# Appendix D

# Emissions Inventory Methods and Results for the Proposed Amendments

Date of Release: June 23, 2020
Date of Hearing: August 27, 2020

APPENDIX D

## LIST OF ACRONYMS AND ABBREVIATIONS USED IN APPENDIX D

| Acronyms and Abbreviations | Description |
|---|---|
| ACT | Advanced Clean Trucks |
| CA | California |
| CARB | California Air Resources Board |
| DDP | Durability Demonstration Program |
| DR | Deterioration Rate |
| ECU | Engine Control Unit |
| EMA | Truck and Engine Manufacturers Association |
| EMFAC | Emission Factors Inventory Model |
| ER | Emission Rate |
| EWIR | Emission Warranty Information Reporting |
| FTP | Federal Test Procedure |
| GHG | Greenhouse Gas |
| GVWR | Gross Vehicle Weight Rating |
| HD | Heavy-Duty |
| HHD | Heavy Heavy-Duty |
| HDIUT | Heavy-Duty In-Use Testing |
| ICT | Innovative Clean Transit |
| LHD | Light Heavy-Duty Diesel |
| LHD2 | Light-Heavy-Duty Trucks |
| LLC | Low Load Cycle |
| MAW | Moving Average Window |
| MHD | Medium Heavy-Duty |
| MY | Model Year |
| NOx | Oxides Of Nitrogen |
| NTE | Not-To-Exceed |
| OBUS | Other Buses |
| PM | Particulate Matter |
| PTO | Power Take-Off |
| SBUS | School Buses |
| SCF | Speed Correction Factor |
| SCR | Selective Catalytic Reduction |
| TBSP | Truck and Bus Surveillance Program |
| UBUS | Urban Buses |
| UDDS | Urban Dynamometer Driving Schedule |
| UL | Useful Life |
| VMT | Vehicle Miles Traveled |
| ZEV | Zero-Emission Vehicle |
| ZMR | Zero Mile Emission Rate |

Date of Release: June 23, 2020
Date of Hearing: August 27, 2020

# APPENDIX D

This appendix provides further details on the emissions inventory methods and results for the Proposed Amendments. The calculations conducted for these analyses are contained in the Heavy-Duty Omnibus Regulation Emission Benefit Files (CARB, 2020c).

## I. OVERVIEW

The proposed Heavy-Duty Omnibus regulation improves public health through reducing Oxides of Nitrogen (NOx) emissions from all new heavy-duty (HD) engines intended for use in vehicles with gross vehicle weight rating (GVWR) greater than10,000 lbs. In particular, there is a need for NOx reductions in South Coast and San Joaquin Valley air basins to meet National Ambient Air Quality Standards for ozone. The Proposed Amendments have different components that ensure heavy-duty engines will emit much lower NOx emissions throughout their lifetimes. The proposed regulation only applies to on-road heavy-duty engines that are first sold in California (hereafter referred to CA-sold).[1] Thus, emissions reductions were only modelled for vehicles originally sold in California (see Section II.A for further details). This regulation includes:

- A tightened standard on the Federal Test Procedure (FTP),
- A new low-load certification cycle (LLC),
- Improvements to the existing heavy-duty in-use testing (HDIUT) program,
- Improvements to the durability demonstration program (DDP),
- Lengthened warranty and useful life (UL) mileages, and
- Amendments to the emission warranty information reporting (EWIR) program and corrective action procedures..

This appendix summarizes methods California Air Resources Board (CARB) staff used to estimate NOx emissions benefits for the Proposed Amendments and presents the results of this analysis. CARB staff used CARB's mobile source emissions inventory model, Emission FACtors (EMFAC) 2017 (CARB, 2019a), which incorporates the latest available information on vehicle emission rates, population and vehicle miles travelled. This model was used to estimate emissions for baseline, with the Proposed Amendments, and two alternative scenarios.

## II. EMISSIONS INVENTORY METHODS

In emissions inventories, emissions are calculated as the product of a pollutant emission rate (e.g., grams of pollutant per mile) per some unit of activity (e.g., miles

[1] The emissions inventory analysis described in this appendix does not assume any manufacturers participate in the 50-State National Option described in Chapter III, Section A.1.1.2 of this Staff Report.



Date of Release: June 23, 2020
Date of Hearing: August 27, 2020

driven) multiplied by that activity and population. Details on heavy-duty activity, emission rates, and populations can be found in the EMFAC 2017 Technical Documentation (CARB, 2018c). Note that only NOx emissions benefits were quantified for this program. This is because technologies that reduce NOx (e.g., an improved selective catalytic reduction [SCR] catalyst) are expected to have minimal impact on particulate matter (PM) and greenhouse gas (GHG) emissions. This emissions benefit analysis includes running exhaust emissions, start exhaust emissions, and idle exhaust emissions from heavy-duty vehicles. Within this analysis, CARB staff considered four different scenarios as described below:

1. **Baseline** – A business as usual scenario without the proposed Low NOx regulation.
2. **Proposed Amendments** – CA-sold only scenario with all parts of the Low NOx regulation.
3. **Alternative 1** – similar to Proposed Amendments but with an earlier phase-in of certain parts of the Low NOx regulation.
4. **Alternative 2** – National scenario that has weaker standards for model years 2024-2026 and then matches the Proposed Amendments for model years 2027 and newer. Note that this standard applies to all vehicles in California.

The Proposed Amendments apply to medium-duty and heavy-duty diesel-cycle engines and heavy-duty Otto-cycle engines and vehicles with GVWR above 10,000 lbs. The requirements for the Proposed Amendments, Alternative 1, and Alternative 2 are listed below in Tables 1 to 3, respectively. The values as presented in Tables 1 to 3 represent the input variables that were used in the emissions modelling. The warranty and useful life mileages take into account the first occurring of the miles, years, or hours to determine which of them ends the useful life and warranty coverage period. They differ from the values that are presented in their corresponding tables of this Staff Report which show only the mileage component for the useful life and warranty periods.

APPENDIX D

## Table 1. Proposed Amendments (CA-sold vehicles only)

| Standards, Test Procedures and Elements | Units | MY 2024-26 | MY 2027-30 | MY 2031 & Newer |
|---|---|---|---|---|
| **FTP** | g/bhp-hr | 0.050 | 0.020 | 0.020 |
| **LLC** | g/bhp-hr | 0.20 | 0.040 | 0.040 |
| **Idling** | g/hr | 10 | 5 | 5 |
| **HDIUT Method In-Use Threshold** | g/bhp-hr | Binned MAW 1.5x Standards | Binned MAW w/ Cold Start 1.5x Standards | Binned MAW w/ Cold Start 1.5x Standards |
| **DDP** | NA | 100% UL aging | 100% UL aging | 100% UL aging |
| **UL**[3] | 10^3×miles | 435/185/110/110* | 600/270/190/155* | 800/350/270/200* |
| **Warranty**[2] | 10^3×miles | 289/139/103/50* | 308/172/135/104* | 400/221/189/148* |
| **EWIR*** | -- | Modified EWIR | Modified EWIR | Modified EWIR |

Note: DDP= Durability Demonstration Program, EWIR= Emission Warranty Information Reporting and corrective actions, FTP= Federal Test Procedure, HDIUT= Heavy-Duty In-Use Testing, LLC= Low Load Cycle, MAW= Moving Average Window, MY=Model Year, NTE= Not-to-Exceed, UL= Useful Life

Units: g/bhp-hr= Grams Per Brake Horsepower-Hour, g/hr= Grams Per Hour. Staff changed the proposed LLC standard after the emission benefits were modeled, lowering it from 0.06 to 0.04 g/bhp-hr. The emission benefits were modeled with LLC standard for MY 2027 and subsequent at 0.06 g/bhp-hr, rather than 0.04 g/bhp-hr, so staff expects emission benefits would be slightly higher than modeled, and cost-effectiveness would be slightly better than modeled.

