Appendix D

Emissions Inventory Methods and Results

Proposed Heavy-Duty Inspection and Maintenance Regulation

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I. Overview

This appendix presents the methodology and results of the emissions inventory analysis conducted to examine the effects of the proposed Heavy-Duty Inspection and Maintenance (HD I/M) regulation on criteria emissions from heavy duty vehicles operating in California. The calculations conducted for this analysis are contained in the Heavy-Duty Inspection and Maintenance Regulation Emission Benefit Files (CARB, 2021o).

To estimate emissions benefits from the Proposed Regulation, staff calculated scaling factors that are applied to the deterioration rate (DR) for heavy-duty vehicles in Emission FACtor (EMFAC) model to reflect the lower rate of mal-functioning engine and emissions control systems due to induced repairs and better maintenance required by the proposed HD I/M regulation. Three major factors would affect heavy-duty vehicle emission rates, particularly DRs: effective repair rates, repair durability, and inspection frequency. Staff developed a mathematical model, also known as MIL-ON solver model, which takes into account the effects of these three factors in reducing the number of trucks with a mal-functioning aftertreatment system and/or engine components as the proposed HD I/M program is implemented.

The emission inventory analysis results presented in this document are relative to the legal baseline, which does not account for the impact of the proposed Heavy-Duty Omnibus regulation. The analysis demonstrates that in 2023 the proposed regulation would result in about 2.7 tons per day (tpd) and 2.1 tpd oxides of nitrogen (NOx) emissions reductions in the San Joaquin Valley (SJV) and South Coast (SC) air basins, respectively, along with a statewide NOx emissions reduction of 6.4 tpd. The HD I/M emissions reductions in 2023 would mainly be driven by the deployment of a network of Portable Emission AcQuisition Systems (PEAQS). PEAQS systems are remote sensing devices that measure the emissions from trucks passing by and identify the high emitting trucks for enforcement purposes. These systems are initially planned to be deployed at major state highway routes in the SJV and SC air basins.

After 2024, with the full implementation of periodic testing in the proposed HD I/M regulation, higher emission benefits are expected. In 2037, the proposed HD I/M regulation is expected to result in 22.1 tpd NOx emissions reduction in SC, and 21.5 tpd in SJV, and in total 81.3 tpd statewide. In 2050, the statewide NOx emissions reduction is expected to reach 110 tpd.

II. Introduction and Background

Over the years, California Air Resources Board (CARB or Board) has adopted regulations designed to reduce emissions from heavy-duty truck fleets by mandating vehicles to meet stricter emissions standards, and requiring replacement of older engines with cleaner engine technology that includes diesel particulate filters, oxides of nitrogen (NOx) controls, and On-Board Diagnostic (OBD) systems. As a result of these collective efforts, emissions from heavy-duty vehicles are lower than in previous years and are continuing to decline. Although, emissions from heavy-duty trucks are declining, they are still significant; and the majority of heavy-duty truck emissions are now associated with vehicles whose engines and emissions control systems are mal-functioning or poorly maintained. CARB staff estimate that, without a new HD I/M program, by 2031, 65 percent of particulate matter (PM) emissions and 47 percent of oxides of nitrogen (NOx) emissions from heavy-duty diesel trucks would be due to mal-functioning emissions control systems (CARB, 2020e).

The proposed HD I/M program was part of the Lower In-Use Emission Performance Level measure and first introduced in the 2016 Mobile Source Strategy (CARB, 2016a) and 2016 State Strategy for the State Implementation Plan (SIP) (CARB, 2017a), as one of SIP measures for South Coast (SC) and San Joaquin Valley (SJV). This program was then further mentioned in the San Joaquin Valley Supplement to the 2016 State SIP Strategy (CARB, 2018a). As directed by Senate Bill (SB) 210 (SB210, 2019) in 2019, CARB staff, in consultation with its State agency partners,[1] have worked together to develop a comprehensive HD I/M program proposal. SB 210 requires that on-road heavy-duty non-gasoline combustion vehicles with gross vehicle weight rating (GVWR) greater than 14,000 pounds be included in the forthcoming HD I/M program in order to operate in California and ties in-state vehicle registration with the California Department of Motor Vehicles (DMV) to program compliance. This ensures that the program will achieve maximum emissions reductions. The proposed HD I/M regulation continues to be a critical piece of CARB's 2020 Mobile Source Strategy (CARB, 2020d), as required by SB 44 (SB44, 2019). The proposed HD I/M program is part of the suite of new measures to further reduce emissions from heavy-duty vehicles, especially to help with the near-term air quality challenges in the SC and SJV air basins.

[1] The California Department of Motor Vehicles (DMV), California Highway Patrol (CHP), the Bureau of Automotive Repair (BAR), and the California Department of Food and Agriculture (CDFA).

The proposed HD I/M regulation would help ensure vehicles' emissions control systems remain well-maintained. Under the HD I/M program, vehicles with emission control component mal-functions would be more readily identified for timely repairs, thereby reducing in-use NOx and PM emissions from heavy-duty non-gasoline combustion vehicles operating in California, including out-of-state (OOS) vehicles.

The implementation of the proposed HD I/M program would progressively phase in as follows:

- **First Phase**: Starting in January 2023, CARB would have roadside high emitting vehicle screening (remote sensing devices and/or CARB's Portable Emissions AcQuisition System, known as PEAQS) with a focus in the SJV and SC air basins. At the same time, vehicle owners would be required to establish accounts in HD I/M database by the start of the second phase of program implementation to receive an HD I/M compliance certificate.
- **Second Phase**: Starting in approximately July 2023, the enforcement of compliance certificate requirements would start, and California DMV would hold vehicle registrations of non-compliant California-registered vehicles.
- **Third Phase**: Starting in approximately 2024, vehicle owners would demonstrate compliance with the periodic vehicle testing (e.g., OBD and opacity tests).

