2025 Emission Factor Update for Off-Road Diesel Engines

Technical Documentation

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CALIFORNIA
AIR RESOURCES BOARD

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1 Executive Summary

The California Air Resources Board (CARB) is updating off-road diesel engine emission factors with the release of CARB's 2025 Load-Dependent NOx Methodology and CARB's 2025 Off-road Diesel Emission Factors. The results of this work will replace CARB's 2017 Off-Road Diesel Emission Factors and apply to most off-road equipment types, excluding marine engines, locomotives, and transport refrigeration units (TRU). This update includes:

1. New load-dependent oxides of nitrogen (NOx) emission factors based on real-world activity monitoring and emissions testing, and
2. New particulate matter (PM), hydrocarbon (HC), and carbon monoxide (CO) emission factors based on U.S. EPA engine certification data and California sales data.

This analysis uses real-world activity data collected using Hydraulic, Electrical, and Mechanical (HEM) data loggers installed on both construction and agricultural equipment for approximately one year each. During this time, the equipment was used by owner/operators in normal service for real-world activities and work.

In a separate effort, CARB staff collected NOx emissions during simulated operations designed to collect data at a wide variety of engine load points using Portable Emissions Measurement System (PEMS) devices.

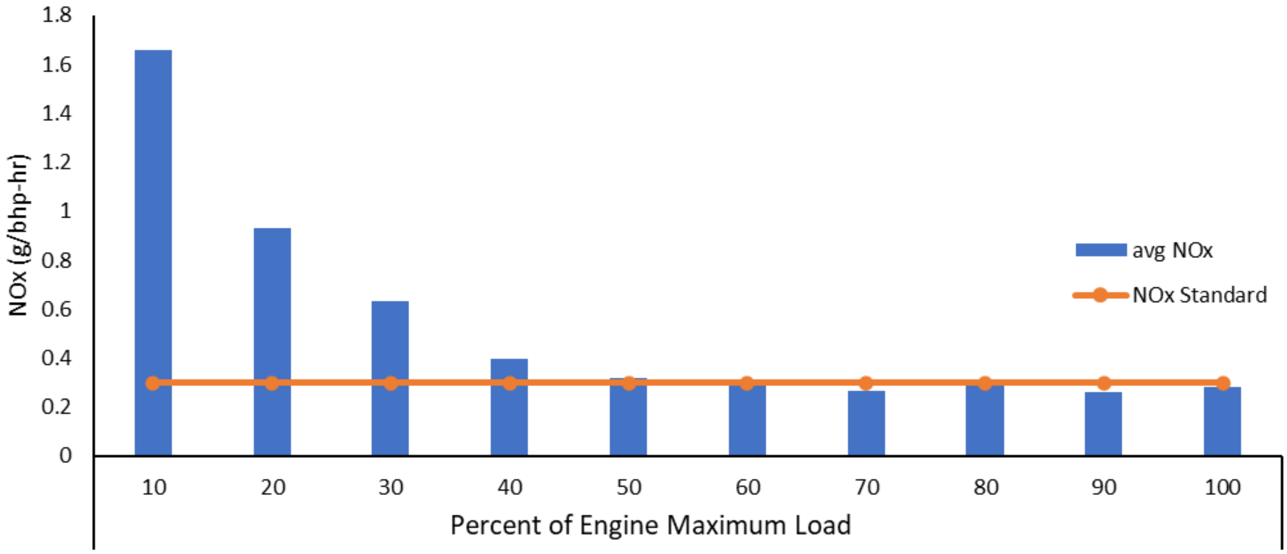
Combining data from the HEM data logger and PEMS devices culminated in a first-of-its-kind effort for off-road equipment emissions inventory development, basing NOx emissions on real-world data collection, including a NOx emissions assessment at low loads.

Any previous methodology for calculating off-road NOx emissions uses a single engine load for each equipment type and a single NOx emission factor for each horsepower group and model year, representing the average load and NOx emission factor for that type of equipment. The load-dependent NOx emissions methodology splits equipment activity into different engine loads and shows the different emission factors at each of these different engine loads. The load-dependent NOx methodology also allows the emission inventory to reflect both the fraction of time and NOx emissions during engine idling periods.

Additionally, CARB updated PM, HC, and CO emission factors for off-road diesel engines beginning in model year 2017, using the latest engine certification and sales data from 2017 to 2023.

In summary, this is the first time for mobile emissions inventory development that CARB has quantified off-road diesel NOx emissions at different load bins, and off-road idle and non-idle NOx emissions resulting from real-world data analysis. One key finding in the analysis shows that NOx emission factors at lower loads are significantly higher than emission factors at higher loads, per unit of work. Figure 1 exemplifies this, displaying NOx emission factors by load bin for Tier 4 Final off-road diesel engines rated between 75 and 750 horsepower (blue bars), along with the Tier 4 Final emission standard (orange line).

Figure 1 NOx Emission Factor by Load Bin (Tier 4 Final, 75 to 750 Horsepower)



When these NOx emission factors are applied to different equipment, the impact depends on how much of total activity is spent at the different loads. For example, an engine operating continuously at 10% load could emit up to five times above the emission standard, on average. Meanwhile, an engine operating continuously at 90% load would emit below the emission standard.

2 Load-Dependent NOx Emission Factors for Off-road Engines

2.1 Goals of the Analysis

This document describes the sequence of actions and explains how data were grouped and averaged to create the load-dependent NOx emission factors. While the methodology involves complex and extensive analysis, a simplified process is listed in the following steps:

1. Determine the time off-road engines spend at different loads, and at idle, using real-world data.
2. Determine the amount of NOx off-road diesel engines emit at different load bins, and at idle, from PEMS data.
3. Determine the average power utilized in each load bin.
4. Multiply results from steps 1 to 3 to create load-dependent NOx emission factors based on load bins and idling.

This load-dependent NOx analysis is only applicable to Tier 2 and newer off-road diesel engines. Tier 2 engine standards were manufactured beginning with Model Year (MY) 2001, and were in effect through MY 2005 engines, depending on horsepower bin (see Figure 5). Excluded in these updates are Tier 1 and older off-road engines because they lack engine control units (ECU). Without ECUs, different types of data loggers and methodology are required to record instantaneous engine load, speed, temperature, and more. This could be an area for future study.

2.2 Data Sources

HEM Data Loggers: Activity data were collected using HEM data loggers, with 156 individual tests of off-road equipment for approximately one year. There were separate data collection efforts for construction equipment and agricultural tractors. HEM data loggers are small, inexpensive, easy to install, and can be left on equipment for many months at a time. They capture months of real-world activity and instantaneous engine load data, but no emissions data. This information defines what percentage of activity happens at each load point, and what percentage of activity occurs when the equipment is idling.

The HEM logger data sets include 64 tests of construction equipment, and 92 tests of agricultural tractors, collected from 2016 to 2023. More information on these studies is available online[1].

PEMS Units: NOx emissions were collected using PEMS units during simulated real-world tasks for a period lasting four to eight hours, with 50 individual tests of off-road equipment. PEMS units capture emissions at different engine loads but are difficult to use in real-world off-road applications for both logistical and safety reasons. Therefore, the simulated testing was completed by trained operators to emulate real-world conditions.

The PEMS data sets are comprised of a 2011 study of 27 individual tests of off-road equipment and a 2019 study of 23 individual tests of off-road equipment, or 50 tests in total (see Table 5 and Table 6 in Appendix B). These two datasets provide second-by-second output including engine horsepower per second (necessary for load calculations), time at different loads, and NOx emissions.

Figure 2 shows, on the left, a size comparison of a HEM logger to a U.S. quarter. And on the right is a photo of a PEMS unit, emphasizing the installation complexity with the size, weight, wiring, and necessary connections. All equipment tested were equipped with off-road engines certified to the Tier 2 level or newer.

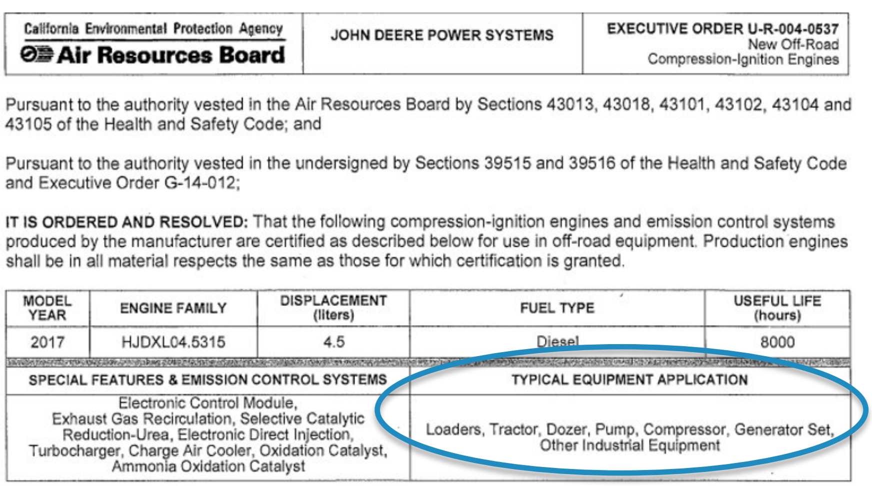
[1] *https://ww2.arb.ca.gov/resources/documents/off-road-equipment-research?keywords=2025*

Figure 2 Photo examples of HEM data logger (left) and PEMS equipment (right)

The NOx emissions data collected is representative of a variety of off-road engines used in many equipment categories and sectors. These engine families are shown Appendix B in Table 5 and Table 6.

Each engine has certification to be used in a wide variety of equipment types, such as construction, mining, industrial, agricultural, portable diesel generators and pumps, and more. Figure 3 shows an example of the engine family certification documentation for off-road engine HJDXL04.5315, one of the engine families where PEMS data was collected. This engine family is used in a wide range of applications and industries. Figure 4 shows two examples, where the same engine is used in an off-road generator[2] and an agricultural tractor[3].

Figure 3 Engine Certificate for Off-Road Engine HJDXL04.5315



California Environmental Protection Agency Air Resources Board	JOHN DEERE POWER SYSTEMS	EXECUTIVE ORDER U-R-004-0537 New Off-Road Compression-Ignition Engines

Pursuant to the authority vested in the Air Resources Board by Sections 43013, 43018, 43101, 43102, 43104 and 43105 of the Health and Safety Code; and

Pursuant to the authority vested in the undersigned by Sections 39515 and 39516 of the Health and Safety Code and Executive Order G-14-012;

IT IS ORDERED AND RESOLVED: That the following compression-ignition engines and emission control systems produced by the manufacturer are certified as described below for use in off-road equipment. Production engines shall be in all material respects the same as those for which certification is granted.

MODEL YEAR	ENGINE FAMILY	DISPLACEMENT (liters)	FUEL TYPE	USEFUL LIFE (hours)
2017	HJDXL04.5315	4.5	Diesel	8000

SPECIAL FEATURES & EMISSION CONTROL SYSTEMS	TYPICAL EQUIPMENT APPLICATION
Electronic Control Module, Exhaust Gas Recirculation, Selective Catalytic Reduction-Urea, Electronic Direct Injection, Turbocharger, Charge Air Cooler, Oxidation Catalyst, Ammonia Oxidation Catalyst	Loaders, Tractor, Dozer, Pump, Compressor, Generator Set, Other Industrial Equipment

2 *https://www.atlascopco.com/en-us/construction-equipment/products-na/qas-95-jd-t4f.html*
3 *https://www.deere.com/en/tractors/utility-tractors/6-family-utility-tractors/6105e-utility-tractor/*

Figure 4 Two Example End Uses of Off-Road Engine Family HJDXL04.5315

Because the use of these engines is broad and not limited to a single end use or sector, CARB staff uses the results in all off-road mobile sectors except for marine engines, locomotives, and transport refrigeration units (TRU). While the engines tested are also used in generators, CARB staff plan to update generator emission factors after further sector-specific testing in 2025. However, it is important to note that real-world use of these engines in different sectors varies significantly. Consider an example where a generator is consistently running at 75% of maximum power to provide electrical power, and an agricultural tractor is running between 10 and 40% of maximum power. In this example analysis, the generator's emissions should be calculated using this engine family's emission factor utilizing a load between 70 and 80% of maximum power, while the agricultural tractor's emissions should be calculated using a load from 10 to 40% only. This is how the PEMS dataset is applied to different equipment types with different results, depending on how the equipment is used in the field, and demonstrates why HEM data loggers collecting data of real-world activity patterns is a crucial companion to the PEMS testing data.

2.2.1 Activity Groups

CARB staff grouped the activity data from the HEM and PEMS loggers by sector and by horsepower. Activity refers to the percent of total engine running time spent at different loads, and at idle, not the annual hours of use per year. The data was grouped by sector to reflect that real-world operations vary significantly between construction, agriculture, and other sectors. Other off-road sectors are assigned the average activity across all loggers.

Additionally, CARB staff defined activity groups by horsepower grouping to reflect that larger equipment and smaller equipment often have different duty cycles. Table 1 lists each horsepower bin and associated horsepower range, and this mapping is used throughout the report.

Table 1 Description of Horsepower Bins

Horsepower Bin	Horsepower Range
11	Under 11
25	11 ≤ hp < 25
50	25 ≤ hp < 50
75	50 ≤ hp < 75
100	75 ≤ hp < 100
175	100 ≤ hp < 175
300	175 ≤ hp < 300
600	300 ≤ hp < 600
750	600 ≤ hp < 750
9999	750 or Greater

Engines operating below and above 175 horsepower share similar equipment profiles. This cutoff is based on CARB's previous in-depth equipment profile analysis that can be found in a more detailed explanation in Table 9 of CARB's 2021 Agricultural Equipment Emission Inventory Technical Document[4]. As such, data is split at 175 horsepower, creating a below-175 horsepower group (notated as LOW) and an above-175 horsepower group (notated as HIGH). In the future, CARB staff aim to further differentiate the LOW grouping by splitting this category into one for engines rated up to 74 horsepower and one for engines rated 75 to 174 horsepower, for a total of three categories.

Table 2 outlines how equipment are categorized by sector, with separate activity bins for construction, agriculture (Ag), and their averages (Combo) that will be used for non-construction/non-agricultural sectors. Future sectors will be added when available.

Table 2 New Activity Groups

	LOW: 0 to 174 hp (25, 50, 75, 100, 175 hp bin)	HIGH: 175+ hp (300, 600, 750 hp bin)
Construction, Mining, Oil Drilling, Industrial	Construction Bin LOW	Construction Bin HIGH
Agriculture	Ag Bin LOW	Ag Bin HIGH
Average	Combo Bin LOW	Combo Bin HIGH

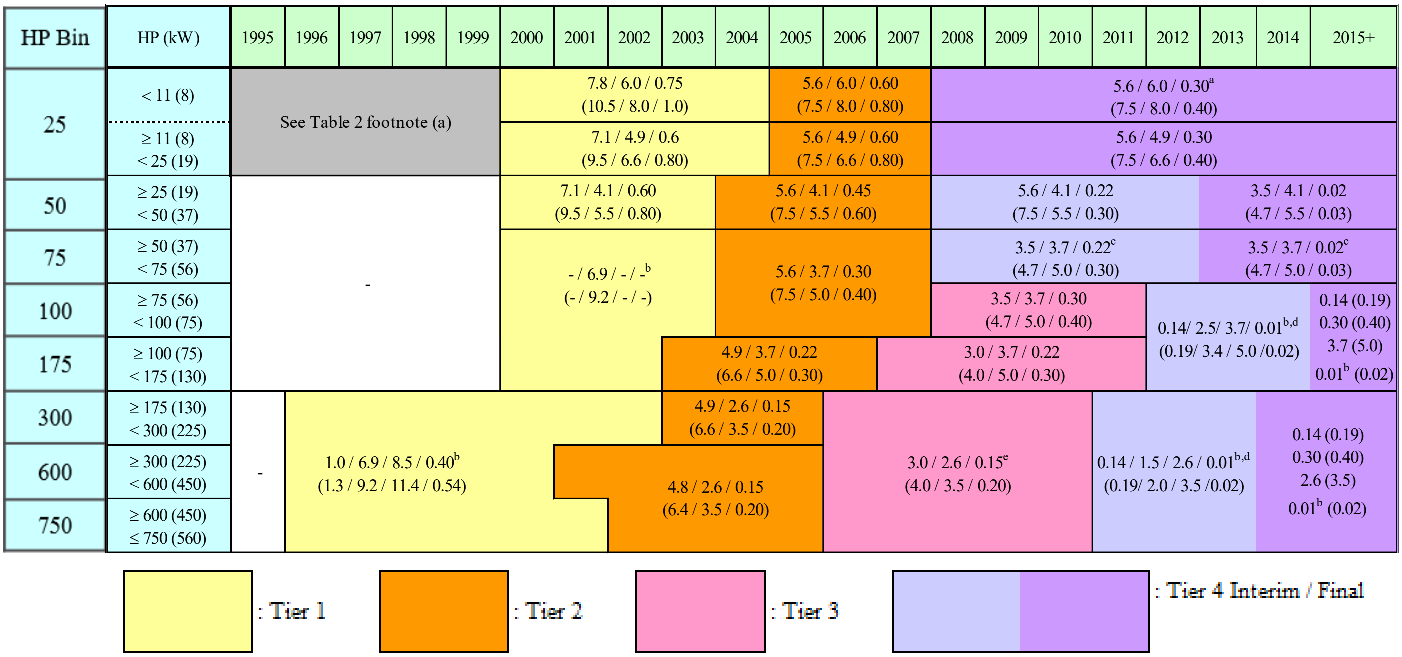
2.2.2 NOx Emission Groups

Figure 5 presents the emission standards chart for off-road diesel engines in California. An emission standard represents the maximum allowable level of pollution an engine may

[4] CARB's 2021 Agricultural Equipment Emission Inventory Technical Document https://ww2.arb.ca.gov/sites/default/files/2021-08/AG2021_Technical_Documentation_0.pdf

produce per unit of energy. Engines must meet the standards based on their engine horsepower and model year.

Figure 5 Off-Road Compression-Ignition (Diesel) Engine Standards [NMHC+NOx/CO/PM in g/bhp-hr (g/kW-hr)]



The number of PEMS data points were not sufficient to create groupings for each Tier and horsepower bin. Therefore, CARB staff grouped the data according to groups of engines that have the same NOx standards, thereby removing the boundaries of engine tier, horsepower bin, and model year. This creates different NOx groupings than presented in Figure 5, and better reflects characteristic similarities.

For example, the NOx standard of 3.5 grams per brake horsepower-hour (g/bhp-hr) is shared across some Tier 3, Tier 4 Interim (4i), and Tier 4 Final (4F) engines that are in the 50, 75, and 100 horsepower bins for model years beginning in 2008. Using the emission standard-dependent NOx groupings, these are all grouped together and labeled as NOx09 (see Figure 6). Table 3 lists the load-dependent NOx groupings that are based on NOx standards and used in the new methodology. The first column lists the tier and engine horsepower descriptions, then the corresponding NOx group name, and NOx standards in the last two columns.

Table 3 Load-Dependent NOx Groupings based on NOx Standards

NOx Description	NOx Group	NOx Standard (g/bhp-hr)	NOx Standard (g/kw-hr)
Tier 0	NOx01	15	20.12
Tier 1 - Over 50 Hp	NOx02	6.9	9.25
Tier 1 - Under 11 Hp	NOx03	7.8	10.46

Tier 1 - 11 to 49 Hp	NOx04	7.1	9.52
Tier 2 - Over 300 Hp	NOx05	4.8	6.44
Tier 2 - 100 to 299 Hp	NOx06	4.9	6.57
Tier 2.4i.4F - Under 100 Hp	NOx07	5.6	7.51
Tier 3 -100 to 750 Hp	NOx08	3.0	4.02
Tier 3.4i.4F - 25 to 99 Hp	NOx09	3.5	4.69
Tier 4i - 175 to 750 Hp	NOx10	1.5	2.01
Tier 4i - Over 750 Hp	NOx11	2.6	3.49
Tier 4i - 75 to 174 Hp	NOx12	2.5	3.35
Tier 4F - 76 to 750 Hp	NOx13	0.3	0.40

Figure 6 and Figure 7 re-create the chart from Figure 5 using the load-dependent NOx groupings. Figure 6 colors the chart according to the emission standard-dependent NOx groupings. Figure 7 follows the same color scheme, but inserts the engine tier. This demonstrates that NOx09, shaded in bright blue, spans Tier 3, Tier 4 Interim, and Tier 4 Final, as well as multiple horsepower bins and model years.