* Diesel Class 8; GVWR >33,000 lbs. / Diesel Class 6-7; 19,500 < GVWR ≤ 33,000 lbs. /Diesel Class 4-5; 14,000 lbs. < GVWR ≤ 19,500 lbs. / HD Otto (gasoline).

[2] The mileages shown for useful life and warranty are listed in the form of HHD/MHD/LHD/HD Otto. For warranty, the mileages shown are the average miles covered when considering the miles, years, and hours provisions within the proposed requirements. For example, using the warranty, for HHD in the baseline in Table 1, which represents the model year 2022 Step 1 warranty requirements, manufacturers must cover emissions warranty to 350,000 miles or 5 years, whichever comes first. On average, HHD vehicles reach 289,000 miles before they reach age of 5 years, so the table shows “289” for HHD.

## Table 2. Alternative 1 Scenario (CA-sold vehicles only)

| Standards, Test Procedures and Elements | Units | MY 2022-23 | MY 2024-26 | MY 2027-30 | MY 2031 & Newer |
|---|---|---|---|---|---|
| **FTP** | g/bhp-hr | 0.050 | 0.020 | 0.020 | 0.020 |
| **LLC** | g/bhp-hr | 0.20 | 0.040 | 0.040 | 0.040 |
| **Idling** | g/hr | 10 | 5 | 5 | 5 |
| **HDIUT Method In-Use Threshold** | g/bhp-hr | Binned MAW 1.5x Standards | Binned MAW w/ Cold Start 1.5x Standards | Binned MAW w/ Cold Start 1.5x Standards | Binned MAW w/ Cold Start 1.5x Standards |
| **DDP** | NA | Baseline | 100% UL aging | 100% UL aging | 100% UL aging |
| **UL**[3] | 10^3×miles | 435/185/110/110* | 435/185/110/110* | 600/270/190/155* | 800/350/270/200* |
| **Warranty**[3] | 10^3×miles | 289/139/103/50* | 289/139/103/50* | 308/172/135/104* | 400/221/189/148* |
| **EWIR*** | -- | Baseline | Modified EWIR | Modified EWIR | Modified EWIR |

Note: DDP= Durability Demonstration Program, EWIR= Emission Warranty Information Reporting and corrective actions, FTP= Federal Test Procedure, HDIUT= Heavy-Duty In-Use Testing, LLC= Low Load Cycle, MAW= Moving Average Window, MY=Model Year, NTE= Not-to-Exceed, UL= Useful Life

Units: g/bhp-hr= Grams Per Brake Horsepower-Hour, g/hr= Grams Per Hour. The emission benefits for Alternative 1 were modeled with LLC standard for MY 2027 and subsequent at 0.06 g/bhp-hr, rather than 0.04 g/bhp-hr, so staff expects emission benefits would be slightly higher than modeled, and cost-effectiveness would be slightly better than modeled.

* Diesel Class 8; GVWR >33,000 lbs. / Diesel Class 6-7; 19,500 < GVWR ≤ 33,000 lbs. /Diesel Class 4-5; 14,000 lbs. < GVWR ≤ 19,500 lbs. / HD Otto (gasoline).

[3] The mileages shown for useful life and warranty are listed in the form of HHD/MHD/LHD/HD Otto. For warranty, the mileages shown are the average miles covered when considering the miles, years, and hours provisions within the proposed requirements. For example, using the warranty, for HHD in the baseline in Table 1, which represents the model year 2022 Step 1 warranty requirements, manufacturers must cover emissions warranty to 350,000 miles or 5 years, whichever comes first. On average, HHD vehicles reach 289,000 miles before they reach age of 5 years, so the table shows “289” for HHD.

**Table 3. Alternative 2 (National program; includes all heavy-duty vehicles)**

| Standards, Test Procedures and Elements | Units | MY 2024-26 | MY 2027-2030 | MY 2031 & Newer |
|---|---|---|---|---|
| **FTP** | g/bhp-hr | 0.15 | 0.10 | 0.10 |
| **LLC** | g/bhp-hr | 0.70 | 0.70 | 0.70 |
| **Idling** | g/hr | Baseline | Baseline | Baseline |
| **HDIUT Method In-Use Threshold** | g/bhp-hr | EMA modified NTE 0.22 | EMA modified NTE 0.22 | EMA modified NTE 0.22 |
| **DDP** | NA | Baseline | Baseline | Baseline |
| **UL** | 10^3×miles | Baseline | Baseline | Baseline |
| **Warranty[4]** | 10^3×miles | 289/139/103/50 | 289/139/103/50 | 289/139/103/50 |
| **EWIR*** | NA | Baseline | Baseline | Baseline |

Note: DDP= Durability Demonstration Program, EMA= Truck and Engine Manufacturers Association, EWIR= Emission Warranty Information Reporting and corrective actions, FTP= Federal Test Procedure, HDIUT= Heavy-Duty In-Use Testing, LLC= Low Load Cycle, MY=Model Year, NTE= Not-to-Exceed, UL= Useful Life

Units: g/bhp-hr= Grams Per Brake Horsepower-Hour, g/hr= Grams Per Hour

* Diesel Class 8; GVWR >33,000 lbs. / Diesel Class 6-7; 19,500 < GVWR ≤ 33,000 lbs. /Diesel Class 4-5; 14,000 lbs. < GVWR ≤ 19,500 lbs. / HD Otto (gasoline)

[4] The mileages shown for warranty are listed in the form of HHD/MHD/LHD/HD Otto. For warranty, the mileages shown are the average miles covered when considering the miles, years, and hours provisions within the baseline and proposed warranty requirements. For example, for HHD in the baseline in Table 1, which represents the model year 2022 Step 1 warranty requirements, manufacturers must cover emissions warranty to 350,000 miles or 5 years, whichever comes first. On average, HHD vehicles reach 289,000 miles before they reach age of 5 years, so the table shows “289” for HHD.