This appendix presents the methodology and results of the emissions inventory analysis conducted to examine the effects of the Proposed Regulation on emissions from heavy duty vehicles operating in California. Note that only NOx and PM emissions are quantified for this program. This is because inspection and maintenance of aftertreatment systems and engine components of mal-functioning vehicles are expected to have minimal impact on other criteria pollutants or greenhouse gas emissions.

III. Emissions Inventory Method

Staff used the EMFAC 2021 model (CARB, 2021a) to assess the emission reductions associated with the proposed HD I/M regulation. EMFAC is California's official on-road (e.g., cars, trucks, and buses) mobile source emissions inventory model, which is used by CARB for various clean air planning and policy development purposes. EMFAC2021 incorporates CARB's latest understanding of statewide and regional vehicle activities, and emissions; and reflects recently adopted heavy duty vehicle regulations such as Advanced Clean Trucks and Heavy Duty Omnibus.

Two baselines, and two corresponding sets of scenarios with the proposed HD I/M regulation are considered in the emission benefit analysis. One baseline has incorporated Heavy-Duty Omnibus, and it is taken directly from the public available version of EMFAC2021 (v1.0.1) (referred to as the "modified baseline"). The other baseline is developed without accounting for Heavy-Duty Omnibus, which is pending Office of Administrative Law (OAL) approval at the time of this Staff Report release (referred to as the "legal baseline").

In EMFAC, heavy-duty vehicle base emission rates are comprised of two major components: zero-mile rate (ZMR) and deterioration rate (DR). DR reflects emission increases due to engine and aftertreatment malfunction, as vehicles age and accrue mileage. More details can be found in the EMFAC2021 Technical Support Document (CARB, 2021i). The proposed HD I/M regulation would require vehicle owners to demonstrate that their vehicles' emissions control systems are properly functioning, thereby reducing excess NOx and PM emissions resulting from mal-functioning engine and aftertreatment control system components. To estimate emissions benefits from the proposed regulation, staff calculated scaling factors that are applied to the DR in EMFAC to reflect lower rate of deterioration due to induced repairs and better maintenance required by the proposed HD I/M regulation.

In the Proposed Regulation, three major factors would affect heavy-duty vehicle emission rates, particularly DRs:

- **Effective repair rates**: this is a combination of the efficacy of the HD I/M program in a) identifying the mal-functioning vehicles; and b) inducing effective repairs that result in real world emission reductions. The effective repair rates would vary as the Proposed Regulation phases in, and they are modeled to be dynamic to reflect the situations where it is more difficult to identify and repair mal-functioning vehicles, such as when the fleet becomes much cleaner (i.e., as the number of high emitting vehicles shrink significantly, it becomes more difficult to identify and repair them).
- **Repair durability**: The light duty Smog Check program (BAR, 2020) has proven that not all repairs are durable; and while HD I/M program can ensure a mal-functioning vehicle is repaired, there is still a chance for the vehicle to re-fail after a limited timeframe. MacKay's national survey data (refer to Appendix F of the Staff Report for details) on heavy-duty vehicle and engine component replacement intervals were used to estimate the annual re-fail rates for repaired vehicles.

- **Inspection frequency**: The proposed HD I/M regulation would require vehicle owners to periodically submit inspection data to the reporting system. The mal-functioning vehicles would be more likely to be identified and repaired earlier with more frequent inspections.

Staff have developed a mathematical model, also known as MIL-ON solver model, which takes into account the effects of these three factors in reducing the number of trucks with mal-functioning aftertreatment system and engine components as the proposed HD I/M program is implemented. Utilizing this information, emission DRs in EMFAC2021 were adjusted to estimate emission reductions resulting from the proposed HD I/M program. The emission rate (ER) ratio with and without HD I/M regulation is calculated as:

$$\frac{ER_{HD\ I/M}}{ER_{baseline}} = \frac{ZMR + X * DR(Odo)}{ZMR + DR(Odo)}$$

Equation (1)

Where ZMR refers to zero-mile emission rate; DR is deterioration rate, which is expressed as a power function of odometer reading (CARB, 2021i); and X is used to adjust DR, which is represented by the ratio of trucks (N^D) with mal-functioning aftertreatment system and engine components between the baseline and the proposed regulatory scenario as:

$$X = \frac{N^D_{HD\ I/M}}{N^D_{baseline}}$$

Equation (2)