Figure 6 Load-Dependent NOx Groupings by NOxID

HP Bin	HP	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016+
11	< 11	NOx01	NOx01	NOx01	NOx01	NOx01	NOx03	NOx03	NOx03	NOx03	NOx03	NOx07	NOx07	NOx07	NOx07	NOx07	NOx07	NOx07	NOx07	NOx07	NOx07	NOx07	NOx07
25	≥ 11 < 25	NOx01	NOx01	NOx01	NOx01	NOx01	NOx04	NOx04	NOx04	NOx04	NOx04	NOx07	NOx07	NOx07	NOx07	NOx07	NOx07	NOx07	NOx07	NOx07	NOx07	NOx07	NOx07
50	≥ 25 < 49	NOx01	NOx01	NOx01	NOx01	NOx01	NOx04	NOx04	NOx04	NOx04	NOx07	NOx07	NOx07	NOx07	NOx07	NOx07	NOx07	NOx07	NOx07	NOx09	NOx09	NOx09	NOx09
75	≥ 50 < 74	NOx01	NOx01	NOx01	NOx01	NOx01	NOx02	NOx02	NOx02	NOx02	NOx07	NOx07	NOx07	NOx07	NOx09	NOx09	NOx09	NOx09	NOx09	NOx09	NOx09	NOx09	NOx09
100	≥ 75 < 99	NOx01	NOx01	NOx01	NOx01	NOx01	NOx02	NOx02	NOx02	NOx02	NOx07	NOx07	NOx07	NOx07	NOx09	NOx09	NOx09	NOx09	NOx12	NOx12	NOx12	NOx13	NOx13
175	≥ 100 < 174	NOx01	NOx01	NOx01	NOx01	NOx01	NOx02	NOx02	NOx02	NOx06	NOx06	NOx06	NOx06	NOx08	NOx08	NOx08	NOx08	NOx08	NOx12	NOx12	NOx12	NOx13	NOx13
300	≥ 175 < 299	NOx01	NOx02	NOx02	NOx02	NOx02	NOx02	NOx02	NOx02	NOx06	NOx06	NOx06	NOx08	NOx08	NOx08	NOx08	NOx08	NOx10	NOx10	NOx10	NOx13	NOx13	NOx13
600	≥ 300 < 599	NOx01	NOx02	NOx02	NOx02	NOx02	NOx02	NOx05	NOx05	NOx05	NOx05	NOx05	NOx08	NOx08	NOx08	NOx08	NOx08	NOx10	NOx10	NOx10	NOx13	NOx13	NOx13
750	≥ 600 < 750	NOx01	NOx02	NOx02	NOx02	NOx02	NOx02	NOx02	NOx05	NOx05	NOx05	NOx05	NOx08	NOx08	NOx08	NOx08	NOx08	NOx10	NOx10	NOx10	NOx13	NOx13	NOx13
9999	> 750	NOx01	NOx01	NOx01	NOx01	NOx01	NOx02	NOx02	NOx02	NOx02	NOx02	NOx02	NOx05	NOx05	NOx05	NOx05	NOx05	NOx11	NOx11	NOx11	NOx11	NOx11	NOx11

Figure 7 Load-Dependent NOx Groupings by Engine Tier

HP Bin	HP	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016+
11	< 11	0	0	0	0	0	1	1	1	1	1	2	2	2	4F	4F	4F	4F	4F	4F	4F	4F	4F
25	≥ 11 < 25	0	0	0	0	0	1	1	1	1	1	2	2	2	4F	4F	4F	4F	4F	4F	4F	4F	4F
50	≥ 25 < 49	0	0	0	0	1	1	1	1	1	2	2	2	2	4i	4i	4i	4i	4i	4F	4F	4F	4F
75	≥ 50 < 74	0	0	0	1	1	1	1	1	1	2	2	2	2	4i	4i	4i	4i	4i	4F	4F	4F	4F
100	≥ 75 < 99	0	0	0	1	1	1	1	1	1	2	2	2	2	3	3	3	3	4i	4i	4i	4F	4F
175	≥ 100 < 174	0	0	1	1	1	1	1	1	2	2	2	2	3	3	3	3	3	4i	4i	4i	4F	4F
300	≥ 175 < 299	0	1	1	1	1	1	1	1	2	2	2	3	3	3	3	3	4i	4i	4i	4F	4F	4F
600	≥ 300 < 599	0	1	1	1	1	1	2	2	2	2	2	3	3	3	3	3	4i	4i	4i	4F	4F	4F
750	≥ 600 < 750	0	1	1	1	1	1	1	2	2	2	2	3	3	3	3	3	4i	4i	4i	4F	4F	4F
9999	> 750	0	0	0	0	0	1	1	1	1	1	1	2	2	2	2	2	4i	4i	4i	4i	4F	4F

2.3 Combining Activity and NOx Emissions

Emission factors are the emissions per unit of energy, measured in grams per brake horsepower-hour (g/bhp-hr) in CARB's off-road emission inventories. This analysis reflects activity at different engine loads and NOx emission factors at different engine loads, and creates load-dependent NOx emission factors. Based on activity profile analysis and NOx standards, and establishing Activity Groups and NOx Groups, Figure 8 displays the new Activity and NOx groupings by horsepower bin and model year.

Figure 8 New Activity and NOx Groups by Horsepower Bin and Model Year

HP Bin	HP	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016+
11	< 11	NOx01	NOx01	NOx01	NOx01	NOx01	NOx03	NOx03	NOx03	NOx03	NOx03	NOx07	NOx07	NOx07	NOx07	NOx07	NOx07	NOx07	NOx07	NOx07	NOx07	NOx07	NOx07
25	≥ 11 < 25	NOx01	NOx01	NOx01	NOx01	NOx01	NOx04	NOx04	NOx04	NOx04	NOx04	NOx07	NOx07	NOx07	NOx07	NOx07	NOx07	NOx07	NOx07	NOx07	NOx07	NOx07	NOx07
50	≥ 25 < 49	NOx01	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	NOx04	NOx04	NOx04	NOx07	NOx07	NOx07	NOx07	NOx07	NOx07	NOx07	NOx07	NOx07	NOx09	NOx09	NOx09	NOx09
75	≥ 50 < 74	NOx01	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	NOx02	NOx02	NOx02	NOx07	NOx07	NOx07	NOx07	NOx09	NOx09	NOx09	NOx09	NOx09	NOx09	NOx09	NOx09	NOx09
100	≥ 75 < 99	NOx01	NOx01	NOx01	NOx01	NOx01	NOx02	NOx02	NOx02	NOx02	NOx07	NOx07	NOx07	NOx07	NOx09	NOx09	NOx09	NOx09	NOx12	NOx12	NOx12	NOx13	NOx13
175	≥ 100 < 174	NOx01	NOx01	NOx01	NOx01	NOx01	NOx02	NOx02	NOx02	NOx06	NOx06	NOx06	NOx06	NOx08	NOx08	NOx08	NOx08	NOx08	NOx12	NOx12	NOx12	NOx13	NOx13
300	≥ 175 < 299	NOx01	NOx02	NOx02	NOx02	NOx02	NOx02	NOx02	NOx02	NOx06	NOx06	NOx06	NOx08	NOx08	NOx08	NOx08	NOx08	NOx10	NOx10	NOx10	NOx13	NOx13	NOx13
600	≥ 300 < 599	NOx01	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	NOx05	NOx05	NOx05	NOx05	NOx05	NOx08	NOx08	NOx08	NOx08	NOx08	NOx10	NOx10	NOx10	NOx13	NOx13	NOx13
750	≥ 600 < 750	NOx01	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	NOx02	NOx05	NOx05	NOx05	NOx05	NOx08	NOx08	NOx08	NOx08	NOx08	NOx10	NOx10	NOx10	NOx13	NOx13	NOx13
9999	> 750	NOx01	NOx01	NOx01	NOx01	NOx01	NOx02	NOx02	NOx02	NOx02	NOx02	NOx02	NOx05	NOx05	NOx05	NOx05	NOx05	NOx11	NOx11	NOx11	NOx11	NOx11	NOx11

Activity Bin LOW

Activity Bin HIGH

Activity Bin LOW has ten NOx groupings and Activity Bin HIGH has eight NOx groupings, for a total of 18 different combinations of activity and NOx groupings. Construction and agriculture each have their own Activity Bins based on separate data logging, whereas other off-road sectors use an average of the Activity Bins (see Table 3). The average for other sectors is weighted based on time, as it includes data from all data loggers. As mentioned, when more data become available for engines under 75 horsepower, CARB staff plan to create an additional activity bin from 0 to 75 horsepower.

2.3.1 Idling Periods

Emission inventory analysis of the data establishes new criteria when identifying idling periods. Idling NOx emissions are measured in grams per hour (g/hr), not grams per brake horsepower-hour (g/bhp-hr). CARB staff made this change due to challenges accurately and consistently identifying the horsepower during idling periods. Idling emissions are calculated separately from non-idling emissions and then added to non-idling emissions to determine total NOx emissions from the engine.

In the datasets for activity and emissions, CARB staff identified idling as periods when the engine load is zero or there is steady-state idling. Steady-state idling is identified as a 15-second or longer period where the instantaneous engine speed deviates from the average engine speed by less than 5%, and the engine speed remains less than 1,100 rpm (rotations per minute). CARB staff selected these metrics by reviewing the PEMS test data for periods where the engine was running but there was no demand on the engine, and the equipment was not moving or using implements or attachments, or other power take-off. Each manufacturer and engine had a slightly different engine speed while the engine met the definition of idling described in this report, falling between 800 and 1,100 rpm.

This definition is intended only to identify periods of idling in the existing data, not to create a new definition of idling across the dozens of engine manufacturers and hundreds of engine models.

In the testing data, there were also short periods of zero-load demand between tasks when the rpm may still be high, and the engine has not slowed to idling speeds. Generally, these periods were a couple of seconds long. These points are not included in the definition of idling in this document, as the engine has not returned to a steady-state idling condition.

2.4 Load Calculation

An engine load is a unitless number representing how hard an engine works in relation to its maximum possible output. Using both the PEMS units and HEM data loggers, engine load is calculated for every second each engine was in operation. Each second-by-second load is grouped into load bins, listed in Table 4. There are 10 load bins, from 0 to 10% (using between 0 and 10% of the maximum rated power) to 90 to 100% (using 90 to 100% of the maximum power), in increments of 10. The average engine load is calculated within each of the 10 load bins.

Table 4 Load Bin Description

Load Bin	Engine Load Range
10	Under 10
20	$10 \le load < 20$
30	$20 \le load < 30$
40	$30 \le load < 40$
50	$40 \le load < 50$
60	$50 \le load < 60$
70	$60 \le load < 70$
80	$70 \le load < 80$
90	$80 \le load < 90$
100	$90 \le load < 100$

The PEMS units provided output data to calculate load using a basic load equation in Equation 1, which divides the engine horsepower used at that second by the maximum horsepower of the engine.

Equation 1 Basic Load Equation

$$Load = \frac{instantaneous\ engine\ horsepower}{max\ engine\ horsepower}$$

The HEM loggers provided engine parameters to calculate load using the engine-based calculations in Equation 2. This divides the power output occurring at that second by the maximum power the engine has output.

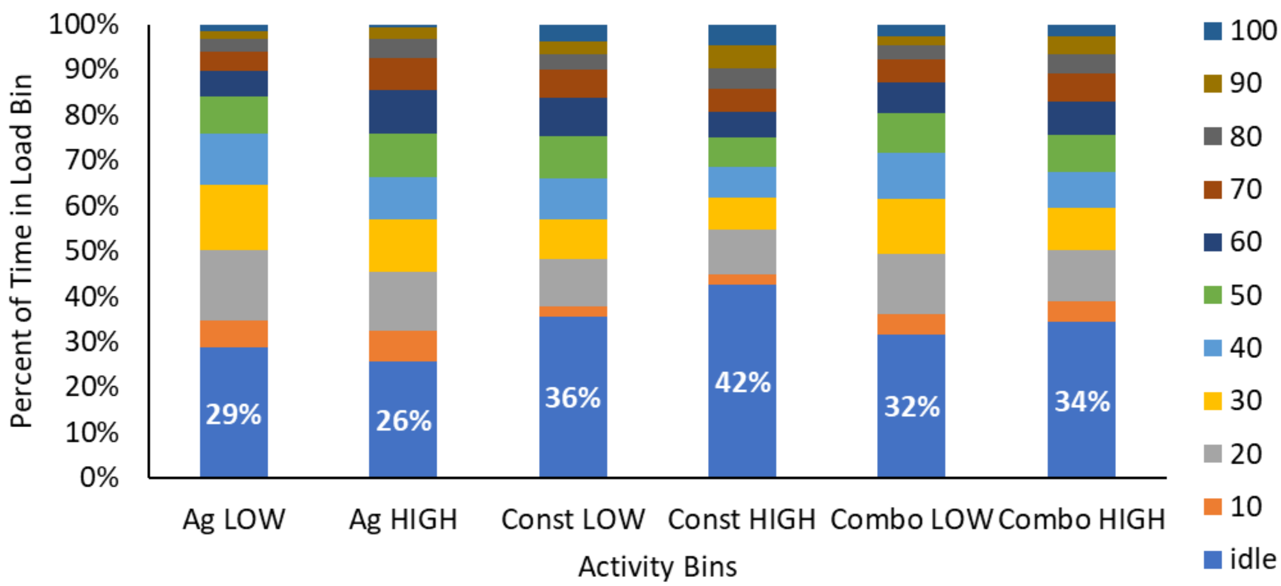
Equation 2 Load Equation Based on Engine Parameters

$$Load = \frac{\frac{2\,\pi * speed}{60} * \frac{(Actual\,\%\,Torque - Nominal\,Friction\,Torque)}{100} * \frac{Reference\,Torque}{745.7}}{\frac{2\,\pi * Max\,speed}{60} * \frac{(Actual\,\%\,Torque - Nominal\,Friction\,Torque)}{100} * \frac{Reference\,Torque}{745.7}}$$

2.5 Time in Load Bin

The stacked bar chart in Figure 9 plots the percent of time in load bin for each activity bin, by sector. Agriculture (Ag), Construction (Const), and their average (Combo) percent of time in load bin are shown for activity bins LOW and HIGH, including time spent idling.

Figure 9 Off-road Activity profiles, time in load bin



2.6 NOx Emissions by Load Bin

Figure 10 is a bar chart using blue bars to plot the average NOx emission factor by load bin for each NOx Grouping in units of grams per brake horsepower-hour. The orange line plots the NOx Standard for each NOx group. For every NOx Group, NOx emissions are highest in the low load bins, specifically bins 10, 20, and 30, whereas the high load bins have lower NOx emission factors than the low load bins. Furthermore, the low load bins, in nearly every case, emit above the NOx Standard for each NOx Group while the high load bins emit at or below the NOx Standard. The NOx emission factor for Tier 4 Final engines is expanded in Figure 11, due to scale. As a reminder, Table 3 lists the NOx Standard for each NOx Group.

Figure 10 Off-road NOx Emissions by Load Bin as compared to NOx Standard

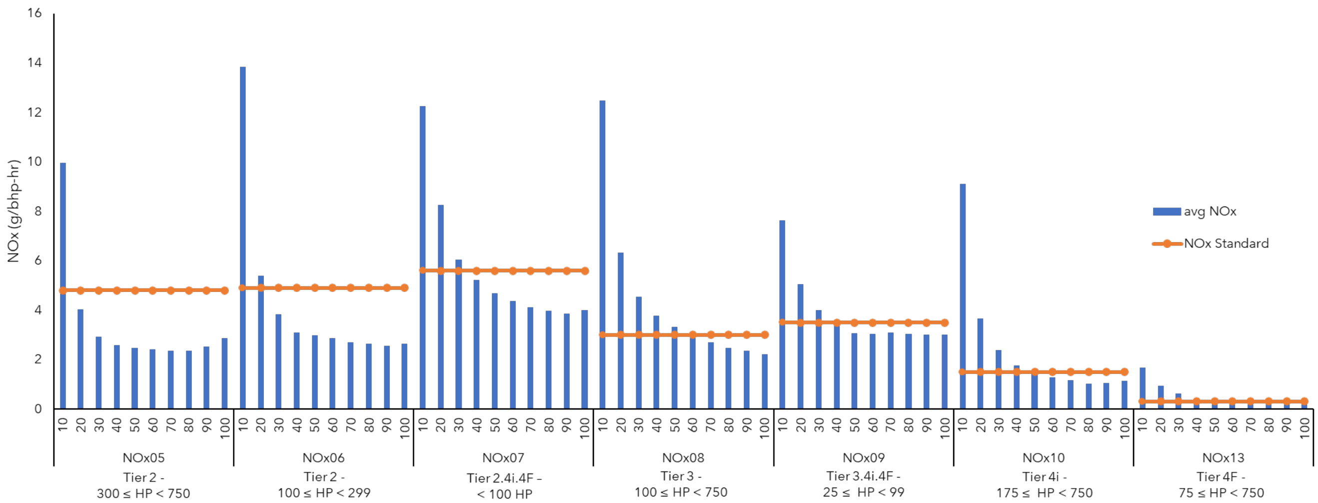
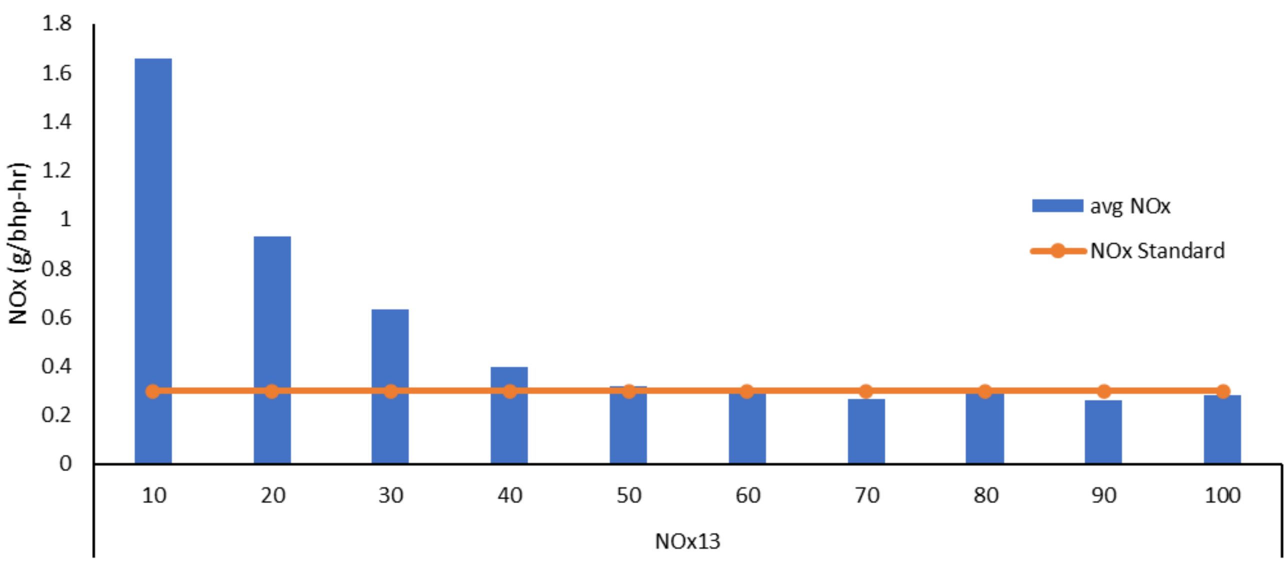


Figure 11 Off-Road NOx Emissions by Load Bin, Tier 4 Final, 75 to 750 Hp (NOx13)



The PEMS units did not collect data from engines categorized in groups over 750 horsepower, or Tier 4 Interim engines from 75 to 175 horsepower (groups NOx11 or NOx12). For these groups, CARB staff used the closest engine group to those with missing data and used a ratio based on the certification standard. For example, for Tier 4 Interim engines from 75 to 175, the NOx emission standard is 2.5 g/bhp-hr. The closest engine by size and emission standard are the Tier 3 engines from 75 to 100 horsepower, with an emission standard of 3.5 g/bhp-hr. In this case, the 75 to 175 horsepower engine emission factors are based on the Tier 3 engine results, with a reduction factor of 2.5 / 3.5, or 0.714, to reflect the difference in the standards. This could be an area for future research and improvement.

Furthermore, the PEMS testing was not performed on Tier 0 or Tier 1 engines, so there is no data for NOx groups 1 through 4. For these cases, NOx emission factors are left unchanged.

The PEMS emissions data are applicable for most off-road sectors (excluding locomotives, marine, and TRUs) because the same engine families are used in multiple types of equipment across different sectors. Engines emit the same NOx regardless of sector or type of equipment that uses it. This means the NOx groupings are not sector specific. Only the activity groups are sector specific since they correlate to the way an engine is used.

2.7 Off-road NOx Emission Factor

The new method for calculating NOx emissions accounts for the percent of time spent in each load bin (including idle), the average engine power in each load bin, and the NOx emission factor in each load bin (including idle). For example, a 120-hp piece of equipment with a Model Year 2004 engine would be categorized as having an activity profile within Activity Bin LOW based on its horsepower rating, and a NOx emission factor within the NOx grouping called NOx06 based on its Model Year and horsepower rating.

Figure 12, Figure 13, and Figure 14 provide a visualization to demonstrate the new methodology. The figures display the percent of time in load bin for Bin LOW, the percent of average engine power in load bin for Activity Bin LOW, and the NOx emission factor for Tier 2 engines in the 175-horsepower bin (NOx06), respectively. Each value, by load bin, is multiplied together and explained with equations that follow below.

Figure 12 shows the relative time distribution for an example piece of equipment that falls into Activity Bin LOW. As shown in Figure 12, the equipment spends 29% of its time idling. The lower load bins generally account for the majority of time spent, with a combined 64% when idling or in load bins under 30.

Figure 12 Example Activity in Bin LOW: Percent of Time in Load Bin

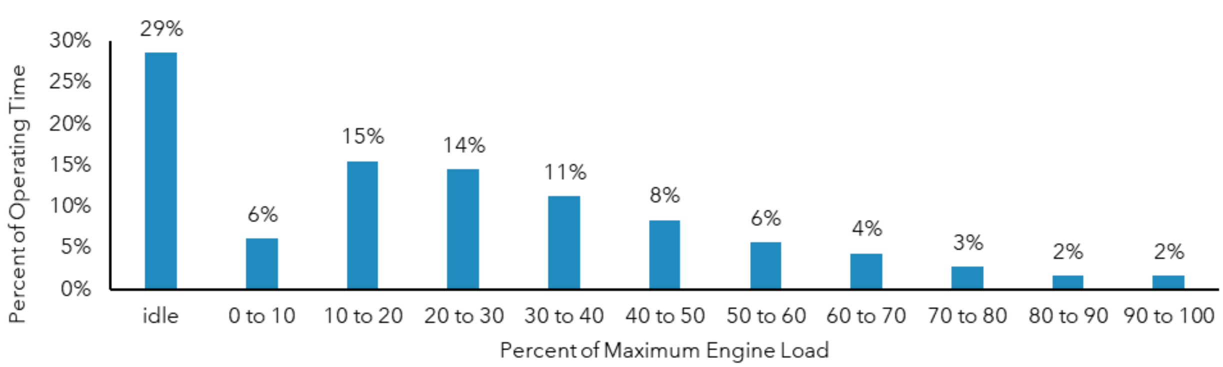


Figure 13 plots the percent of average engine load utilized in each load bin for an example piece of equipment in Activity Bin LOW. For example, when an engine is running between 70 and 80% load, the average load is 74%.

