0February 20, 2020

SPECIFICATION SHEET: CMV_C3 2016v1 Platform

Description: Category 3 Commercial Marine Vessel (cmv_c3) emissions, for simulating 2016 and future year air quality

1. Executive Summary

Commercial Marine Vessel (CMV) emissions for ships with Category 3 (i.e., large) engines having displacement of at least 30 liters per cylinder are modeled in the cmv_c3 sector as point sources. The cmv_c1c2 modeling sector includes emissions in U.S. state and federal waters and in surrounding areas of Canada, Mexico, and international waters. CMV C3 emissions were developed for the 2017 National Emission Inventory (NEI) based on Automated Identification System (AIS), a tracking system used by vessels to enhance navigation and avoid collision with other AIS transmitting vessels. The data were retrieved at 5-minute intervals, spatially allocated into gridded datasets, and summed into hourly point source emissions files for modeling. The year 2016 cmv_c1c2 sector emissions were backcast from the 2017 NEI CMV emissions based on national U.S. Army Corps of Engineers Entrance and Clearance data. The 2017 NEI CMV emissions were also projected to 2023 and 2028 based on factors derived from the Locomotive and Marine rule Regulatory Impact Assessment (RIA)[1]. Base and future year inventories were processed for air quality modeling with the Sparse Matrix Operating Kernel Emissions (SMOKE) modeling system version 4.7. National and state-level emission summaries for key pollutants are provided.

2. INTRODUCTION

This document details the approach and data sources used for developing 2016, 2023, and 2028 emissions for the Commercial Marine Vessel, Category 3 (cmv_c3) sector. The 2016v1 platform cmv_c3 inventory was based on data developed for the U.S. EPA 2017 NEI, although the data were adjusted to better represent 2016 and converted to an hourly pseudo-gridded point inventory format that can support simulating plume rise for these sources. For more information on the development of the 2017 NEI C3 CMV emissions, see the Category 3 Commercial Marine Vessel 2017 Emissions Inventory Report (ERG, 2019).

The cmv_c3 sector contains large engine CMV emissions. Category 3 (C3) marine diesel engines are those at or above 30 liters per cylinder, typically these are the largest engines rated at 3,000 to 100,000 hp. C3 engines are typically used for propulsion on ocean-going vessels including container ships, oil tankers, bulk carriers, and cruise ships. Emissions control technologies for C3 CMV sources are limited due to the nature of the residual fuel used by these vessels.[2] The cmv_c3 sector contains sources that traverse state and federal waters; along with sources in waters not covered by the NEI in surrounding areas of Canada, Mexico, and international waters.

The cmv_c3 sources that operate outside of state waters but within the federal Emissions Control Area (ECA) are encoded with a Federal Information Processing Standard (FIPS) state code of 85, with the "county code" digits representing broad regions such as the Atlantic, Gulf of Mexico, and Pacific. The ECA areas include parts of the Gulf of Mexico, and parts of the Atlantic and Pacific coasts. CMV C3 sources around Puerto Rico, Hawaii and Alaska are outside are included in the 2016v1 inventory but are in separate files from the emissions around the continental U.S. (CONUS). The cmv_c3 sources in the 2016v1 inventory are categorized as operating either in-port or underway and are encoded using the source classification codes (SCCs) listed in Table 1 which distinguish between diesel and residual fuel, in port areas versus underway, and main and auxiliary engines. In addition to C3 sources in state and federal waters, the cmv_c3 sector includes emissions in waters not covered by the NEI (FIPS = 98) and

[1] https://www.epa.gov/regulations-emissions-vehicles-and-engines/final-rule-control-emissions-air-pollution-locomotive
[2] https://www.epa.gov/regulations-emissions-vehicles-and-engines/regulations-emissions-marine-vessels

taken from the "ECA-IMO-based" C3 CMV inventory[3]. The ECA-IMO inventory is also used for allocating the FIPS-level emissions to geographic locations for regions within the domain not covered by the AIS selection boxes as described in the next section.

Table 1. 2016v1 platform SCCs for cmv_c3 sector

SCC	Tier 1 Description	Tier 2 Description	Tier 3 Description	Tier 4 Description
2280002103	C3	Diesel	Port	Main
2280002104	C3	Diesel	Port	Auxiliary
2280002203	C3	Diesel	Underway	Main
2280002204	C3	Diesel	Underway	Auxiliary
2280003103	C3	Residual	Port	Main
2280003104	C3	Residual	Port	Auxiliary
2280003203	C3	Residual	Underway	Main
2280003204	C3	Residual	Underway	Auxiliary

3. Inventory Development Methods

The cmv_c3 inventory is brand new for the 2016v1 platform. It was developed in conjunction with the CMV inventory for the 2017 NEI. Prior to creation of the 2017 NEI, "The EPA received Automated Identification System (AIS) data from United States Coast Guard (USCG) in order to quantify all ship activity which occurred between January 1 and December 31, 2017. The International Maritime Organization's (IMO's) International Convention for the Safety of Life at Sea (SOLAS) requires AIS to be fitted aboard all international voyaging ships with gross tonnage of 300 or more, and all passenger ships regardless of size (IMO, 2002). In addition, the USCG has mandated that all commercial marine vessels continuously transmit AIS signals while transiting U.S. navigable waters. As the vast majority of C3 vessels meet these requirements, any omitted from the inventory due to lack of AIS adoption are deemed to have a negligible impact on national C3 emissions estimates. The activity described by this inventory reflects ship operations within 200 nautical miles of the official U.S. baseline. This boundary is roughly equivalent to the border of the U.S Exclusive Economic Zone and the North American Emission Control Area (ECA), although some non-ECA activity is captured as well (Figure 1)."

