hours or other emissions from long-haul combination trucks in Hawaii, Puerto Rico, or the Virgin Islands.

All parking space counts are the same as 2016beta except Maryland, which submitted an update for 2016v1.

The states of Colorado, Maine, New Jersey, and New York requested that no reductions be applied to the hoteling activity based on parking space availability. For these states, we did not apply any reductions based on parking space availability and left the hours that were computed using the updated method for 2016v1; or in the case of New Jersey, their submitted activity; unchanged. Otherwise, the submitted data from New Jersey would have been subject to reductions. The submitted data from Georgia did not exceed the maximum value in any county, so their submitted data did not need to be reduced.

Finally, the county total hoteling must be split into separate values for extended idling (SCC 2202620153) and Auxiliary Power Units (APUs) (SCC 2202620191). New Jersey's submittal of hoteling activity specified a 30% APU split, and this was used for all New Jersey counties. For the rest of the country, a 12.4% APU split was used for the year 2016, meaning that APUs are used for 12.4% of the hoteling hours.

**Emission factor table development**

MOVES2014b was run in emission rate mode to create emission factor tables using CB6 speciation for the years 2016, 2020, 2023, and 2028, for all representative counties and fuel months. MOVES was run for all counties in Alaska, Hawaii, and Virgin Islands, and for a single representative county in Puerto Rico. The county databases (CDBs) used to run MOVES to develop the emission factor tables were updated from those used in the 2016beta platform.

Age distributions are a key input to MOVES in determining emission rates. The age distributions for 2016v1 were updated based on vehicle registration data obtained from the CRC A-115 project[7], subject to reductions for older vehicles determined according to CRC A-115 methods but using additional age distribution data that became available as part of the 2017 NEI submitted input data. One of the findings of CRC project A-115 is that IHS data contain higher vehicle populations than state agency analyses of the same Department of Motor Vehicles data, and the discrepancies tend to increase with increasing vehicle age (i.e., there are more older vehicles in the IHS data). The CRC project dealt with the discrepancy by releasing datasets

[7] http://crcsite.wpengine.com/wp-content/uploads/2019/05/ERG_FinalReport_CRCA100_28Feb2017.pdf

based on raw (unadjusted) information and adjusted sets of age distributions, where the adjustments reflected the differences in population by model year of 2014 IHS data and 2014 submitted data from a single state.

For the 2016 platform and 2017 NEI, EPA repeated the CRC's assessment of IHS vs. state discrepancies but with updated 2017 information and for more states. The 2017 light-duty vehicle (LDV) populations from the CRC A-115 project were compared by model year to the populations submitted by state/local (S/L) agencies for the 2017 NEI. The comparisons by model year were used to develop adjustment factors that remove older age LDVs from the IHS dataset. Out of 31 S/L agencies that provided data, 16 provided LDV population and age distributions with snapshot dates of January 2017, July 2017, or 2018. The other 15 had either unknown or older (back to 2013) data pull dates, so were not a fair comparison to the 2017 IHS data.

We reviewed the population by model year comparisons for each of the 16 geographic areas vs. IHS separately for source type 21 and for source type 31 plus 32 together. We reallocated the S/L agency populations of cars (source type 21) and light trucks (source types 31 and 32) to match IHS car and light-duty truck splits by county for consistent VIN decoding. We also removed the state of Georgia from the pool of S/L agencies used to calculate the adjustment factors to avoid its influence on a pooled geographic adjustment. Georgia already works closely with IHS on VIN decoding, and as a result, their submittal matched IHS. The IHS data are higher than the pooled state data by 6.5 percent for cars and 5.9 percent for light trucks

We calculated the vehicle age distribution adjustment factors as one minus the fraction of vehicles to remove from IHS to equal the state data, with two exceptions. The model year range 2006/2007 to 2017 receives no adjustment and the model year 1987 receives a capped adjustment that equals the adjustment to 1988. Table 4 below shows the fraction of vehicles to keep by model year based on this analysis. The adjustments were applied to the 2016 IHS-based age distributions from CRC project A-115 prior to use in 2016v1. In addition, we removed the county-specific fractions of antique license plate vehicles present in the registration summary from IHS. Nationally, the prevalence of antique plates is only 0.8 percent, but as high as 6 percent in some states (e.g., Mississippi).

**Table 4.** Older Vehicle Adjustments Showing the Fraction of IHS Vehicle Populations to Retain for 2016v1 and 2017 NEI

| Model Year | Cars | Light Trucks |
|---|---|---|
| pre-1989 | 0.675 | 0.769 |
| 1989 | 0.730 | 0.801 |
| 1990 | 0.732 | 0.839 |

| Model Year | Cars | Light Trucks |
|---|---|---|
| 1991 | 0.740 | 0.868 |
| 1992 | 0.742 | 0.867 |
| 1993 | 0.763 | 0.867 |
| 1994 | 0.787 | 0.842 |
| 1995 | 0.776 | 0.865 |
| 1996 | 0.790 | 0.881 |
| 1997 | 0.808 | 0.871 |
| 1998 | 0.819 | 0.870 |
| 1999 | 0.840 | 0.874 |
| 2000 | 0.838 | 0.896 |
| 2001 | 0.839 | 0.925 |
| 2002 | 0.864 | 0.921 |
| 2003 | 0.887 | 0.942 |
| 2004 | 0.926 | 0.953 |
| 2005 | 0.941 | 0.966 |
| 2006 | 1 | 0.987 |
| 2007-2017 | 1 | 1 |

In addition to removing the older and antique plate vehicles from the IHS data, we accounted for 25 counties that were outliers because their fleet age was significantly younger than typical. We limited our outlier identification to LDV source types 21, 31, and 32, because they're the most important. Many rural counties also have outliers for low-population source types such as Transit Bus and Refuse Truck; these do not have much of an impact on the inventory overall and reflect sparse data in low-population areas and therefore do not require correction.

The most extreme examples of LDV outliers were Light Commercial Truck age distributions where over 50 percent of the population in the entire county is 0 and 1 years old. These sorts of young fleets can happen if the headquarters of a leasing or rental company is the owner/entity of a relatively large number of vehicles relative to the county-wide population. While the business owner of thousands of new vehicles may reside in a single county, the vehicles likely operate in broader areas without being registered where they drive. To avoid creating artificial low spots of LDV emissions in these outlier counties, we flagged all counties above a 0.35 fraction of new vehicles and excluded their age distribution from the final set of grouped age distributions that went into the 2016v1 CDBs.

The 2016 age distributions were then grouped using a population-weighted average of the source type populations of each county in the representative county group. The end product was age distributions for each of the 13 source types in each of the 315 representative counties for 2016v1. It should be noted that the long-haul truck source types 53 (Single Unit) and 62 (Combination Unit) are a nationwide average due to the long-haul nature of their operation.

Input data tables provided by states were reviewed before they were used[8]. Some submitted data tables were found to be from previous emissions modeling platforms, primarily NEI 2014v2, 2016 alpha, or 2016 beta, and these were not explicitly used as most were already incorporated into the CDBs. All average speed distributions in 2016v1 came from the CRC A-100 study, and most age distributions (other than accepted submittals for New Jersey, Pima Arizona, and Wisconsin) came from methods described above for 2016 v1. The following submitted MOVES input data (other than the activity data discussed above) were incorporated into the 2016v1 base year MOVES CDBs:

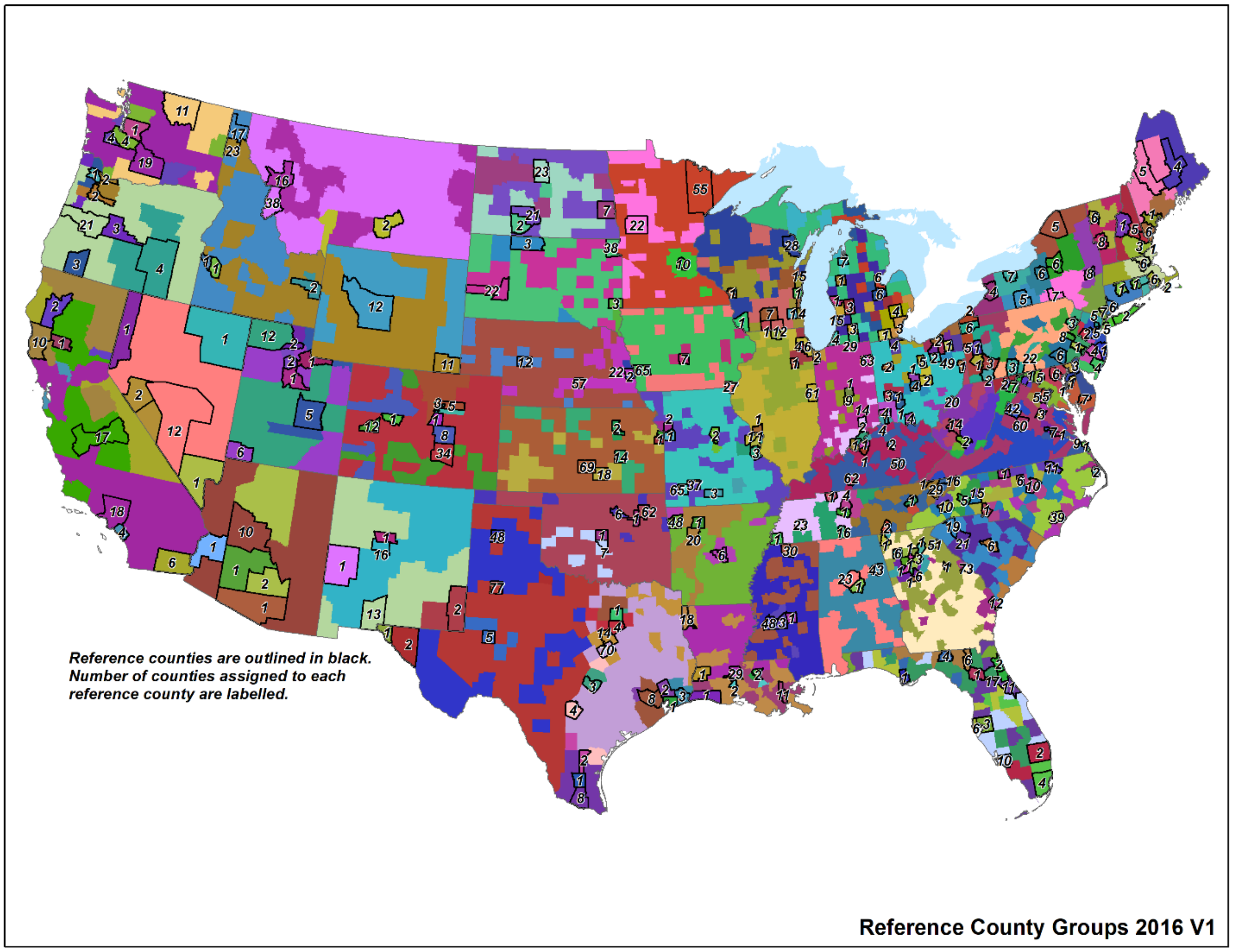
- Chicago (IL) Metropolitan Agency for Planning: FF10 VMT, FF10 VPOP, Month/Day VMT Fraction, Ramp Fractions
- Georgia Department of Natural Resources: Fuel Supply (county assignments to fuel type groups)
- Louisville (KY) Metro Air Pollution Control District: Road Type Distributions, Ramp Fractions
- Maryland Department of the Environment: Truck Stop Locations (these affect the spatial surrogate but not the MOVES run)
- New Jersey Department of Environmental Protection: Age Distribution
- Pima (AZ) Association of Governments: Age Distribution, I/M Coverage, Day VMT Fraction, Road Type Distribution
- Wisconsin Department of Natural Resources: Age Distribution, I/M Coverage