Figure 13 Example Activity in Bin LOW: Percent of Average Engine Power in Load Bin

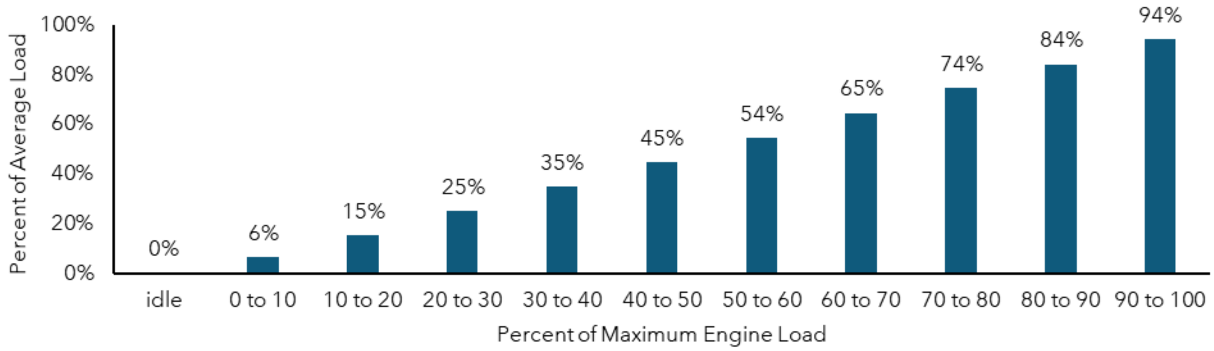
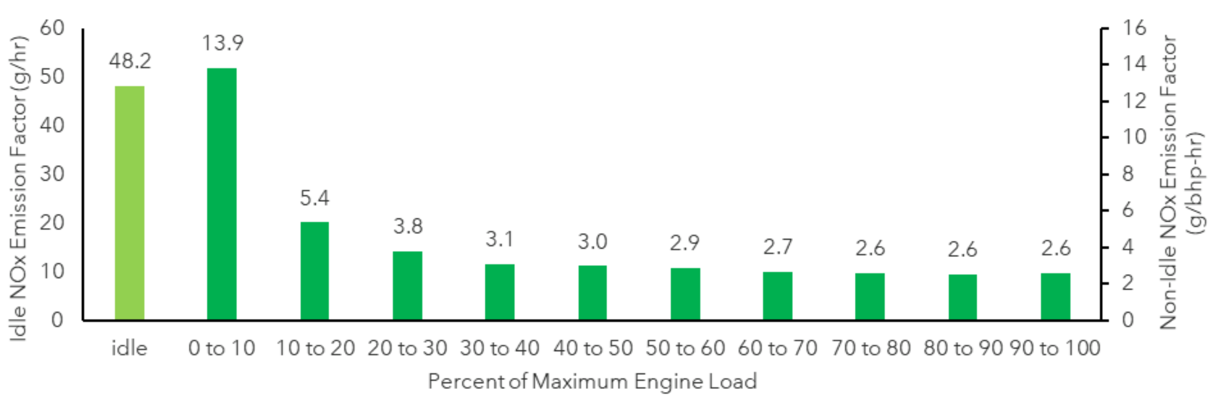


Figure 14 shows the NOx emission factor for idle and non-idle emissions for an example piece of equipment in the group for Tier 2 engines with NOx grouping NOx06 (175 and 300 horsepower bins). The light green bar on the left provides the idle emission factor, measured in grams per hour (g/hr), and uses the left-hand axis. The dark green bars measure non-idle emissions on the right-hand axis using grams per brake horsepower-hour (g/bhp-hr). Among the non-idle emission factor, emissions are highest in the lowest load bins (under 30% load). Idle emissions are also high but should not be compared at this point to non-idle emissions due to different units.

Figure 14 Example NOx Emission Factor in NOx06, the Tier 2, 175 Horsepower Bin



2.7.1 Load-Dependent NOx Emissions Equations and Application in Emissions Inventory

Equation 3 and Equation 4 present the idle and non-idle NOx Emission Factor equations. Equation 3 multiplies the fraction of time spent idling per hour by the idling NOx emission factor by load bin. Units are in grams per hour (g/hr).

Equation 4 multiplies the time spent in each load bin, the NOx emission factor for that bin, and the average load for each load bin. Units are in grams per brake horsepower hour (g/bhp-hr). Appendix A lists all NOx emission factors.

Equation 3 Idle NOx Emission Factor

$$NOx\ EF_{idle}\left(\frac{g}{hr}\right) = \ ActivityID_{idle}(\%time) \times NOxID_{idle}\left(\frac{g}{hr}\right)$$

Equation 4 Non-Idle NOx Emission Factor

$$NOx\ EF_{non-idle}\left(\frac{g}{bhphr}\right) = \left[\sum_{i=load\ bin}^{10} ActivityID_i(\%time) \times NOxID_i\left(\frac{g}{bhphr}\right) \times AvgLoad_i(unitless)\right]$$

Equation 5 and Equation 6 are the NOx emission equations to be used in the off-road diesel emission inventories.

Equation 5 calculates idle NOx emissions in tons per day (tpd) by multiplying the idle NOx emission factor, annual hours of use, and a unit conversion. Note that the idling emissions already account for the portion of time spent idling, per Equation 3.

Equation 6 calculates non-idle NOx emissions using the non-idle NOx emission factor that results from the 10 load bins in Equation 4. To calculate non-idling emissions, multiply the non-idle emission factor, annual hours of use, average engine horsepower (hp) in that bin. Note that the percent of time spent not idling is accounted for in the emission factor, per Equation 4.

Both equations use a unit conversion that converts emissions from grams per year to tons per day, the unit used in CARB's offroad emission inventories.

Equation 5 Idle NOx Emissions Equation

$$NOx_{idle}(tpd) = NOx\ EF_{idle}\left(\frac{g}{hr}\right) \times Annual\ Activity\left(\frac{hr}{yr}\right) \times \frac{1\ lb}{453.6\ g} \times \frac{1\ ton}{2000\ lb} \times \frac{1\ hr}{365\ day}$$

Equation 6 Non-Idle NOx Emissions Equation

$$\begin{aligned} NOx_{non-idle}(tpd) \\ &= NOx\ EF_{non-idle}\left(\frac{g}{bhphr}\right) \times Annual\ Activity\left(\frac{hr}{yr}\right) \times EngineHp(hp) \\ &\times \frac{1\ lb}{453.6\ g} \times \frac{1\ ton}{2000\ lb} \times \frac{1\ hr}{365\ day} \end{aligned}$$

Equation 7 adds the two parts from Equation 5 and Equation 6, idle NOx emission and non-idle NOx emissions, together and then multiplies the emissions by the equipment population.

Equation 7 NOx Emissions Equation

$$NOx\ (tpd) = \{NOx_{idle}\ (tpd) + \ NOx_{non-idle}(tpd)\}\ \times Population$$

3 PM, HC, and CO Emission Factors for Off-road Engines

3.1 Data Sources

Off-road diesel engine manufacturers are required meet CARB and U.S. EPA engine certification requirements and report their engine emissions to demonstrate compliance with State and federal regulations. This non-road compression ignition certification data[5] from 2017 to 2023, was used in conjunction with weighted sales data to update PM (Particulate Matter), HC (Hydrocarbons), and CO (Carbon Monoxide) emission factors. CARB's 2025 emission factor updates for PM, HC, and CO will replace CARB's 2017 emission factors of the same pollutants, which are used for all off-road diesel engines (excluding marine engines, locomotives, and transport refrigeration units). These updates affect Calendar Year 2017 and newer model year engines.

The U.S. EPA certification data categorizes engines by their power category using kilowatt ranges. The data contains over 7,000 engines for model years 2017 to 2023. According to California engine sales data, nearly 3,000 engine families were sold during 2017 to 2023. The two data sources were used together to create a sales-weighted emissions analysis. The power category ranges are converted to the equivalent horsepower ranges, and then data is grouped by Horsepower Bin (shown previously in Table 1). It is important to note that manufacturer use of emission credits, Family Emissions Limits (FEL), or similar flexibility programs are how engines may legally be sold while emitting over the standard.

Figure 15 plots sales-weighted PM emissions from an estimated 35,000 engines sold and reported in the 175-horsepower bin, along with a dashed yellow line indicating the Tier 4 Final PM emission standard is established at 0.015 g/bhp-hr. Only about 3% of the 175-horsepower bin engines are still emitting at or above this emission standard.

[5] https://www.epa.gov/system/files/documents/2024-02/nonroad-compression-ignition-2011-present.xlsx

Figure 15 Sales-Weighted PM Emissions from 175 Horsepower Bin Engine Certification Data

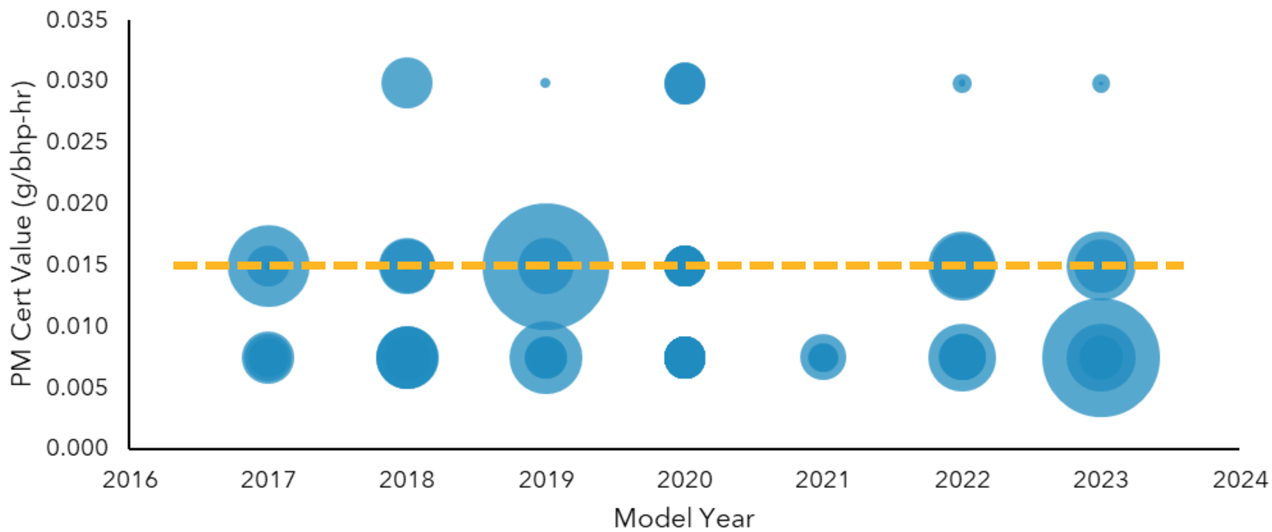


Figure 16 plots sales-weighted HC emissions from an estimated 30,400 engines reporting in the 175-horsepower bin along with a dashed pink line indicating the Tier 4 Final HC emission standard is established at 0.14 g/bhp-hr. This standard is greater than the highest engine emissions.

Figure 16 Sales-Weighted HC Emissions from 175 Horsepower Bin Engine Certification Data

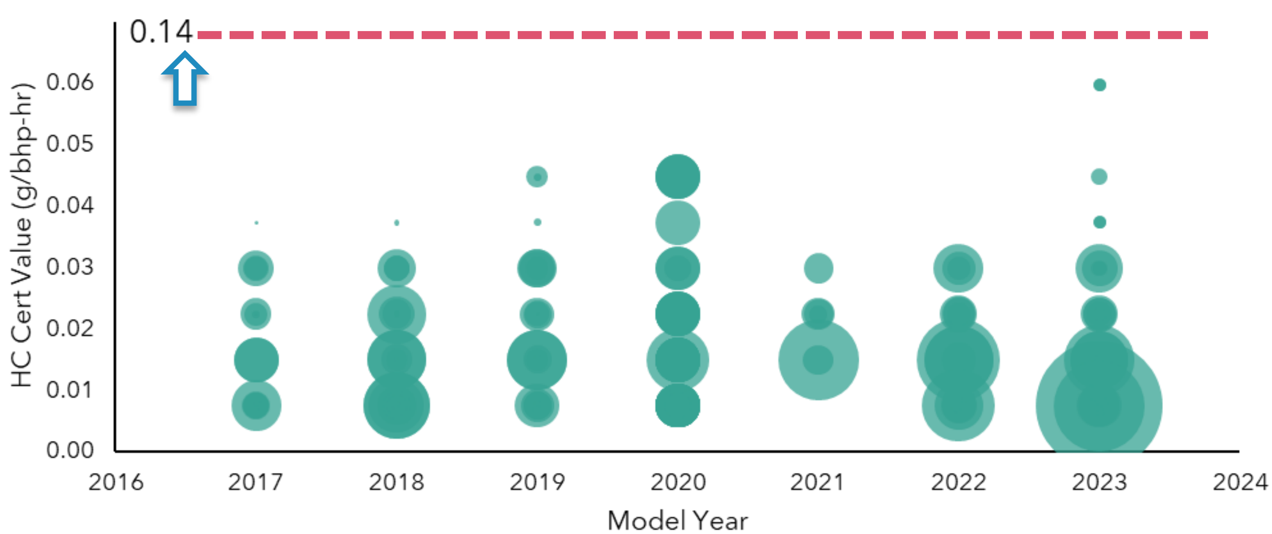


Figure 17 plots sales-weighted CO emissions from an estimated 13,000 engines reporting in the 175-horsepower bin along with a dashed brown line indicating the Tier 4 Final CO emission standard is established at 3.7 g/bhp-hr. Again, this emission standard is much higher than any of the reported engines.

Figure 17 CO Emissions from 175 Horsepower Bin Engine Certification Data

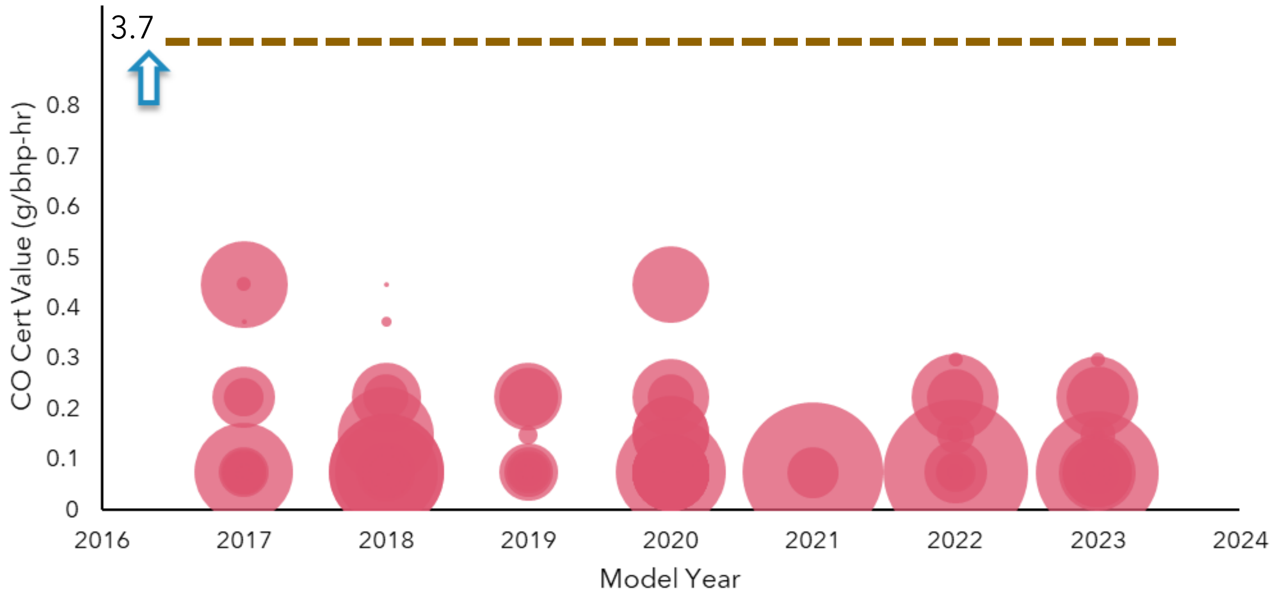
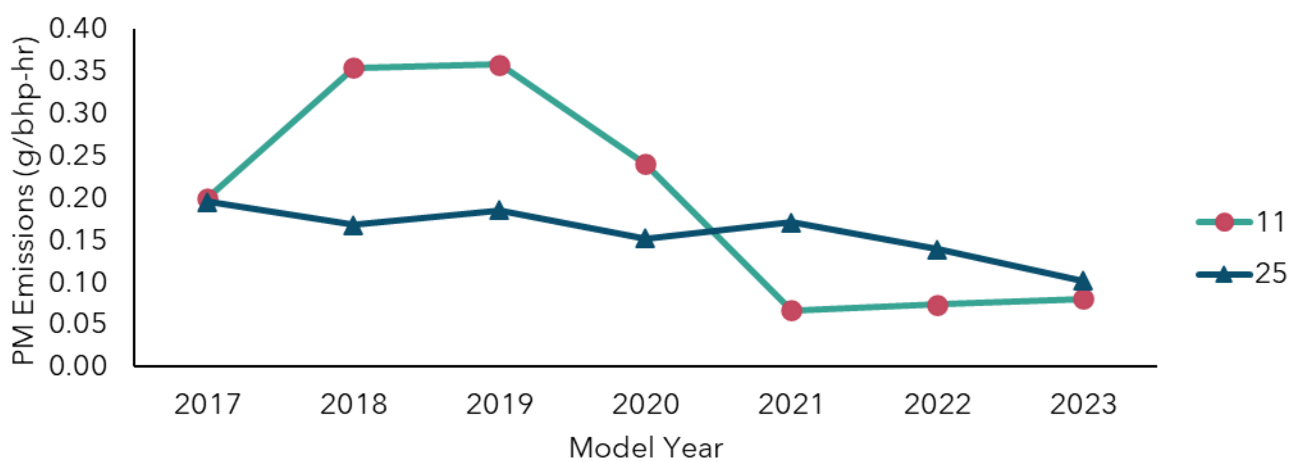


Figure 18, Figure 19, and Figure 20 plot the average PM, HC, and CO emissions, respectively, for each horsepower bin, by model year. First, the reported certification data is averaged using weighted by sales data to calculate the new zero-hour emission factor by Model Year for each horsepower bin. Reported years span from 2017 to 2023. Future year emission factors are predicted using linear regression. Note Figure 18 is split into two scales as the magnitude of emissions in engines below 25 horsepower is an order of magnitude higher than engines above 25 horsepower.