[3] https://www.epa.gov/sites/production/files/2017-08/documents/2014v7.0_2014_emismod_tsdv1.pdf

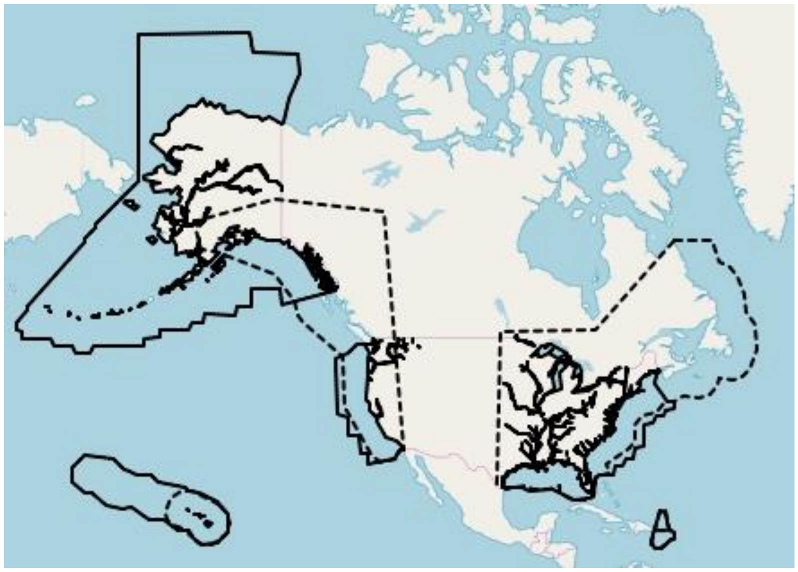

Figure 1. 2017NEI/2016 platform geographical extent (solid) and U.S. ECA (dashed)

The 2017 NEI data were computed based on Automated Identification System (AIS) data from the United States Coast Guard for the year of 2017. The AIS data were coupled with ship registry data that contained engine parameters, vessel power parameters, and other factors such as tonnage and year of manufacture which helped to separate the C3 vessels from the C1C2 vessels. Where specific ship parameters were not available, they were gap-filled. The types of vessels that remain in the C3 data set include: bulk carrier, chemical tanker, liquified gas tanker, oil tanker, other tanker, container ship, cruise, ferry, general cargo, fishing, refrigerated vessel, roll-on/roll-off, tug, and yacht.

Prior to use, the AIS data were reviewed - data deemed to be erroneous were removed, and data found to be at intervals greater than 5 minutes were interpolated to ensure that each ship had data every five minutes. The five-minute average data provide a reasonably refined assessment of a vessel's movement. For example, using a five-minute average, a vessel traveling at 25 knots would be captured every two nautical miles that the vessel travels. For slower moving vessels, the distance between transmissions would be less.

The emissions were calculated for each C3 vessel in the dataset for each 5-minute time range and allocated to the location of the message following to the interval. Emissions were calculated according to Equation 1.

$$Emissions_{interval} = Time\ (hr)_{interval} \times\ Power(kW) \times EF(\frac{g}{kWh}) \times LLAF \qquad (1)$$

Power is calculated for the propulsive (main), auxiliary, and auxiliary boiler engines for each interval and emission factor (EF) reflects the assigned emission factors for each engine, as described below. LLAF represents the low load adjustment factor, a unitless factor which reflects increasing propulsive emissions during low load operations. Time indicates the activity duration time between consecutive intervals.

Emissions were computed according to a computed power need (kW) multiplied by the time (hr) and by an engine-specific emission factor (g/kWh) and finally by a low load adjustment factor that reflects increasing propulsive emissions during low load operations.

The resulting emissions were available at 5-minute intervals. Code was developed to aggregate these emissions to modeling grid cells and up to hourly levels so that the emissions data could be input to SMOKE for emissions modeling with SMOKE. Within SMOKE, the data were speciated into the pollutants needed by the air quality model[4], but since the data were already in the form of point sources at the center of each grid cell, and they were already hourly, no other processing was needed within SMOKE. SMOKE requires an annual inventory file to go along with the hourly data, so those files were also generated for each year.

On January 1st, 2015, the ECA initiated a fuel sulfur standard which regulated large marine vessels to use fuel with 1,000 ppm sulfur or less. These standards are reflected in the cmv_c3 inventories.

There were some areas needed for modeling that the AIS request boxes did not cover (see Figure 1). These include a portion of the St. Lawrence Seaway transit to the Great Lakes, a small portion of the Pacific Ocean far offshore of Washington State, portions of the southern Pacific Ocean around off the coast of Mexico, and the southern portion of the Gulf of Mexico that is within the 36-km domain used for air quality modeling. In addition, a determination had to be made regarding whether to use the existing Canadian CMV inventory or the more detailed AIS-based inventory. In 2016v1, the AIS-based inventory was used in the areas for which data were available, and the areas not covered were gap-filled with inventory data from the 2016beta platform, which included data from Environment Canada and the 2011 ECA-IMO C3 inventory.

For the gap-filled areas not covered by AIS selections or the Environment Canada inventory, the 2016beta nonpoint C3 inventory was converted to a point inventory to support plume rise calculations for C3 vessels. The nonpoint emissions were allocated to point sources using a multi-step allocation process because not all of the inventory components had a complete set

[4] Ammonia (NH_3) was also added by SMOKE in the speciation step

of county-SCC combinations. In the first step, the county-SCC sources from the nonpoint file were matched to the county-SCC points in the 2011 ECA-IMO C3 inventory. The ECA-IMO inventory contains multiple point locations for each county-SCC. The nonpoint emissions were allocated to those points using the $PM_{2.5}$ emissions at each point as a weighting factor.

Cmv_c3 underway emissions that did not have a matching FIPS in the ECA-IMO inventory were allocated using the 12 km 2014 offshore shipping activity spatial surrogate (surrogate code 806). Each county with underway emissions in the area inventory was allocated to the centroids of the cells associated with the respective county in the surrogate. The emissions were allocated using the weighting factors in the surrogate.