Once the input data were incorporated into the CDBs, a new set of representative counties was developed. Each county in the continental U.S. was classified according to its state, altitude (high or low), fuel region, the presence of inspection and maintenance programs, the mean light-duty age, and the fraction of ramps. A binning algorithm was executed to identify "like counties", and then specific requests for representative county groups by states were honored from the states of Maryland, New York, New Jersey, Wisconsin, Michigan, and Georgia. The final result was 315 representative counties (up from 304 in 2016 beta) as shown in Figure 1. The representative counties themselves changed substantially; of the 315 representative counties, 145 were not representative counties in 2016 beta. The CDBs for these 145 counties were developed from the 2014NEIv2 counties and updated to represent the year 2016. For more information on the development of the 2016 age distributions and representative

[8] ftp://newftp.epa.gov/air/emismod/2016/v1/reports/onroad/2016v1%20Plans%20for%20CDB%20Input%20Data_20190718.xlsx

counties and the review of the input data, see the memoranda "Onroad 2016v1 documentation_20191007" and "RepCountiesFor2016v1-2017_13jun2019" (ERG, 2019).

**Figure 1. Representative Counties in 2016v1**




To create the 2016v1 emission factors, MOVES was run separately for each representative county and fuel month for each temperature bin needed for calendar year 2016. The CDBs used to run MOVES include the state-specific control measures such as the California low emission vehicle (LEV) program, except that fuels were updated to represent calendar year 2016. In addition, the range of temperatures run along with the average humidities used were specific to the year 2016.The MOVES results were post-processed into CSV-formatted emission factor tables that can be read by SMOKE-MOVES.

## California inventory development

The California Air Resources Board (CARB) provided their own onroad emissions inventories based on their EMFAC2017 model. EMFAC2017 was run by CARB for model years 2016, 2023, 2028, and 2035. Details on how SMOKE-MOVES emissions were adjusted to match the CARB-based 2016 inventory are provided in the Emissions Processing Requirements section of this document.

**SCC descriptions**

SCCs in the onroad sector follow the format 220**FVV**0**RPP**, where:

- F = MOVES fuel type (1 for gasoline, 2 for diesel, 3 for CNG, 5 for E-85, and 9 for electric)
- VV = MOVES vehicle (aka source) type (see Table 1)
- R = MOVES road type (1 for off-network, 2 for rural restricted, 3 for rural unrestricted, 4 for urban restricted, 5 for urban unrestricted)
- PP = SMOKE aggregate process. In the activity data, the last two digits of the SCC are always 00, because activity data is process independent. MOVES separately tracks over a dozen processes, but for computational reasons it is not practical to model all of these processes separately within SMOKE-MOVES. Instead, "aggregate" processes are used in SMOKE. To support this, the MOVES processes are mapped to SMOKE aggregate processes according to Table 4.

Regarding electric vehicle activity: The only mobile emissions created by electric vehicles are PM from brake and tire wear. MOVES2014b does not create separate emission factors for electric vehicles. To capture brake and tire emissions from electric vehicles, VMT from electric vehicles is mapped to gasoline SCCs within SMOKE using the SCCXREF file, but for the brake and tire processes only. Brake and tire emission factors are assumed to be independent of fuel type. This assumption allows brake and tire emissions from electric vehicles to be modeled using the brake and tire emission factors for gasoline vehicles. Since electric vehicle VMT is *not* mapped to the exhaust or evaporative processes, exhaust and evaporative emissions are not generated from electric vehicles. Since all brake and tire emissions are on-network, only the VMT dataset, and not the VPOP dataset, needs to include electric vehicles. For this reason, electric vehicle VPOP is often removed from the inventory prior to running SMOKE-MOVES.

**Table 4: SMOKE-MOVES aggregate processes**

| MOVES Process ID | Process description | SMOKE aggregate process |
|---|---|---|
| 01 | Running Exhaust | 72 |
| 02 | Start Exhaust | 72 |
| 09 | Brakewear | 40 |
| 10 | Tirewear | 40 |
| 11 | Evap Permeation | 72 |
| 12 | Evap Fuel Vapor Venting | 72 |
| 13 | Evap Fuel Leaks | 72 |
| 15 | Crankcase Running Exhaust | 72 |
| 16 | Crankcase Start Exhaust | 72 |
| 17 | Crankcase Extended Idle Exhaust | 53 |
| 18 | Refueling Displacement Vapor Loss | 62 |
| 19 | Refueling Spillage Loss | 62 |
| 90 | Extended Idle Exhaust | 53 |
| 91 | Auxiliary Power Exhaust | 91 |

# 4. ANCILLARY DATA

### Spatial Allocation

Onroad county activity data were allocated to a national 12km grid for EPA air quality modeling applications using spatial surrogates. The surrogates were derived based on various types of spatial data and referred to by a name and a three-digit code. Technically, within SMOKE-MOVES, activity is gridded first, and then emissions are calculated based on gridded activity data for each month. VMT is allocated using spatial surrogates based on Annual Average Daily Travel (AADT)[9], with one surrogate for restricted roads and another surrogate for unrestricted roads. Prior to creation of the surrogates, the FHWA road types in the Shapefiles were mapped to MOVES road types. The HPMS road types are: 1 – interstate, 2 – principal arterial other freeways and expressways, 3 – principal arterial – other, 4 – minor arterial – other, 5 – major collector, 6 – urban minor collector. These were mapped to MOVEs road types as follows: MOVES road type 2 (rural restricted access) = HPMS interstates (type 1) in rural areas; MOVES road type 3 (rural unrestricted access) = HPMS types 2, 3, 4, and 5 in rural areas; MOVES road

[9] https://www.fhwa.dot.gov/policyinformation/hpms/shapefiles.cfm; ftp://newftp.epa.gov/air/emismod/2016/alpha/spatial_surrogates/shapefiles/

type 4 (urban restricted access) = HPMS types 1 and 2 in urban areas; MOVES road type 5 (urban unrestricted access) = HPMS types 3, 4, and 5 in urban areas.

To eliminate the impact of discrepancies in urban and rural classifications between activity data and the underlying AADT data, spatial surrogates the distinguish between urban and rural road types were not used. Such discrepancies have caused problematic hot spots in the past when using surrogates specific to rural or urban roads. Also for 2016v1, the same types of spatial surrogates based on AADT were used, but the values were recomputed using a corrected calculation that appropriately weighted the amount of AADT along each link while considering the length of each link.

Hoteling emissions use a truck stops surrogate (205), which is based on the same truck stop parking space data that were used when applying reductions to hoteling activity. The four states for which hoteling reductions were not applied (CO, ME, NJ, and NY) also requested that we not spatially allocate hoteling emissions using the truck stops surrogate, because doing so may have resulted in overallocation of hoteling emissions to a small area (i.e. hot spots). Instead, hoteling emissions in those four states are allocated using the All Restricted AADT surrogate (242).

The AADT and truck stop surrogates were updated for the beta platform and slightly for the 2016v1 platform based on state feedback. Off-network emissions use surrogates that depend on the vehicle type. Reports summarizing total emissions by spatial surrogate at the state and county level have been developed and national totals are shown below.

Onroad emissions totals, because of SMOKE-MOVES' dependence on gridded meteorology, can vary between grid resolutions. To ensure consistency in onroad emissions between different grid resolutions, when processing emissions at 36km resolution, emissions at 12km resolution are aggregated to 36km resolution instead of rerunning SMOKE-MOVES directly at the 36km resolution. One minor exception is for EPA's 36US3 grid, which includes part of Southeast Alaska. For Southeast Alaska only, SMOKE-MOVES was run for the 36US3 grid using activity and emission factors for Alaska. Alaska onroad emissions were treated as a separate sector called "onroad_nonconus" and then merged with onroad and onroad_ca_adj, which are both aggregated from 12km to 36km.

A table of total onroad emissions by spatial surrogate for the continental US is provided in Table 5.