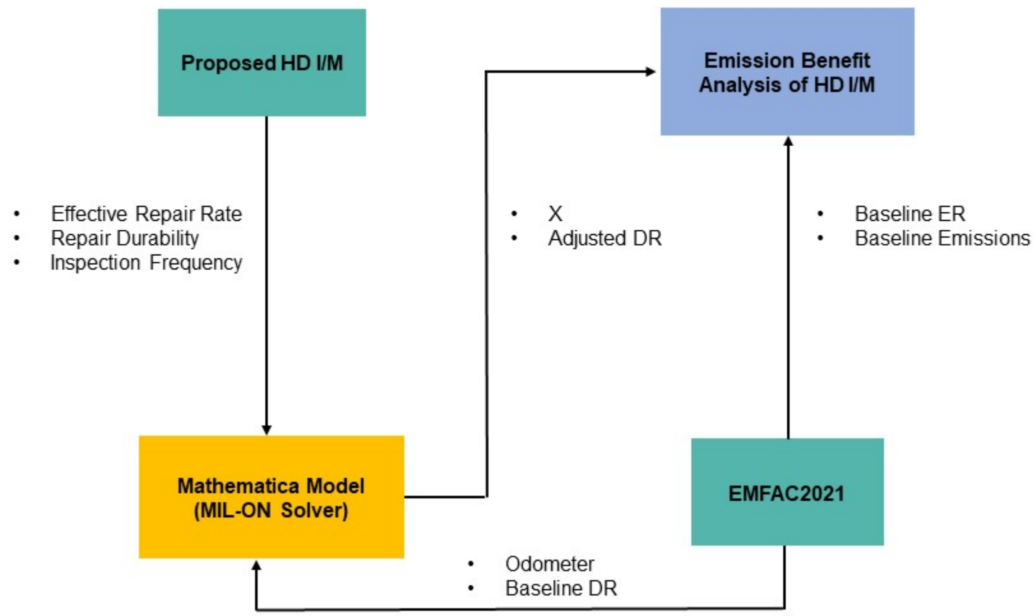
Figure D-1 illustrates the schematic of HD I/M emission inventory development and how different components are integrated:

(1) Major parameters are derived from the HD I/M proposal (e.g. effective repair rate, repair durability, and inspection frequency) and EMFAC model (e.g. odometer schedule, and baseline deterioration rate);

(2) The mathematical model integrates these parameters to obtain adjusted emission deterioration rates resulting from the proposed HD I/M program;

(3) Results from Step (2) are combined with EMFAC2021 to estimate emission benefits resulting from the implementation of the HD I/M program.

Figure D-1: HD I/M Emission Inventory Development



This emissions benefit analysis shows total NOx and PM exhaust emissions from heavy-duty vehicles, including running, start, and idling exhaust emissions. Within this analysis, CARB staff considered four different scenarios as described below:

- **Legal Baseline**: A business as usual scenario without the proposed HD I/M regulation. As noted earlier, this baseline does not account for the impact of Heavy-Duty Omnibus regulation due to pending OAL approval.
- **Proposed Regulation:** A scenario with the proposed HD I/M regulation with semiannual (i.e., twice per year) OBD testing requirement for OBD-equipped vehicles, and semiannual smoke opacity testing and visual inspection requirement for non-OBD-equipped vehicles. The periodic testing component would be complemented by roadside emissions monitoring to detect high emitting vehicles between periodic test cycles and require additional testing and repair to ensure emissions control components are operating properly.
- **Alternative 1**: A scenario with similar required elements as Proposed Regulation, but with less stringent periodic testing requirement, which would lower the overall effective repair rates. Specifically, there would be annual vehicle compliance testing requirement (instead of semiannually in the

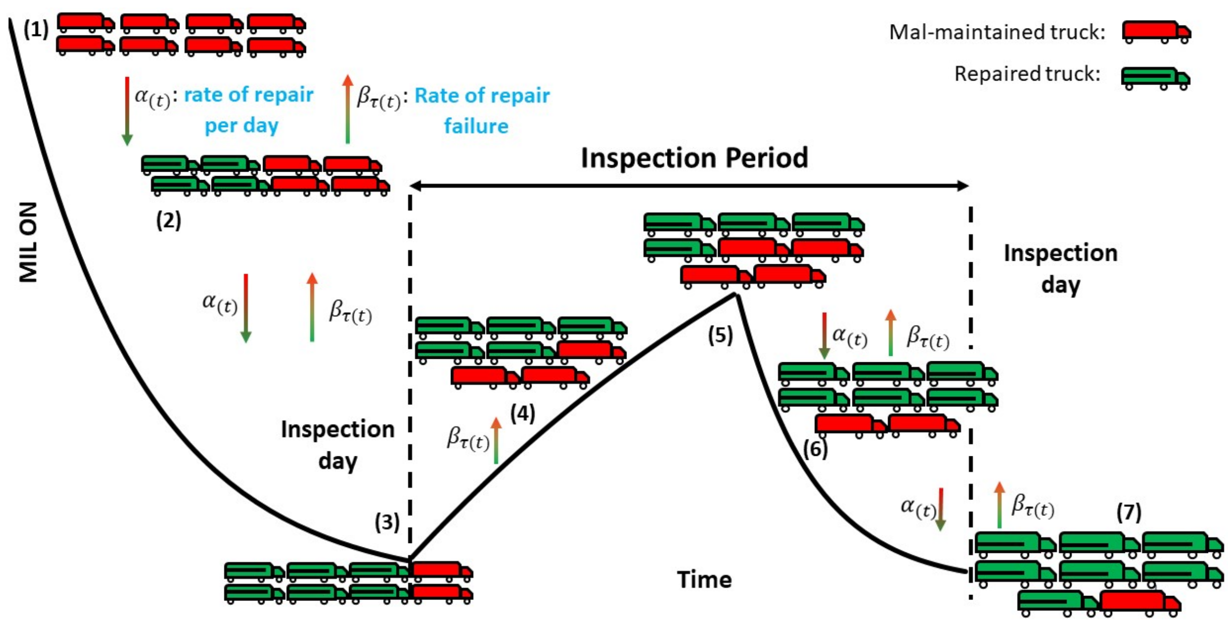
Proposed Regulation) and only for ten percent of fleet vehicle population. It would also provide exemptions to new vehicles.