## A. Vehicle Population and Vehicle Miles Travelled

CARB staff used heavy-duty vehicle populations and activity assumptions incorporated into EMFAC 2017 to generate an emissions inventory. This analysis includes EMFAC vehicle categories with GVWR > 10,000 lbs., which are light-heavy-duty trucks (LHD2)[5], all medium heavy-duty trucks (T6), all heavy heavy-duty trucks (T7), school buses (SBUS), motor coaches, power take-off (PTO), All Other Buses (diesel), other buses (OBUS; gasoline), and urban buses (UBUS).

The inventory for this analysis excludes zero-emission and low NOx buses required by Innovative Clean Transit (ICT) (CARB, 2020a), Zero-Emission Airport Shuttle Bus (CARB, 2020b), and Assembly Bill 739 (CLI, 2017). This inventory analysis has two different baselines: (i) a legal baseline that accounts for all adopted regulations and (ii) an adjusted baseline that accounts for all adopted regulations and also excludes all heavy-duty zero-emissions trucks required by the Advanced Clean Trucks (ACT) Regulation (CARB, 2019c) noted herein as the ACT-adjusted baseline. Note that only engine-certified (not chassis-certified, i.e. subject to standards (CARB, 2012)) LHD2 vehicles were considered[5]. CARB staff determined from certification data that only 2.5 percent diesel-fueled vehicles and 0.33 percent for gasoline-fueled LHD2 vehicles are engine certified[5].

The requirements for the Proposed Amendments and Alternative 1 would only apply to CA-sold vehicles. To estimate the percentage of California-registered vehicles that were originally sold out-of-state, CARB staff used the *First Sold* field in the Department of Motor Vehicles registration data. This field indicates whether a vehicle registered in California was originally purchased out-of-state. CARB staff assumed that all out-of-state registered vehicles were originally sold outside of California. More details on this method are described further in Appendix F Section II.A of Proposed Advanced Clean Trucks Regulation (CARB, 2019b).

[5] This appendix uses EMFAC emissions inventory terminology, where LHD2 is defined as heavy-duty vehicles with GVWR 10,001 to 14,000 pounds. The Staff Report refers to such vehicles as “medium-duty” and uses LHDD to mean “Light heavy-duty diesel engines 14,001-19,500 pounds GVWR”.

## B. Emission Rates

Benefits for the Low NOx regulation are calculated as the difference in the NOx emissions with (Proposed Amendments) and without (baseline) the Low NOx regulation in place. To calculate emission rates for Proposed Amendments scenario, scaling factors were applied to baseline NOx emission rate. These factors are calculated as:

$$Scaling\ Factor = \frac{Low\ NOx\ Emission\ Rate}{Baseline\ Emission\ Rate} \quad (1)$$

CARB staff accounted for the impact of new certification standards, HDIUT improvements, lengthened warranty mileage, and new idling requirements to estimate new Low NOx emission rates.

In EMFAC, emission rates are calculated as:

$$ER\left(\frac{g}{mile}\right) = (ZMR + DR \times Odometer) \times SCF \quad (2)$$

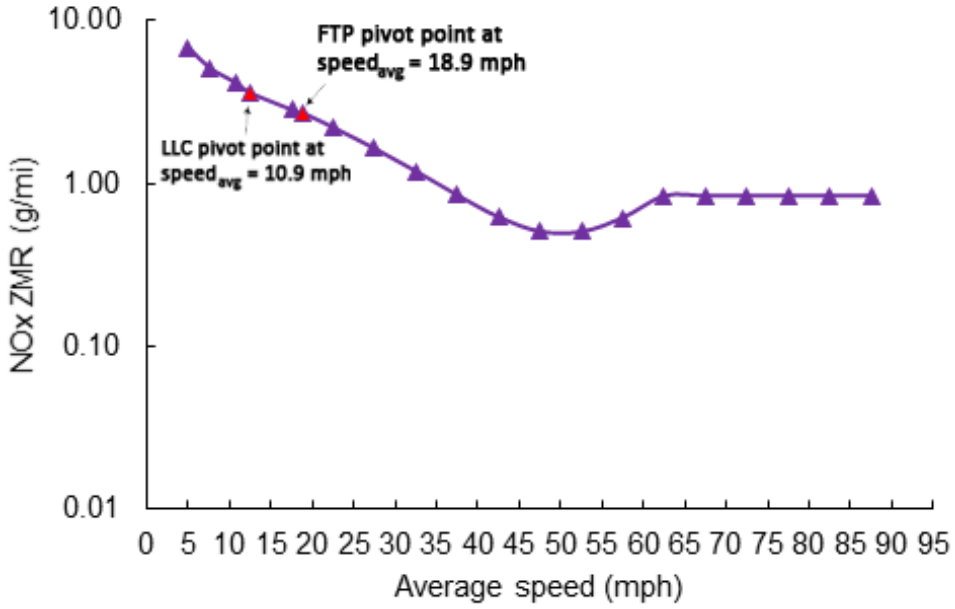
Where ER is the emission rate, ZMR is the zero mile emission rate, DR is the deterioration rate and SCF is the speed correction factor. More details can be found in EMFAC2017 Technical Support Documentation (CARB, 2018c).

### a. FTP and LLC Standards

Speed-dependent ZMR were adjusted to reflect reductions from new certification standards for the existing FTP and certification standards on a new LLC. The baseline emission rates are for a 2010 engine certified to 0.2 g/bhp-hr, which came from in-use testing data performed using different drive cycles spanning a range of average speeds on a dynamometer. Note that in-use emission rates are higher than the certification standards.

The average speed of the FTP cycle is 18.9 mph, while the average speed for LLC is 10.9 mph. Thus, it is expected that certification standards on LLC and FTP will have different impacts on speed-dependent ZMRs. In particular, an LLC certification standard should have the largest impact at lower speeds. To model new speed-dependent Low NOx ZMRs, pivot points for both cycles were used as shown in Figure 1 below to account for their impact simultaneously. To compare more directly to certification standards, EMFAC emission rates in grams per mile shown in Figure 1 were adjusted to g/bhp-hour using bhp-hr data broadcasted by the engine control unit (ECU).

**Figure 1. Baseline speed-dependent NOx ZMR with FTP and LLC pivot points**




At speeds below or at the LLC average speed, Low NOx ZMRs are calculated as

$$ZMR_{Low\ NOx} = ZMR_{baseline} \times \frac{Low\ NOx\ LLC\ Standard \times Adjustment\ Factor}{In\text{-}Use\ Baseline\ emission\ rate\ (1.15\ g/bhp\text{-}hr)} \quad (3)$$

Note that the certification standard for LLC was adjusted to an in-use emission rate, which are higher than the certified emission rates. The adjustment for in-use ZMR are described in further detail below in Section C. Similarly, Low NOx ZMRs at or higher than the FTP average speed were calculated as