**Table 5. 2016fh onroad Continental US emissions by spatial surrogate (tons/year)**

| Surrogate | Description | CO | NH3 | NOX | PM10_PRI | PM25_PRI | SO2 | VOC |
|---|---|---|---|---|---|---|---|---|
| 205 | Extended Idle Locations | 36,139 | 230 | 78,126 | 862 | 794 | 36 | 13,711 |
| 239 | Total Road AADT | | | | | | | 5,755 |
| 242 | All Restricted AADT | 4,988,761 | 34,545 | 1,175,197 | 62,163 | 38,140 | 8,744 | 194,836 |
| 244 | All Unrestricted AADT | 8,483,785 | 65,543 | 1,773,993 | 164,217 | 67,525 | 17,788 | 477,839 |
| 258 | Intercity Bus Terminals | 565 | | 147 | 2 | 2 | 0 | 34 |
| 259 | Transit Bus Terminals | 5,321 | | 53 | 3 | 3 | 0 | 149 |
| 304 | NLCD Open + Low | 29,412 | | 829 | 33 | 29 | 1 | 3,874 |
| 306 | NLCD Med + High | 303,293 | | 15,209 | 369 | 333 | 17 | 19,917 |
| 307 | NLCD All Development | 5,607,685 | | 546,312 | 11,516 | 10,195 | 910 | 1,073,380 |
| 308 | NLCD Low + Med + High | 418,367 | | 40,054 | 814 | 722 | 62 | 62,127 |
| 506 | Education | 16,289 | | 629 | 16 | 15 | 1 | 637 |

**Temporal Allocation**

For on-network and hoteling emissions, VMT and HOTELING activity were temporalized from annual or monthly values to hourly and SMOKE was run for every day of the year. The VMT inventory is monthly for all sources. Some of the original VMT data sources did not specify monthly values, in which case monthly values for VMT were filled into the inventory prior to running SMOKE. In those instances, monthly temporalization is usually based on an existing monthly inventory (e.g. EPA default data). The hoteling activity dataset is annual and is temporalized to monthly within SMOKE using the MOVES default monthly profile for combination trucks.

For off-network emissions, VPOP is strictly treated as an annual value and does not need to be temporalized. The annual HOTELING inventory was temporalized to month, day of the week, and hour of the day using temporal profiles. This is an analogous process to on-network emissions except that speed is not included in the calculation of hoteling.

In addition to temporalization of activity, emissions temporalization is affected by meteorology. Meteorology is not used in the development of the temporal profiles, but rather it impacts the calculation of the hourly emissions through the SMOKE program Movesmrg. The result is that the emissions vary at the hourly level by grid cell. More specifically, the on-network (RPD) and the off-network parked vehicle (RPV, RPH, and RPP) processes use gridded meteorology directly. Movesmrg determines the temperature for each hour and grid cell and uses that information to select the appropriate emission factor for the specified SCC/pollutant/mode combination. RPP uses the gridded minimum and maximum temperature for the day. The combination of these four processes (RPD, RPV, RPH, and RPP) make up the total onroad sector emissions.

VMT was also temporalized from month to day of the week, and then to hourly through temporal profiles. Day-of-week and hour-of-day temporal profiles are mostly based on CRC-sponsored A-100 data assembled developed for use in 2014NEIv2. These profiles include a combination of county-specific, MSA-specific, and regional average profiles. The CRC A-100 data includes distinct profiles for passenger vehicles, commercial trucks, and combination trucks. CRC A-100 does not provide profiles for buses, refuse trucks, or motor homes. For motor homes, passenger vehicle weekly profiles and commercial truck hourly profiles were used[10] For intercity and transit buses, the weekly and hourly profiles for commercial trucks were used. School buses and refuse trucks use the hourly profiles for commercial trucks and a weekly profile called LOWSATSUN. This profile attributes most emissions to weekdays and only a very small amount on weekends, since the vast majority of school bus and refuse truck activity occurs on weekdays. Hoteling activity uses the same weekly profiles as the VMT, but uses inverted hourly profiles, since most hoteling activity occurs when vehicles are *not* driving. Additional details on the CRC A-100 project can be found on the CRC web site (Report A-100. Improvement of Default Inputs for MOVES and SMOKE-MOVES. Final Report. February 2017[11]). Additional information on the CRC A-100 implementation into the modeling platform can be found in the TSD Preparation of Emission Inventories for the 2014v7.1 2014 Emissions Modeling Platform (EPA, 2018).

The on-network processes (RPD) require a speed profile (SPDPRO) that consists of vehicle speed by hour for a typical weekday and weekend day. Unlike other sectors, the temporal profiles and SPDPRO will impact not only the distribution of emissions through time but also the total magnitude of emissions. Because SMOKE-MOVES (for RPD) calculates emissions from VMT,

[10] Note that motor homes comprise a very small portion of the inventory, and choices for profiles to map them to were limited. Passenger vehicles seemed appropriate because they do not have the lower on weekends feature that heavy duty profiles have.

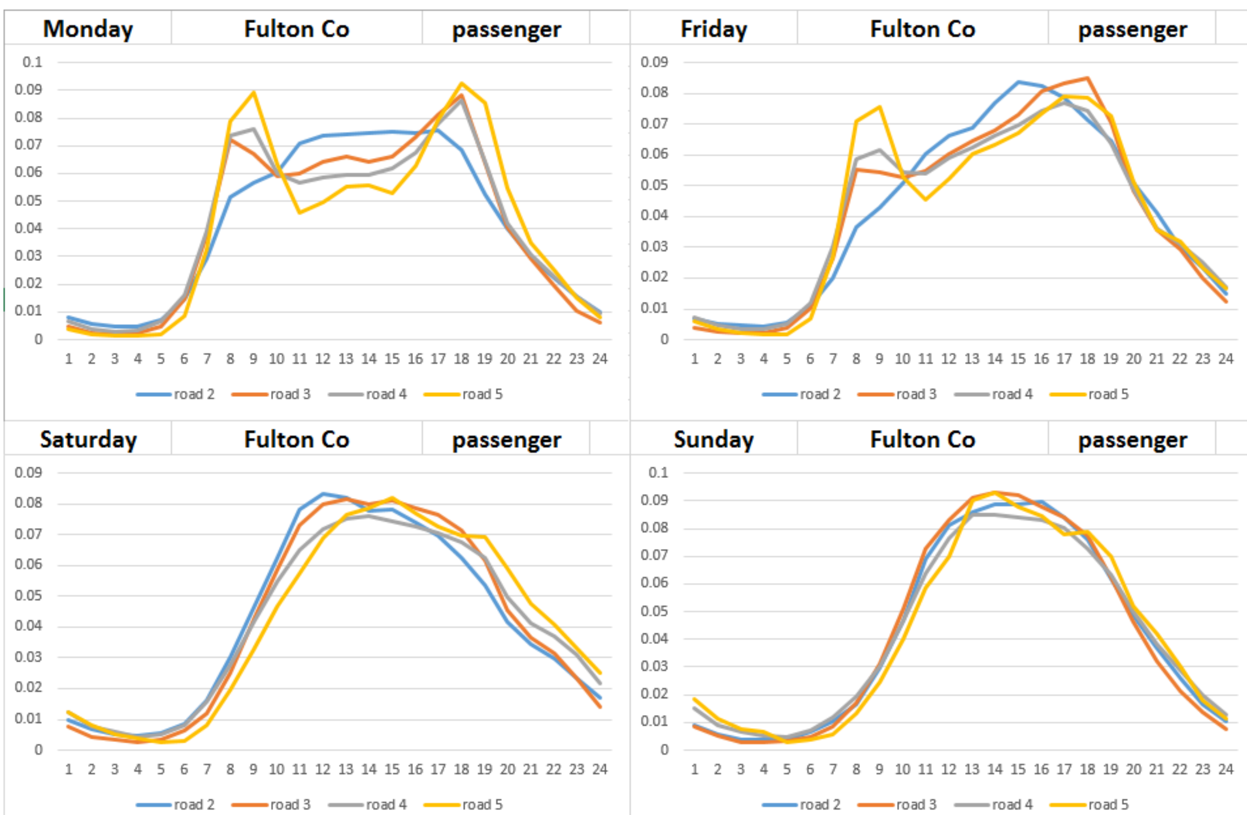
[11] https://crcao.org/reports/recentstudies2017/A-100/ERG_FinalReport_CRCA100_28Feb2017.pdf.

speed and meteorology, if one shifted the VMT or speed to different hours, it would align with different temperatures and hence different emission factors. In other words, two SMOKE-MOVES runs with identical annual VMT, meteorology, and MOVES emission factors, will have different total emissions if the temporalization of VMT changes.

Weekly and hourly temporal profiles provided by CARB for the 2011 platform were used for California sources.

Alaska, Hawaii, Puerto Rico, and Virgin Islands all used regional average temporal profiles from the CRC A-100 data. AK/HI used the West region average; PR/VI used the South region average. Plots of hour-of-day profiles for passenger vehicles and combination trucks in Fulton County, GA, are shown in Figure 2. Separate plots are shown for Monday, Friday, Saturday, and Sunday, and each line corresponds to a particular MOVES road type (i.e., road type 2 = rural restricted, 3 = rural unrestricted, 4 = urban restricted, and 5 = urban unrestricted). Figure 3 shows which counties have temporal profiles specific to that county, and which counties use regional average profiles.