Figure 18 Average PM Emissions by Horsepower Bin (Top and Bottom)



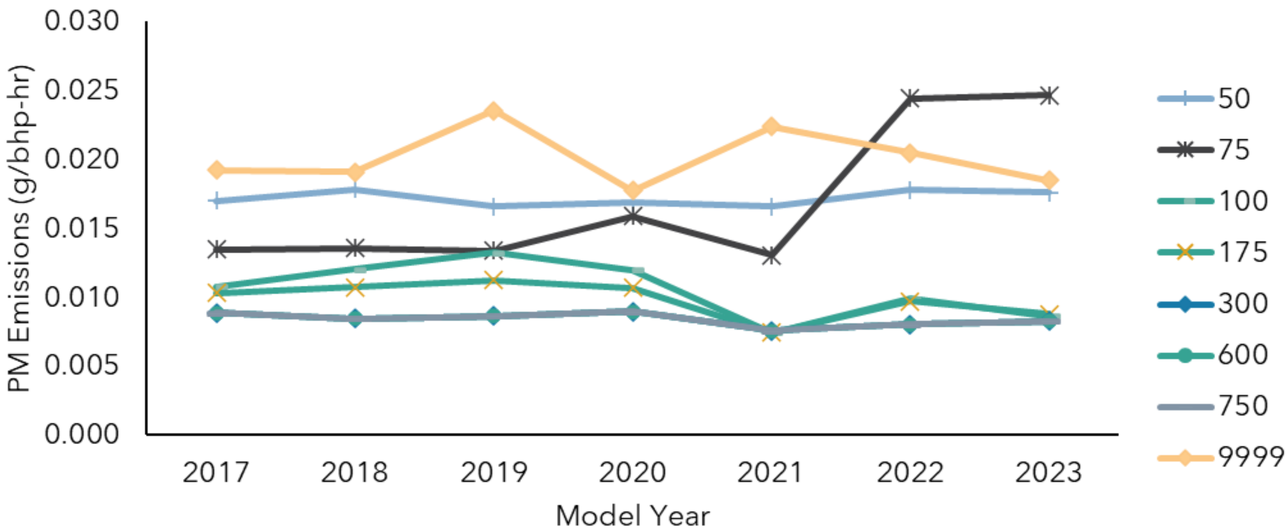


Figure 19 Average HC Emissions by Horsepower Bin

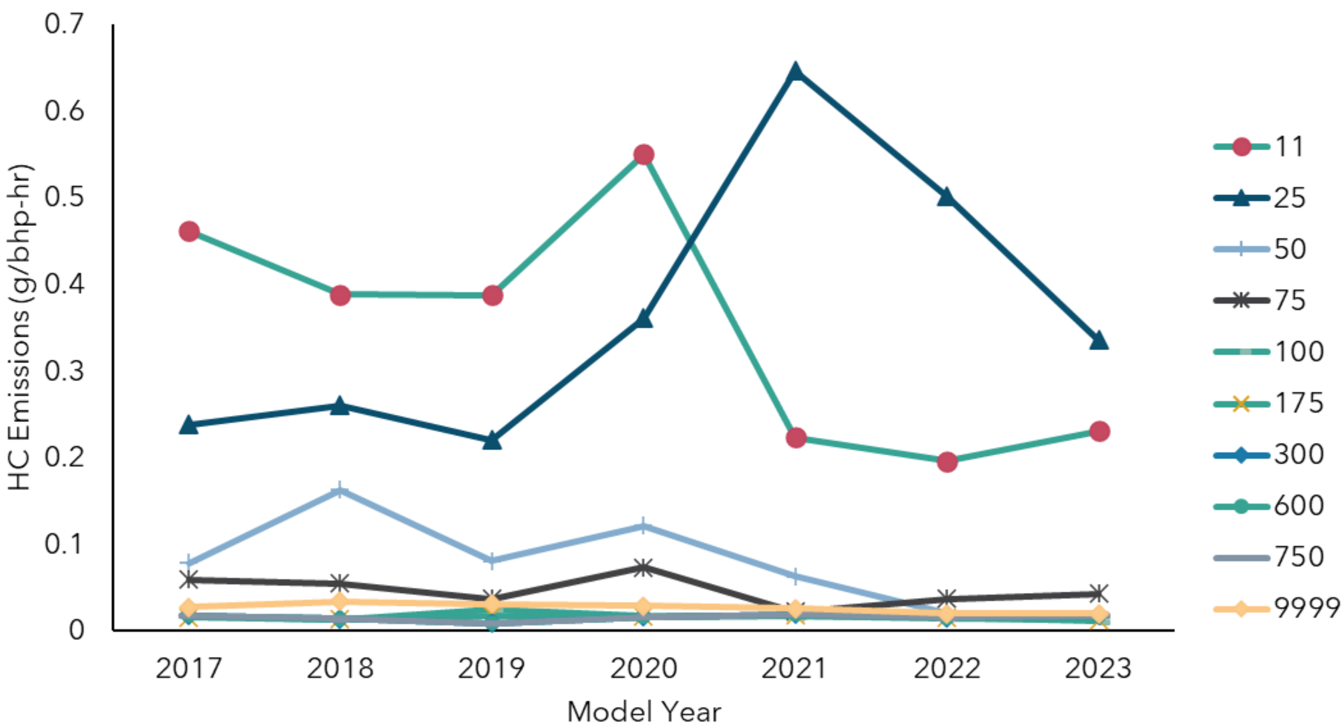
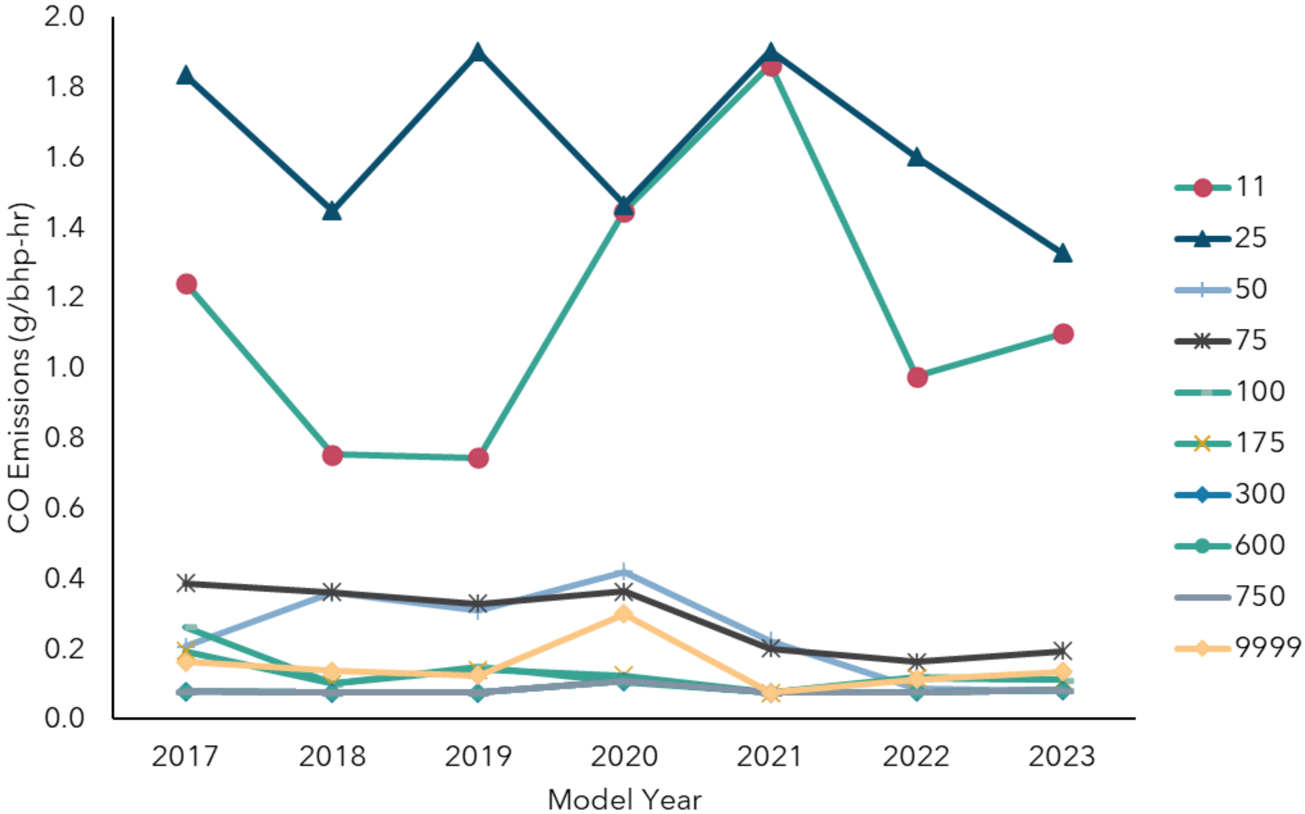


Figure 20 Average CO Emissions by Horsepower Bin



The linear relationship between the average emission factor and model year was used to predict future emission factors. The regression reduces emissions until each bin reaches the Tier 4 Final emission standard, meaning the prediction years trend downward towards the pollutant's emission standard. When a horsepower bin's emission factor is trending below the Tier 4 Final standard, it is assumed the emission factor remains at that level and is held constant out to 2050, assuming engine manufacturers have exhausted all emission credits and there will be no further change to the Tier 4 Final emission standards. This establishes the zero-hour emission factor. This process is repeated for each horsepower bin, and for each of the three pollutants (PM, HC, and CO).

An engine's deterioration rate represents the increase in emissions as an engine ages. This assumes an engine becomes more polluting the longer it is used. This emission factor update does not re-evaluate changes in engine deterioration, so the pollutant's emission factor deterioration rate is updated using a comparison ratio to the 2017 deterioration rate for pollutants other than NOx (see Appendix C for the new emission factors).

Equation 8 calculates emissions using the standard emission factor equation measured in grams per brake horsepower-hour (g/bhp-hr). The zero-hour emission factor is added to the product of an equipment's accumulated hours and the deterioration rate.

Equation 8 Standard Emission Factor Equation

$$Emission\ Factor\ (\frac{g}{bhphr}) = EF_{zh} + (EF_{dr} \times Accumulated\ Hours)$$

where:

$$EF_{zh} = \text{zero hour emission factor } (\frac{g}{bhphr})$$

$$EF_{dr} = deterioration\ rate\ (\frac{g}{bhphr^2})$$

3.1.1 Comparison

Figure 21, Figure 22, and Figure 23 compare the previous 2017 PM (yellow line), HC (orange line), and CO (purple line) zero-hour emission factors versus the new 2025 zero-hour emission factors for engines (blue line) in the 175-horsepower bin, respectively. The blue line shows reported sales-weighted engine certification averages for years 2017 to 2023, and predictions beginning in 2024 onward, which fall below the emission standard for each pollutant.

Figure 21 Comparison of 2017 and 2025 PM Emission Factors in the 175 Horsepower Bin

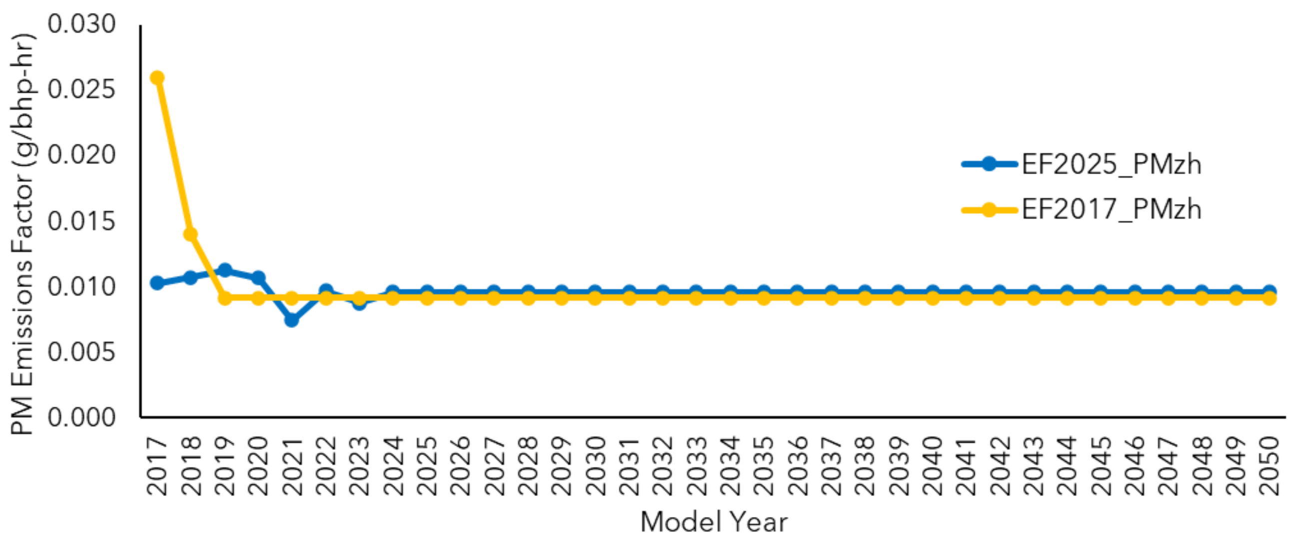


Figure 22 Comparison of 2017 and 2025 HC Emission Factors in the 175 Horsepower Bin

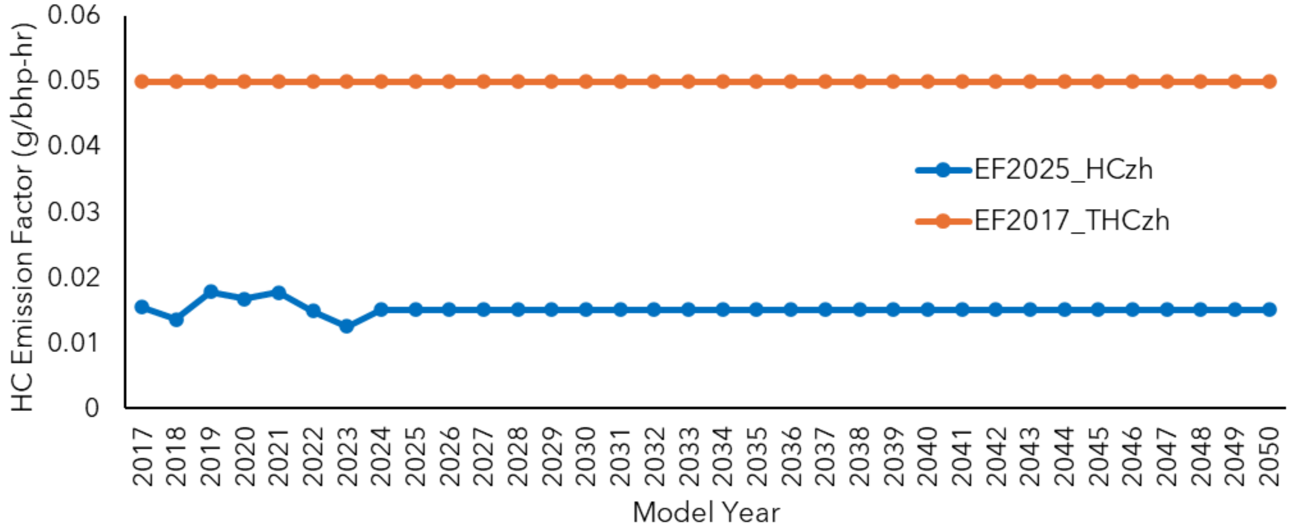
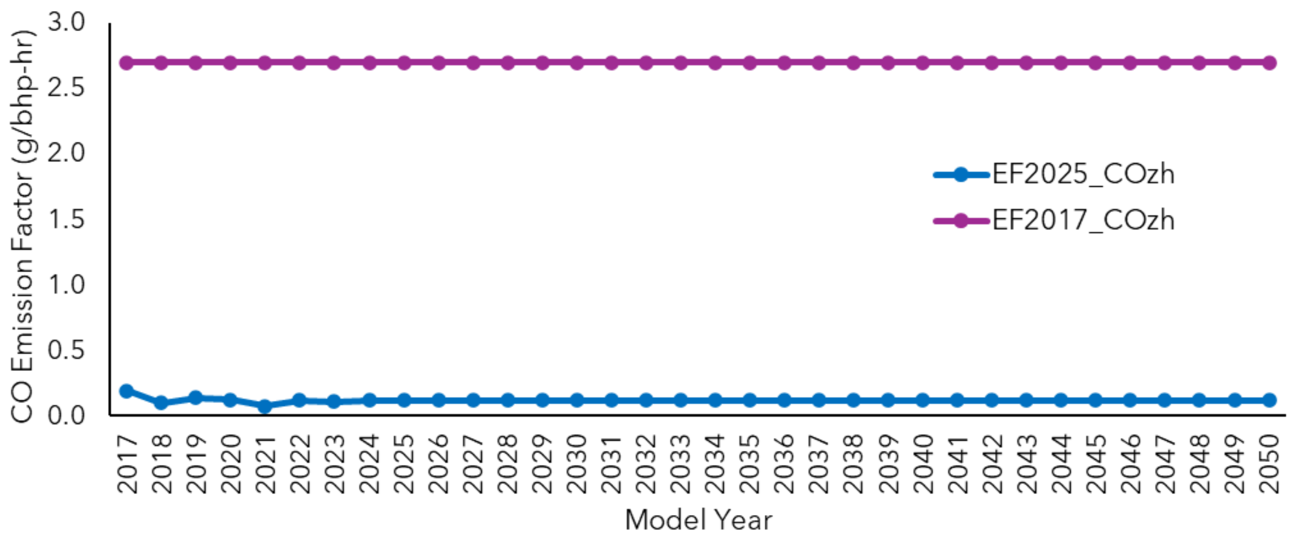


Figure 23 Comparison of 2017 and 2025 CO Emission Factors in the 175 Horsepower Bin



4 Impacts of this Update

CARB developed new methodology for calculating load-dependent NOx emissions for off-road diesel engines (excluding locomotive, marine, and transport refrigeration units) in a first-of-its kind analysis. This data driven method encompasses multiple contracts and includes real-world and simulated data for nearly 200 pieces of off-road equipment. This update identifies issues of increased NOx emissions during low-load cycles and quantifies idle versus non-idle NOx emissions. As a result, CARB has a better understanding of low-load emission cycles, will be able to model low-load cycles in its off-road diesel emission inventories, and be able to address these concerns when developing the next generation of

Tier 5 engines certification cycles and engine standards. Furthermore, CARB can identify the role idling emissions play and its relationship to non-idling emissions.

This crucial analysis characterizes how off-road engines at low-load cycles are exhibiting higher emissions per unit work that are above the NOx Standard while generally meeting NOx standards at higher loads. Furthermore, engines spend more time idling or at lower loads. This combination of higher emissions at lower loads and greater time at these lower loads may lead to an overall increase in NOx emissions in some emission inventories, depending on the average equipment distribution in a sector.

The second major update includes 2025 off-road diesel emission factors for PM, HC, and CO. The updated emission factors use engine certification data and weighted California sales data from 2017 to 2023. The 2025 emission factors replace the 2017 emission factors for the three pollutants.

With additional testing, there are several areas for refinement. First, additional data is required to split the 0 to 175 horsepower activity bin into two groups, one below and one above 75 horsepower, for activity profiles used in the load-dependent NOx methodology. Next, CARB staff could gather additional data on NOx emission factors for engines over 750 horsepower and for Tier 4 Interim engines between 75 to 175 horsepower. While testing engines older than Tier 2 is difficult due to a lack of ECU data, further PEMS testing could allow for expanding the load-dependent NOx emission methodology update to other pollutants such as PM.

5 Appendix A: Off-road Load-Dependent NOx Emission Factors

Activity Group	NOx Group	Non-Idle NOx EF (g/bhp-hr)	Idle NOx EF (g/hr)	Load Factor
Ag Bin Low	NOx06	0.836576263	16.00917	0.257172
Ag Bin Low	NOx07	1.272577137	22.45953	0.257172
Ag Bin Low	NOx08	0.906945489	23.57539	0.257172
Ag Bin Low	NOx09	0.863080112	15.46861	0.257172
Ag Bin Low	NOx12	0.641145226	11.49096	0.257172
Ag Bin Low	NOx13	0.108484775	6.474348	0.257172
Ag Bin High	NOx05	0.773641146	12.37002	0.294074
Ag Bin High	NOx06	0.928118195	14.33456	0.294074
Ag Bin High	NOx08	0.988621534	21.10934	0.294074
Ag Bin High	NOx10	0.47925835	22.64596	0.294074
Ag Bin High	NOx11	0.718434749	10.28897	0.294074
Ag Bin High	NOx13	0.114620149	5.797112	0.294074
Combo Bin Low	NOx06	0.848285113	17.71967	0.27396
Combo Bin Low	NOx07	1.297365132	24.85922	0.27396
Combo Bin Low	NOx08	0.906547662	26.09431	0.27396
Combo Bin Low	NOx09	0.890645945	17.12135	0.27396
Combo Bin Low	NOx12	0.661622702	12.71872	0.27396
Combo Bin Low	NOx13	0.106563719	7.166101	0.27396
Combo Bin High	NOx05	0.746776836	16.52317	0.289364
Combo Bin High	NOx06	0.870111413	19.14728	0.289364
Combo Bin High	NOx08	0.910058652	28.19664	0.289364
Combo Bin High	NOx10	0.437965937	30.24918	0.289364
Combo Bin High	NOx11	0.686824351	13.74342	0.289364
Combo Bin High	NOx13	0.105910875	7.743449	0.289364
Construction Bin Low	NOx06	0.866645907	19.9169	0.29681
Construction Bin Low	NOx07	1.334246893	27.94174	0.29681
Construction Bin Low	NOx08	0.908880796	29.32998	0.29681
Construction Bin Low	NOx09	0.929851723	19.24439	0.29681
Construction Bin Low	NOx12	0.690746994	14.29583	0.29681
Construction Bin Low	NOx13	0.104459136	8.054692	0.29681
Construction Bin High	NOx05	0.721878488	20.46763	0.284727
Construction Bin High	NOx06	0.81607076	23.71818	0.284727
Construction Bin High	NOx08	0.836530199	34.92782	0.284727
Construction Bin High	NOx10	0.399526332	37.47035	0.284727
Construction Bin High	NOx11	0.657168024	17.02429	0.284727
Construction Bin High	NOx13	0.097782979	9.591988	0.284727

6 Appendix B: Engine Families in PEMS Testing

Table 5 Engine Information for PEMS Testing in 2013

Test Count	Year	Tier	Engine Family	Engine Model	Rated Power (bhp)	Rated Speed (RPM)	Engine Hours
1	2007	2	7JDXL04.5062	4045TT095	99	2200	1182
2	2010	3	AJDXLO6.8106	4045HT054	99	2250	242
3	2007	3	7JDXL06.8101	6068HDW69	225	2200	1735
4	2006	2	6JDXL04.5062	4045TT089	92	2300	2599
5	2006	2	6JDXL04.5062	4045TT093	99	2200	946
6	2009	3	9KLXL11.0DD6	SAA6D125E-5	273	2000	900
7	2004	2	n/a	3056E	156	2300	2294
8	2008	3	n/a	C13	520	2100	tbd
9	2006 (Rebuild)	2	n/a	C9 637D	280	2200	>10000
10	2006 (Rebuild)	2	n/a	C15 IND (LHX14568)	540	2100	>10000
11	2006	3	6VSXL12 .1CE3	D12DEBE3	269	1700	5233
12	2003	2	3CPXL14.6ESK	3406E	338	2000	17149
13	2008	3	8PKXL06.6PJ1	C6.6	163	2200	3815
14	2011	3	APKXL06.6PJ2	C6.6	171	2200	289
15	2010	3	APKXL06.6PJ1	C6.6	163	2200	1308
16	2008	3	8PKXL06.6PJ1	C6.6	163	2200	2706
17	2010	3	APKXL06.6PJ1	C6.6	168	2200	952
18	2011	3	APKXL06.6PJ2	C6.6	171	2200	345
19	2010	3	APKXL06.6PJ1	C6.6	193	2200	439
20	2011	3	APKXL06.6PJ2	C6.6	171	2200	242
21	2012	4i	CCPXL0903HPB	ACERT C9.3	223	2000	24
22	2011	4i	BCPXL09.3HPA	ACERT C9.3	296	2200	296
23	2012	4i	CCPXL15.2HPA	ACERT C15	316	2000	32
24	2012	4i	CCPXL0903HPB	ACERT C9.3	223	2000	44
25	2011	4i	BCPXL09.3HPA	ACERT C9.3	296	2200	589
26	2007	3	7KLXL0409AAC	SAA6D107E-1	155	2000	2097
27	2012	3	BKLXL0275AAG	SAA4D107E-1	148	2000	245

Table 6 Engine Information for PEMS Testing in 2019

Test Count	Engine Model Year	Tier	Engine Family	Engine Model	Rated Horsepower (bhp)	Rated Speed (rpm)	Engine Hours
28	2015	4F	FPKXL07.0BN1	C7.1 ACERT	203.7	1800	2051.1
29	2015	4F	FPKXL07.0BN1	C7.1 ACERT	203.7	1800	2056.2
30	2015	4F	FPKXL07.0BN1	C7.1 ACERT	203.7	1800	2060
31	2015	4F	FPKXL07.0BN1	C7.1 ACERT	203.7	1800	2062.7
32	2015	4F	FPKXL07.0BN1	C7.1 ACERT	187.7	1800	2054.4
33	2015	4F	FPKXL07.0BN1	C7.1 ACERT	187.7	1800	2057
34	2015	4F	FPKXL04.4MT1	C4.4 ACERT	115	2200	1594
35	2015	4F	FPKXL04.4MT1	C4.4 ACERT	115	2200	1600.7
36	2016	4F	GCPXL09.3HTF	C9.3 ACERT	318	1600	1611
37	2016	4F	GCPXL09.3HTF	C9.3 ACERT	318	1600	1612.4
38	2016	4F	GCPXL09.3HTF	C9.3 ACERT	318	1600	1615.4
39	2017	4F	HJDXL09.0301	6090HDW36	364.6	2100	353
40	2017	4F	HJDXL09.0301	6090HDW36	364.6	2100	358.7
41	2017	4F	HJDXL04.5315	4045HT096	126	2200	694.8
42	2017	4F	HJDXL04.5315	4045HT096	126	2200	697.9
43	2014	4F	EJDXL13.5300	6135HT003	396.8	2000	1991.5
44	2014	4F	EJDXL13.5300	6135HT003	396.8	2000	1996
45	2017	4F	HSZXL05.2RXA	AR-4HK1X	172.2	2000	348.6
46	2017	4F	HSZXL05.2RXA	AR-4HK1X	172.2	2000	349.6
47	2014	4F	EJDXL13.5300	6135HDW11	396.8	2000	91.8
48	2014	4F	EJDXL13.5300	6135HDW11	396.8	2000	96.8
49	2015	4F	FCPXL15.2HTF	C15.2 ACERT	356.5	1700	3652.2
50	2015	4F	EJDXL13.5300	C15.2 ACERT	356.5	1700	3654.3

7 Appendix C: PM, HC, and CO Emission Factors

Zero-hour (zh) reflects the emissions from an engine that is new.