The resulting point emissions centered on each grid cell were converted to an annual point 2010 flat file format (FF10). Pictures of the emissions are shown in Section 7 of this document. A set of standard stack parameters were assigned to each release point in the cmv_c3 inventory. The assigned stack height was 65.62 ft, the stack diameter was 2.625 ft, the stack temperature was 539.6 °F, and the velocity was 82.02 ft/s. Emissions were computed for each grid cell needed for modeling.

Adjustment of the 2017 NEI CMV C3 to 2016

Because the NEI emissions data were for 2017, an analysis was performed of 2016 versus 2017 entrance and clearance data (ERG, 2019a). Annual, monthly, and daily level data were reviewed. Annual ratios of entrance and clearance activity were developed for each ship type as shown in Table 2. For vessel types with low populations (C3 Yacht, tug, barge, and fishing vessels), an annual ratio of 0.98 was applied.

Table 2. 2017 to 2016 projection factors for C3 CMV

Ship Type	Annual Ratio[a]
Barge	1.551
Bulk Carrier	1.067
Chemical Tanker	1.031
Container Ship	1.0345
Cruise	1.008
Ferry Ro Pax	1.429
General Cargo	0.888
Liquified Gas Tanker	1.192
Miscellaneous Fishing	0.932

Ship Type	Annual Ratio[a]
Miscellaneous Other	1.015
Offshore	0.860
Oil Tanker	1.101
Other Tanker	1.037
Reefer	0.868
Ro Ro	1.007
Service Tug	1.074

[a] Above ratios are applied to the 2017 emission values to estimate 2016 values

The cmv_c3 projection factors were pollutant-specific and region-specific. Most states are mapped to a single region with a few exceptions. Pennsylvania and New York were split between the East Coast and Great Lakes, Florida was split between the Gulf Coast and East Coast, and Alaska was split between Alaska East and Alaska West. The non-federal factors listed in this table were applied to sources outside of U.S. federal waters (FIPS 98). Volatile Organic Compound (VOC) Hazardous Air Pollutant (HAP) emissions were projected using the VOC factors. NH3 emissions were held constant at 2014 levels.

4. Ancillary Data

Spatial Allocation

The 2017NEI emissions data were computed at 5-minute intervals and adjusted to 2016 levels as described above. The data were then gridded and converted into a pseudo-point inventory where each point is at the center of a grid cell, and the emissions in that cell are the sum of the emissions in the area covered by the grid cell over the specified hour. Details regarding the conversion of the area source NEI2014v2 cmv_c3 inventory to the point source format are available in Section 3 of this document. A set of standard stack parameters were assigned to each release point in the cmv_c3 inventory. The assigned stack height was 65.62 ft, the stack diameter was 2.625 ft, the stack temperature was 539.6 °F, and the velocity was 82.02 ft/s. Emissions were computed for each grid needed for modeling.

Temporal Allocation

As discussed above, the inventory was summed to hourly value from emissions data computed at 5-minute intervals, therefore no temporal profiles were used by SMOKE. A corresponding annual inventory file was also developed as required by SMOKE for processing hourly point emissions. Because the AIS data were from the year 2017 and not 2016, analyses were performed to determine whether it would be appropriate to preserve the appropriate days-of-week with respect to 2016. The analyses indicated regional day-of-week signals in the data, particularly around holidays, and on weekends for some ship types. To address the annual differences in day-of-week, first the emissions data from the 2017 holidays were mapped to the matching 2016 holiday. Once the holidays were mapped the non-holidays were mapped from 2017 to 2016 such that the emissions from an individual day of week in a specific sequential week in the year was copied. For example, the 24th Wednesday of 2016 was mapped to the 24th Wednesday in the 2017 calendar. The details of the mapping of 2016 dates to 2017 dates are provided the ancillary file datemap_2017_to_2016.csv.

At specific hours in certain locations, particularly around ports, exceptionally high emissions values were identified in the first version of the CMV emissions files. These high emissions values were found to be caused by vessels "hoteling", meaning that ships remained in a single location for more than an hour. The emissions were originally assigned to a single hour due to an artifact of how the original five-minute data were aggregated during the 2017 NEI development process. To produce more realistic data for modeling purposes, all hoteling emissions longer than one hour were equally apportioned across all the hours during which the ship was stationary - up to the duration of the hoteling for that vessel, but only up to a maximum of 400 hours. Any emissions that would have occurred after the 400^{th} hour were removed from the inventory. A total of 3,790 tons of NOX associated with hoteling activity over 400 hours was dropped across the entire modeling domain for c3. Decreases over 100 tons per year of NOX due to the hoteling adjustments occurred in Alameda Co, CA; Nueces Co, TX; Hudson Co, NJ; San Juan Co, WA; Los Angeles Co, CA; and Charleston Co, SC. These adjusted data were developed in January and February of 2020, so any data from fall of 2019 does not have these hoteling or day of week mapping adjustments.

Chemical Speciation

The cmv_c3 sector includes emissions for particulate matter < 2.5 μm ($PM_{2.5}$), oxides of nitrogen (NOx), and VOC, among other criteria pollutants. These three inventory pollutants must be converted to air quality modeling species through an emissions processing step referred to as "chemical speciation". The U.S. EPA SPECIATE[5] database was used to develop factors to map the inventory species to the chemical species required for air quality modeling. All of the emissions in the cmv_c3 sector were assigned the $PM_{2.5}$ speciation profile 5675AE6 (Marine Vessel – Auxiliary Engine – Marine Gas Oil) and the VOC speciation profile 2480 (Industrial Cluster, Ship Channel, Downwind Sample). 5675AE6 is an update of profile 5675 to support AE6 PM speciation. The components of these profiles are shown in Table 3 and Table 4. Note that because the entire cmv_c3 sector is integrated, so the NONHAPTOG profile is used

[5] https://www.epa.gov/air-emissions-modeling/speciate-version-45-through-40

instead of the VOC profile. The VOC-to-TOG conversion factor for profiles 2480 is 1.033. In the profile, SOAALK is an extra tracer, so the factors sum to 1.0 if SOAALK is excluded from the sum. The cmv_c3 NOx emissions were speciated using a 90:9.2:0.8 split for NO:NO2:HONO. In addition, NH_3 was added to the inventory through a multiplicative factor of 0.019247*$PM_{2.5}$.