**Figure 2. Sample onroad diurnal profiles for Fulton County, GA**



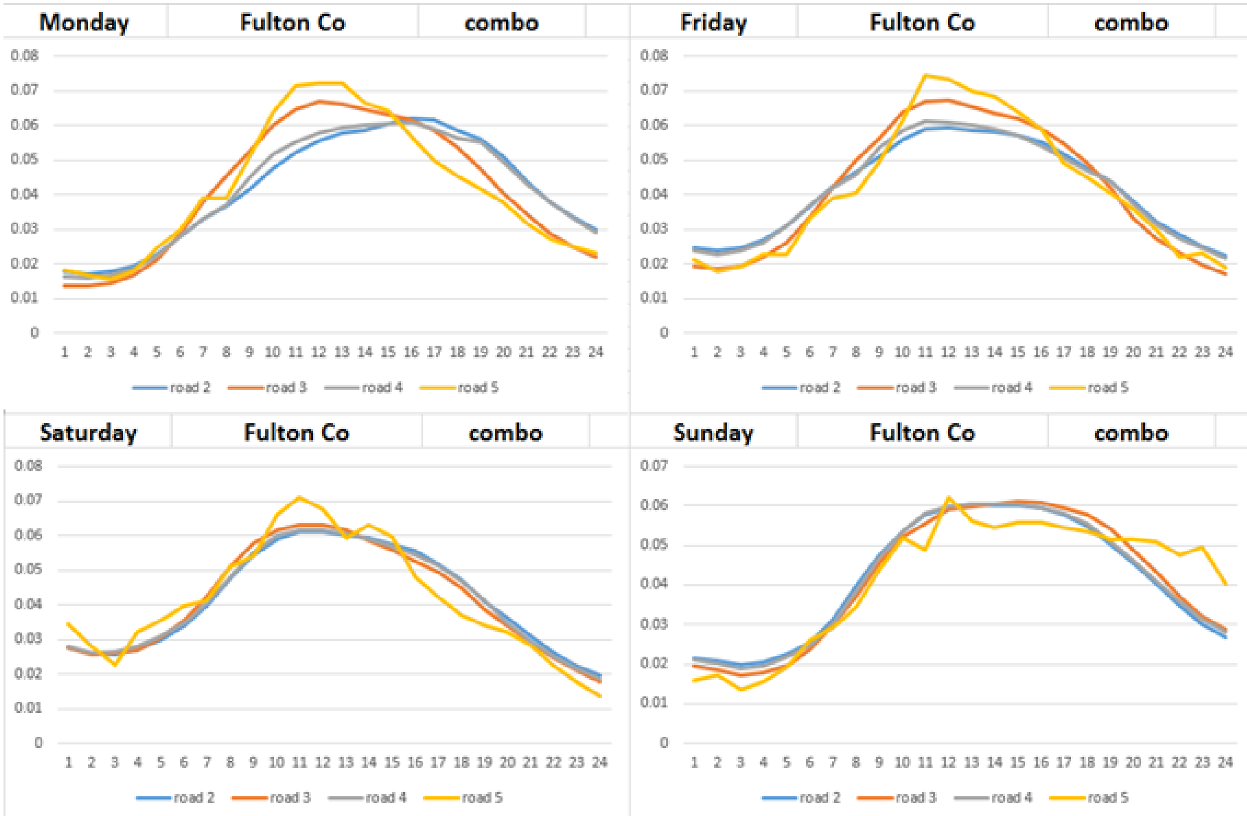
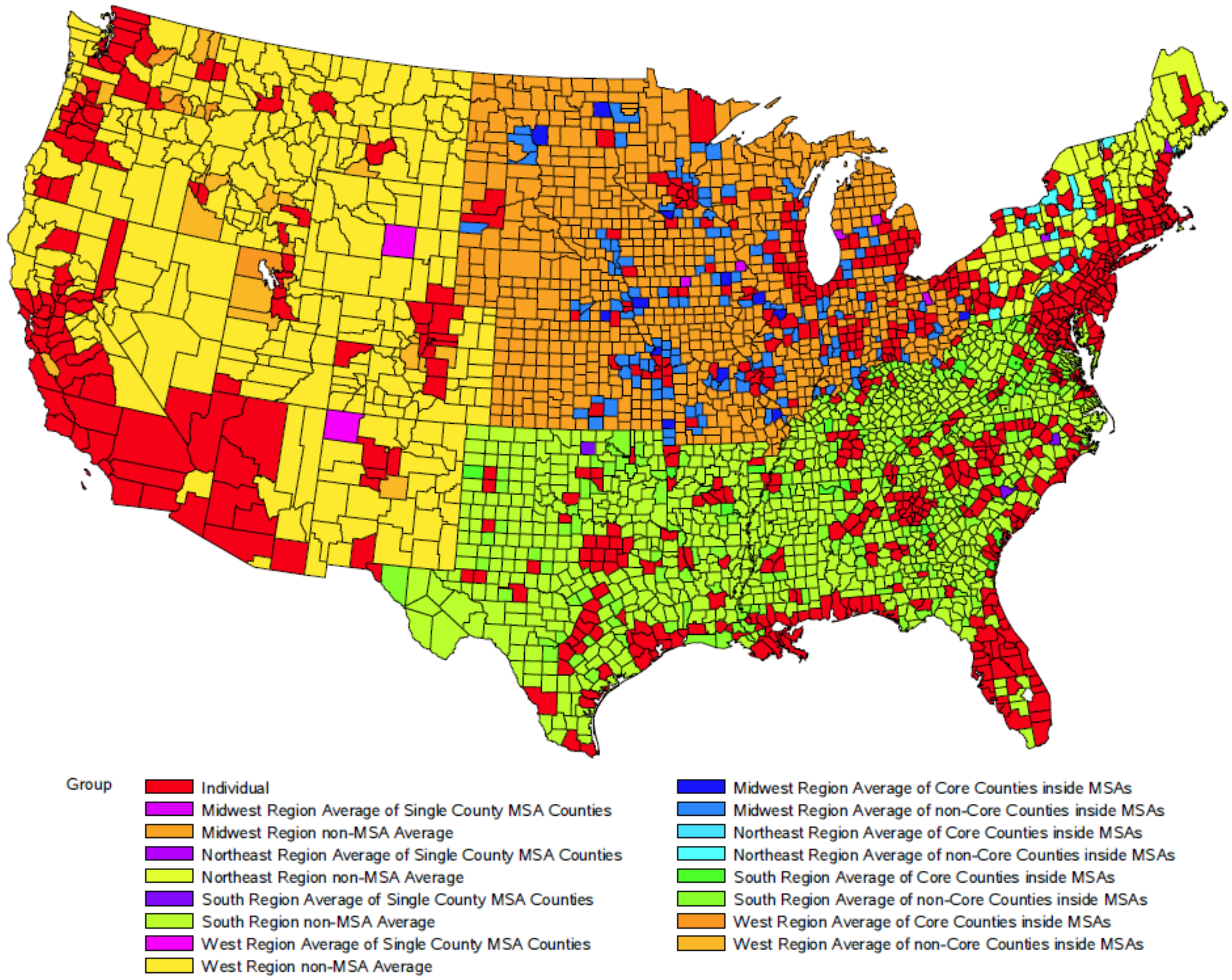

Monday
Fulton Co
combo
Friday
Fulton Co
combo
Saturday
Fulton Co
combo
Sunday
Fulton Co
combo
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
road 2
road 3
road 4
road 5

**Figure 3. MOVES Speeds and Temporal Profiles used in CRC A-100**




## Chemical Speciation

Chemical speciation of onroad emissions is internal to MOVES2014b except for brake and tire-wear particulate matter (PM) speciation, which occurs in SMOKE. MOVES has access to more detailed data and can produce a more accurate speciation than could SMOKE. The emission factor tables from MOVES include both unspeciated emissions totals in grams for criteria air pollutants (CAPs) and hazardous air pollutants (HAPs), and speciated emissions totals for CB6 model species in moles (or grams for PM). The GSREF and GSPRO used by SMOKE-MOVES do not do any actual speciation. The GSREF file has no function and only exists to prevent a SMOKE error. The GSPRO and MEPROC files in SMOKE work in tandem to select which species and pollutants to include in SMOKE outputs. The MEPROC includes all unspeciated pollutants, and the GSPRO maps unspeciated pollutants to individual model species (e.g. PM2_5 to all individual PM species). Model-ready emissions files will include all species in the GSPRO that are mapped to one or more pollutants present in the MEPROC. Movesmrg reports include all of those model species, plus all of the pollutants listed in the MEPROC.

For California sources, as described in the Emissions Processing Requirements section, the SMOKE-MOVES emissions are adjusted so that annual emissions totals match CARB-provided data. For pollutants that are speciated, such as NOX, PM2.5, and VOC, only the unspeciated emissions are matched to the totals provided by CARB. All speciation is determined by MOVES, even in California. For example, the same adjustment factors are applied to all VOC species as well as VOC_INV, resulting in a VOC total that matches CARB-supplied data, but a VOC speciation that matches MOVES.

The previous version of MOVES, MOVES2014a, created emission factors for an older version of the CB6 mechanism, used for CAMx modeling. MOVES2014b creates emission factors for the newer version of the CB6 mechanism used by CMAQ, in which the XYL species is replaced with XYLMN and NAPH, and which includes an additional tracer called SOAALK. The emission factor tables for v1 platform, which were generated in MOVES2014b, include these new species. Therefore, the extra CB6-CMAQ conversion step that was required in past platforms is no longer needed.

Additional details on chemical speciation for MOVES and SMOKE-MOVES can be found in the TSD Preparation of Emission Inventories for the 2014v7.1 2014 Emissions Modeling Platform (EPA, 2018).

**Other Ancillary Files Needed for SMOKE-MOVES**

SMOKE-MOVES requires several other types of ancillary files:

- MCXREF: Maps individual counties to representative counties.
- MFMREF: Maps actual months to fuel months for each representative county. May through September are mapped to the July fuel month, and all other months to the January fuel month. All representative counties must be listed in this file.
- MRCLIST: Lists emission factor table filenames for each representative county.
- MEPROC: Lists which pollutants to include in the SMOKE run; see Chemical Speciation section for more information.
- METMOVES: Gridded daily minimum and maximum temperature data. This file is created by the SMOKE program Met4moves and is used for RatePerProfile (RPP) processing.

- CFPRO: Applies adjustment factors to emissions. This is described in the Emissions Processing Requirements section.

# 5. Emissions Projection Methods

To compute future year emissions for the onroad sector, VMT, VPOP, and Hoteling activity data were projected to each future year. MOVES was then run to compute emission factors for each future year. For the 2016v1 platform, future year emissions were developed for 2020, 2023 and 2028. Future year emissions data for California were provided CARB.

**Activity data development**

Vehicle Miles Traveled (VMT)

For 2016v1, annual VMT data from the AEO2019 reference case were used to calculate national projection factors for VMT by fuel and vehicle type. Specifically, the following two AEO2019 tables were used:

- Light Duty (LD): Light-Duty VMT by Technology Type (table #51: https://www.eia.gov/outlooks/aeo/data/browser/#/?id=51-AEO2019&cases=ref2019&sourcekey=0)
- Heavy Duty (HD): Freight Transportation Energy Use (table #58: https://www.eia.gov/outlooks/aeo/data/browser/#/?id=58-AEO2019&cases=ref2019&sourcekey=0)

MOVES fuel and vehicle types were mapped to AEO fuel and vehicle classes as follows:

- Gas LD (motorcycles + cars + light trucks) were mapped to the combination of Gasoline internal combustion engines (ICE), plug-in gasoline hybrids, electric-gasoline hybrids, and also natural gas, propane, and methanol (those last three are minor).
- Diesel LD were mapped to TDI diesel ICE + electric-diesel hybrid.
- E-85 LD were mapped to ethanol-flex fuel ICE.
- Electric LD were mapped to all electric vehicle classes + fuel cell hydrogen.
- Gas buses and single unit trucks were mapped to all motor gasoline vehicles from the AEO HD report.
- Diesel buses and single unit trucks were mapped to all diesel vehicles from the AEO HD report.
- CNG buses were mapped to all CNG vehicles from the AEO HD report.
- Gas combination trucks were mapped to only the “heavy” motor gasoline vehicles.