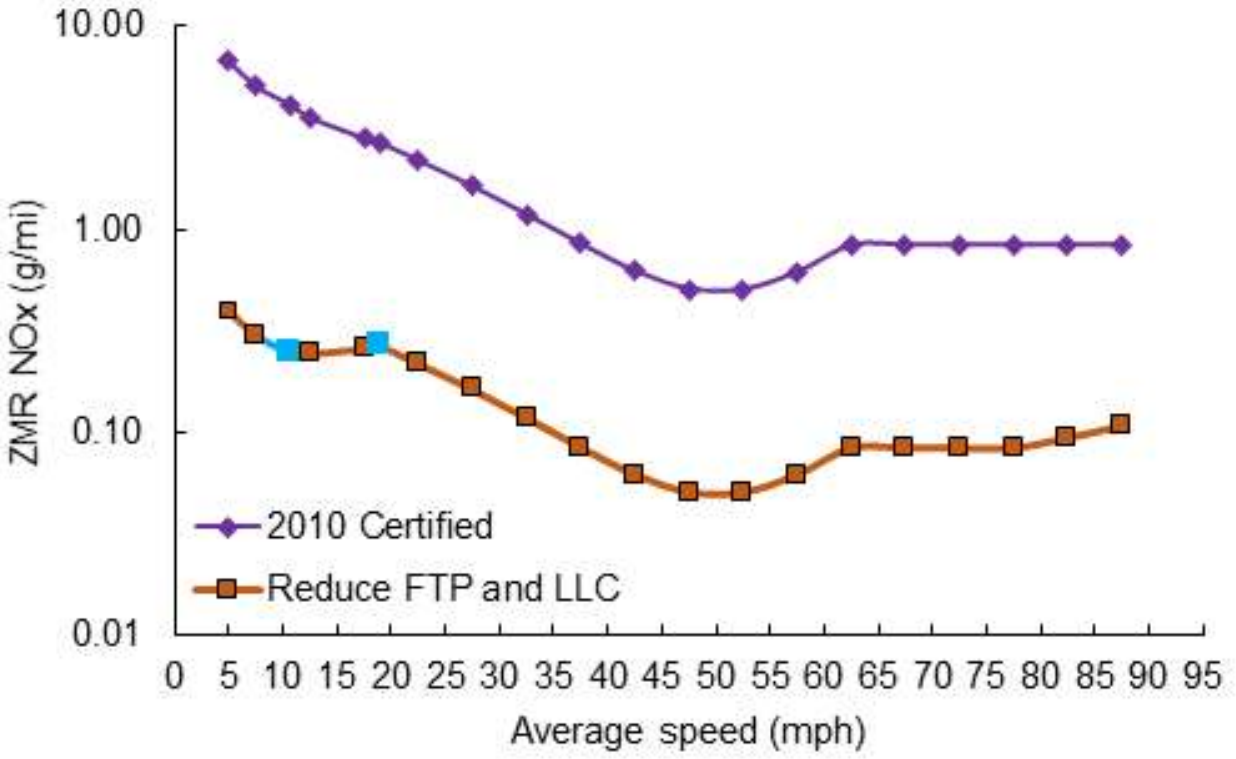
$$ZMR_{Low\ NOx} = ZMR_{baseline} \times \frac{Low\ NOx\ FTP\ Standard}{Baseline\ 2010\ Certified\ Standard\ (0.2\ g/bhp\text{-}hr)} \quad (4)$$

At speeds in between the FTP and LLC average speeds, new emission rates were calculated as a weighted average between the calculated ZMRs at FTP and LLC average speeds.

CARB staff expects that tightening certification standards on FTP will also result in ZMR reductions at the LLC average speed. To account for this, CARB staff determined from SwRI phase 2 tests that an 83.6 percent reduction on FTP resulted in 76.5 percent reduction on LLC (Sharp, 2020). Thus, CARB staff assumed that 92 percent of emissions reductions that occur at FTP average speed will translate to emissions reductions at LLC.

Below is an example of baseline speed-dependent emission rates (purple) and emission rates with certification standards on both FTP and LLC of 0.02 g/bhp-hr (black). Note that tightening the FTP standard results in reductions at all speeds, while a new LLC standard results in additional reductions at lower speeds.

**Figure 2. Speed-dependent ZMR baseline and with the proposed FTP and LLC standards**




### C. Improvements to Heavy-Duty In-Use Testing Program

Improvements to the HDIUT program are expected to close the gap between real-world in-use emission rates and certified emissions rates. CARB staff's analysis of truck and bus surveillance program (TBSP) data indicate that in-use emission rates for 0.2 g/bhp-hr certified engines are on average 0.683 g/bhp-hr on the Urban Dynamometer Driving Schedule (UDDS) (CARB, 2018c).

Emissions reductions from the "Truck and Engine Manufacturers Association's (EMA's) Modified Not-To-Exceed (NTE) Proposal" were estimated by using the HDIUT dataset. More test time coverage (i.e. less in-use testing time is excluded) in the newer NTE would increase its effectiveness in reducing emission rates. CARB staff estimated that there would be approximately 11 percent more coverage for EMA's modified NTE.

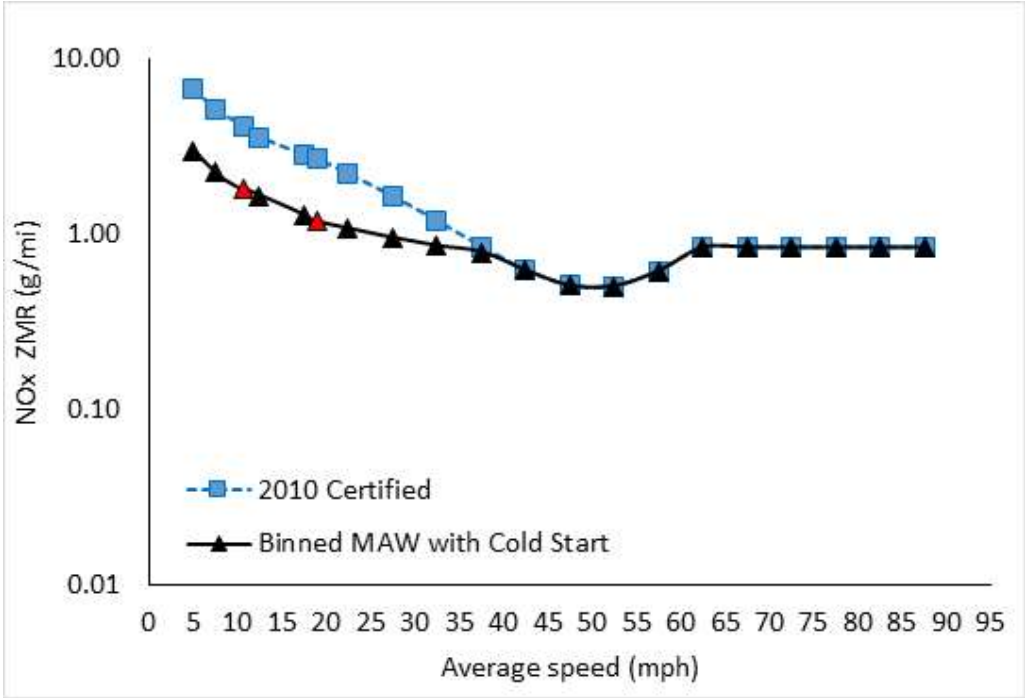
Thus, CARB staff assumed that these in-use emission rates were reduced by the percentage of additional test coverage. Moving Average Window (MAW) and NTE are two different methods to evaluate in-use emissions. The MAW method is designed to capture and evaluate a full range of real world driving operation, where the NTE method specifically evaluates one type of operation when the engine is operating at a continuous high speed and load. Given the differences between NTE and MAW, a different approach was used to calculate the effectiveness of both Binned MAW and Binned MAW with Cold Start. CARB staff assumed that in-use emissions will be less than 1.5x FTP standard with Binned MAW with Cold Start and 2.25x FTP standard with Binned MAW without any cold start.