Deterioration rate (dr) reflects the engine's deterioration rate over time and its accumulated lifetime hours.

Model Year	Horsepower Bin	PMzh (g/bhp-hr)	PMdr (g/bhp-hr^2)	THCzh (g/bhp-hr)	THCdr (g/bhp-hr^2)	COzh (g/bhp-hr)	COdr (g/bhp-hr^2)
2017	11	0.199997	0	0.461737	0.000185	1.242336	0.000126
2018	11	0.354696	0	0.388998	0.000156	0.754957	7.66E-05
2019	11	0.357936	0	0.387764	0.000155	0.7457	7.57E-05
2020	11	0.240115	0	0.550327	0.00022	1.446658	0.000147
2021	11	0.067113	0	0.22371	8.95E-05	1.86425	0.000189
2022	11	0.073883	0	0.196327	7.85E-05	0.977601	9.92E-05
2023	11	0.081004	0	0.230868	9.23E-05	1.099029	0.000112
2024	11	0.079138	0	0.1711	6.84E-05	1.04	0.000106
2025	11	0.079138	0	0.154202	6.17E-05	1.04	0.000106
2026	11	0.079138	0	0.154202	6.17E-05	1.04	0.000106
2027	11	0.079138	0	0.154202	6.17E-05	1.04	0.000106
2028	11	0.079138	0	0.154202	6.17E-05	1.04	0.000106
2029	11	0.079138	0	0.154202	6.17E-05	1.04	0.000106
2030	11	0.079138	0	0.154202	6.17E-05	1.04	0.000106
2031	11	0.079138	0	0.154202	6.17E-05	1.04	0.000106
2032	11	0.079138	0	0.154202	6.17E-05	1.04	0.000106
2033	11	0.079138	0	0.154202	6.17E-05	1.04	0.000106
2034	11	0.079138	0	0.154202	6.17E-05	1.04	0.000106
2035	11	0.079138	0	0.154202	6.17E-05	1.04	0.000106
2036	11	0.079138	0	0.154202	6.17E-05	1.04	0.000106
2037	11	0.079138	0	0.154202	6.17E-05	1.04	0.000106
2038	11	0.079138	0	0.154202	6.17E-05	1.04	0.000106
2039	11	0.079138	0	0.154202	6.17E-05	1.04	0.000106
2040	11	0.079138	0	0.154202	6.17E-05	1.04	0.000106
2041	11	0.079138	0	0.154202	6.17E-05	1.04	0.000106
2042	11	0.079138	0	0.154202	6.17E-05	1.04	0.000106
2043	11	0.079138	0	0.154202	6.17E-05	1.04	0.000106
2044	11	0.079138	0	0.154202	6.17E-05	1.04	0.000106
2045	11	0.079138	0	0.154202	6.17E-05	1.04	0.000106
2046	11	0.079138	0	0.154202	6.17E-05	1.04	0.000106
2047	11	0.079138	0	0.154202	6.17E-05	1.04	0.000106
2048	11	0.079138	0	0.154202	6.17E-05	1.04	0.000106
2049	11	0.079138	0	0.154202	6.17E-05	1.04	0.000106
2050	11	0.079138	0	0.154202	6.17E-05	1.04	0.000106

Model Year	Horsepower Bin	PMzh (g/bhp-hr)	PMdr (g/bhp-hr^2)	THCzh (g/bhp-hr)	THCdr (g/bhp-hr^2)	COzh (g/bhp-hr)	COdr (g/bhp-hr^2)
2017	25	0.19586	0	0.238727	9.55E-05	1.836181	0.000186
2018	25	0.168437	0	0.260553	0.000104	1.448555	0.000147
2019	25	0.186084	0	0.220358	8.81E-05	1.90113	0.000193
2020	25	0.152635	0	0.361431	0.000145	1.465767	0.000149
2021	25	0.171429	0	0.646775	0.000259	1.904213	0.000193
2022	25	0.139601	0	0.501707	0.000201	1.603194	0.000163
2023	25	0.10191	0	0.336435	0.000135	1.328628	0.000135
2024	25	0.133004	0	0.152	6.08E-05	1.520047	0.000154
2025	25	0.133004	0	0.152	6.08E-05	1.520047	0.000154
2026	25	0.133004	0	0.152	6.08E-05	1.520047	0.000154
2027	25	0.133004	0	0.152	6.08E-05	1.520047	0.000154
2028	25	0.133004	0	0.152	6.08E-05	1.520047	0.000154
2029	25	0.133004	0	0.152	6.08E-05	1.520047	0.000154
2030	25	0.133004	0	0.152	6.08E-05	1.520047	0.000154
2031	25	0.133004	0	0.152	6.08E-05	1.520047	0.000154
2032	25	0.133004	0	0.152	6.08E-05	1.520047	0.000154
2033	25	0.133004	0	0.152	6.08E-05	1.520047	0.000154
2034	25	0.133004	0	0.152	6.08E-05	1.520047	0.000154
2035	25	0.133004	0	0.152	6.08E-05	1.520047	0.000154
2036	25	0.133004	0	0.152	6.08E-05	1.520047	0.000154
2037	25	0.133004	0	0.152	6.08E-05	1.520047	0.000154
2038	25	0.133004	0	0.152	6.08E-05	1.520047	0.000154
2039	25	0.133004	0	0.152	6.08E-05	1.520047	0.000154
2040	25	0.133004	0	0.152	6.08E-05	1.520047	0.000154
2041	25	0.133004	0	0.152	6.08E-05	1.520047	0.000154
2042	25	0.133004	0	0.152	6.08E-05	1.520047	0.000154
2043	25	0.133004	0	0.152	6.08E-05	1.520047	0.000154
2044	25	0.133004	0	0.152	6.08E-05	1.520047	0.000154
2045	25	0.133004	0	0.152	6.08E-05	1.520047	0.000154
2046	25	0.133004	0	0.152	6.08E-05	1.520047	0.000154
2047	25	0.133004	0	0.152	6.08E-05	1.520047	0.000154
2048	25	0.133004	0	0.152	6.08E-05	1.520047	0.000154
2049	25	0.133004	0	0.152	6.08E-05	1.520047	0.000154
2050	25	0.133004	0	0.152	6.08E-05	1.520047	0.000154
2017	50	0.016998	1.89E-06	0.078515	3.14E-05	0.206572	2.10E-05
2018	50	0.017845	1.98E-06	0.162837	6.51E-05	0.360099	3.65E-05
2019	50	0.016584	1.84E-06	0.081249	3.25E-05	0.30875	3.13E-05
2020	50	0.016859	1.87E-06	0.1214	4.86E-05	0.419947	4.26E-05
2021	50	0.016593	1.84E-06	0.063399	2.54E-05	0.222363	2.26E-05
2022	50	0.01779	1.97E-06	0.02095	8.38E-06	0.086229	8.75E-06

Model Year	Horsepower Bin	PMzh (g/bhp-hr)	PMdr (g/bhp-hr^2)	THCzh (g/bhp-hr)	THCdr (g/bhp-hr^2)	COzh (g/bhp-hr)	COdr (g/bhp-hr^2)
2023	50	0.01763	1.96E-06	0.018886	7.55E-06	0.081435	8.26E-06
2024	50	0.0137	1.52E-06	0.028652	1.15E-05	0.129598	1.32E-05
2025	50	0.0137	1.52E-06	0.028652	1.15E-05	0.129598	1.32E-05
2026	50	0.0137	1.52E-06	0.028652	1.15E-05	0.129598	1.32E-05
2027	50	0.0137	1.52E-06	0.028652	1.15E-05	0.129598	1.32E-05
2028	50	0.0137	1.52E-06	0.028652	1.15E-05	0.129598	1.32E-05
2029	50	0.0137	1.52E-06	0.028652	1.15E-05	0.129598	1.32E-05
2030	50	0.0137	1.52E-06	0.028652	1.15E-05	0.129598	1.32E-05
2031	50	0.0137	1.52E-06	0.028652	1.15E-05	0.129598	1.32E-05
2032	50	0.0137	1.52E-06	0.028652	1.15E-05	0.129598	1.32E-05
2033	50	0.0137	1.52E-06	0.028652	1.15E-05	0.129598	1.32E-05
2034	50	0.0137	1.52E-06	0.028652	1.15E-05	0.129598	1.32E-05
2035	50	0.0137	1.52E-06	0.028652	1.15E-05	0.129598	1.32E-05
2036	50	0.0137	1.52E-06	0.028652	1.15E-05	0.129598	1.32E-05
2037	50	0.0137	1.52E-06	0.028652	1.15E-05	0.129598	1.32E-05
2038	50	0.0137	1.52E-06	0.028652	1.15E-05	0.129598	1.32E-05
2039	50	0.0137	1.52E-06	0.028652	1.15E-05	0.129598	1.32E-05
2040	50	0.0137	1.52E-06	0.028652	1.15E-05	0.129598	1.32E-05
2041	50	0.0137	1.52E-06	0.028652	1.15E-05	0.129598	1.32E-05
2042	50	0.0137	1.52E-06	0.028652	1.15E-05	0.129598	1.32E-05
2043	50	0.0137	1.52E-06	0.028652	1.15E-05	0.129598	1.32E-05
2044	50	0.0137	1.52E-06	0.028652	1.15E-05	0.129598	1.32E-05
2045	50	0.0137	1.52E-06	0.028652	1.15E-05	0.129598	1.32E-05
2046	50	0.0137	1.52E-06	0.028652	1.15E-05	0.129598	1.32E-05
2047	50	0.0137	1.52E-06	0.028652	1.15E-05	0.129598	1.32E-05
2048	50	0.0137	1.52E-06	0.028652	1.15E-05	0.129598	1.32E-05
2049	50	0.0137	1.52E-06	0.028652	1.15E-05	0.129598	1.32E-05
2050	50	0.0137	1.52E-06	0.028652	1.15E-05	0.129598	1.32E-05
2017	75	0.013477	1.26E-06	0.059592	1.49E-05	0.387546	1.03E-05
2018	75	0.013566	1.27E-06	0.055344	1.38E-05	0.362276	9.62E-06
2019	75	0.013393	1.25E-06	0.036961	9.24E-06	0.329075	8.74E-06
2020	75	0.015895	1.48E-06	0.073526	1.84E-05	0.363529	9.65E-06
2021	75	0.013045	1.22E-06	0.022525	5.63E-06	0.201791	5.36E-06
2022	75	0.024458	2.28E-06	0.037161	9.29E-06	0.162788	4.32E-06
2023	75	0.024656	2.30E-06	0.042911	1.07E-05	0.193164	5.13E-06
2024	75	0.011	1.03E-06	0.040568	1.01E-05	0.231392	6.15E-06
2025	75	0.011	1.03E-06	0.040568	1.01E-05	0.231392	6.15E-06
2026	75	0.011	1.03E-06	0.040568	1.01E-05	0.231392	6.15E-06
2027	75	0.011	1.03E-06	0.040568	1.01E-05	0.231392	6.15E-06
2028	75	0.011	1.03E-06	0.040568	1.01E-05	0.231392	6.15E-06

Model Year	Horsepower Bin	PMzh (g/bhp-hr)	PMdr (g/bhp-hr^2)	THCzh (g/bhp-hr)	THCdr (g/bhp-hr^2)	COzh (g/bhp-hr)	COdr (g/bhp-hr^2)
2029	75	0.011	1.03E-06	0.040568	1.01E-05	0.231392	6.15E-06
2030	75	0.011	1.03E-06	0.040568	1.01E-05	0.231392	6.15E-06
2031	75	0.011	1.03E-06	0.040568	1.01E-05	0.231392	6.15E-06
2032	75	0.011	1.03E-06	0.040568	1.01E-05	0.231392	6.15E-06
2033	75	0.011	1.03E-06	0.040568	1.01E-05	0.231392	6.15E-06
2034	75	0.011	1.03E-06	0.040568	1.01E-05	0.231392	6.15E-06
2035	75	0.011	1.03E-06	0.040568	1.01E-05	0.231392	6.15E-06
2036	75	0.011	1.03E-06	0.040568	1.01E-05	0.231392	6.15E-06
2037	75	0.011	1.03E-06	0.040568	1.01E-05	0.231392	6.15E-06
2038	75	0.011	1.03E-06	0.040568	1.01E-05	0.231392	6.15E-06
2039	75	0.011	1.03E-06	0.040568	1.01E-05	0.231392	6.15E-06
2040	75	0.011	1.03E-06	0.040568	1.01E-05	0.231392	6.15E-06
2041	75	0.011	1.03E-06	0.040568	1.01E-05	0.231392	6.15E-06
2042	75	0.011	1.03E-06	0.040568	1.01E-05	0.231392	6.15E-06
2043	75	0.011	1.03E-06	0.040568	1.01E-05	0.231392	6.15E-06
2044	75	0.011	1.03E-06	0.040568	1.01E-05	0.231392	6.15E-06
2045	75	0.011	1.03E-06	0.040568	1.01E-05	0.231392	6.15E-06
2046	75	0.011	1.03E-06	0.040568	1.01E-05	0.231392	6.15E-06
2047	75	0.011	1.03E-06	0.040568	1.01E-05	0.231392	6.15E-06
2048	75	0.011	1.03E-06	0.040568	1.01E-05	0.231392	6.15E-06
2049	75	0.011	1.03E-06	0.040568	1.01E-05	0.231392	6.15E-06
2050	75	0.011	1.03E-06	0.040568	1.01E-05	0.231392	6.15E-06
2017	100	0.010782	5.04E-07	0.017092	4.00E-06	0.262908	6.98E-06
2018	100	0.012024	5.61E-07	0.013813	3.23E-06	0.101824	2.70E-06
2019	100	0.013229	6.17E-07	0.024529	5.74E-06	0.150474	4.00E-06
2020	100	0.01198	5.59E-07	0.017705	4.14E-06	0.105507	2.80E-06
2021	100	0.007457	3.48E-07	0.01724	4.03E-06	0.07457	1.98E-06
2022	100	0.00991	4.63E-07	0.015463	3.62E-06	0.117543	3.12E-06
2023	100	0.008646	4.04E-07	0.011599	2.71E-06	0.111351	2.96E-06
2024	100	0.010031	4.69E-07	0.015276	3.57E-06	0.118653	3.15E-06
2025	100	0.010031	4.68E-07	0.015276	3.57E-06	0.118653	3.15E-06
2026	100	0.010031	4.68E-07	0.015276	3.57E-06	0.118653	3.15E-06
2027	100	0.010031	4.68E-07	0.015276	3.57E-06	0.118653	3.15E-06
2028	100	0.010031	4.70E-07	0.015276	3.57E-06	0.118653	3.15E-06
2029	100	0.010031	4.68E-07	0.015276	3.57E-06	0.118653	3.15E-06
2030	100	0.010031	4.68E-07	0.015276	3.57E-06	0.118653	3.15E-06
2031	100	0.010031	4.68E-07	0.015276	3.57E-06	0.118653	3.15E-06
2032	100	0.010031	4.68E-07	0.015276	3.57E-06	0.118653	3.15E-06
2033	100	0.010031	4.68E-07	0.015276	3.57E-06	0.118653	3.15E-06
2034	100	0.010031	4.68E-07	0.015276	3.57E-06	0.118653	3.15E-06

Model Year	Horsepower Bin	PMzh (g/bhp-hr)	PMdr (g/bhp-hr²)	THCzh (g/bhp-hr)	THCdr (g/bhp-hr²)	COzh (g/bhp-hr)	COdr (g/bhp-hr²)
2035	100	0.010031	4.68E-07	0.015276	3.57E-06	0.118653	3.15E-06
2036	100	0.010031	4.68E-07	0.015276	3.57E-06	0.118653	3.15E-06
2037	100	0.010031	4.68E-07	0.015276	3.57E-06	0.118653	3.15E-06
2038	100	0.010031	4.68E-07	0.015276	3.57E-06	0.118653	3.15E-06
2039	100	0.010031	4.68E-07	0.015276	3.57E-06	0.118653	3.15E-06
2040	100	0.010031	4.68E-07	0.015276	3.57E-06	0.118653	3.15E-06
2041	100	0.010031	4.68E-07	0.015276	3.57E-06	0.118653	3.15E-06
2042	100	0.010031	4.68E-07	0.015276	3.57E-06	0.118653	3.15E-06
2043	100	0.010031	4.68E-07	0.015276	3.57E-06	0.118653	3.15E-06
2044	100	0.010031	4.68E-07	0.015276	3.57E-06	0.118653	3.15E-06
2045	100	0.010031	4.68E-07	0.015276	3.57E-06	0.118653	3.15E-06
2046	100	0.010031	4.68E-07	0.015276	3.57E-06	0.118653	3.15E-06
2047	100	0.010031	4.68E-07	0.015276	3.57E-06	0.118653	3.15E-06
2048	100	0.010031	4.68E-07	0.015276	3.57E-06	0.118653	3.15E-06
2049	100	0.010031	4.68E-07	0.015276	3.57E-06	0.118653	3.15E-06
2050	100	0.010031	4.68E-07	0.015276	3.57E-06	0.118653	3.15E-06
2017	175	0.010311	4.80E-07	0.015516	3.63E-06	0.193133	5.11E-06
2018	175	0.010747	5.02E-07	0.013684	3.20E-06	0.100962	2.67E-06
2019	175	0.011256	5.26E-07	0.017855	4.18E-06	0.140629	3.72E-06
2020	175	0.010699	5.00E-07	0.016787	3.93E-06	0.125015	3.31E-06
2021	175	0.007457	3.49E-07	0.017753	4.15E-06	0.07457	1.97E-06
2022	175	0.009701	4.53E-07	0.014884	3.48E-06	0.118417	3.13E-06
2023	175	0.008781	4.10E-07	0.012552	2.94E-06	0.112147	2.97E-06
2024	175	0.0096	4.49E-07	0.015125	3.54E-06	0.121332	3.21E-06
2025	175	0.0096	4.49E-07	0.015125	3.54E-06	0.121332	3.21E-06
2026	175	0.0096	4.49E-07	0.015125	3.54E-06	0.121332	3.21E-06
2027	175	0.0096	4.49E-07	0.015125	3.54E-06	0.121332	3.21E-06
2028	175	0.0096	4.49E-07	0.015125	3.54E-06	0.121332	3.21E-06
2029	175	0.0096	4.49E-07	0.015125	3.54E-06	0.121332	3.21E-06
2030	175	0.0096	4.49E-07	0.015125	3.54E-06	0.121332	3.21E-06
2031	175	0.0096	4.49E-07	0.015125	3.54E-06	0.121332	3.21E-06
2032	175	0.0096	4.49E-07	0.015125	3.54E-06	0.121332	3.21E-06
2033	175	0.0096	4.49E-07	0.015125	3.54E-06	0.121332	3.21E-06
2034	175	0.0096	4.49E-07	0.015125	3.54E-06	0.121332	3.21E-06
2035	175	0.0096	4.49E-07	0.015125	3.54E-06	0.121332	3.21E-06
2036	175	0.0096	4.49E-07	0.015125	3.54E-06	0.121332	3.21E-06
2037	175	0.0096	4.49E-07	0.015125	3.54E-06	0.121332	3.21E-06
2038	175	0.0096	4.49E-07	0.015125	3.54E-06	0.121332	3.21E-06
2039	175	0.0096	4.49E-07	0.015125	3.54E-06	0.121332	3.21E-06
2040	175	0.0096	4.49E-07	0.015125	3.54E-06	0.121332	3.21E-06