- **Alternative 2:** In addition to the required elements in the primary proposal, Alternative 2 would require more stringent periodic testing on affected vehicles, i.e., additional dynamometer testing on non-OBD-equipped vehicles with engine model year 2010 through 2012 for NOx emission monitoring and quarterly (i.e, four times per year) rather than semiannual OBD testing requirement on OBD-equipped vehicles. These additional requirements would result in higher effective PM and NOx related repair rates for affected heavy-duty vehicles.

A. MIL-ON Solver (Mathematical framework)

Staff developed a mathematical model according to the needs and available parameters defined by the Proposed Regulation. Figure D-2 illustrates the schematic of the model.

Figure D-2: Schematic of the MIL-ON Solver Model



Under the proposed HD I/M regulation, a fraction of mal-functioning trucks would be repaired and added to the repaired trucks. At the same time, trucks that received repairs would not stay repaired indefinitely and repairs would re-fail according to their projected lifetime. These processes can be mathematically modeled as:

$$\frac{dN^D_{(t)}}{dt} = -\alpha_{(t)} N^D_{(t)} + \dot{M}_{(t)} + \sum_{\tau} \beta_{\tau(t)}\, N^C_{\tau(t)} \qquad \text{Equation (3)}$$

where $N^D_{(t)}$ represents the percentage of the mal-functioning trucks at any point in time, $M_{(t)}$ is the percentage of the mal-functioning trucks in the baseline and $\alpha_{(t)}$ represents the rate of repairs. $\beta_{\tau(t)}$ denotes the failure rate of repairs with age τ and $N^C_{(t)}$ is the percentage of repaired (clean) trucks that carry repairs with age τ respectively. The total percentage of the repaired clean trucks ($N^C_{(t)}$) can be derived as:

$$N^C_{(t)} = \sum_{\tau} N^C_{\tau(t)} \qquad \text{Equation (4)}$$

The average rate of repair failure can be defined as:

$$\overline{\beta}_{(t)} = \frac{\sum_{\tau} \beta_{\tau(t)}\, N^C_{\tau(t)}}{\sum_{\tau} N^C_{\tau(t)}} \qquad \text{Equation (5)}$$

The relationship between baseline mal-functioning percentage, the fraction that receives repairs, and the percentage of the mal-functioning trucks at any point in time can be shown using the following equation:

$$N^C_{(t)} + N^D_{(t)} = M_{(t)} \qquad \text{Equation (6)}$$

Combining Equations 4-6 the percentage of mal-functioning trucks as a function of time can be derived using a differential equation as shown below:

$$\frac{dN^D_{(t)}}{dt} = -\alpha_{(t)} N^D_{(t)} + \dot{M}_{(t)} + \overline{\beta}_{(t)}(M_{(t)} - N^D_{(t)}) \qquad \text{Equation (7)}$$

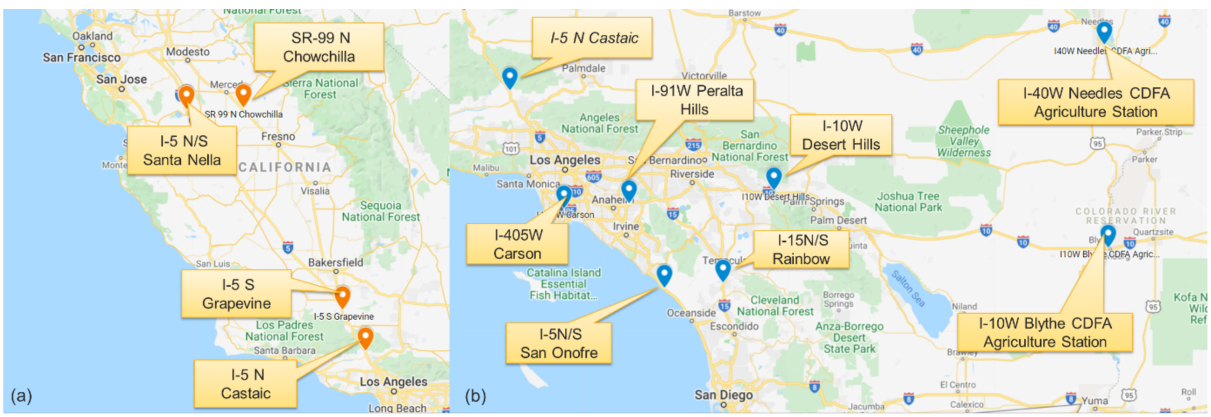
By solving the Equation 7 for each vehicle category and model year, the percentage of mal-functioning vehicles can be obtained for the HD I/M regulatory proposal. In Equation 7, $\overline{\beta_{(t)}}$ has been estimated based on the MacKay dataset (refer to Repair Durability section). For determining the repair rate per day ($\alpha_{(t)}$), a repair rate scheduling technique was employed. The technique distributes the effective repair rates to each day within an inspection period, while it conserves the effective repair rates.

B. Effective Repair Rates

1. Determining the Efficacy of Roadside Monitoring Program

Because of the immediate need for near term emissions reductions to meet federally mandated air quality standards in SC and SJV air basins, the proposed HD I/M regulation would first kick off in 2023 with a high emitting vehicle screening program. CARB plans to establish a PEAQS network of at least 14 unattended units along with two mobile units within the SJV and Southern California by January 1, 2023 (Figure D-3). Specifically, with two PEAQS systems already installed in San Bernardino County (installed in 2019) and Riverside County (installed in 2020), two to three additional systems will be installed over the course of 2021 in Madera, Kern, and Los Angeles Counties. In 2022, CARB will install the remaining nine to ten systems in Los Angeles, Merced, and Riverside Counties.