**Table 4. Summary of improved HDIUT programs and their assumed decrease in emission rates from the baseline UDDS value.**

| Model Year | NOx FTP std | Real world emission rate [g/bhp-hr] | Percent reduction from 0.683 g/bhp hr |
|---|---|---|---|
| 2024 – EMA's Proposed Modified NTE | 0.2 | 0.61 | 11% |
| 2024 - Binned MAW | 0.2 | 0.45 | 34% |
| 2027 - Binned MAW w/ Cold Start | 0.2 | 0.3 | 56% |

Figure 3 demonstrates the impact of an improved HDIUT program. The baseline speed-dependent ZMRs (blue) and ZMRs with Binned MAW with Cold Start. At lower speeds, reductions in the ZMR are more substantial because ZMRs are higher at lower speeds and would therefore be most impacted by an improved in-use testing program. There are no reductions at higher speeds because these emission factors already meet the limit of 0.3 g/bhp-hr, which translates ~1 g/mile.

**Figure 3. Speed-dependent ZMR baseline and with an improved HDIUT Program**



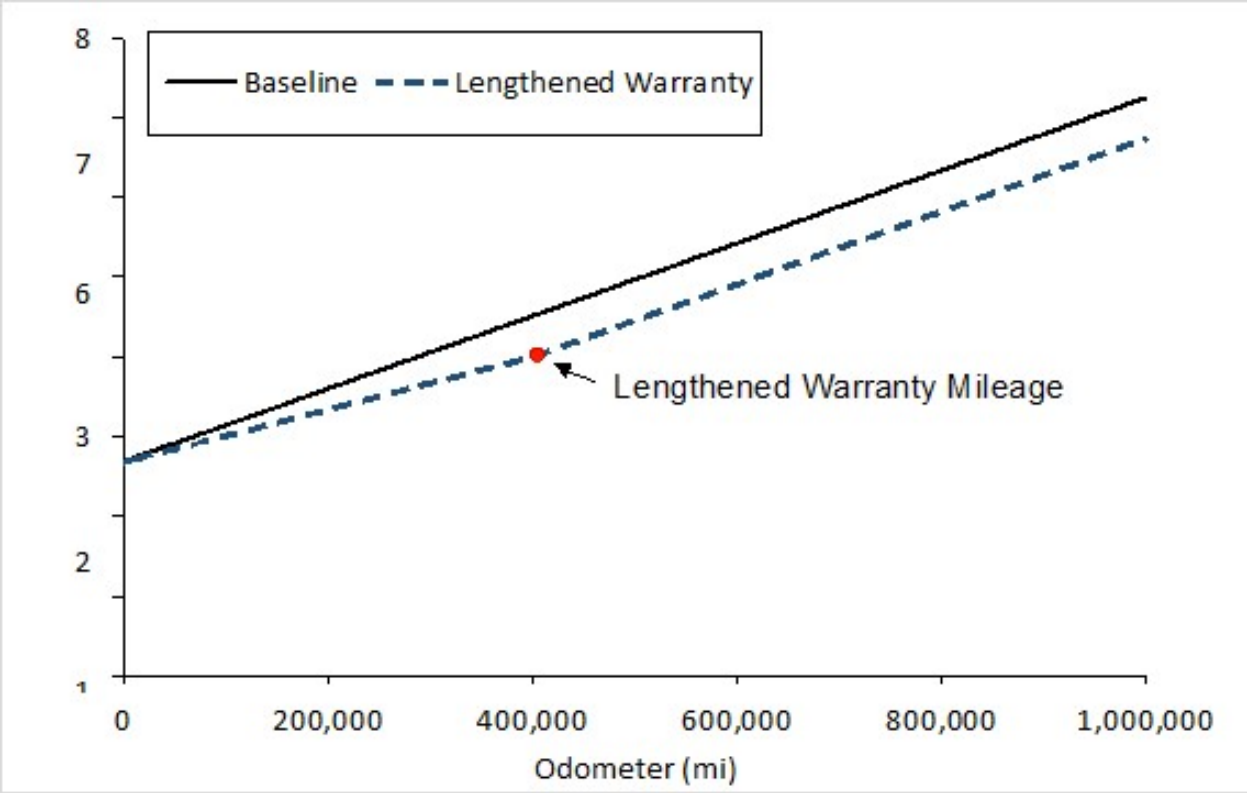

## D. Lengthened Warranty/Durability/EWIR

Fleet average emission rates increase due to deterioration of a larger fraction of vehicles with tampering, mal-maintenance, and malfunction as fleet-wide odometer mileage increases. The lengthened warranty requirement in the Proposed Amendments reduces deterioration rates within the warranty mileage period. Note that the impact of lengthened useful life and warranty, a strengthened DDP, and EWIR and corrective action components of the Low NOx regulation were combined; these components are expected to reduce deterioration-related emissions, but there is currently insufficient information to model each element individually. Note that EMFAC 2017 does not account for the Heavy-Duty Engine Warranty Amendments (Step 1 warranty) which were adopted in 2018 (CARB, 2018b). When estimating benefits of the Proposed Amendments and alternatives, CARB staff adjusted the EMFAC 2017 baseline to account for the Step 1 warranty mileages (289/139/103/50, see Table 1). Although CARB staff explicitly accounted for the Step 1 mileages when estimating benefits of each scenario, the benefits quantified for Step 1 warranty were not subtracted from the EMFAC 2017 baseline for Low NOx because accounting for the Step 1 NOx benefits would not significantly impact the NOx emissions reductions

calculated here. For example, in 2030 this program only resulted in a 0.45 percent reduction from the baseline (CARB, 2018a).

To estimate changes to deterioration, CARB staff extended the emission rate at the baseline warranty mileage and extended it to the lengthened warranty mileage in the Proposed Amendments. This has the effect of reducing the slope of the deterioration rate within the new warranty period. The figure below demonstrates the impact of lengthening the warranty mileage from 289,000 miles to 400,000 miles. Emission rates increase at a lower rate within the warranty period, exhibited by the shallower slope (dashed line). At 400,000 miles, the fleet-average emission rate is 1.9 g/mile with the lengthened warranty, instead of 2.3 g/mile without the lengthened warranty.

**Figure 4. Odometer-dependent NOx Emission Rates (Baseline and Lengthened Warranty)**




## E. New Idling Requirements

Idle exhaust emissions output from EMFAC were scaled by a simple ratio of the idling standards required by the Proposed Amendments and the baseline idling standard. The standards and ratios are shown below in Table 5.