- Diesel combination trucks were mapped to only the “heavy” diesel vehicles.

Total VMT for each MOVES fuel and vehicle grouping was calculated for the years 2016, 2020, 2023, and 2028 based on the AEO-to-MOVES mappings above. From these totals, 2016-2023 and 2016-2028 VMT trends were calculated for each fuel and vehicle grouping. Those trends became the national VMT projection factors. The AEO2019 tables include data starting from the year 2017. Since we were projecting from 2016, 2016-to-2017 projection factors were calculated from AEO2018, and then multiplied by 2017-to-future projection factors from AEO2019.
The 2016-to-future year VMT projection factors used for the 2016v1 platform are provided in Table 6.

**Table 6. Factors to Project 2016 VMT to 2023 and 2028**

| SCC6 | description | 2023 factor | 2028 factor |
|---|---|---|---|
| 220111 | LD gas | 5.99% | 6.99% |
| 220121 | LD gas | 5.99% | 6.99% |
| 220131 | LD gas | 5.99% | 6.99% |
| 220132 | LD gas | 5.99% | 6.99% |
| 220142 | Buses gas | 8.43% | 19.86% |
| 220143 | Buses gas | 8.43% | 19.86% |
| 220151 | MHD gas | 8.43% | 19.86% |
| 220152 | MHD gas | 8.43% | 19.86% |
| 220153 | MHD gas | 8.43% | 19.86% |
| 220154 | MHD gas | 8.43% | 19.86% |
| 220161 | HHD gas | -51.15% | -64.99% |
| 220221 | LD diesel | 86.79% | 177.3% |
| 220231 | LD diesel | 86.79% | 177.3% |
| 220232 | LD diesel | 86.79% | 177.3% |
| 220241 | Buses diesel | 14.30% | 21.23% |
| 220242 | Buses diesel | 14.30% | 21.23% |
| 220243 | Buses diesel | 14.30% | 21.23% |
| 220251 | MHD diesel | 14.30% | 21.23% |
| 220252 | MHD diesel | 14.30% | 21.23% |
| 220253 | MHD diesel | 14.30% | 21.23% |
| 220254 | MHD diesel | 14.30% | 21.23% |
| 220261 | HHD diesel | 12.91% | 17.85% |
| 220262 | HHD diesel | 12.91% | 17.85% |
| 220342 | Buses CNG | 65.57% | 88.00% |
| 220521 | LD E-85 | -0.70% | -10.03% |
| 220531 | LD E-85 | -0.70% | -10.03% |
| 220532 | LD E-85 | -0.70% | -10.03% |
| 220921 | LD Electric | 1258% | 2695% |
| 220931 | LD Electric | 1258% | 2695% |
| 220932 | LD Electric | 1258% | 2695% |

The base factors for VMT projections are national factors only. But, VMT trends can be different in different parts of the country, especially for passenger vehicles due to varying human population trends in different parts of the country. Human population data were available from the BenMAP model by county for several years, including 2017, 2023, and 2028 (https://www.woodsandpoole.com/ circa 2015). These human population data were used to create modified county-specific VMT projection factors for LD vehicles only. The same human population dataset was used in the 2011 platform (population_projections_11jan2016, v1). Note that 2017 is being used as the base year since 2016 human population is not available in this dataset. A newer human population dataset was assessed but it did not have trustworthy near-term (e.g., 2023/2028) projections, and was therefore not used. For example, in the newer data set, rural areas of NC were projected to have more growth than urban areas, which is the opposite of what has happened in recent years.

Using the national VMT projection factors as a baseline, counties that were projected to have higher than average human population growth had their LD VMT projection factors increased compared to the national average, and vice versa. National total projected VMT will not be affected, but LD VMT growth will vary from county to county based on the human population trend in each county. The formula is:

> *projection factor for county X = national factor * pop_factor_dampened*
> where *pop_factor = (pop trend in county X)/(pop trend nationwide)*,
> and *pop_factor_dampened = 1 + 0.5*(pop_factor - 1).*

"Dampening" of the pop_factor is applied so that human population does not have an outsized effect on the LD VMT growth. The dampening factor of 0.5 is based on analysis performed for the 2011 platform and was preferred over factors of 0.25 or 1.0.

For example, if nationally LD VMT is grown by 2%, and human population growth in County X is 25% higher than the national average population growth, then the LD VMT in County X will grow by 14.75%. (If dampening were not applied, LD VMT would grow by 27.5% in this county.) If in County Y, human population growth is 10% less than the national average growth, then LD VMT is decreased by 3.1% in this county.

The human population dataset does not include AK/HI/PR/VI (i.e., nonCONUS), so no human population adjustments were applied in nonCONUS areas. In the 2011 platform, nonCONUS areas were not projected at all because they were not needed for the modeling studies being performed, but they are needed in the v1 platform.

Future year projections of VMT based on both AEO2019 and human population are known as EPA projections. Note that EPA projections include projections of state-submitted 2016 VMT where available, and they are not a national projection of 2016 EPA default VMT. VMT submitted by state and local agencies were also considered for the future year activity data. Several agencies provided future year VMT. All of these VMT submissions are the same as the submissions from beta platform except for New Jersey and the Louisville metro, for which there were new submissions for v1 platform:

- CT, GA, NJ, NC, WI, Pima County AZ* (future VMT provided by HPMS type)
- NH (future VMT provided by SCC/month)
- OH (future VMT provided by road type)
- Clark County NV (future VMT provided by vehicle type)
- 5-county Louisville metro area (future VMT provided by county total only)
- MA (future VMT provided by county total only)
- *Pima AZ provided VMT for 2022, which was used to represent 2023 as-is. Pima did not provide 2028 VMT, so the EPA projection was used for 2028 Pima VMT.*

Where necessary, state-provided data were split to SCC/month (full FF10) using SCC and month distributions from the EPA projection. We also redistributed VMT between the LD car and truck vehicle types (21/31/32) based on splits from the EPA projection, using the same procedure as for 2016 activity data.

EPA data were used for North Carolina bus VMT; other vehicles used data submitted by the state, consistent with the 2016 VMT.

<u>Vehicle Population (VPOP)</u>

Projecting future year VPOP data began with calculations of VMT/VPOP ratios for each county, fuel, and vehicle type from the 2016 VMT and VPOP data. Those ratios were then applied to the future year projected VMT to estimate future year VPOP.

Future year VPOP data submitted by state and local agencies were then incorporated into the VPOP projections. Future year VPOP data were provided by state and local agencies in NH, NJ, NC, WI, Pima County, AZ and Clark County, NV. All of these submissions were the same as for the 2016beta platform except for New Jersey, which provided a new submission for the 2016v1 platform. For Pima County, just like with the VMT, future year VPOP was only provided for 2022 (used directly for 2023) and not for 2028. Where necessary, VPOP was split to SCC (full FF10) using SCC distributions from the EPA projection.

Just like with VMT, VPOP was also redistributed between the LD car and truck vehicle types (21/31/32) based on splits from the EPA projection, and used the EPA projection for buses in North Carolina and state-provided VPOP for all other vehicles in North Carolina.

Hoteling hours (HOTELING)

Projecting hoteling hours to the future began by calculating 2016 inventory HOTELING/VMT ratios for each county for combination long-haul trucks on restricted roads only. Those ratios were then applied to the future year projected VMT for combination long-haul trucks on restricted roads to calculate future year hoteling. Some counties had hoteling activity but did not have combination long-haul truck restricted road VMT in 2016; in those counties, the national AEO2018-based projection factor for diesel combination trucks was used to project 2016 hoteling to the future years. This procedure gives county-total hoteling for the future years. Each future year also has a distinct APU percentage based on MOVES input data that was used to split county total hoteling to each SCC: 22.6% APU for 2023, and 25.9% APU for 2028.

The second step in estimating future year hoteling hours was to incorporate future year hoteling data submitted by state and local agencies. The only state that submitted future year hoteling activity was New Jersey. Their future year hoteling data, which were updated for v1 platform, were provided in the same format as the 2016 data, so the same procedure to convert to FF10 was applied as in 2016. New Jersey specified a 30% APU split for each future year, just like for 2016.

**Emission factor table development**

Emission factors for onroad vehicles are expected to vary significantly in the future as emissions per vehicle rates are decreased due to regulatory and market-based drivers. To account for the expectation that onroad sources will have lower emissions in the future, the emission factors must be recalculated. To support this, the MOVES2014b model was run separately for each future year but using the same meteorological data as for the base year of 2016 with fuels that represent each future year, along with adjustments to age distributions and incorporation of state-supplied data. The remaining inputs to MOVES used were consistent with those in 2014NEIv2.

Historically, EPA used the same vehicle age distributions in base and future years for on-road emission inventory development. The economic recession of 2008 produced an anomalous “dip” in the age distribution profiles due to reduced vehicle sales, and so it is not appropriate to leave in a particular "age" of vehicle for all calendar years. Thus, EPA developed an age distribution projection tool that is a macro-based Excel file which projects each source type's age distribution to a future year using a similar approach to what was used to generate the national projected age distributions in MOVES2014. In response to state concerns that the established tool might lose the local characteristics and approach a national average in the future, EPA/ERG developed an alternate method to move the recession dip for LDVs for use in future years of the 2016 v1 platform. The approach is documented separately with examples in the memoranda AgeDistributionProjection_20190814.docx (ERG, 2019).

Future year MOVES inputs were provided by some state. Specifically, North Carolina, Connecticut, Wisconsin, and New Jersey all provided future year I/M Coverage input data. In addition, New Jersey provided future year Month VMT Fractions, and the Chicago area MPO (CMAP) provided future year ramp fractions. EPA accepted all future data for the 2016 v1 platform. The MOVES runs covered all 315 representative counties in the CONUS as well as all boroughs/counties in Alaska, Hawaii, the Virgin Islands, and San Juan Municipio (Puerto Rico). The MOVES emission rate lookup tables were speciated and processed for SMOKE using the post-processing code *aq_cb6_saprc_1Aug2019*.