Model Year	Horsepower Bin	PMzh (g/bhp-hr)	PMdr (g/bhp-hr^2)	THCzh (g/bhp-hr)	THCdr (g/bhp-hr^2)	COzh (g/bhp-hr)	COdr (g/bhp-hr^2)
2041	175	0.0096	4.49E-07	0.015125	3.54E-06	0.121332	3.21E-06
2042	175	0.0096	4.49E-07	0.015125	3.54E-06	0.121332	3.21E-06
2043	175	0.0096	4.49E-07	0.015125	3.54E-06	0.121332	3.21E-06
2044	175	0.0096	4.49E-07	0.015125	3.54E-06	0.121332	3.21E-06
2045	175	0.0096	4.49E-07	0.015125	3.54E-06	0.121332	3.21E-06
2046	175	0.0096	4.49E-07	0.015125	3.54E-06	0.121332	3.21E-06
2047	175	0.0096	4.49E-07	0.015125	3.54E-06	0.121332	3.21E-06
2048	175	0.0096	4.49E-07	0.015125	3.54E-06	0.121332	3.21E-06
2049	175	0.0096	4.49E-07	0.015125	3.54E-06	0.121332	3.21E-06
2050	175	0.0096	4.49E-07	0.015125	3.54E-06	0.121332	3.21E-06
2017	300	0.008866	3.28E-07	0.018345	4.29E-06	0.079366	2.10E-06
2018	300	0.008464	3.13E-07	0.014074	3.29E-06	0.074603	1.97E-06
2019	300	0.008652	3.20E-07	0.008911	2.09E-06	0.074584	1.97E-06
2020	300	0.008989	3.33E-07	0.016809	3.93E-06	0.108304	2.86E-06
2021	300	0.007564	2.80E-07	0.019718	4.61E-06	0.07457	1.97E-06
2022	300	0.008031	2.97E-07	0.015417	3.61E-06	0.076404	2.02E-06
2023	300	0.00829	3.07E-07	0.017943	4.20E-06	0.083318	2.20E-06
2024	300	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	2.21E-06
2025	300	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	2.21E-06
2026	300	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	2.21E-06
2027	300	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	2.21E-06
2028	300	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	2.21E-06
2029	300	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	2.21E-06
2030	300	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	2.21E-06
2031	300	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	2.21E-06
2032	300	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	2.21E-06
2033	300	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	2.21E-06
2034	300	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	2.21E-06
2035	300	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	2.21E-06
2036	300	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	2.21E-06
2037	300	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	2.21E-06
2038	300	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	2.21E-06
2039	300	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	2.21E-06
2040	300	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	2.21E-06
2041	300	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	2.21E-06
2042	300	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	2.21E-06
2043	300	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	2.21E-06
2044	300	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	2.21E-06
2045	300	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	2.21E-06
2046	300	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	2.21E-06

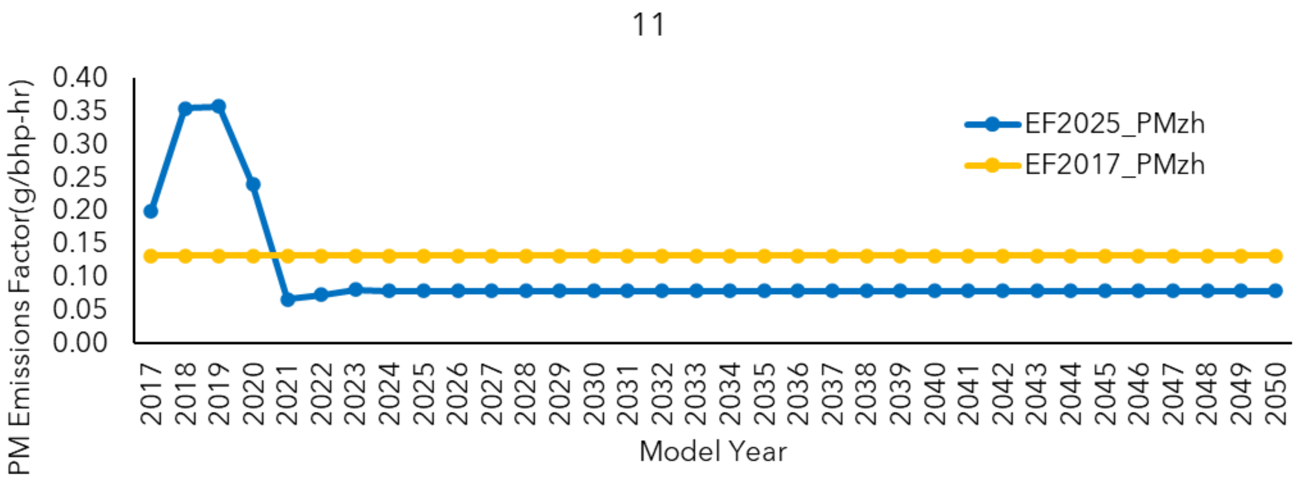
Model Year	Horsepower Bin	PMzh (g/bhp-hr)	PMdr (g/bhp-hr^2)	THCzh (g/bhp-hr)	THCdr (g/bhp-hr^2)	COzh (g/bhp-hr)	COdr (g/bhp-hr^2)
2047	300	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	2.21E-06
2048	300	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	2.21E-06
2049	300	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	2.21E-06
2050	300	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	2.21E-06
2017	600	0.008866	3.28E-07	0.018345	4.29E-06	0.079366	1.57E-06
2018	600	0.008464	3.13E-07	0.014074	3.29E-06	0.074603	1.48E-06
2019	600	0.008652	3.20E-07	0.008911	2.09E-06	0.074584	1.48E-06
2020	600	0.008989	3.33E-07	0.016809	3.93E-06	0.108304	2.14E-06
2021	600	0.007564	2.80E-07	0.019718	4.61E-06	0.07457	1.48E-06
2022	600	0.008031	2.97E-07	0.015417	3.61E-06	0.076404	1.51E-06
2023	600	0.00829	3.07E-07	0.017943	4.20E-06	0.083318	1.65E-06
2024	600	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	1.66E-06
2025	600	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	1.66E-06
2026	600	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	1.66E-06
2027	600	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	1.66E-06
2028	600	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	1.66E-06
2029	600	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	1.66E-06
2030	600	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	1.66E-06
2031	600	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	1.66E-06
2032	600	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	1.66E-06
2033	600	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	1.66E-06
2034	600	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	1.66E-06
2035	600	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	1.66E-06
2036	600	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	1.66E-06
2037	600	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	1.66E-06
2038	600	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	1.66E-06
2039	600	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	1.66E-06
2040	600	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	1.66E-06
2041	600	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	1.66E-06
2042	600	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	1.66E-06
2043	600	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	1.66E-06
2044	600	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	1.66E-06
2045	600	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	1.66E-06
2046	600	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	1.66E-06
2047	600	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	1.66E-06
2048	600	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	1.66E-06
2049	600	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	1.66E-06
2050	600	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	1.66E-06
2017	750	0.008866	3.27E-07	0.018345	4.29E-06	0.079366	1.57E-06
2018	750	0.008464	3.14E-07	0.014074	3.29E-06	0.074603	1.48E-06

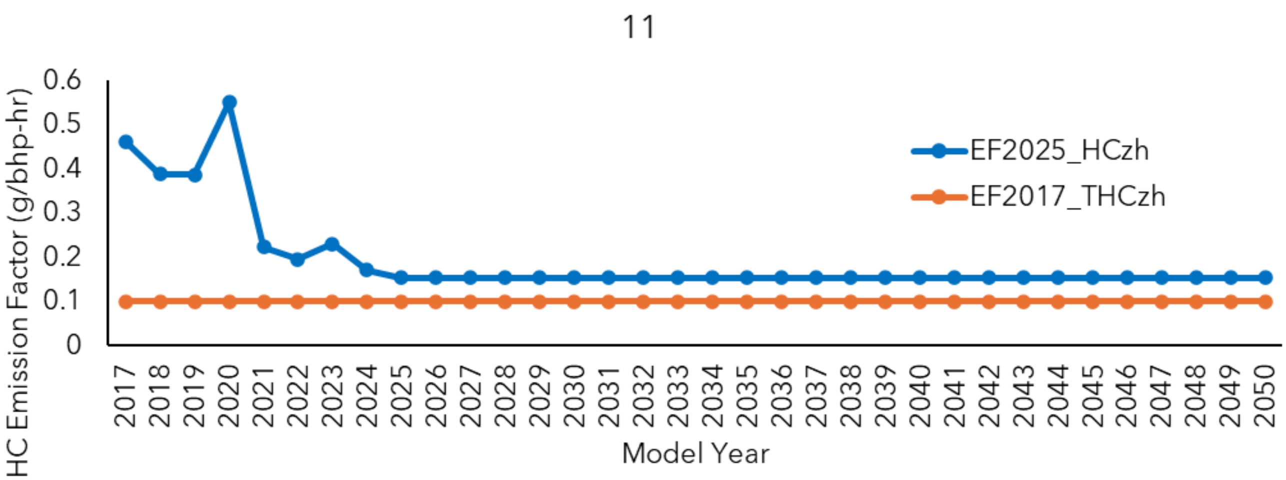
Model Year	Horsepower Bin	PMzh (g/bhp-hr)	PMdr (g/bhp-hr^2)	THCzh (g/bhp-hr)	THCdr (g/bhp-hr^2)	COzh (g/bhp-hr)	COdr (g/bhp-hr^2)
2019	750	0.008652	3.20E-07	0.008911	2.09E-06	0.074584	1.48E-06
2020	750	0.008989	3.33E-07	0.016809	3.93E-06	0.108304	2.14E-06
2021	750	0.007564	2.80E-07	0.019718	4.61E-06	0.07457	1.48E-06
2022	750	0.008031	2.97E-07	0.015417	3.61E-06	0.076404	1.51E-06
2023	750	0.00829	3.07E-07	0.017943	4.20E-06	0.083318	1.65E-06
2024	750	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	1.66E-06
2025	750	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	1.66E-06
2026	750	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	1.66E-06
2027	750	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	1.66E-06
2028	750	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	1.66E-06
2029	750	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	1.66E-06
2030	750	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	1.66E-06
2031	750	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	1.66E-06
2032	750	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	1.66E-06
2033	750	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	1.66E-06
2034	750	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	1.66E-06
2035	750	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	1.66E-06
2036	750	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	1.66E-06
2037	750	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	1.66E-06
2038	750	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	1.66E-06
2039	750	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	1.66E-06
2040	750	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	1.66E-06
2041	750	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	1.66E-06
2042	750	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	1.66E-06
2043	750	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	1.66E-06
2044	750	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	1.66E-06
2045	750	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	1.66E-06
2046	750	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	1.66E-06
2047	750	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	1.66E-06
2048	750	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	1.66E-06
2049	750	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	1.66E-06
2050	750	0.008541	3.16E-07	0.0154	3.60E-06	0.0838	1.66E-06
2017	9999	0.019253	1.07E-06	0.027461	6.43E-06	0.162309	3.21E-06
2018	9999	0.019109	1.06E-06	0.034447	8.06E-06	0.137479	2.72E-06
2019	9999	0.023559	1.31E-06	0.031327	7.33E-06	0.125205	2.48E-06
2020	9999	0.017763	9.89E-07	0.029413	6.88E-06	0.299303	5.92E-06
2021	9999	0.022413	1.25E-06	0.026456	6.19E-06	0.0748	1.48E-06
2022	9999	0.020497	1.14E-06	0.019951	4.67E-06	0.114443	2.26E-06
2023	9999	0.018486	1.03E-06	0.019877	4.65E-06	0.136408	2.70E-06
2024	9999	0.0201	1.12E-06	0.027857	6.52E-06	0.147111	2.91E-06

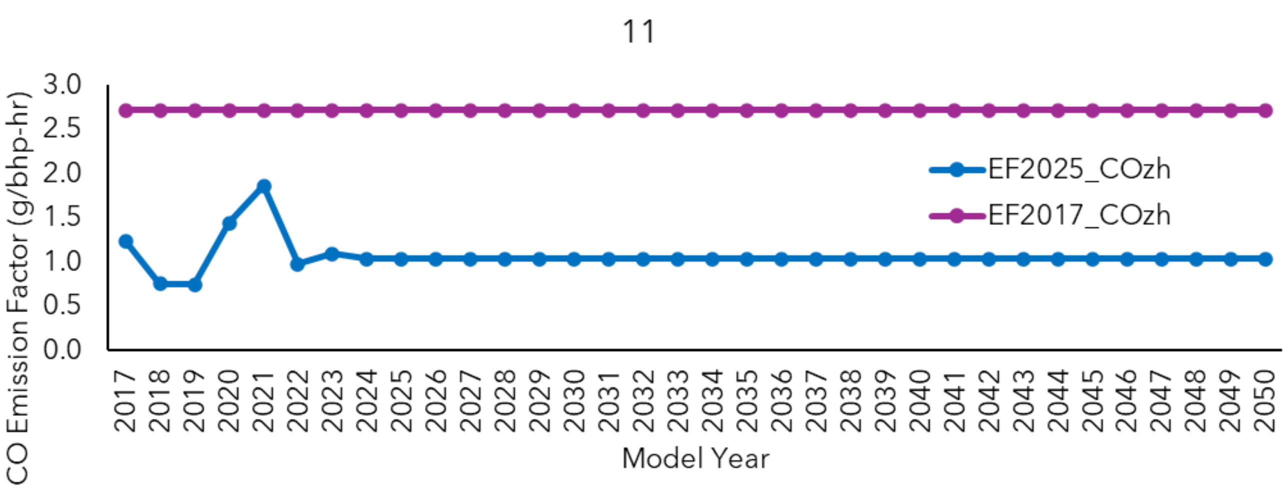
Model Year	Horsepower Bin	PMzh (g/bhp-hr)	PMdr (g/bhp-hr^2)	THCzh (g/bhp-hr)	THCdr (g/bhp-hr^2)	COzh (g/bhp-hr)	COdr (g/bhp-hr^2)
2025	9999	0.02	1.11E-06	0.027857	6.52E-06	0.147111	2.91E-06
2026	9999	0.02	1.11E-06	0.027857	6.52E-06	0.147111	2.91E-06
2027	9999	0.02	1.11E-06	0.027857	6.52E-06	0.147111	2.91E-06
2028	9999	0.02	1.11E-06	0.027857	6.52E-06	0.147111	2.91E-06
2029	9999	0.0199	1.10E-06	0.027857	6.52E-06	0.147111	2.91E-06
2030	9999	0.0199	1.10E-06	0.027857	6.52E-06	0.147111	2.91E-06
2031	9999	0.0199	1.10E-06	0.027857	6.52E-06	0.147111	2.91E-06
2032	9999	0.0199	1.10E-06	0.027857	6.52E-06	0.147111	2.91E-06
2033	9999	0.0198	1.10E-06	0.027857	6.52E-06	0.147111	2.91E-06
2034	9999	0.0198	1.10E-06	0.027857	6.52E-06	0.147111	2.91E-06
2035	9999	0.0198	1.10E-06	0.027857	6.52E-06	0.147111	2.91E-06
2036	9999	0.019148	1.06E-06	0.027857	6.52E-06	0.147111	2.91E-06
2037	9999	0.019148	1.06E-06	0.027857	6.52E-06	0.147111	2.91E-06
2038	9999	0.019148	1.06E-06	0.027857	6.52E-06	0.147111	2.91E-06
2039	9999	0.019148	1.06E-06	0.027857	6.52E-06	0.147111	2.91E-06
2040	9999	0.019148	1.06E-06	0.027857	6.52E-06	0.147111	2.91E-06
2041	9999	0.019148	1.06E-06	0.027857	6.52E-06	0.147111	2.91E-06
2042	9999	0.019148	1.06E-06	0.027857	6.52E-06	0.147111	2.91E-06
2043	9999	0.019148	1.06E-06	0.027857	6.52E-06	0.147111	2.91E-06
2044	9999	0.019148	1.06E-06	0.027857	6.52E-06	0.147111	2.91E-06
2045	9999	0.019148	1.06E-06	0.027857	6.52E-06	0.147111	2.91E-06
2046	9999	0.019148	1.06E-06	0.027857	6.52E-06	0.147111	2.91E-06
2047	9999	0.019148	1.06E-06	0.027857	6.52E-06	0.147111	2.91E-06
2048	9999	0.019148	1.06E-06	0.027857	6.52E-06	0.147111	2.91E-06
2049	9999	0.019148	1.06E-06	0.027857	6.52E-06	0.147111	2.91E-06
2050	9999	0.019148	1.06E-06	0.027857	6.52E-06	0.147111	2.91E-06