Table 3. PM2.5 Speciation Profile 5675AE6

Species	Factor
PCA	0.019125
PEC	0.070922
PFE	0.00078
PMG	0.003333
PMOTHR	0.249598
PNCOM	0.106383
POC	0.425532
PSI	0.003404
PSO4	0.12078
PTI	0.000142

Table 4. NONHAPTOG Speciation Profile 2480

Species	Factor	Molecular weight
ETH	0.0149	28.0532
ETHA	0.0321	30.069
ETHY	0.0218	26.0373
IOLE	0.0119	56.2694
ISOP	0.00957	68.117
OLE	0.0308	29.0229
PAR	0.5584	15.0347
PRPA	0.0363	44.0956
SOAALK	0.2244	81.5503
TOL	0.1114	96.4914
UNR	0.0571	16.3928
XYLMN	0.1157	110.2229

5. EMISSIONS PROJECTION METHODS

Growth rates for cmv_c3 emissions from 2016 to 2023 and 2028 were developed using a forthcoming EPA report on projected bunker fuel demand. The report projects bunker fuel consumption by region out to the year 2030. Bunker fuel usage was used as a surrogate for marine vessel activity. To estimate future year emissions of CO, CO2, hydrocarbons, PM10, and

PM2.5, the bunker fuel growth rate from 2016 to 2023, and 2028 were directly applied to the estimated 2016 emissions.

Growth factors for NOx emissions were handled separately to account for the phase in of Tier 3 vessel engines. To estimate these emissions, the NOx growth rates from the EPA C3 Regulatory Impact Assessment (RIA)[6] were refactored to use the new bunker fuel usage growth rates. The assumptions of changes in fleet composition and emissions rates from the C3 RIA were preserved and applied to the new bunker fuel demand growth rates for 2023, and 2028 to arrive at the final growth rates.

The 2023 and 2028 projection factors are shown in Table 5. Some regions for which 2016 projection factors were available did not have 2023 or 2028 projection factors specific to that region, so factors from another region were used as follows:

- Alaska was projected using North Pacific factors.
- Hawaii was projected using South Pacific factors.
- Puerto Rico and Virgin Islands were projected using Gulf Coast factors.
- Emissions outside Federal Waters (FIPS 98) were projected using Other factors.
- California was projected using a separate set of state-wide projection factors based on CMV emissions data provided by the California Air Resources Board (CARB). These factors are shown in Table 6.

Table 5. 2016-to-2023 and 2016-2028 CMV C3 projection factors outside of California

Region	2016-to-2023 NOX	2016-to-2023 other pollutants	2016-to-2028 NOX	2016-to-2028 other pollutants
US East Coast	-6.05%	27.71%	-7.54%	49.71%
US South Pacific (ex. California)	-24.79%	20.89%	-33.97%	45.86%
US North Pacific	-3.37%	22.57%	-4.07%	41.31%
US Gulf	-6.88%	20.82%	-12.40%	36.41%
US Great Lakes	8.71%	14.55%	19.80%	28.29%
Other	23.09%	23.09%	42.58%	42.58%

Non-Federal Waters	2016-to-2023	2016-to-2028
SO2	-77.21%	-73.60%
PM (main engines)	-36.06%	-25.93%
PM (aux. engines)	-39.69%	-30.14%
Other pollutants	+23.09%	+42.58%

[6] https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P1005ZGH.TXT

Table 6. 2016-to-2023 and 2016-2028 CMV C3 projection factors for California

Pollutant	2016-to-2023	2016-to-2028
CO	18.0%	34.0%
NOx	15.6%	32.7%
PM_{10} / $PM_{2.5}$	20.5%	38.1%
SO_2	18.3%	33.2%
VOC	24.2%	46.1%

6. EMISSIONS PROCESSING REQUIREMENTS

CMV_c3 emissions were processed for air quality modeling using the Sparse Matrix Operator Kernel Emissions (SMOKE[7]) modeling system. Because data are hourly, every day was processed. This cmv_c3 sector was processed through SMOKE as point sources. This is a 3-D sector in which all emissions are output to an inline point source file to support plume rise calculations within the air quality model. No 2-D gridded emissions were generated for this sector.

7. EMISSIONS SUMMARIES

Table 7 compares annual, national total cmv_c3 emissions for the 2016 v1 platform to cmv_c3 emissions from previous modeling platforms. Table 8 shows national totals by SCC for US state and federal waters. Table 9 and Table 10 show comparisons for state total NOx and SO_2 emissions, respectively. Figure 2 and Figure 3 are gridded emissions plots of annual total NOx and SO_2. Additional plots and maps are available online through the LADCO website[8] and the Intermountain West Data Warehouse[9]. Descriptions of the emissions platform cases shown in the tables and plots below are as follows:

2014fd = NEI2014v2 and 2014 NATA

2016fe = 2016 alpha platform (grown from NEI2014v2)

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

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

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[7] http://www.smoke-model.org/index.cfm

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

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

Table 7. Comparison of national total annual CAPS cmv_c3 emissions (tons/yr)

Pollutant	2014fd	2016fe	2016ff	2016fh	2023ff	2023fh	2028ff	2028fh
CO	57,395	57,395	57,631	48,713	71,580	60,006	83,564	69,467
NH3	97	97	100	234	125	289	145	334
NOX	596,198	596,198	593,212	439,866	533,744	406,888	509,625	393,957
PM10	19,187	19,187	8,038	13,191	9,980	16,256	11,646	18,806
PM2.5	17,775	17,775	7,173	12,136	8,906	14,956	10,394	17,302
SO2	158,990	15,899	15,806	64,917	19,621	80,020	22,890	92,561
VOC	26,042	26,042	26,125	26,732	32,455	32,993	37,890	38,236