**California inventory development**

CARB provided EMFAC2017-based onroad emissions inventories for both 2023 and 2028. These inventories are consistent with the 2016 inventory, in that they include separate totals for on-network and off-network, but do not include NH3 or refueling. Details on how SMOKE-MOVES emissions are adjusted to match the CARB-based 2023 and 2028 inventories are provided in the Emissions Processing Requirements section of this document.

# 6. Emissions Processing Requirements

SMOKE-MOVES was used to prepare the MOVES data for input to air quality modeling. Additional background on SMOKE-MOVES is provided in the Introduction section of this document.

Because of the special consideration given to onroad emissions in California, California emissions were run through SMOKE-MOVES as a separate sector from the rest of the country. The California onroad sector is called "onroad_ca_adj", while the "onroad" sector includes the rest of the continental U.S. Note that SMOKE-MOVES was run separately for three other grids that cover Alaska, Hawaii, and Puerto Rico + the Virgin Islands. Prior to running SMOKE-MOVES for the continental U.S., the activity data (VMT, VPOP, HOTELING, and SPEED) were subset to include all states except California (onroad sector), for the onroad_ca_adj sector to be California only.

Processing onroad emissions through SMOKE-MOVES consisted of these steps:

1) Run the RatePerDistance (RPD), RatePerHour (RPH), RatePerProfile (RPP), and RatePerVehicle (RPV) components through SMOKE-MOVES. These components, which are described in the Introduction section of this document, must be run separately, with each producing a separate set of gridded 2-D emissions files.

2) Run the onroad merge job, which uses the SMOKE program Mrggrid to merge the RPD, RPH, RPP, and RPV emissions together, creating a single set of gridded 2-D emissions files for this sector. The onroad and onroad_ca_adj emissions are not together and instead are kept as separate sectors throughout this process.

<u>DAYS_PER_RUN</u>

For RPD/RPH/RPP/RPV processing, SMOKE-MOVES can be run more efficiently by processing multiple days of emissions at once. For example, Movesmrg can create one 7-day emissions file much more quickly than it can create seven individual 1-day emissions files. The primary drawback to using this multi-day Movesmrg functionality is an increase in the memory usage. To turn on this feature, EPA's emissions modeling platform scripts feature a setting called DAYS_PER_RUN, to set the number of days to process in a single Movesmrg instance. The recommended value for DAYS_PER_RUN is 7; but the default is 1 because some computer systems may not have enough memory to support the 7 day per run setting. DAYS_PER_RUN is strictly a script setting used to configure other files and parameters used by SMOKE and is not used by SMOKE directly.

If DAYS_PER_RUN > 1, Movesmrg will output a single multi-day emissions file. The run scripts will use the I/O API utility m3xtract to split up the multi-day emissions file into single day (25-hour) emissions files that can be used downstream.

Multi-day Movesmrg runs will never cross months. For example, if DAYS_PER_RUN = 7, then the last Movesmrg run of January will start on January 29th and end on January 31st (3 days), and the first Movesmrg run of February will start on February 1st and end on February 7th.

Using the multi-day Movesmrg functionality requires multi-day meteorology files formatted for SMOKE. For example, if DAYS_PER_RUN = 7, the METCRO2D files output from the Meteorology-Chemistry Interface Processor (MCIP) must be 7 days + 1 hour (169 hours) long. The m3xtract program can be used to concatenate METCRO2D files in support of this requirement.

Memory and processing time considerations

Processing of RPD/RPH/RPP/RPV emissions in SMOKE-MOVES can be slow and memory intensive. On EPA computing systems, it took 2 to 3 hours to process one 7-day block of RPD emissions, using up to 20 GB of memory. Run times and memory requirements for RPV are less than half that of RPD. RPP and RPH emissions do not have high run times or memory requirements. Decreasing the value of DAYS_PER_RUN will decrease the memory requirements.

Since most of the processing time in SMOKE-MOVES is spent reading emission factor tables, processing for sub-national domains (e.g., the Northeast US only) can be much faster, because SMOKE-MOVES only reads emission factor tables for counties that are inside the modeling domain.

If using a particularly large CFPRO file, as is done for the onroad_ca_adj sector described below, this can greatly impact the run time.

CFPRO file

Movesmrg supports an optional input called the CFPRO file[12], which can be used to adjust emissions from SMOKE-MOVES on the fly. The CFPRO was used to adjust emissions in California so that annual emissions from SMOKE-MOVES equal CARB inventories in the onroad_ca_adj sector.

The following steps were used to develop the CFPRO file for adjusting the California onroad mobile emissions:

1. Onroad emissions for California were processed through SMOKE-MOVES without any adjustments. These emissions were processed with the sector name “onroad_ca” (as opposed to onroad_ca_adj). For the onroad_ca sector, it was only necessary to process RPD/RPH/RPP/RPV, not the subsequent merge. Also, only the emissions reports for onroad_ca were needed, not the gridded model-ready emissions.
2. Annual totals from onroad_ca (see Movesmrg report post-processing section below) were computed and compared to emissions totals from CARB-provided inventories for all CAPs. This comparison was done at the highest level of detail possible, depending on the resolution of the CARB inventory. In this case, that was by county, diesel/non-diesel, vehicle, on-network/off-network, and SMOKE-MOVES aggregate process.

[12] https://www.cmascenter.org/smoke/documentation/4.6/html/ch08s09s02.html#sect_input_cfpro

3. Factors were calculated from that comparison for every California county, SCC, pollutant, and species, and then converted to a CFPRO-formatted file for use in SMOKE-MOVES. All VOC species and VOC HAPs used the factors computed from VOC, which effectively means that we are matching CARB's total VOC but using the VOC speciation from MOVES. The same applies for PM2.5 and its model species. To reduce the risk of processing errors, we set USE_EXP_CONTROL_FAC_YN = Y when running Movesmrg and specified each pollutant and model species in the CFPRO individually.
4. Onroad emissions for California were processed through SMOKE-MOVES a second time using the CFPRO. This is sector name "onroad_ca_adj", and these emissions will be included in the final set of emissions for air quality modeling. Annual emissions totals in the onroad_ca_adj sector should match the CARB inventory at the same level of detail that was used to compare the inventories in Step 2.

The 2016 CARB inventory from EMFAC2017 does not include refueling or NH3. CARB requested that MOVES emissions be used for those pollutants and categories. Therefore, the adjustments described above were only applied to non-refueling processes for pollutants other than NH3.

Movesmrg report post-processing

For most sectors, an annual or monthly emissions inventory was available prior to running SMOKE. The onroad sector was unique in that emissions values are not known until after SMOKE-MOVES is run. After SMOKE-MOVES was run, an FF10-formatted inventory was developed based on reports produced by SMOKE-MOVES.

Movesmrg creates reports by county and SCC for all pollutants and species for each day, or block of days depending on the DAYS_PER_RUN setting. A Python script called the Movesmrg report post-processor reads all daily (or if DAYS_PER_RUN=7, weekly) Movesmrg reports for the year, aggregates and sums them together, and creates a set of monthly and annual reports by state, county, state/SCC, and county/SCC. This script is provided as a utility in the beta platform script package. Memory requirements for this script are even higher than that for running SMOKE-MOVES. For example, on EPA systems, RPD report processing requires up to 64 GB of memory and uses under one hour of run time per month of processing. RPV memory requirements and run time are about one-third that of RPD, while RPP and RPH do not have high memory requirements or run times.

Following completion of the Movesmrg report post-processor for both onroad and onroad_ca_adj, monthly county-SCC reports were converted to FF10 format, primarily to aid in the generation of comparison reports and summaries. This FF10 is provided in the v1 platform package. As standard practice, we do not include all model species in these onroad FF10s.

Instead we only include CAPs, $NO_X$ and PM species, NONHAPTOG by mode, and certain VOC HAPs.

# 7. EMISSIONS SUMMARIES

National and state totals by pollutant for the v1 platform cases are provided here, and some example plots. Additional onroad mobile plots and maps are available online through the LADCO website[13] and the Intermountain West Data Warehouse[14].

Descriptions of the emissions platform cases shown in the tables and plots below are as follows:

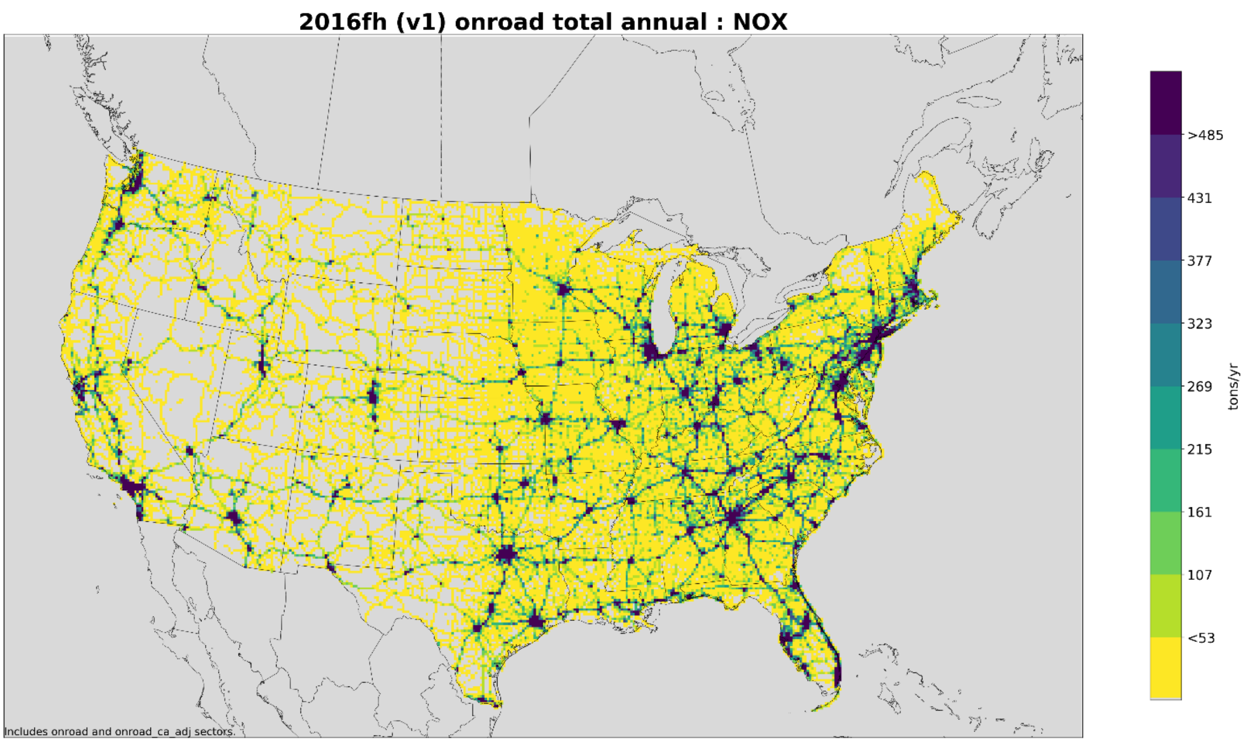
2014fd = 2014NEIv2 and 2014 NATA

2016fe = 2016 alpha platform (grown from 2014NEIv2)