Figure D-3: Proposed Locations for Unattended PEAQS System Installation in San Joaquin Valley (a) and Southern California (b)[2]



Staff used the California Statewide Travel Demand Model (CSTDM) to derive the percentage of truck traffic that can be captured by the proposed PEAQS sites as compared to the total truck traffic within the SJV and SC air basins. The CSTDM model is the official statewide activity-based travel demand model commissioned and maintained by the California Department of Transportation (Caltrans) (Caltrans, 2021). The CSTDM model uses input from traffic networks, population, employment, and transportation surveys, and outputs loaded network data that provides detailed, high-resolution traffic information.

[2] The PEAQS unit at I-5N Castaic will support both air basins.

In this analysis, the California daily-averaged highway network data from 2015 were used to retrieve heavy-duty truck population and activity. To get the capture fraction, staff estimated (1) the traffic passing by each PEAQS unit and (2) the total distinct traffic moving through the air basins. In summary, as shown in Table D-1, the five PEAQS units placed in SJV would be estimated to capture approximately 38.1 percent of the total heavy-duty truck traffic within the basin and the ten PEAQS units would cover 26.2 percent of the total heavy-duty truck traffic in SC, with a total of 28.8 percent for all PEAQS units in the two air basins. With high emitting vehicles screened in SJV and SC, it is likely that inter-regional tractors (such as Class 7-8 California International Registration Plan (IRP) and OOS trucks) traveling in these two regions would bring co-benefit to the rest of the California. Therefore, 28.8 percent coverage rate is used to represent the efficacy of the PEAQS units for inter-regional tractors in the rest of California.

Table D-1: Fraction of Traffic Captured by PEAQS Units in SJV and SC

Locations	Capture Rate
SJV	38.1%
SC	26.2%
SC and SJV	28.8%

2. Repair Rates Estimates

As mentioned earlier, the effective repair rate depends on the efficacy of the proposed HD I/M program in a) identifying the mal-functioning, or non-compliant vehicles; and b) inducing effective repairs of non-compliant vehicles that result in real world emission reductions.

Percentage of Identified Non-compliant Vehicles

The Proposed Regulation would improve the identification rate of non-compliant vehicles progressively with the deployment of high emitting vehicle screening program along with periodic inspection requirements. As discussed above, in 2023, staff estimated that with a network of PEAQS systems initially rolled out at major state highway routes in SJV and SC air basins, about 38 percent and 26 percent, respectively, of heavy-duty vehicles travelling through these regions could be covered by these systems. Considering that a significant fraction of trucks travelling through SC and SJV are inter-regional, the reductions resulting from near-road monitoring systems would result in emissions reduction in other parts of the State that these inter-regional trucks may travel through. According to EMFAC estimates, 52 percent of inter-regional VMT occurs in SJV and SC regions. Based on CARB's past PEAQS pilot deployment, PEAQS' efficacy in identifying high emitting trucks that passes by the systems is estimated to be about 81 percent.[3] Thus, when taking into account these various factors, staff estimated the percentage of mal-functioning vehicles that can be identified is about 31 percent in SJV, 21 percent in SC, and 12 percent [4] for inter-regional tractors in the rest of California (excluding SJV and SC) in 2023 due to the Proposed Regulation.

Starting in 2024, the proposed periodic testing requirement of the program would take effect. Staff expects an increase in CARB's ability for identifying mal-functioning vehicles as compared to the identification rates in 2023 and estimated them based on data available through BAR's light-duty Smog Check program. Staff assumed statewide identification rates for mal-functioning non-OBD and OBD-equipped vehicles of 70 percent and 82 percent, respectively, in 2024-2025 (BAR, 2020). As part of staff's fraud detection strategy, the submitted test data would be mined for anomalies that might have resulted from improper activity. Analysis of submitted test data for fraudulent activity would be ongoing aspect of the proposed HD I/M program as more submitted test data come in over time. Hence, starting in 2026, staff assumed an increase in mal-functioning vehicle identification rate of 10 percent from the estimated rates in 2024 and 2025 due to the improvement in CARB's fraud detection of the submitted test data, as well as the expansion of PEAQS/RSD network throughout the State. Staff assumed statewide identification rates for mal-functioning non-OBD and OBD-equipped vehicles of 80 percent and 92 percent, respectively, in 2026 and later.

Table D-2 summarizes staff's estimated incremental percentage of mal-functioning vehicles that could be identified by CARB under the proposed regulation across different years. Further details can be found in Appendix F of the Staff Report.

Table D-2. Estimated Percentage of Non-Compliant Vehicles that Could be Identified by the Proposed HD I/M Regulation

Calendar Year	Region	Non-OBD	OBD
2023	SJV	31%	31%
2023	SC	21%	21%
2023	Rest of CA	12%	12%

[3] Staff assumed a 90 percent efficacy in capturing the license plate, and 90 percent efficacy for capturing the high emitting vehicles with an illuminated MIL. Combining these two factors, staff applied a correction factor of 81 percent to the resulting capture rate

[4] SJV: [100% vehicle coverage] x [81% PEAQS high-emitter identification efficacy] x [38% PEAQS vehicle capture rate] = 31%; SC: [100% vehicle coverage] x [81% PEAQS high-emitter identification efficacy] x [26% PEAQS vehicle capture rate] = 21%; The rest of CA: [52% vehicle coverage] x [81% PEAQS high-emitter identification efficacy] x [28% PEAQS vehicle capture rate] = 12%

Calendar Year	Region	Non-OBD	OBD
2024-2025	Statewide	70%	82%
2026+	Statewide	80%	92%