Table 8. National total annual CAPS cmv_c3 emissions by SCC (tons/yr)

Region	Pollutant	SCC	SCC Description	2016fh	2023fh	2028fh
US State Waters	CO	2280002103	Diesel Port Emissions - Main	1,173	1,443	1,667
US State Waters	CO	2280002104	Diesel Port Emissions - Auxiliary	2,469	3,044	3,507
US State Waters	CO	2280002203	Diesel Underway Emissions - Main	7,630	9,304	10,665
US State Waters	CO	2280002204	Diesel Underway Emissions - Auxiliary	4,049	4,945	5,672
US State Waters	CO	2280003103	Residual Port Emissions - Main	3	4	4
US State Waters	CO	2280003104	Residual Port Emissions - Auxiliary	7	9	10
US State Waters	CO	2280003203	Residual Underway Emissions - Main	17	20	23
US State Waters	CO	2280003204	Residual Underway Emissions - Auxiliary	16	20	22
US Federal Waters	CO	2280002103	Diesel Port Emissions - Main	0	0	0
US Federal Waters	CO	2280002104	Diesel Port Emissions - Auxiliary	0	0	0
US Federal Waters	CO	2280002203	Diesel Underway Emissions - Main	21,210	26,231	30,524
US Federal Waters	CO	2280002204	Diesel Underway Emissions - Auxiliary	5,406	6,683	7,763
US Federal Waters	CO	2280003103	Residual Port Emissions - Main	4	4	5
US Federal Waters	CO	2280003104	Residual Port Emissions - Auxiliary	10	12	14
US Federal Waters	CO	2280003203	Residual Underway Emissions - Main	5,792	7,144	8,271
US Federal Waters	CO	2280003204	Residual Underway Emissions - Auxiliary	927	1,143	1,320
US State Waters	NH3	2280002103	Diesel Port Emissions - Main	0	0	0
US State Waters	NH3	2280002104	Diesel Port Emissions - Auxiliary	0	0	0
US State Waters	NH3	2280002203	Diesel Underway Emissions - Main	0	0	0
US State Waters	NH3	2280002204	Diesel Underway Emissions - Auxiliary	0	0	0
US State Waters	NH3	2280003103	Residual Port Emissions - Main	0	0	0
US State Waters	NH3	2280003104	Residual Port Emissions - Auxiliary	0	0	0
US State Waters	NH3	2280003203	Residual Underway Emissions - Main	0	0	0
US State Waters	NH3	2280003204	Residual Underway Emissions - Auxiliary	0	0	0
US Federal Waters	NH3	2280002103	Diesel Port Emissions - Main	0	0	0
US Federal Waters	NH3	2280002104	Diesel Port Emissions - Auxiliary	0	0	0
US Federal Waters	NH3	2280002203	Diesel Underway Emissions - Main	0	0	0

Region	Pollutant	SCC	SCC Description	2016fh	2023fh	2028fh
US Federal Waters	NH3	2280002204	Diesel Underway Emissions - Auxiliary	0	0	0
US Federal Waters	NH3	2280003103	Residual Port Emissions - Main	0	0	0
US Federal Waters	NH3	2280003104	Residual Port Emissions - Auxiliary	0	0	0
US Federal Waters	NH3	2280003203	Residual Underway Emissions - Main	0	0	0
US Federal Waters	NH3	2280003204	Residual Underway Emissions - Auxiliary	0	0	0
US State Waters	NOX	2280002103	Diesel Port Emissions - Main	6,440	6,263	6,330
US State Waters	NOX	2280002104	Diesel Port Emissions - Auxiliary	22,131	21,361	21,313
US State Waters	NOX	2280002203	Diesel Underway Emissions - Main	58,010	56,504	56,661
US State Waters	NOX	2280002204	Diesel Underway Emissions - Auxiliary	35,890	34,463	34,102
US State Waters	NOX	2280003103	Residual Port Emissions - Main	16	15	15
US State Waters	NOX	2280003104	Residual Port Emissions - Auxiliary	85	80	76
US State Waters	NOX	2280003203	Residual Underway Emissions - Main	150	142	137
US State Waters	NOX	2280003204	Residual Underway Emissions - Auxiliary	201	193	191
US Federal Waters	NOX	2280002103	Diesel Port Emissions - Main	0	0	0
US Federal Waters	NOX	2280002104	Diesel Port Emissions - Auxiliary	0	0	0
US Federal Waters	NOX	2280002203	Diesel Underway Emissions - Main	193,844	174,376	165,744
US Federal Waters	NOX	2280002204	Diesel Underway Emissions - Auxiliary	47,972	43,328	41,226
US Federal Waters	NOX	2280003103	Residual Port Emissions - Main	23	22	22
US Federal Waters	NOX	2280003104	Residual Port Emissions - Auxiliary	127	123	122
US Federal Waters	NOX	2280003203	Residual Underway Emissions - Main	64,043	59,786	58,091
US Federal Waters	NOX	2280003204	Residual Underway Emissions - Auxiliary	10,934	10,233	9,929
US State Waters	PM10	2280002103	Diesel Port Emissions - Main	127	157	182
US State Waters	PM10	2280002104	Diesel Port Emissions - Auxiliary	547	675	778
US State Waters	PM10	2280002203	Diesel Underway Emissions - Main	879	1,072	1,228
US State Waters	PM10	2280002204	Diesel Underway Emissions - Auxiliary	864	1,057	1,213
US State Waters	PM10	2280003103	Residual Port Emissions - Main	2	3	3
US State Waters	PM10	2280003104	Residual Port Emissions - Auxiliary	14	17	19
US State Waters	PM10	2280003203	Residual Underway Emissions - Main	16	19	22
US State Waters	PM10	2280003204	Residual Underway Emissions - Auxiliary	27	33	38
US Federal Waters	PM10	2280002103	Diesel Port Emissions - Main	0	0	0
US Federal Waters	PM10	2280002104	Diesel Port Emissions - Auxiliary	0	0	0
US Federal Waters	PM10	2280002203	Diesel Underway Emissions - Main	2,546	3,147	3,660
US Federal Waters	PM10	2280002204	Diesel Underway Emissions - Auxiliary	1,107	1,366	1,584
US Federal Waters	PM10	2280003103	Residual Port Emissions - Main	3	4	4
US Federal Waters	PM10	2280003104	Residual Port Emissions - Auxiliary	18	22	26
US Federal Waters	PM10	2280003203	Residual Underway Emissions - Main	5,612	6,922	8,012
US Federal Waters	PM10	2280003204	Residual Underway Emissions - Auxiliary	1,430	1,763	2,036
US State Waters	PM2.5	2280002103	Diesel Port Emissions - Main	117	145	167
US State Waters	PM2.5	2280002104	Diesel Port Emissions - Auxiliary	503	621	716