2016ff, 2023ff, and 2028ff = 2016, 2023, and 2028 cases from the 2016 beta platform

2016fh, 2023fh, 2028fh = 2016, 2023, and 2028 v1 platform cases

**Figure 4. 2016fh 12US1 gridded onroad NOX emissions (tons)**




[13] https://www.ladco.org/technical/modeling-results/2016-inventory-collaborative/

[14] http://views.cira.colostate.edu/iwdw/eibrowser2016

**Figure 5. 2016fh 12US1 gridded onroad VOC emissions (tons)**

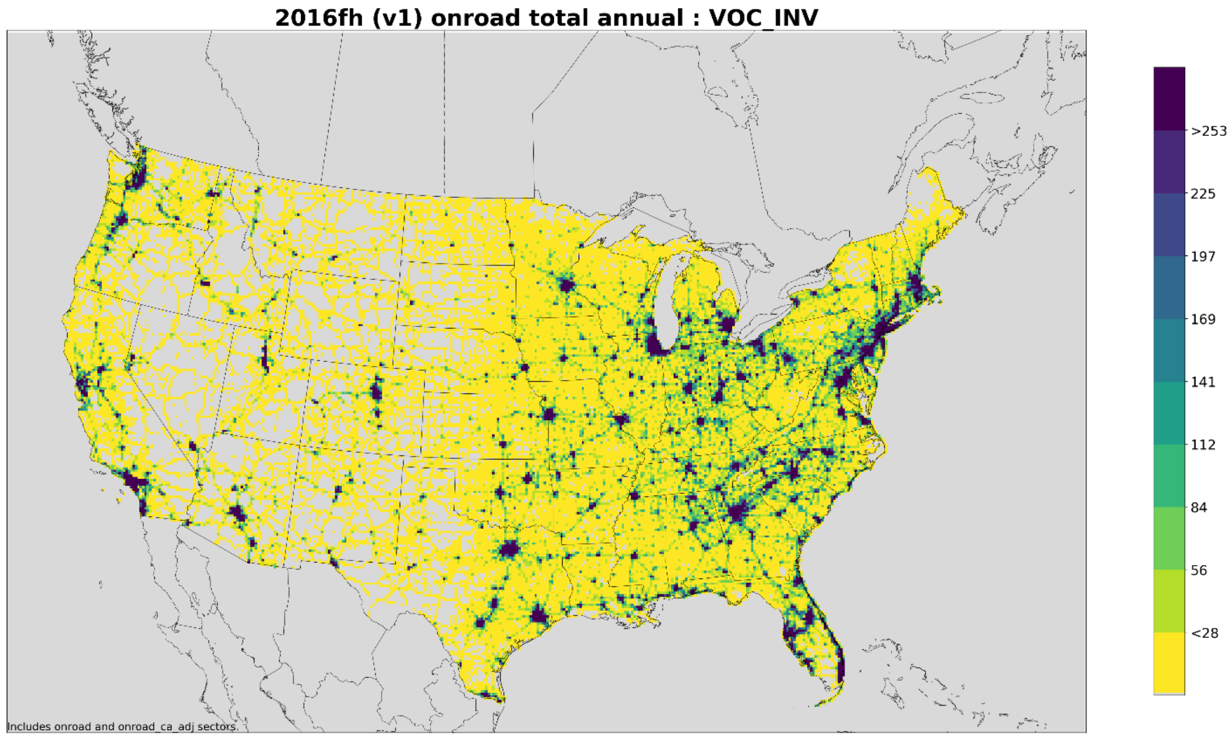



**Table 7. Comparison of national total annual CAPS onroad emissions (tons/yr)**

| Pollutant | 2014fd | 2016fe | 2016ff | 2016fh | 2023ff | 2023fh | 2028ff | 2028fh |
|---|---|---|---|---|---|---|---|---|
| CO | 24,141,986 | 20,446,327 | 20,330,093 | 20,139,268 | 14,251,351 | 13,952,871 | 10,427,337 | 10,436,752 |
| NH3 | 107,684 | 101,230 | 100,841 | 101,205 | 87,246 | 90,071 | 83,631 | 88,676 |
| NOX | 4,835,396 | 4,045,836 | 4,065,540 | 3,663,328 | 1,953,938 | 1,767,687 | 1,353,757 | 1,257,055 |
| PM10 | 301,467 | 272,855 | 272,770 | 242,568 | 224,706 | 202,257 | 211,037 | 191,979 |
| PM2.5 | 161,732 | 130,263 | 130,564 | 118,920 | 78,910 | 73,266 | 63,041 | 59,557 |
| SO2 | 28,094 | 27,356 | 27,547 | 27,744 | 12,397 | 12,595 | 11,547 | 11,806 |
| VOC | 2,346,620 | 1,961,995 | 1,985,763 | 1,878,993 | 1,195,488 | 1,115,406 | 885,883 | 848,229 |

**Table 8. Comparison of state total annual NOx onroad emissions (tons/yr)**

| State | 2014fd | 2016fe | 2016ff | 2016fh | 2023ff | 2023fh | 2028ff | 2028fh |
|---|---|---|---|---|---|---|---|---|
| Alabama | 129,445 | 111,108 | 111,934 | 101,733 | 54,390 | 49,815 | 35,057 | 33,333 |
| Alaska | | | | 11,977 | | 7,089 | | 4,789 |
| Arizona | 118,595 | 98,360 | 94,385 | 81,126 | 51,006 | 43,900 | 35,098 | 30,561 |
| Arkansas | 79,428 | 67,286 | 67,109 | 58,071 | 32,823 | 27,453 | 22,019 | 19,147 |
| California | 274,369 | 230,117 | 230,117 | 223,138 | 102,886 | 108,132 | 82,018 | 95,431 |
| Colorado | 89,794 | 76,686 | 74,065 | 64,061 | 39,591 | 32,771 | 27,749 | 22,928 |
| Connecticut | 30,676 | 24,533 | 23,905 | 20,743 | 10,313 | 8,758 | 7,367 | 6,350 |

| State | 2014fd | 2016fe | 2016ff | 2016fh | 2023ff | 2023fh | 2028ff | 2028fh |
|---|---|---|---|---|---|---|---|---|
| Delaware | 12,066 | 10,073 | 10,064 | 9,327 | 4,367 | 4,051 | 2,904 | 2,856 |
| D.C. | 4,384 | 3,625 | 3,624 | 3,137 | 1,877 | 1,689 | 1,182 | 1,129 |
| Florida | 262,347 | 222,366 | 226,866 | 198,160 | 100,614 | 87,378 | 67,385 | 61,735 |
| Georgia | 177,000 | 161,423 | 174,018 | 153,999 | 80,892 | 67,777 | 57,859 | 47,178 |
| Hawaii | | | | 10,384 | | 5,005 | | 3,220 |
| Idaho | 48,473 | 42,608 | 42,453 | 36,164 | 24,030 | 20,750 | 17,086 | 14,810 |
| Illinois | 168,750 | 131,034 | 130,731 | 117,837 | 60,213 | 57,616 | 41,455 | 41,417 |
| Indiana | 151,846 | 124,377 | 124,091 | 103,694 | 58,239 | 50,764 | 39,979 | 36,034 |
| Iowa | 70,842 | 60,834 | 60,553 | 53,803 | 29,654 | 27,008 | 20,355 | 18,917 |
| Kansas | 73,361 | 61,687 | 61,537 | 54,097 | 30,523 | 26,370 | 20,297 | 17,936 |
| Kentucky | 104,470 | 84,858 | 84,671 | 75,744 | 40,826 | 36,483 | 27,340 | 24,935 |
| Louisiana | 96,957 | 78,020 | 77,873 | 70,320 | 37,308 | 34,208 | 26,109 | 24,474 |
| Maine | 23,094 | 18,801 | 20,038 | 16,291 | 9,447 | 7,562 | 6,756 | 5,575 |
| Maryland | 73,232 | 62,157 | 60,876 | 50,604 | 28,430 | 22,746 | 18,945 | 16,411 |
| Massachusetts | 44,729 | 37,421 | 38,353 | 40,627 | 17,058 | 19,509 | 12,058 | 14,226 |
| Michigan | 134,323 | 105,775 | 106,444 | 97,879 | 48,067 | 45,688 | 32,766 | 31,924 |
| Minnesota | 94,172 | 75,377 | 74,943 | 66,467 | 35,575 | 31,660 | 23,916 | 22,024 |
| Mississippi | 79,571 | 65,701 | 65,597 | 56,425 | 30,586 | 23,975 | 20,258 | 16,749 |
| Missouri | 158,130 | 132,173 | 131,701 | 108,713 | 66,702 | 56,063 | 45,862 | 39,062 |
| Montana | 38,230 | 33,481 | 33,366 | 30,028 | 20,622 | 18,567 | 14,857 | 13,183 |
| Nebraska | 49,178 | 42,709 | 42,519 | 36,279 | 22,148 | 19,189 | 15,321 | 13,319 |
| Nevada | 44,313 | 37,559 | 37,306 | 32,213 | 20,132 | 16,921 | 14,391 | 11,822 |
| New Hampshire | 16,292 | 13,492 | 13,347 | 11,943 | 6,403 | 5,661 | 4,626 | 4,048 |
| New Jersey | 71,433 | 57,508 | 57,291 | 67,673 | 25,309 | 26,747 | 18,972 | 18,664 |
| New Mexico | 72,181 | 66,252 | 65,469 | 57,546 | 34,712 | 30,219 | 24,586 | 21,201 |
| New York | 143,495 | 110,222 | 111,115 | 104,823 | 56,797 | 52,134 | 40,330 | 35,891 |
| North Carolina | 159,301 | 136,660 | 134,247 | 120,721 | 58,732 | 61,156 | 37,208 | 41,377 |
| North Dakota | 36,073 | 27,418 | 27,424 | 23,630 | 13,917 | 12,338 | 9,657 | 8,845 |
| Ohio | 156,663 | 126,024 | 125,836 | 122,966 | 56,925 | 57,560 | 39,713 | 40,015 |
| Oklahoma | 92,071 | 76,481 | 76,320 | 77,176 | 38,859 | 40,173 | 27,014 | 27,934 |
| Oregon | 71,134 | 61,737 | 61,751 | 54,234 | 34,830 | 30,305 | 24,158 | 20,760 |
| Pennsylvania | 174,231 | 140,272 | 140,093 | 122,046 | 64,743 | 57,905 | 44,171 | 40,495 |
| Rhode Island | 12,581 | 10,318 | 10,306 | 8,404 | 4,426 | 3,783 | 3,083 | 2,771 |
| South Carolina | 87,847 | 76,897 | 92,111 | 83,782 | 42,629 | 39,936 | 28,056 | 27,141 |
| South Dakota | 27,734 | 23,643 | 23,565 | 20,500 | 12,532 | 10,918 | 8,746 | 7,671 |
| Tennessee | 147,638 | 126,845 | 126,339 | 106,069 | 61,048 | 51,693 | 40,954 | 35,896 |
| Texas | 413,729 | 353,642 | 353,009 | 303,462 | 164,949 | 133,616 | 115,390 | 96,784 |
| Utah | 74,618 | 66,996 | 66,719 | 58,584 | 34,882 | 31,317 | 25,771 | 23,551 |
| Vermont | 7,619 | 6,179 | 6,172 | 5,314 | 3,045 | 2,670 | 2,142 | 1,928 |
| Virginia | 132,762 | 109,391 | 107,200 | 94,572 | 48,433 | 42,759 | 31,110 | 28,879 |
| Washington | 129,267 | 110,435 | 110,245 | 95,490 | 58,973 | 50,961 | 39,146 | 34,567 |