**Table 5. Baseline and Proposed Idle Standards and Scaling Factors**

| Engine Model Year | Idle Emission Rate (g/hr) | Scaling |
|---|---|---|
| Pre-2024 | 30 (baseline) | 1 |
| 2024 | 10 | 1/3 |
| 2027-30 and 2031 & Newer | 5 | 1/6 |

## III. RESULTS

### A. POPULATION AND VEHICLE MILES TRAVELED

Heavy-duty (GVWR > 10,000 lbs.) engine-certified populations and Vehicle Miles Traveled (VMT) for (i) heavy-duty Zero-Emission Vehicles (ZEVs) required by ACT (vehicle model year 2024 and newer), (ii) Low NOx vehicles with vehicle model years 2025-2027 (or engine model years 2024-2026), (iii) Low NOx vehicles with vehicle model years 2028+ (or engine model years 2027+), (iv) non-Low NOx and non-ZEV with vehicle model years 2024 and newer, (v) vehicle model years 2024+ out-of-state sold vehicles[6], and (vi) all model years prior to vehicle model years 2024. Please note that the ACT populations shown here reflect the sales requirements presented during the Public Hearing to Consider a Proposed Advanced Clean Trucks Regulation in December 2019 and not more recent potential changes to the ACT proposal (CARB, 2019d). Also note that there is typically a one year lag between vehicle and engine model year for non-ZEV heavy-duty diesel vehicles. For example, category (iv) corresponds to heavy-duty non-ZEV vehicles with vehicle model year 2024 and engine model year 2023, which do not have Low NOx requirements.

[6] This includes out-of-state registered vehicles and vehicles registered in California that were originally sold out-of-state

**Figure 5. Projected Vehicle Population**

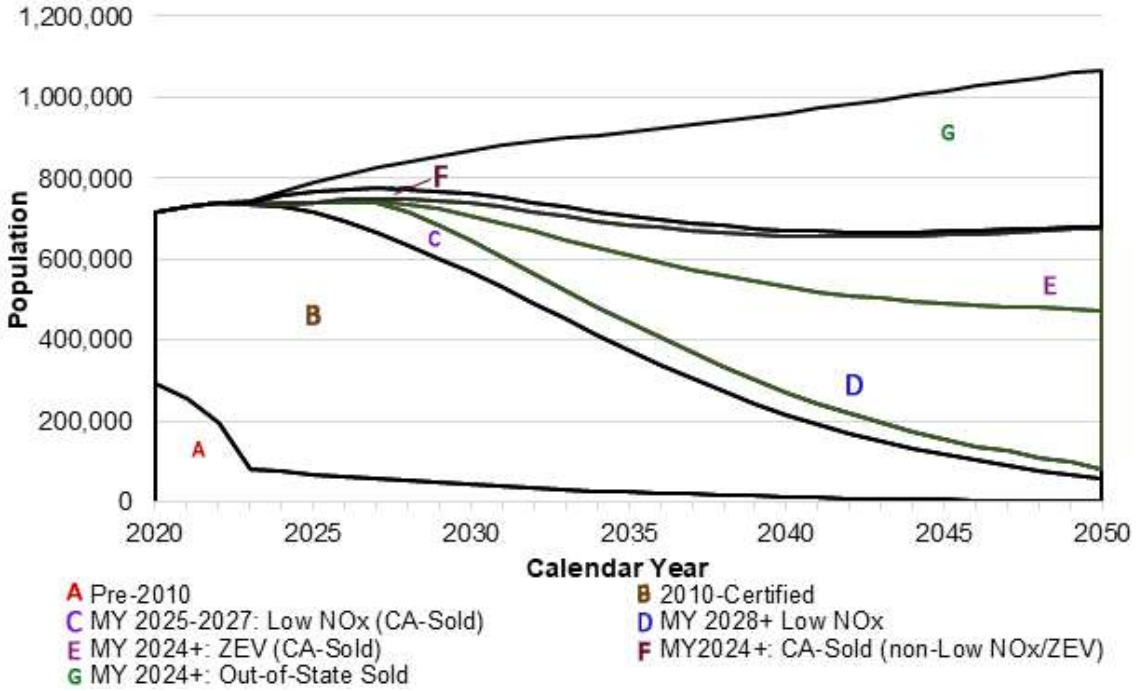
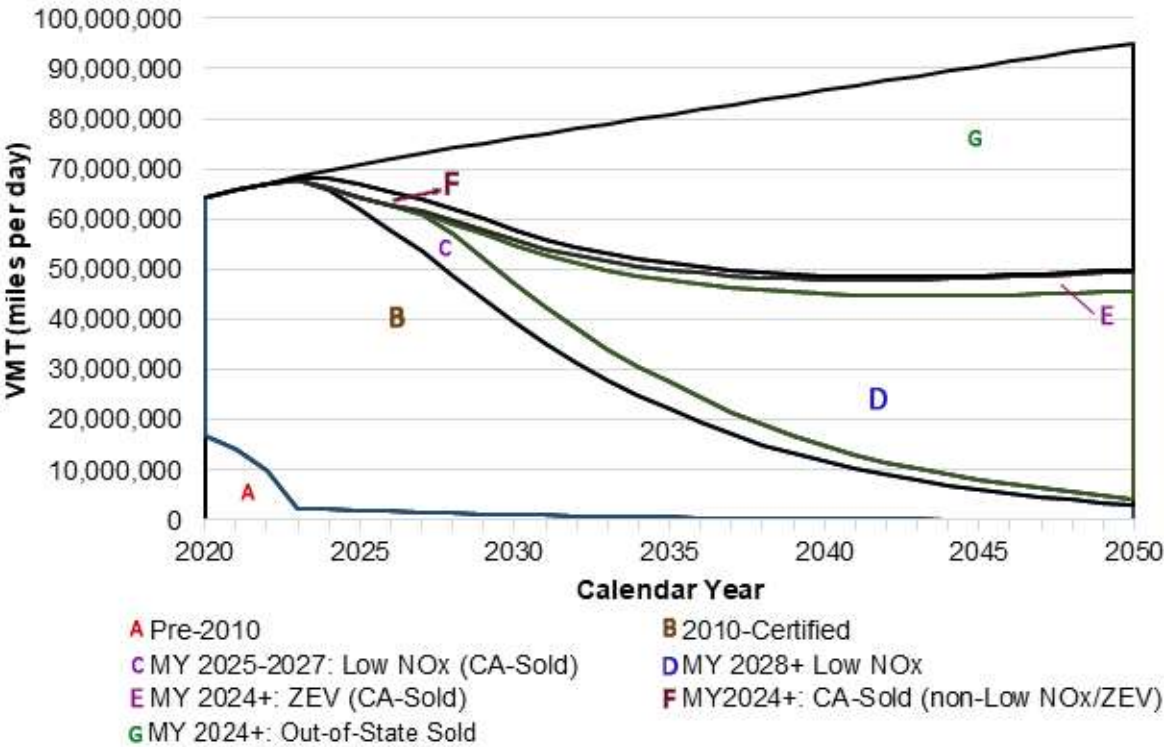