Region	Pollutant	SCC	SCC Description	2016fh	2023fh	2028fh
US State Waters	PM2.5	2280002203	Diesel Underway Emissions - Main	808	986	1,130
US State Waters	PM2.5	2280002204	Diesel Underway Emissions - Auxiliary	795	972	1,116
US State Waters	PM2.5	2280003103	Residual Port Emissions - Main	2	2	3
US State Waters	PM2.5	2280003104	Residual Port Emissions - Auxiliary	13	16	18
US State Waters	PM2.5	2280003203	Residual Underway Emissions - Main	14	18	20
US State Waters	PM2.5	2280003204	Residual Underway Emissions - Auxiliary	25	31	35
US Federal Waters	PM2.5	2280002103	Diesel Port Emissions - Main	0	0	0
US Federal Waters	PM2.5	2280002104	Diesel Port Emissions - Auxiliary	0	0	0
US Federal Waters	PM2.5	2280002203	Diesel Underway Emissions - Main	2,342	2,895	3,368
US Federal Waters	PM2.5	2280002204	Diesel Underway Emissions - Auxiliary	1,019	1,257	1,457
US Federal Waters	PM2.5	2280003103	Residual Port Emissions - Main	3	3	4
US Federal Waters	PM2.5	2280003104	Residual Port Emissions - Auxiliary	17	20	23
US Federal Waters	PM2.5	2280003203	Residual Underway Emissions - Main	5,163	6,368	7,371
US Federal Waters	PM2.5	2280003204	Residual Underway Emissions - Auxiliary	1,315	1,622	1,873
US State Waters	SO2	2280002103	Diesel Port Emissions - Main	131	162	187
US State Waters	SO2	2280002104	Diesel Port Emissions - Auxiliary	1,327	1,634	1,879
US State Waters	SO2	2280002203	Diesel Underway Emissions - Main	1,366	1,660	1,900
US State Waters	SO2	2280002204	Diesel Underway Emissions - Auxiliary	2,077	2,536	2,905
US State Waters	SO2	2280003103	Residual Port Emissions - Main	8	9	10
US State Waters	SO2	2280003104	Residual Port Emissions - Auxiliary	112	135	153
US State Waters	SO2	2280003203	Residual Underway Emissions - Main	91	110	126
US State Waters	SO2	2280003204	Residual Underway Emissions - Auxiliary	216	265	305
US Federal Waters	SO2	2280002103	Diesel Port Emissions - Main	0	0	0
US Federal Waters	SO2	2280002104	Diesel Port Emissions - Auxiliary	0	0	0
US Federal Waters	SO2	2280002203	Diesel Underway Emissions - Main	4,634	5,729	6,666
US Federal Waters	SO2	2280002204	Diesel Underway Emissions - Auxiliary	2,633	3,248	3,764
US Federal Waters	SO2	2280003103	Residual Port Emissions - Main	11	13	15
US Federal Waters	SO2	2280003104	Residual Port Emissions - Auxiliary	145	177	204
US Federal Waters	SO2	2280003203	Residual Underway Emissions - Main	40,916	50,469	58,423
US Federal Waters	SO2	2280003204	Residual Underway Emissions - Auxiliary	11,251	13,871	16,024
US State Waters	VOC	2280002103	Diesel Port Emissions - Main	1,160	1,441	1,676
US State Waters	VOC	2280002104	Diesel Port Emissions - Auxiliary	967	1,200	1,390
US State Waters	VOC	2280002203	Diesel Underway Emissions - Main	5,603	6,883	7,931
US State Waters	VOC	2280002204	Diesel Underway Emissions - Auxiliary	1,579	1,939	2,233
US State Waters	VOC	2280003103	Residual Port Emissions - Main	3	3	4
US State Waters	VOC	2280003104	Residual Port Emissions - Auxiliary	3	4	4
US State Waters	VOC	2280003203	Residual Underway Emissions - Main	12	14	16
US State Waters	VOC	2280003204	Residual Underway Emissions - Auxiliary	6	8	9
US Federal Waters	VOC	2280002103	Diesel Port Emissions - Main	0	0	0

Region	Pollutant	SCC	SCC Description	2016fh	2023fh	2028fh
US Federal Waters	VOC	2280002104	Diesel Port Emissions - Auxiliary	0	0	0
US Federal Waters	VOC	2280002203	Diesel Underway Emissions - Main	12,157	15,029	17,474
US Federal Waters	VOC	2280002204	Diesel Underway Emissions - Auxiliary	2,101	2,597	3,016
US Federal Waters	VOC	2280003103	Residual Port Emissions - Main	3	4	5
US Federal Waters	VOC	2280003104	Residual Port Emissions - Auxiliary	4	5	5
US Federal Waters	VOC	2280003203	Residual Underway Emissions - Main	2,777	3,425	3,965
US Federal Waters	VOC	2280003204	Residual Underway Emissions - Auxiliary	357	440	509