Percentage of Repaired Identified Non-Compliant Vehicles

Staff does not expect all identified mal-functioning or non-compliant vehicles (hereinafter referred to as non-compliant vehicles) would receive repairs, as evidenced in the 2019 CARB's enforcement citation data (CARB, 2020c). Staff projected that the percentage of identified non-compliant vehicles that would effectively get repaired would be 90 percent for in-state vehicles, and remain consistent throughout the implementation of the Proposed Regulation as the tie to vehicle registration is the strongest hook to ensure vehicles get repaired. For OOS vehicles, staff projected 45 percent of identified non-compliant vehicles would get repaired in 2023, consistent with current Heavy-Duty Diesel Inspection Program (HDVIP) citation data that suggests enforcement efforts are about half as effective for OOS vehicles as for in-state vehicles. As enhanced enforcement efforts take effect in the subsequent phases of the proposed regulatory implementation, it is expected that enforcement effectiveness for the OOS vehicle population would improve. Thus, starting in 2024, staff projected an increase in OOS vehicle repair percentage to 68 percent.[5] Table D-3 summarizes staff's estimated percentage of identified non-compliant vehicles that would get repaired under the Proposed Regulation over different years.

Table D-3: Estimated Percentage of Identified Non-Compliant Vehicles that Would Get Repaired by the Proposed HD I/M Regulation

Calendar Year	In-state	OOS
2023	90%	45%
2024+	90%	68%

Combining the two key parameters, percentage of identified non-compliance vehicles (Table D-2) and percentage of repaired identified non-compliant vehicles (Table D-3), staff estimated the effective repair rates by region, vehicle type (non-OBD vs. OBD), registration status (in-state vs. OOS), pollutant over different calendar years, as shown in Table D- 4 and Table D- 5. Please note that in this analysis, staff assumed no NOx benefits for non-OBD vehicles. Similarly, the repair rates under Alternative 1 and Alternative 2 are presented in Table D- 6 and Table D- 7.

[5] Average of 45 percent OOS repair in 2023 and annual 90 percent in-state vehicle repair for 68 percent OOS repair in 2024 and later.

Table D- 4: Effective Repair Rates with PEAQS in SJV and SC at the Initial Phase of the Proposed HD I/M regulation in 2023

Region	Vehicle Type	PM In-State	PM OOS	NOx In-State	NOx OOS
SJV	Non-OBD	28%	14%	0%	0%
SJV	OBD	28%	14%	28%	14%
SC	Non-OBD	19%	10%	0%	0%
SC	OBD	19%	10%	19%	10%
Rest of CA (excluding SJV and SC)	Non-OBD	11%	5%	0%	0%
Rest of CA (excluding SJV and SC)	OBD	11%	5%	11%	5%

Table D- 5: Effective Repair Rates in 2024 and onwards under the Proposed HD I/M Regulation.

Calendar Year	Vehicle Type	PM In-State	PM OOS	NOx In-State	NOx OOS
2024-2025 (Statewide)	Non-OBD	63%	47%	0	0
2024-2025 (Statewide)	OBD	74%	55%	74%	55%
2026+ (Statewide)	Non-OBD	72%	54%	0	0
2026+ (Statewide)	OBD	83%	62%	83%	62%

Table D- 6: Effective Repair Rates in 2024 and Onwards under Alternative 1

Calendar Year	Vehicle Type	PM In-State	PM OOS	NOx In-State	NOx OOS
2024+ (SJV)	Non-OBD	35%	26%	0	0
2024+ (SJV)	OBD	36%	27%	36%	27%
2024+ (SC)	Non-OBD	28%	21%	0%	0%
2024+ (SC)	OBD	30%	22%	30%	22%
2024+ (Rest of CA)	Non-OBD	21%	16%	0	0
2024+ (Rest of CA)	OBD	23%	17%	23%	17%

Table D- 7: Effective Repair Rates in 2024 and Onwards under Alternative 2

Calendar Year	Vehicle Type	PM In-State	PM OOS	NOx In-State	NOx OOS
2024-2025 (Statewide)	Non-OBD (Pre-2009 EMY)	63%	47%	0	0
2024-2025 (Statewide)	Non-OBD (2010-2012 EMY)	63%	47%	63%	47%
2024-2025 (Statewide)	OBD	74%	55%	74%	55%
2026+ (Statewide)	Non-OBD (Pre-2009 EMY)	72%	54%	0	0
2026+ (Statewide)	Non-OBD (2010-2012 EMY)	72%	54%	72%	54%
2026+ (Statewide)	OBD	83%	62%	83%	62%

3. Dynamic Repair Rates

As the fleet becomes cleaner, and the number of non-compliant vehicles shrinks significantly, it is inherently more difficult to identify those vehicles and repair them. Hence, the mathematical model used in this analysis to estimate the impact of the proposed HD I/M program on the overall MIL ON frequency of the fleet accounts for this effect through a concept called dynamic repair rate. The dynamic repair rate assumes that the maximum repair rate is limited by potential fraud percentages. However, as the percentage of mal-functioning trucks decreases, it becomes more difficult to identify those trucks in the fleet, and therefore the repair rate inherently becomes smaller. As shown in Figure D- 4, an S-shaped curve with sigmoid function has been chosen to represent the relationship between dynamic effective repair rates ($r^{dynamic}_{HDIM}$) and the percentage of the mal-functioning trucks ($\overline{N^D}$).

$$r_{HDIM}^{dynamic} = \frac{r_{HDIM}}{1+e^{-90(\overline{N^D}-0.07)}} \qquad \text{Equation (8)}$$

These parameters were selected to ensure that the sigmoid function produces the maximum repair rate at 15 percent, the fleet average of mal-functioning vehicles fraction, and approaches zero once the percentage of mal-functioning trucks become very small. Also, the selected constants of the sigmoid function ensure when the mal-functioning percentage is below 5 percent, the repair rate will fall below 15 percent of the maximum repair rate. Also, when the mal-functioning percentage is above 10 percent, the repair rate exceeds 90 percent of the maximum repair rate. Figure D-5 demonstrates an output example from the mathematical model and illustrates that dynamic repair rate will result in higher mal-functioning truck than the constant one repair rate, hence less emission benefits.