| State | 2014fd | 2016fe | 2016ff | 2016fh | 2023ff | 2023fh | 2028ff | 2028fh |
|---|---|---|---|---|---|---|---|---|
| West Virginia | 40,880 | 33,501 | 32,879 | 29,574 | 15,721 | 14,041 | 10,469 | 9,595 |
| Wisconsin | 104,025 | 85,353 | 88,652 | 80,086 | 42,193 | 35,953 | 30,127 | 25,272 |
| Wyoming | 32,045 | 26,421 | 26,312 | 21,271 | 15,561 | 12,287 | 11,937 | 9,265 |
| Puerto Rico | | | | 9,975 | | 4,459 | | 2,896 |
| Virgin Islands | | | | 443 | | 197 | | 131 |

**Table 9. Comparison of state total annual VOC onroad emissions (tons/yr)**

| State | 2014fd | 2016fe | 2016ff | 2016fh | 2023ff | 2023fh | 2028ff | 2028fh |
|---|---|---|---|---|---|---|---|---|
| Alabama | 67,278 | 57,501 | 59,409 | 56,122 | 36,494 | 34,086 | 24,854 | 24,043 |
| Alaska | | | | 8,228 | | 5,464 | | 4,142 |
| Arizona | 55,882 | 49,152 | 49,587 | 46,260 | 31,438 | 30,240 | 22,958 | 22,321 |
| Arkansas | 33,171 | 27,857 | 28,381 | 25,164 | 17,102 | 13,832 | 12,265 | 10,244 |
| California | 124,804 | 104,935 | 104,935 | 98,202 | 62,769 | 59,681 | 51,830 | 49,148 |
| Colorado | 47,417 | 40,199 | 40,918 | 38,296 | 26,699 | 23,749 | 20,473 | 18,412 |
| Connecticut | 20,593 | 16,398 | 16,278 | 14,748 | 9,766 | 8,781 | 7,771 | 7,107 |
| Delaware | 7,249 | 6,094 | 6,092 | 5,764 | 3,770 | 3,524 | 2,854 | 2,771 |
| D.C. | 3,194 | 2,677 | 2,677 | 2,325 | 1,852 | 1,664 | 1,252 | 1,168 |
| Florida | 146,389 | 125,411 | 131,637 | 116,025 | 79,001 | 66,203 | 57,891 | 50,798 |
| Georgia | 83,824 | 80,530 | 79,742 | 71,340 | 47,411 | 37,466 | 35,472 | 27,947 |
| Hawaii | | | | 8,954 | | 5,418 | | 3,959 |
| Idaho | 22,188 | 19,112 | 19,457 | 17,822 | 12,590 | 11,439 | 9,293 | 8,590 |
| Illinois | 90,736 | 69,891 | 69,915 | 65,574 | 40,478 | 38,523 | 30,020 | 29,271 |
| Indiana | 72,127 | 58,715 | 59,541 | 55,049 | 33,943 | 31,648 | 24,813 | 23,806 |
| Iowa | 37,319 | 31,059 | 31,445 | 29,868 | 18,921 | 18,139 | 13,765 | 13,481 |
| Kansas | 34,632 | 28,794 | 29,311 | 26,779 | 17,962 | 15,905 | 12,928 | 11,620 |
| Kentucky | 47,420 | 38,682 | 39,294 | 36,896 | 23,008 | 21,215 | 16,416 | 15,600 |
| Louisiana | 40,103 | 32,920 | 33,690 | 32,073 | 19,601 | 18,462 | 14,173 | 13,637 |
| Maine | 11,096 | 8,819 | 9,112 | 7,857 | 5,432 | 4,599 | 4,199 | 3,699 |
| Maryland | 33,808 | 28,585 | 27,977 | 23,013 | 17,568 | 13,746 | 12,910 | 10,902 |
| Massachusetts | 29,365 | 24,642 | 23,909 | 24,150 | 14,796 | 15,242 | 11,473 | 11,990 |
| Michigan | 84,777 | 65,938 | 66,921 | 63,809 | 38,136 | 37,051 | 28,471 | 28,268 |
| Minnesota | 58,386 | 44,941 | 45,463 | 41,382 | 27,453 | 24,644 | 20,627 | 19,091 |
| Mississippi | 37,107 | 30,691 | 31,491 | 26,580 | 18,136 | 13,471 | 12,684 | 9,931 |
| Missouri | 68,063 | 56,344 | 56,940 | 52,671 | 35,273 | 32,397 | 25,139 | 23,624 |
| Montana | 19,836 | 16,416 | 16,668 | 16,226 | 11,602 | 11,289 | 8,734 | 8,604 |
| Nebraska | 24,666 | 20,865 | 21,199 | 19,912 | 13,170 | 12,493 | 9,452 | 9,121 |
| Nevada | 20,006 | 17,234 | 18,060 | 16,756 | 11,579 | 10,582 | 8,718 | 8,043 |
| New Hampshire | 9,168 | 7,454 | 7,334 | 6,870 | 4,922 | 4,408 | 4,009 | 3,466 |
| New Jersey | 31,234 | 26,190 | 25,887 | 30,779 | 15,759 | 17,677 | 12,620 | 14,012 |
| New Mexico | 24,625 | 22,090 | 22,671 | 21,179 | 14,254 | 13,113 | 10,546 | 9,874 |

| State | 2014fd | 2016fe | 2016ff | 2016fh | 2023ff | 2023fh | 2028ff | 2028fh |
|---|---|---|---|---|---|---|---|---|
| New York | 78,344 | 58,463 | 58,987 | 57,504 | 38,367 | 36,864 | 29,078 | 28,617 |
| North Carolina | 84,601 | 72,350 | 71,697 | 67,076 | 40,054 | 52,259 | 28,753 | 41,884 |
| North Dakota | 11,496 | 8,203 | 8,292 | 7,645 | 5,223 | 4,750 | 3,922 | 3,641 |
| Ohio | 86,184 | 70,103 | 71,245 | 76,612 | 41,606 | 44,670 | 31,885 | 34,097 |
| Oklahoma | 42,735 | 35,246 | 36,019 | 39,272 | 21,894 | 24,061 | 15,936 | 17,731 |
| Oregon | 40,291 | 34,498 | 34,879 | 32,243 | 22,123 | 20,151 | 15,953 | 14,784 |
| Pennsylvania | 80,517 | 63,954 | 64,409 | 62,012 | 38,036 | 36,570 | 28,017 | 27,577 |
| Rhode Island | 6,042 | 4,890 | 4,888 | 4,301 | 2,908 | 2,593 | 2,258 | 2,089 |
| South Carolina | 46,580 | 40,944 | 42,580 | 40,928 | 24,631 | 23,820 | 17,589 | 17,433 |
| South Dakota | 12,516 | 10,238 | 10,411 | 9,723 | 6,670 | 6,190 | 4,940 | 4,681 |
| Tennessee | 69,074 | 58,953 | 60,121 | 53,649 | 35,170 | 30,760 | 25,039 | 22,550 |
| Texas | 152,522 | 136,105 | 137,732 | 123,997 | 79,975 | 57,051 | 58,849 | 43,448 |
| Utah | 27,964 | 25,180 | 25,566 | 23,554 | 16,141 | 14,788 | 12,533 | 11,633 |
| Vermont | 4,523 | 3,590 | 3,628 | 3,359 | 2,304 | 2,178 | 1,769 | 1,729 |
| Virginia | 65,140 | 54,718 | 54,637 | 50,020 | 32,849 | 29,306 | 23,663 | 22,059 |
| Washington | 70,567 | 59,503 | 60,265 | 54,900 | 38,040 | 34,231 | 27,650 | 25,485 |
| West Virginia | 17,353 | 14,133 | 14,248 | 13,552 | 8,315 | 7,777 | 5,942 | 5,722 |
| Wisconsin | 53,313 | 42,620 | 41,930 | 34,837 | 24,765 | 20,763 | 19,208 | 16,538 |
| Wyoming | 10,392 | 8,168 | 8,291 | 7,585 | 5,530 | 4,918 | 4,287 | 3,824 |
| Puerto Rico | | | | 9,199 | | 5,339 | | 3,854 |
| Virgin Islands | | | | 352 | | 218 | | 161 |