Table 9. Comparison of state total annual NOx cmv_c3 emissions (tons/yr)

State	2014fd	2016fe	2016ff	2016fh	2023ff	2023fh	2028ff	2028fh
Alabama	1,099	1,099	1,088	1,355	1,013	1,262	953	1,187
Alaska			9,280	6,228	8,968	6,018	8,902	5,974
California	27	27	24	13,622	18	15,747	16	18,077
Connecticut	599	599	594	122	558	115	549	113
Delaware	2,329	2,329	2,309	2,087	2,169	1,961	2,135	1,930
D.C.	0	0	0	-	0	-	0	-
Florida	33,003	33,003	32,703	7,425	30,591	6,960	29,461	6,775
Georgia	3,612	3,612	3,581	1,595	3,364	1,499	3,311	1,475
Hawaii			710	2,294	534	1,725	469	1,515
Illinois	87	87	83	139	90	151	100	166
Indiana	18	18	17	230	18	250	20	275
Louisiana	13,695	13,695	13,564	17,428	12,630	16,229	11,881	15,266
Maine	477	477	473	468	444	439	437	432
Maryland	3,230	3,230	3,202	4,521	3,008	4,247	2,960	4,180
Massachusetts	1,484	1,484	1,471	1,064	1,382	1,000	1,360	984
Michigan	37	37	35	5,258	38	5,716	42	6,299
Minnesota	150	150	142	554	155	602	170	664
Mississippi	1,035	1,035	1,025	530	955	494	898	464
New Hampshire	268	268	265	76	249	72	245	71
New Jersey	4,430	4,430	4,392	5,118	4,126	4,808	4,061	4,732
New York	2,139	2,139	2,093	2,445	2,060	2,407	2,110	2,464
North Carolina	8,234	8,234	8,164	425	7,669	399	7,548	393
Ohio	52	52	49	604	53	657	59	724
Oregon	799	799	707	1,930	532	1,452	467	1,274
Pennsylvania	1,192	1,192	1,180	894	1,114	852	1,102	849
Rhode Island	429	429	425	314	399	295	393	291
South Carolina	7,109	7,109	7,048	3,050	6,621	2,866	6,516	2,820
Texas	7,357	7,357	7,287	18,828	6,785	17,532	6,383	16,492

State	2014fd	2016fe	2016ff	2016fh	2023ff	2023fh	2028ff	2028fh
Utah				-		-		-
Virginia	4,132	4,132	4,097	6,720	3,849	6,313	3,787	6,213
Washington	11,170	11,170	10,145	12,945	9,803	12,509	9,732	12,418
Wisconsin	77	77	74	715	80	777	88	856
Puerto Rico			5,935	2,120	5,526	1,974	5,199	1,857
Virgin Islands			2,989	1,820	2,783	1,694	2,618	1,594
Offshore to EEZ	487,929	487,929	468,064	316,943	416,157	287,867	395,655	275,133

Table 10. Comparison of state total annual SO2 cmv_c3 emissions (tons/yr)

State	2014fd	2016fe	2016ff	2016fh	2023ff	2023fh	2028ff	2028fh
Alabama	310	31	31	57	37	69	42	77
Alaska			237	491	290	602	335	694
California	7	1	1	553	1	654	1	736
Connecticut	152	15	15	5	19	6	23	8
Delaware	1,700	170	168	81	215	104	252	122
D.C.	0	0	0	-	0	-	0	-
Florida	8,596	860	852	325	1,061	409	1,223	475
Georgia	1,006	101	100	56	127	71	149	83
Hawaii			21	94	25	114	30	137
Illinois	28	3	3	5	3	6	3	7
Indiana	6	1	1	7	1	9	1	10
Louisiana	3,626	363	360	696	435	841	492	949
Maine	132	13	13	19	17	24	20	28
Maryland	873	87	86	149	110	190	129	223
Massachusetts	392	39	39	46	50	58	58	69
Michigan	12	1	1	186	1	214	1	239
Minnesota	48	5	5	19	5	22	6	25
Mississippi	276	28	27	27	33	33	37	37
New Hampshire	205	21	20	4	26	5	30	5
New Jersey	1,578	158	156	206	199	263	234	309
New York	558	56	55	76	68	94	79	109
North Carolina	2,053	205	203	18	259	23	304	27
Ohio	17	2	2	19	2	22	2	25
Oregon	240	24	21	74	26	90	31	108
Pennsylvania	367	37	36	47	46	60	54	70
Rhode Island	111	11	11	12	14	15	17	18
South Carolina	1,806	181	179	123	228	158	267	185
Texas	2,334	233	232	990	280	1,196	316	1,351

State	2014fd	2016fe	2016ff	2016fh	2023ff	2023fh	2028ff	2028fh
Utah				-		-		-
Virginia	1,127	113	112	250	142	319	167	374
Washington	11,241	1,124	1,026	451	1,258	553	1,450	638
Wisconsin	25	3	2	26	3	29	3	33
Puerto Rico			154	130	186	157	210	178
Virgin Islands			78	85	94	103	107	116
Offshore to EEZ	120,164	12,016	11,560	59,589	14,358	73,507	16,817	85,097