**Figure 6. Projected Vehicle Miles Travelled**



## B. EMISSIONS

NOx emissions for the baseline scenario, Proposed Amendments, Alternative 1, and Alternative 2 for calendar years 2022-2050 are shown below. This includes the legal baseline with all adopted rules (Figure 7 and Table 6) and an ACT-adjusted baseline that excludes heavy-duty ZEV vehicles required by the ACT regulation (Figure 8 and Table 7). Note that the baseline inventory includes NOx emissions from all engine-certified (excluding chassis-certified LHD2) [6] heavy-duty vehicles (GVWR > 10,000 lbs.) operating in California. Note that this also includes out-of-state vehicles that operate in California. Please note that the ACT-adjusted baseline reflects the sales requirements presented during the Public Hearing to Consider a Proposed Advanced Clean Trucks Regulation in December 2019 and not more recent potential changes to the ACT proposal (CARB, 2019d). Please note also that the ACT-adjusted scenarios do not include the heavy-duty zero-emission averaging set provisions as described in Chapter III, Section A.7.5 of this Staff Report. Figure 9 shows NOx emissions for both the legal (gray solid line) and ACT-adjusted (black dotted line) baselines, as well as resulting emissions after the Low NOx regulation for the legal (blue dashed line) and ACT-adjusted (dark orange solid line) baseline. Note that the emissions benefits (i.e. baseline – Low NOx emissions) are lower when the baseline is adjusted for ACT.

**Figure 7. NOx Emissions for all Heavy-Duty Vehicles (Legal Baseline)**

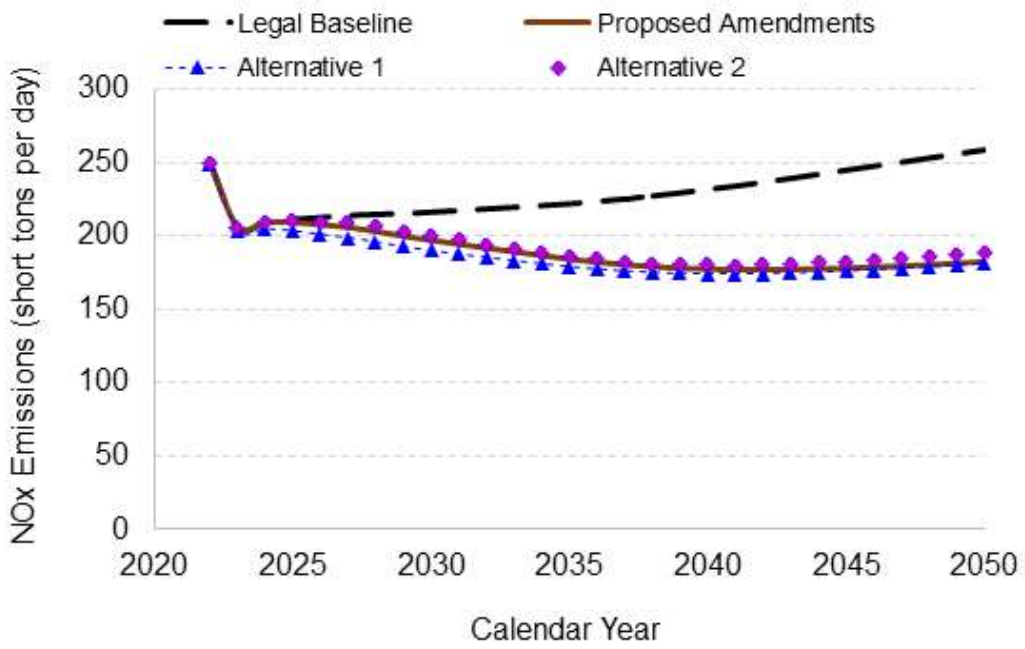


**Figure 8. NOx Emissions for all Heavy-Duty Vehicles (ACT-Adjusted Baseline)[7]**

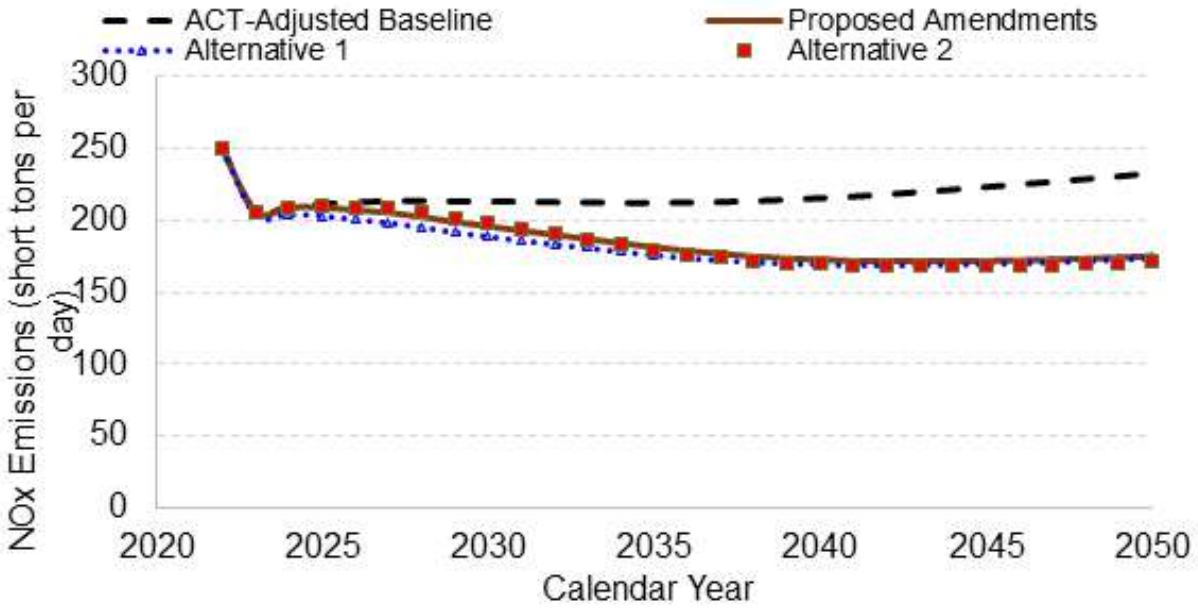
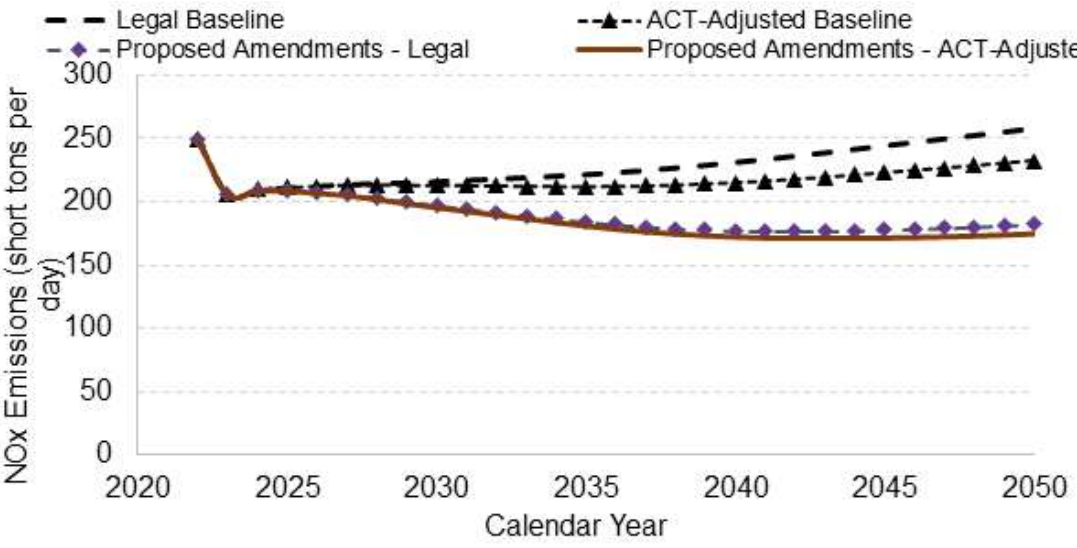