Figure D- 4: Demonstration of Dynamic Repair Rate as a Function of the Percentage of Mal-functioning Vehicles

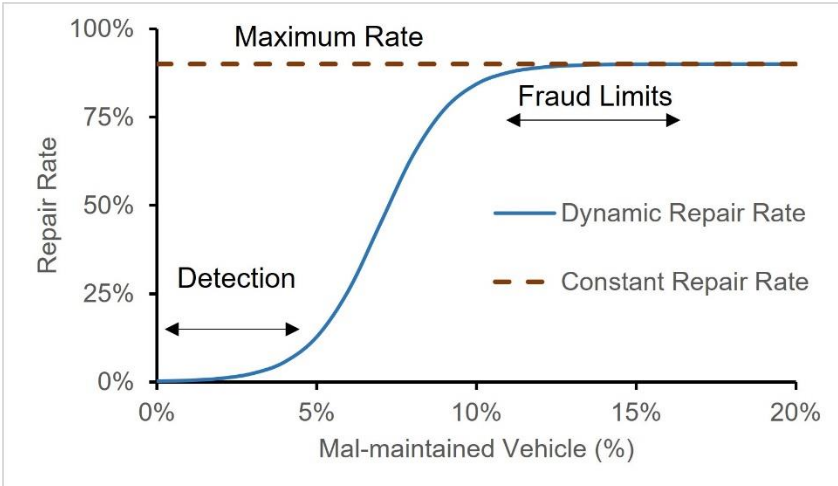
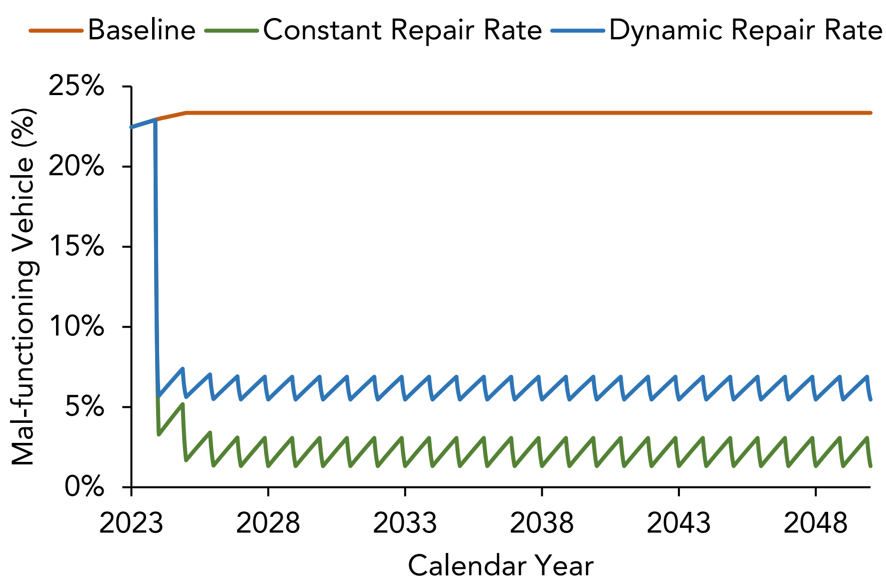


Figure D-5: Effects of Dynamic Repair Rate on Mal-functioning Vehicle Percentage (Class 8 Tractors with vehicle MY2014)



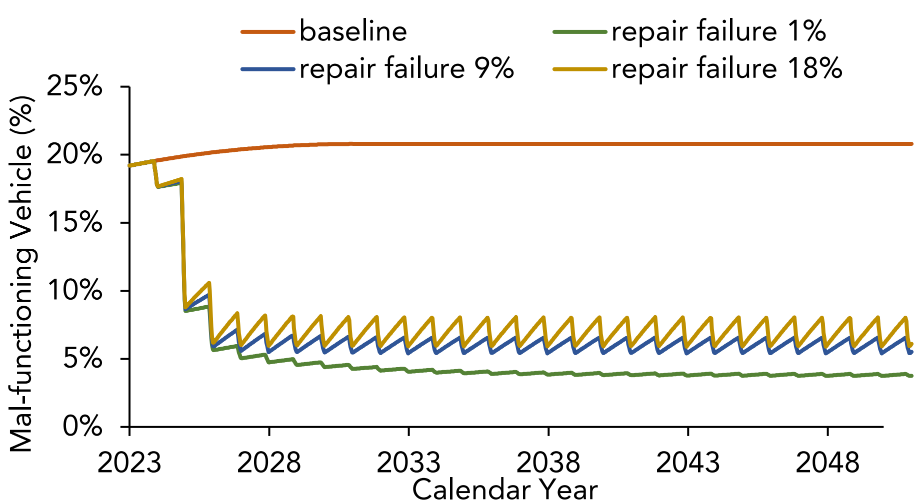
C. Repair Durability

Data from light-duty Smog Check program (BAR, 2020) has demonstrated that not all repairs are durable (Figure D-7). While HD I/M program can ensure a mal-functioning vehicle is repaired, there is still a chance for the vehicle to re-fail after a limited timeframe. MacKay & Company is a management consulting and market research firm for commercial trucking, construction, and agricultural equipment. MacKay's national survey data (refer to Appendix F of the Staff Report for details) on heavy-duty vehicle and engine component replacement intervals were used to estimate the annual re-fail rates for repaired vehicles, as shown in Table D-8. While other factors are kept the same, the sensitivity analysis of repair failure (Figure D-6) shows that less durable, or higher repair failure rates would result in less effective reduction in number of mal-functioning vehicles, and thus limited emission benefits for the proposed HD I/M program.