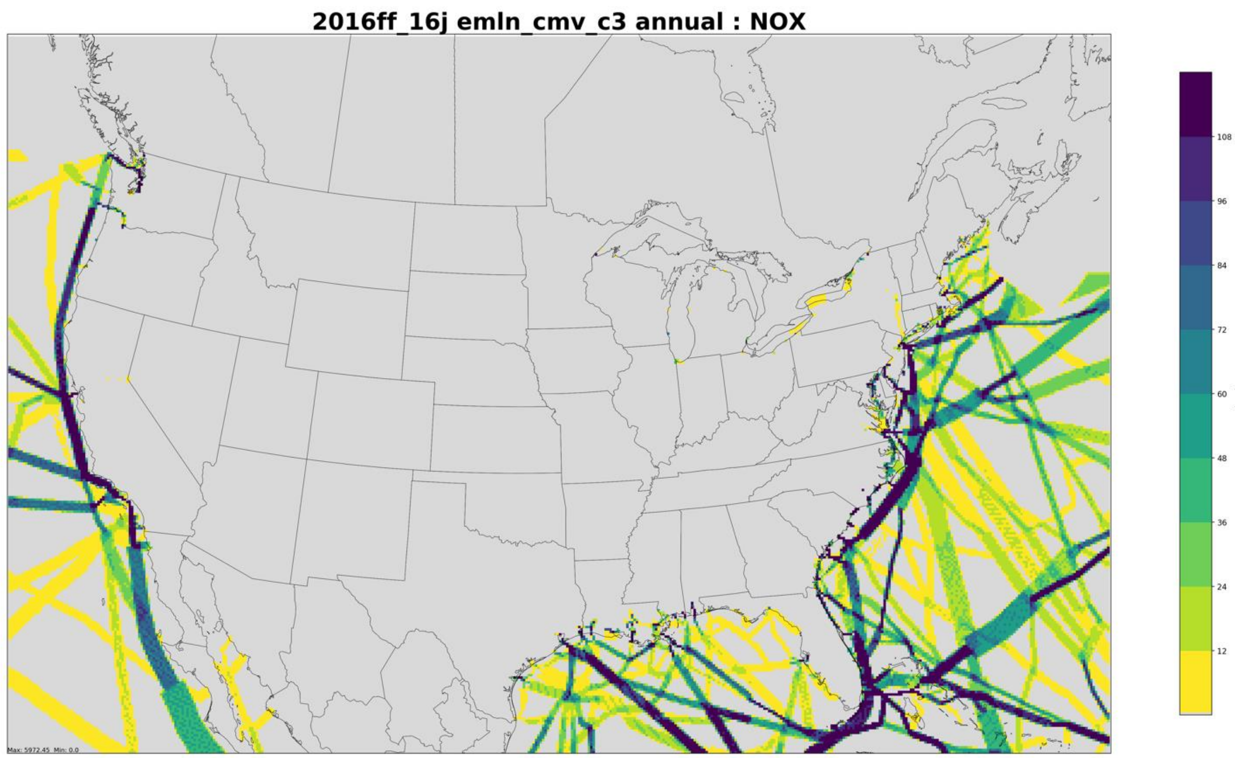

Figure 2. Gridded 2016 NOx emissions from cmv_c3

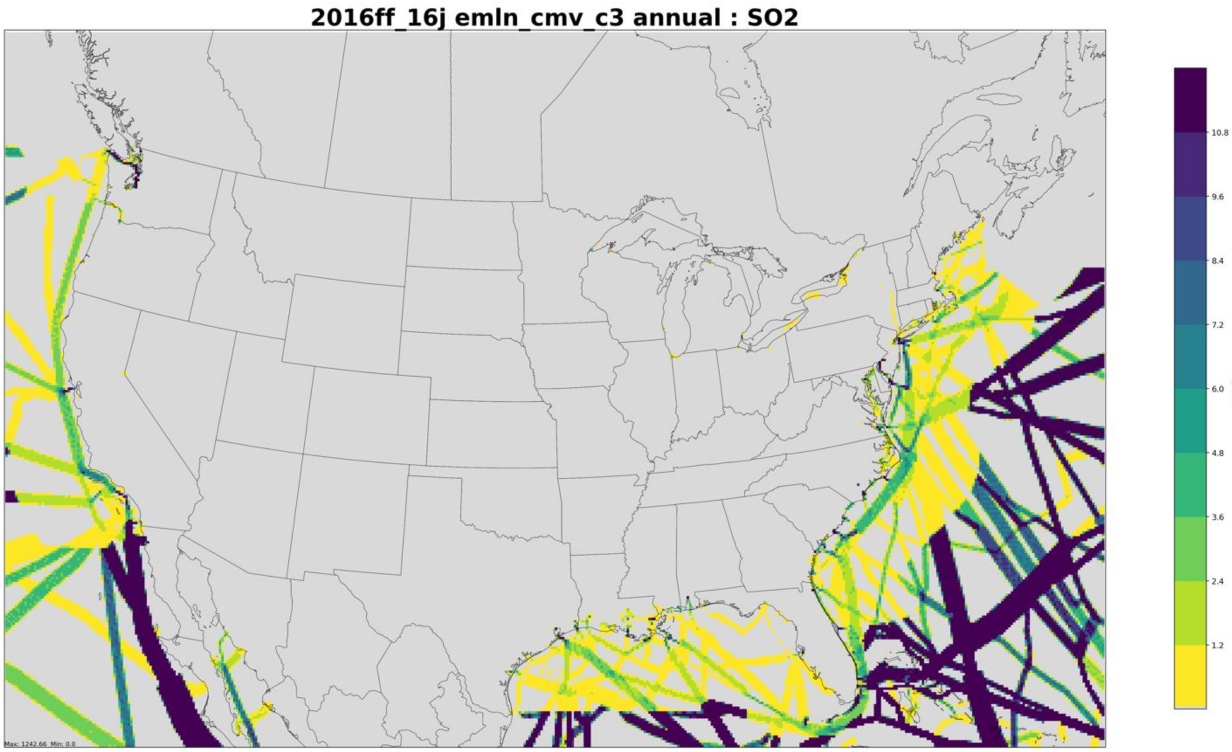

Figure 3. Gridded 2016 SO_2 emissions from cmv_c3