8 Appendix D: Comparison of PM, HC, and CO Emission Factors

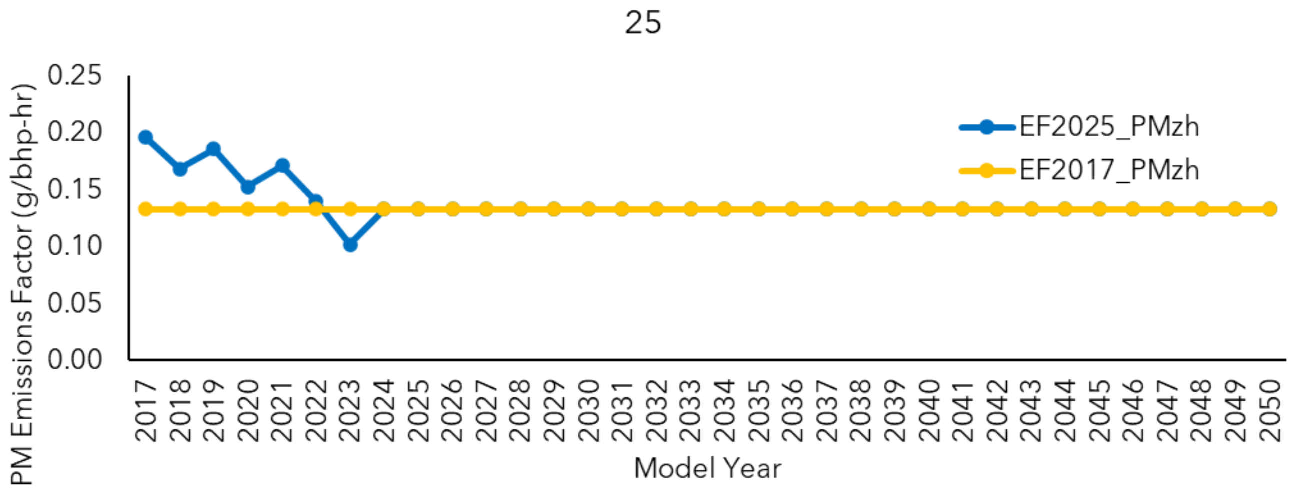
11 Horsepower Bin

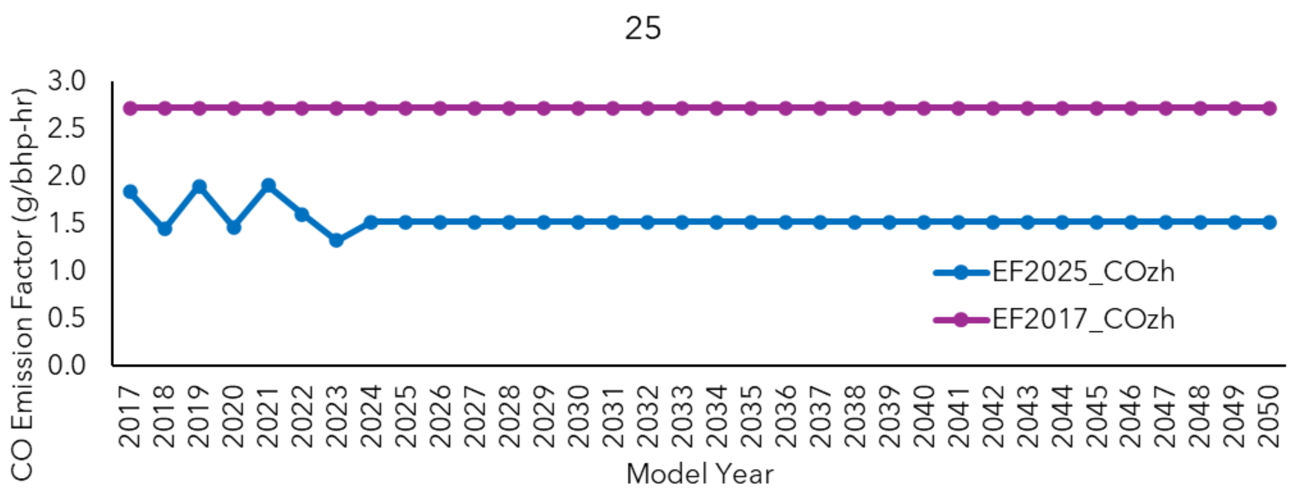


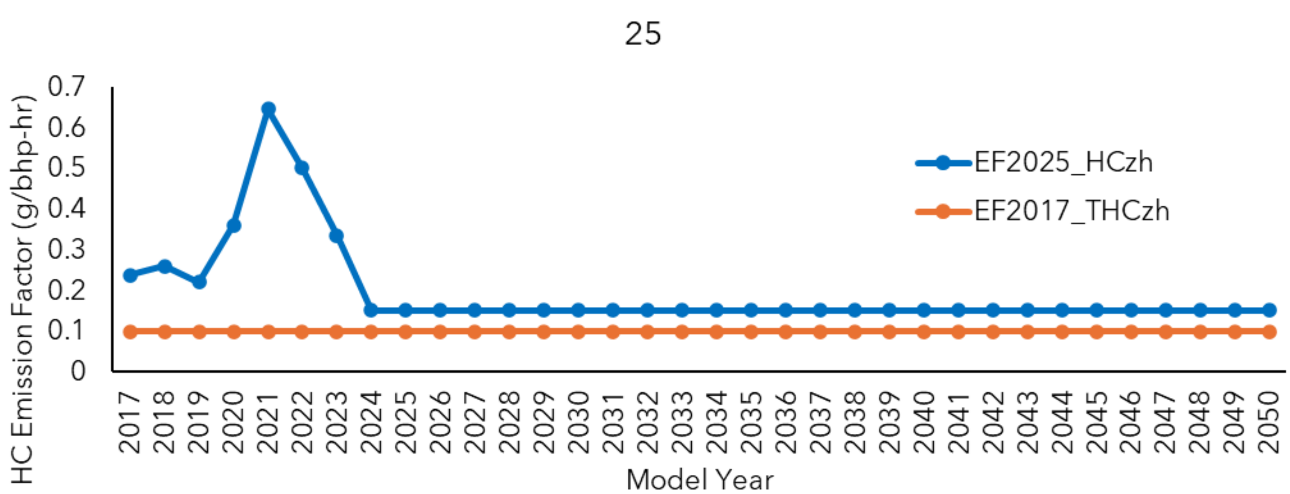




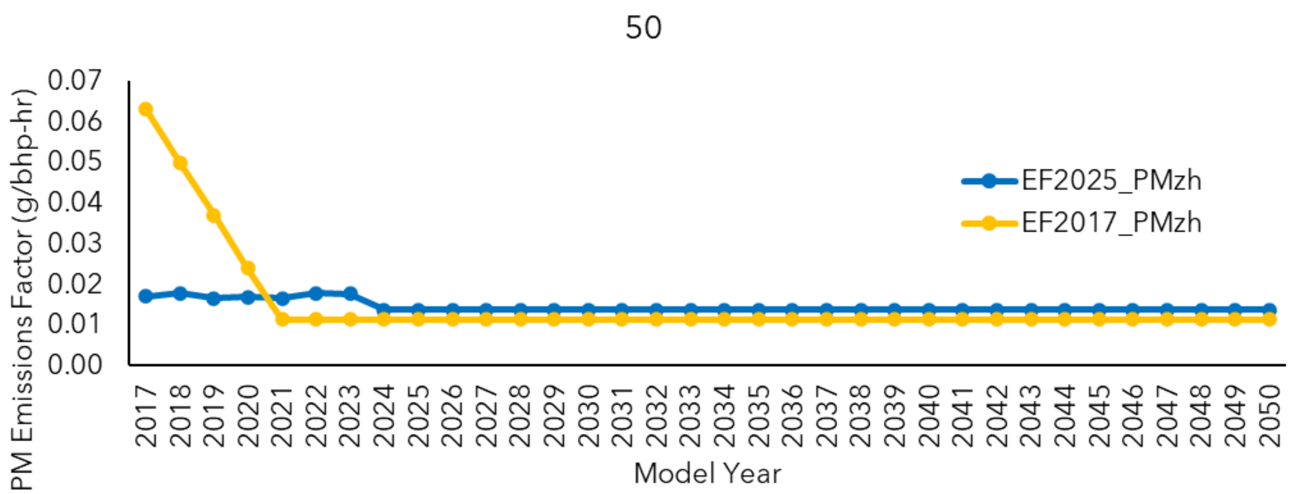
25 Horsepower Bin

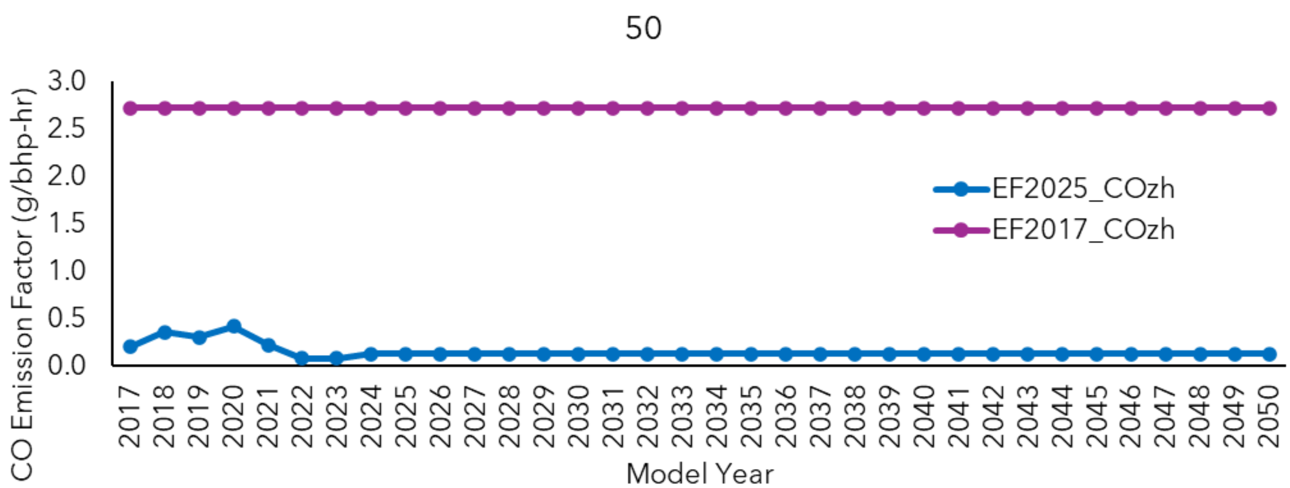


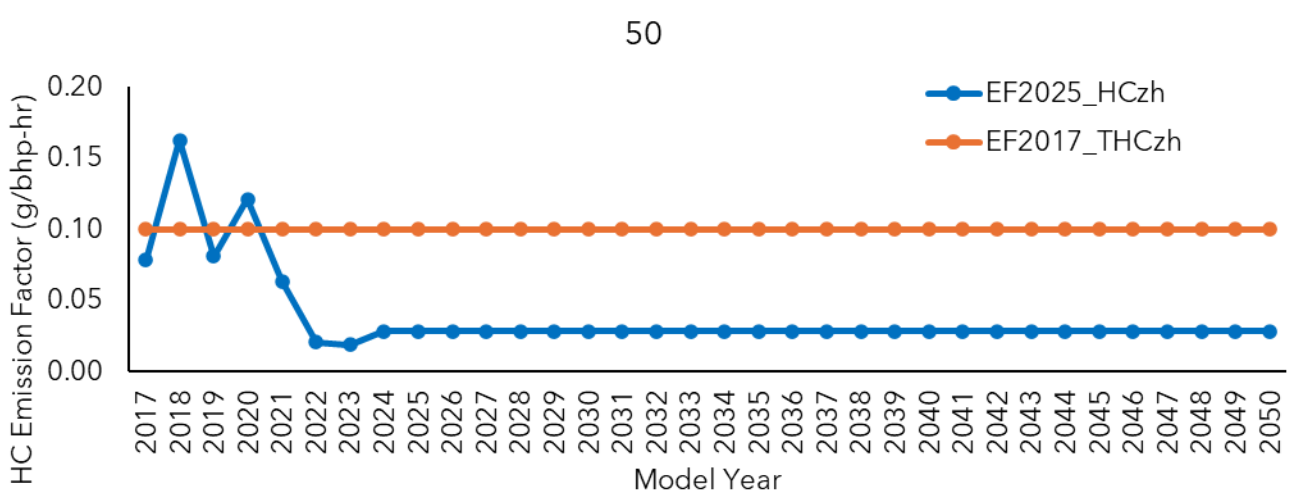




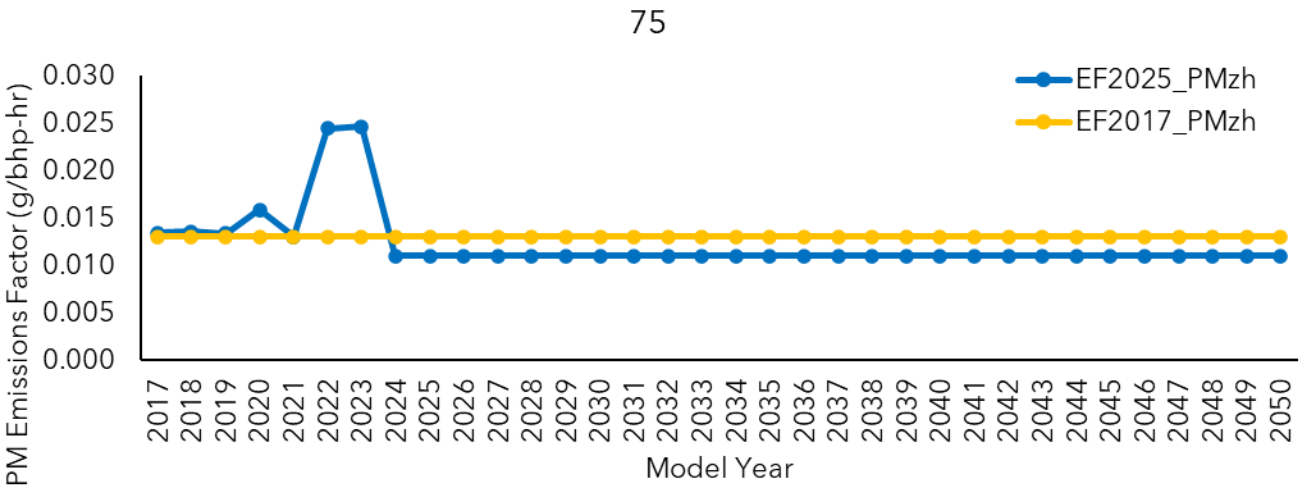
50 Horsepower Bin

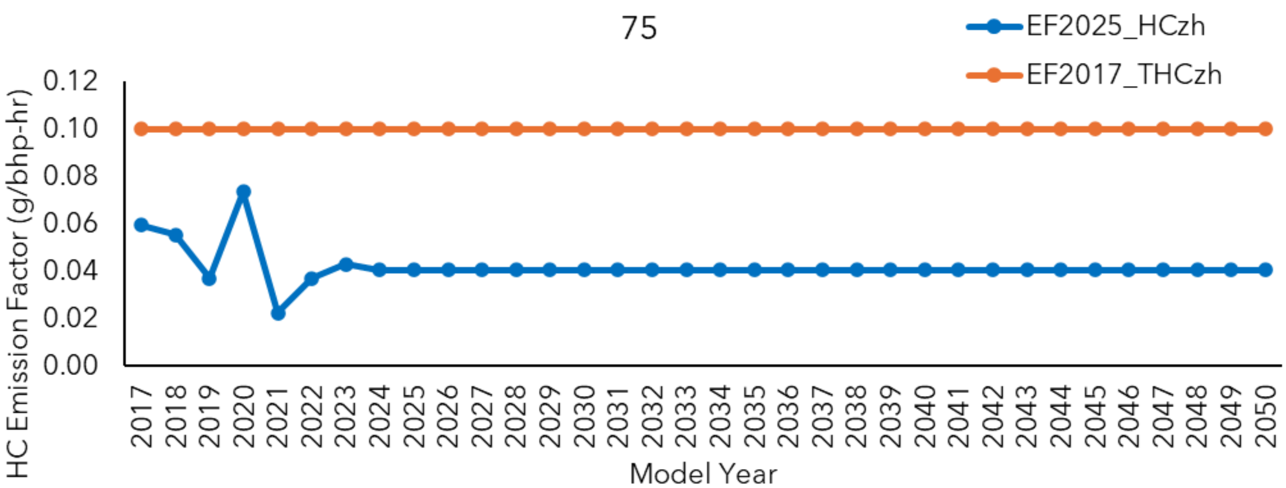


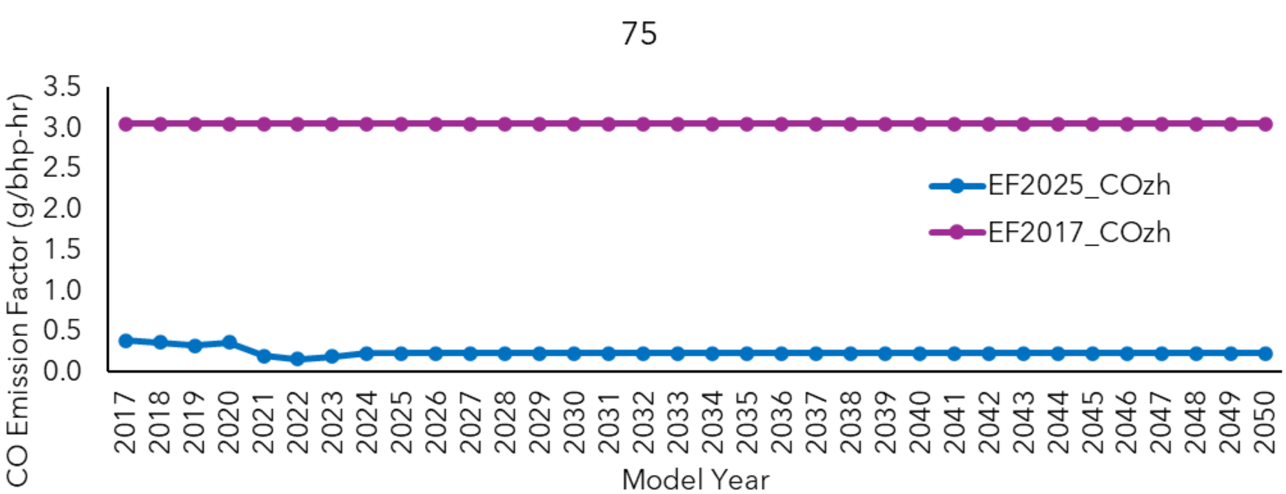




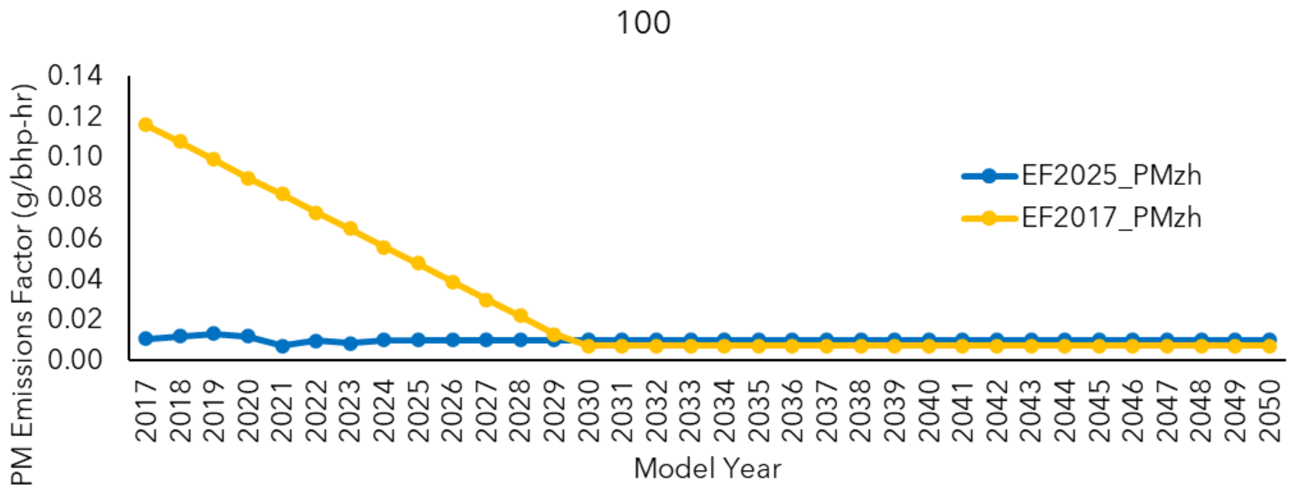
75 Horsepower Bin

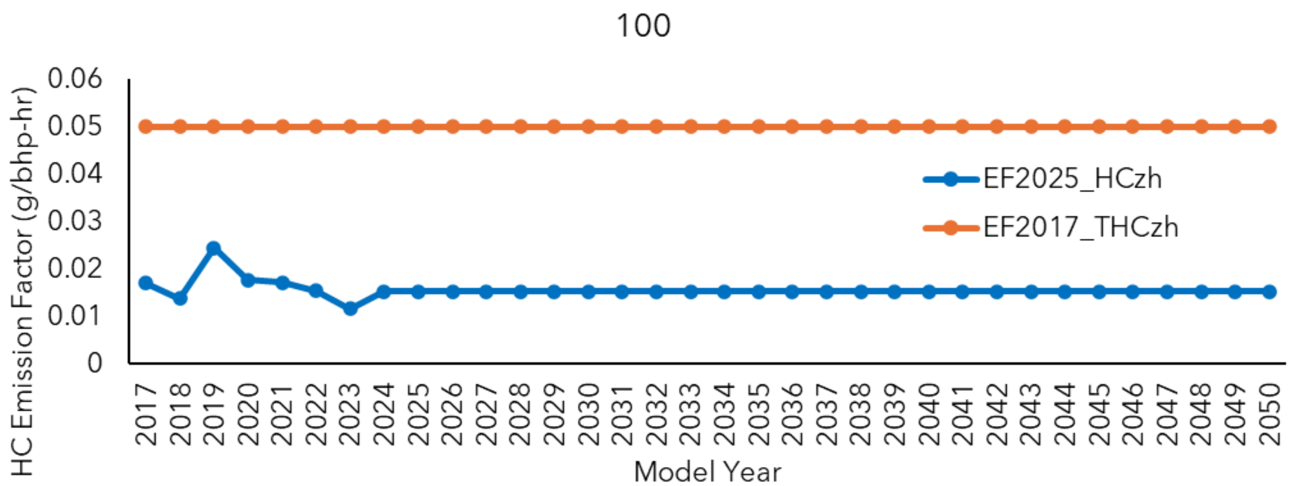


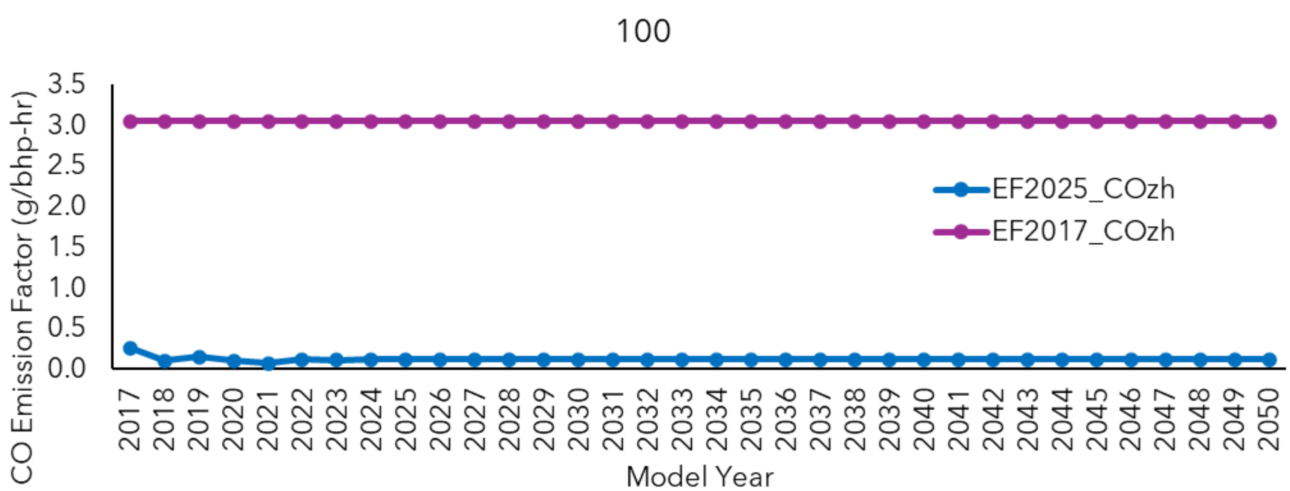