**Figure 9. NOx Emissions for all Heavy-Duty Vehicles (both Legal and ACT-Adjusted Baseline)[7]**




[7] The ACT-adjusted baseline shown here reflects the sales requirements presented during the Public Hearing to Consider a Proposed Advanced Clean Trucks Regulation in December 2019 and not more recent potential changes to the ACT proposal (CARB, 2019d). Also, the ACT-adjusted baseline scenario does not include the heavy-duty zero-emission averaging set provisions as described in Chapter III, Section A.7.5 of this Staff Report.

**Table 6. NOx Emissions (Short Tons per Day) for the Legal Baseline**

| Calendar Year | Baseline | Proposed Amendments | Alternative 1 | Alternative 2 |
|---|---|---|---|---|
| 2022 | 249.74 | 249.74 | 249.38 | 249.74 |
| 2023 | 205.97 | 205.97 | 203.67 | 205.97 |
| 2024 | 209.67 | 209.31 | 204.67 | 209.43 |
| 2025 | 211.50 | 209.19 | 203.30 | 210.17 |
| 2026 | 212.78 | 207.63 | 201.02 | 209.69 |
| 2027 | 214.17 | 205.89 | 198.69 | 208.92 |
| 2028 | 214.90 | 203.06 | 195.82 | 206.55 |
| 2029 | 215.43 | 199.75 | 192.49 | 203.24 |
| 2030 | 216.36 | 196.91 | 189.82 | 200.18 |
| 2031 | 217.52 | 194.30 | 187.45 | 197.18 |
| 2032 | 218.53 | 191.65 | 185.15 | 194.10 |
| 2033 | 219.64 | 189.09 | 182.99 | 191.22 |
| 2034 | 220.78 | 186.51 | 180.84 | 188.45 |
| 2035 | 222.02 | 184.05 | 178.83 | 185.98 |
| 2036 | 223.55 | 181.95 | 177.17 | 183.99 |
| 2037 | 225.29 | 180.19 | 175.87 | 182.40 |
| 2038 | 227.25 | 178.80 | 174.98 | 181.25 |
| 2039 | 229.38 | 177.79 | 174.39 | 180.51 |
| 2040 | 231.68 | 177.17 | 174.12 | 180.19 |
| 2041 | 233.94 | 176.74 | 173.99 | 180.06 |
| 2042 | 236.50 | 176.75 | 174.24 | 180.41 |
| 2043 | 239.15 | 176.96 | 174.67 | 181.00 |
| 2044 | 241.88 | 177.32 | 175.25 | 181.75 |
| 2045 | 244.67 | 177.87 | 176.02 | 182.67 |
| 2046 | 247.37 | 178.48 | 176.83 | 183.63 |
| 2047 | 250.06 | 179.24 | 177.78 | 184.69 |
| 2048 | 252.79 | 180.14 | 178.85 | 185.88 |
| 2049 | 255.53 | 181.18 | 180.03 | 187.18 |
| 2050 | 258.23 | 182.31 | 181.29 | 188.55 |

**Table 7. NOx Emissions (Short Tons per Day) for the ACT-Adjusted Baseline[8]**

| Calendar Year | Baseline | Proposed Amendments | Alternative 1 | Alternative 2 |
|---|---|---|---|---|
| 2022 | 249.74 | 249.74 | 249.38 | 249.74 |
| 2023 | 205.95 | 205.95 | 203.67 | 205.95 |
| 2024 | 209.52 | 209.18 | 204.63 | 209.29 |
| 2025 | 211.14 | 208.99 | 203.23 | 209.86 |
| 2026 | 212.15 | 207.34 | 200.89 | 209.17 |
| 2027 | 213.15 | 205.48 | 198.48 | 208.11 |
| 2028 | 213.27 | 202.53 | 195.49 | 205.37 |
| 2029 | 212.92 | 199.04 | 191.98 | 201.53 |
| 2030 | 212.71 | 195.96 | 189.08 | 197.79 |
| 2031 | 212.64 | 193.07 | 186.42 | 194.06 |
| 2032 | 212.37 | 190.12 | 183.80 | 190.18 |
| 2033 | 212.16 | 187.24 | 181.31 | 186.48 |
| 2034 | 211.95 | 184.31 | 178.80 | 182.85 |
| 2035 | 211.84 | 181.51 | 176.43 | 179.51 |
| 2036 | 212.04 | 179.04 | 174.41 | 176.65 |
| 2037 | 212.47 | 176.93 | 172.75 | 174.21 |
| 2038 | 213.15 | 175.19 | 171.49 | 172.22 |
| 2039 | 214.05 | 173.84 | 170.55 | 170.66 |
| 2040 | 215.16 | 172.89 | 169.94 | 169.56 |
| 2041 | 216.26 | 172.11 | 169.46 | 168.64 |
| 2042 | 217.78 | 171.84 | 169.42 | 168.32 |
| 2043 | 219.40 | 171.76 | 169.55 | 168.22 |
| 2044 | 221.13 | 171.83 | 169.84 | 168.30 |
| 2045 | 222.97 | 172.11 | 170.33 | 168.59 |
| 2046 | 224.76 | 172.46 | 170.88 | 168.94 |
| 2047 | 226.58 | 172.95 | 171.55 | 169.41 |
| 2048 | 228.47 | 173.60 | 172.36 | 170.04 |
| 2049 | 230.41 | 174.38 | 173.28 | 170.79 |
| 2050 | 232.54 | 175.29 | 174.31 | 171.75 |

[8] The ACT-adjusted baseline shown here reflects the sales requirements presented during the Public Hearing to Consider a Proposed Advanced Clean Trucks Regulation in December 2019 and not more recent potential changes to the ACT proposal (CARB, 2019d).