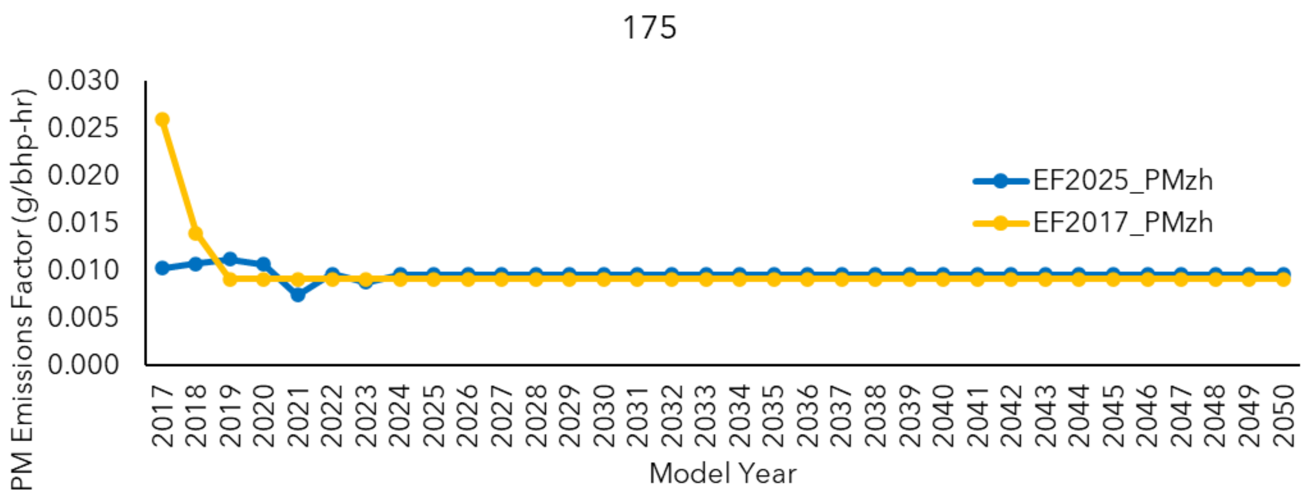
100 Horsepower Bin

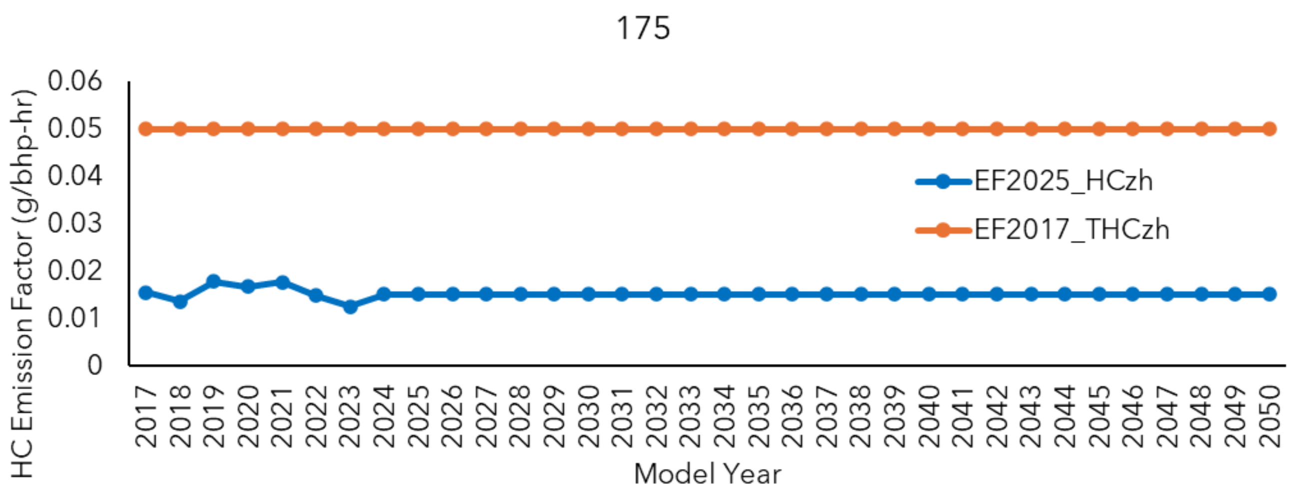


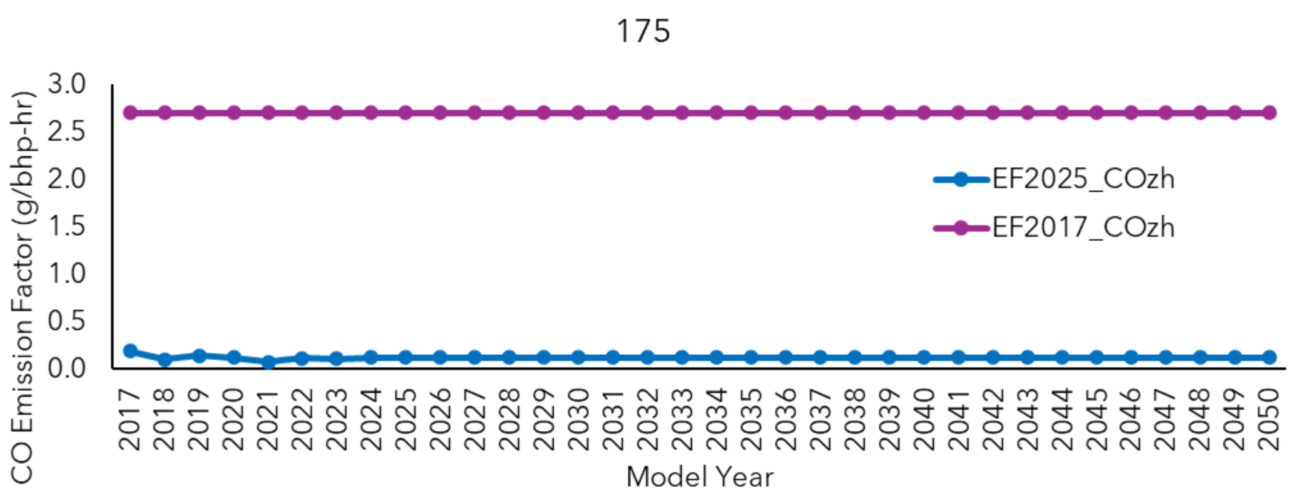




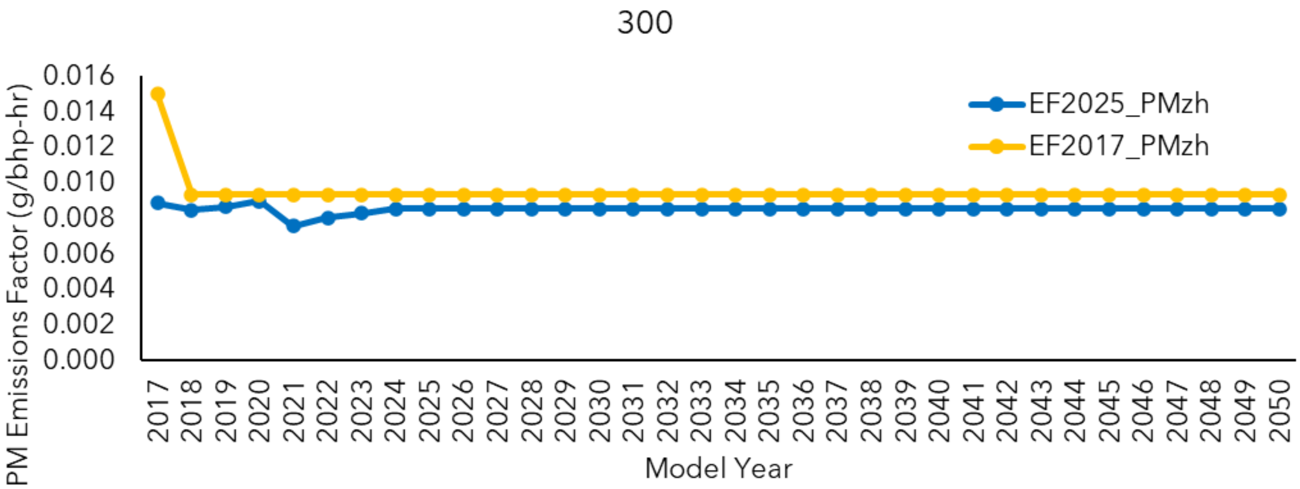
175 Horsepower Bin

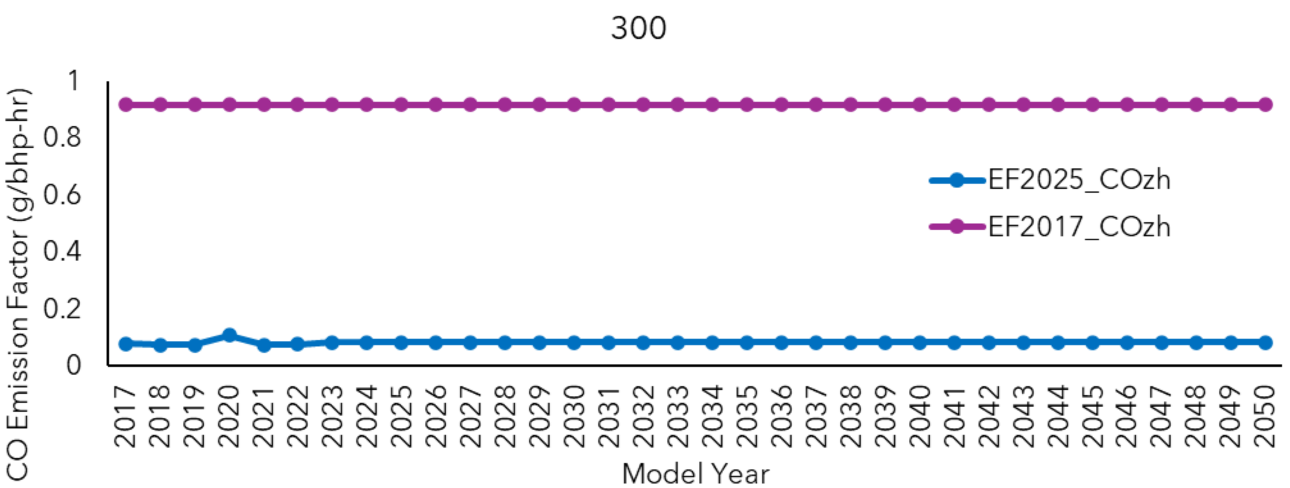


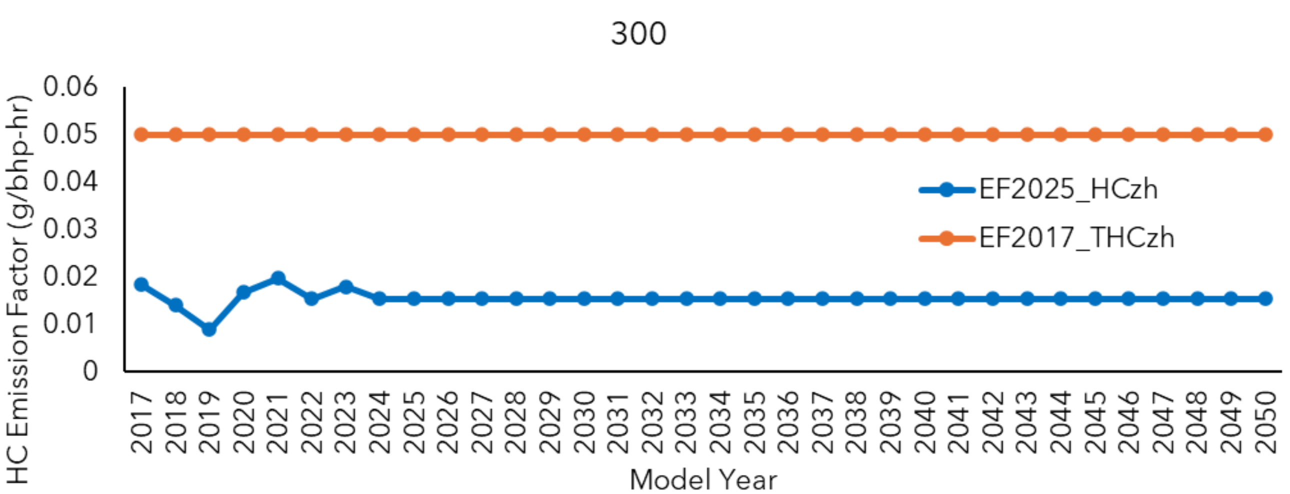




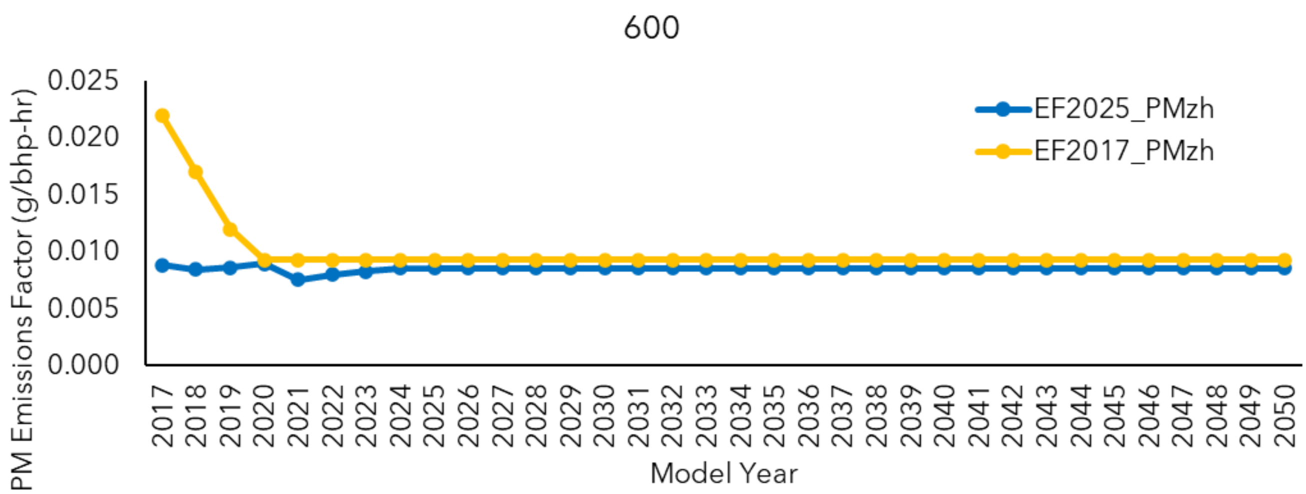
300 Horsepower Bin

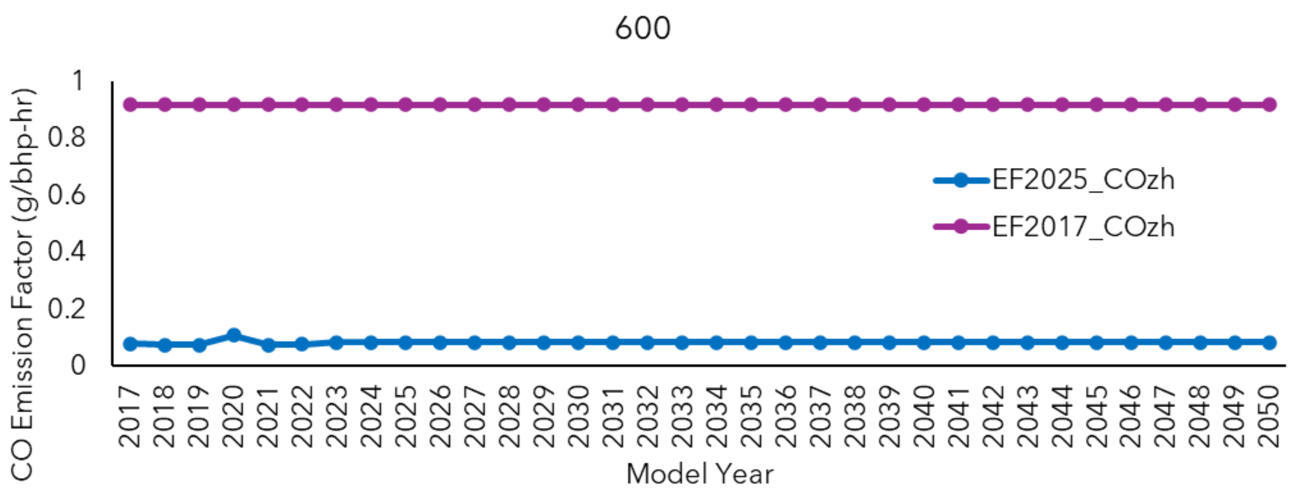


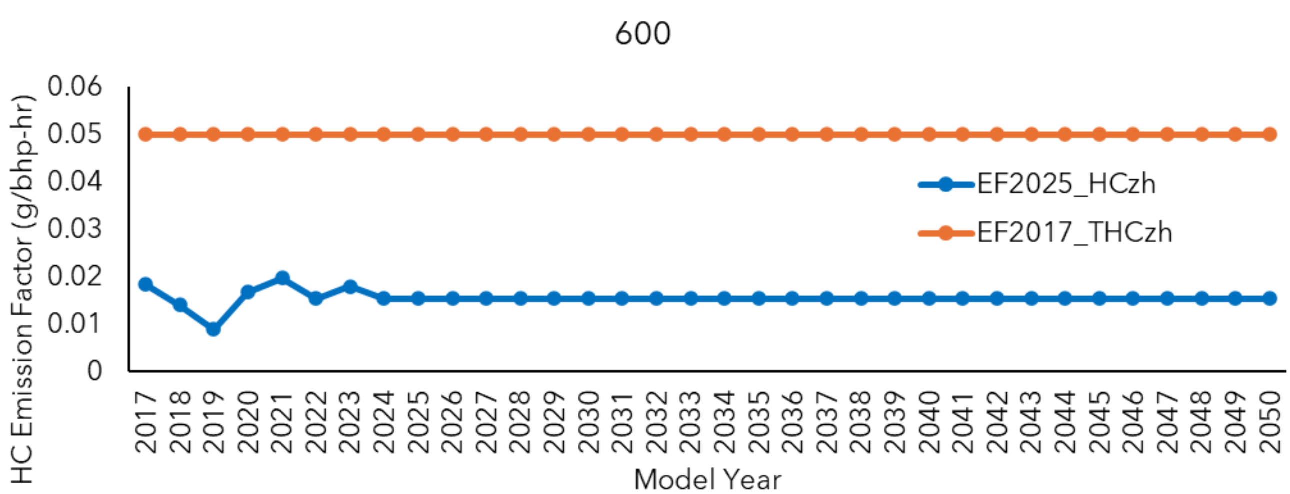




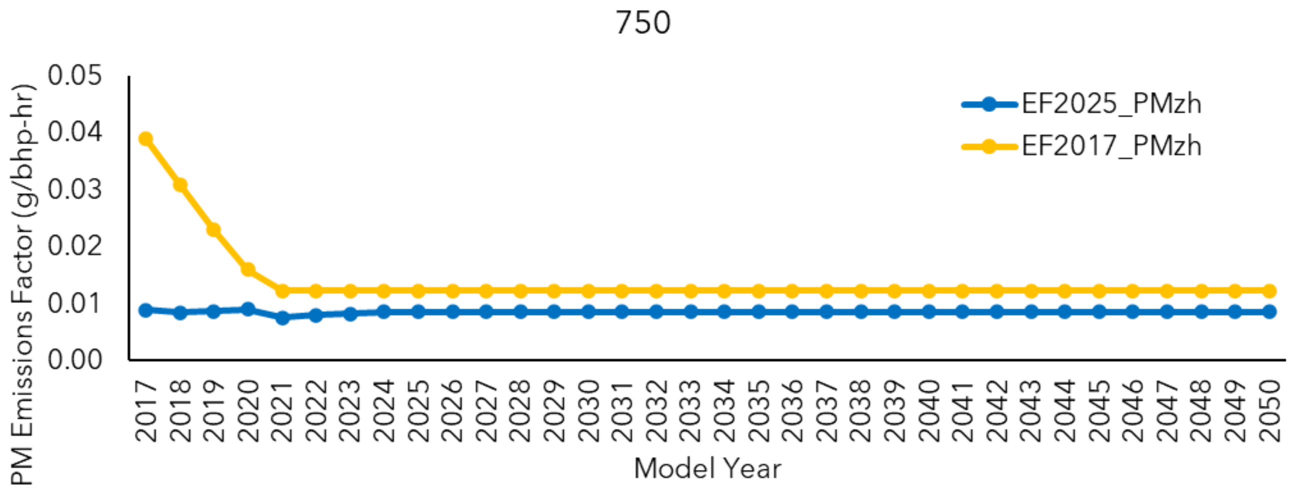
600 Horsepower Bin

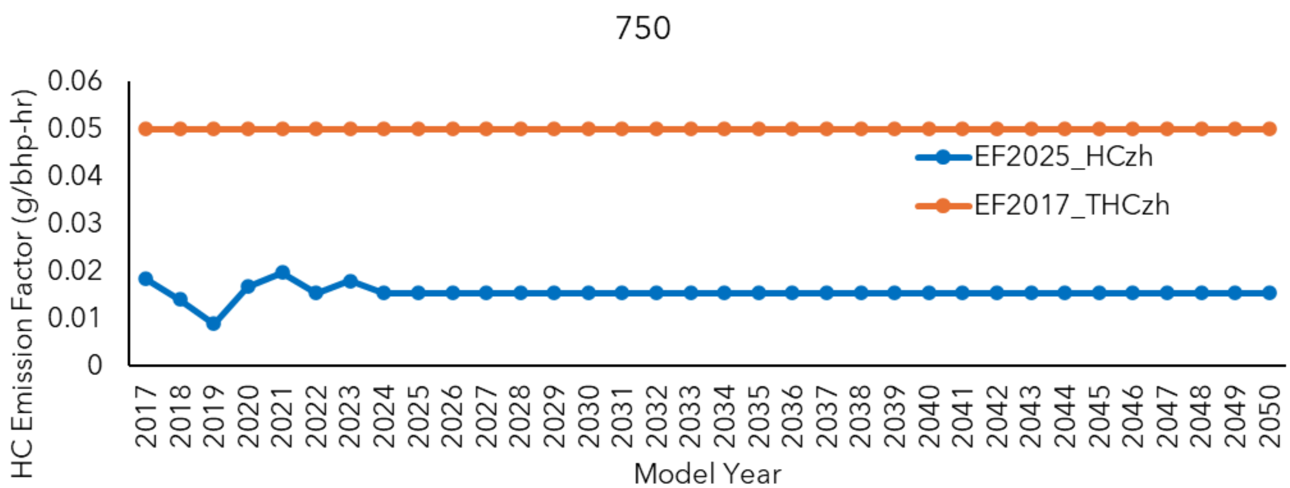


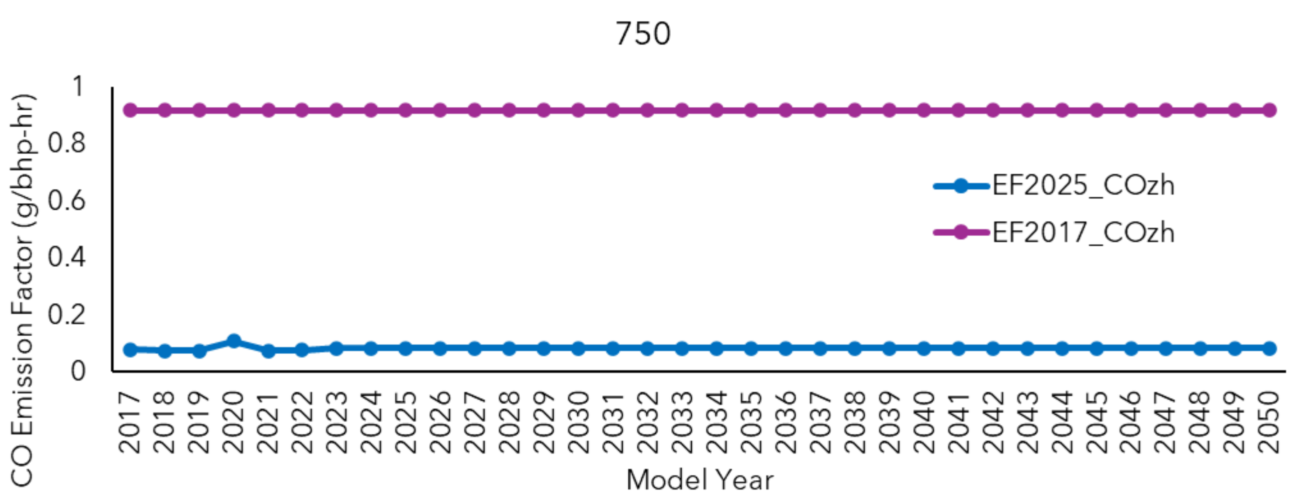




750 Horsepower Bin







9999 Horsepower Bin