Table D-8: Annual Repair Failure Rate Based on McKay Dataset

Vehicle Type	% Annual Repair Failure
Non-OBD	14.4%
OBD	9.07%

Figure D-6: Effects of Repair Failure Rates on Mal-functioning Vehicle Percentage (Class 8 Tractors with MY2014)



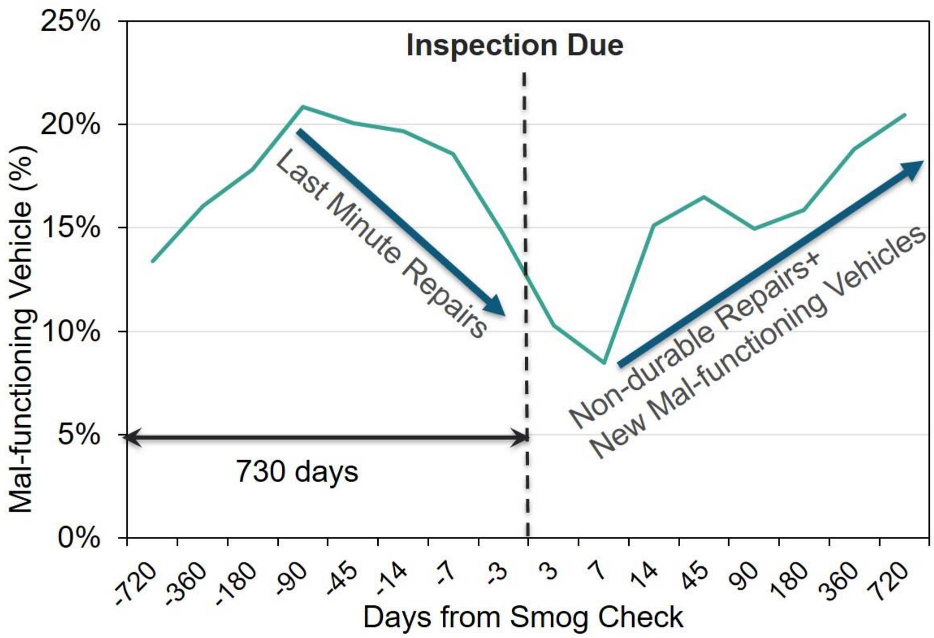
D. Inspection Frequency

The proposed HD I/M regulation would require vehicle owners to periodically submit inspection data to the HD I/M reporting system. The proposed inspection interval and the inspection result submission window under HD I/M and alternatives are shown in Table D-9. With more frequent inspections, it is more likely to identify and repair a higher number of non-compliant vehicles. As illustrated in Figure D-7, light-duty Smog Check's roadside inspection data demonstrates that vehicle owners typically do not address emissions related issues until their smog check is due (CARB, 2019d). Note that the smog check inspection result is good for 90 days, hence, repair rates are assumed to decrease up until 90 days prior to the deadline are observed and it is likely that repairs would happen during the submission window prior to the inspection due date for each inspection interval. This has been modeled by applying a step-wise repair rate per day in the mathematical model, as demonstrated in Figure D-8.

Table D-9: Inspection Interval and Submission Window

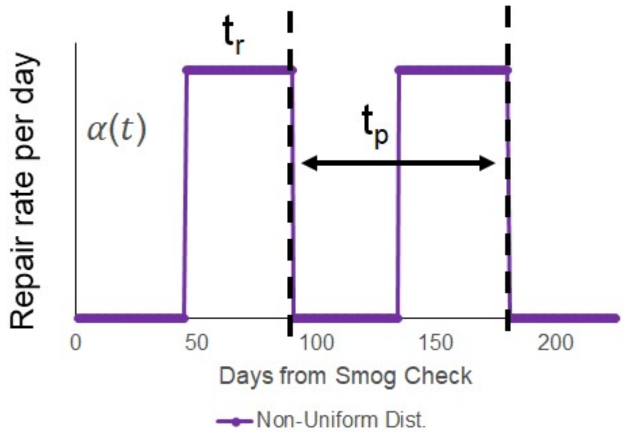
Scenario	Vehicle Type	Submission Window (t_r)	Inspection Interval (t_p)
Proposed Regulation	Non-OBD	90	180
Proposed Regulation	OBD	90	180
Alternative 1	Non-OBD and OBD	90	365
Alternative 2	Non-OBD	45	180
Alternative 2	OBD	45	90

Figure D-7: Evolution of Mal-functioning Light-Duty Vehicle Percentage based on BAR's Random Roadside Inspection Program[6]



[6] The figure is based on data from California's light duty Smog Check program which requires a biannual inspection (one inspection every two years). The increase in mal-functioning percentage is not

Figure D-8: Demonstration of a Step-Wise Function of Repair Rate per Day[7]



t_p: Days between inspection
t_r: Days with increase in repair rate per day

Periodic inspection frequencies influence the periodic behaviors of both "last minute repairs," which reflect the fraction of days that effective repairs occur, and "non-durable repairs" which are more likely to be identified if more frequent inspections are required. The combined effects of periodic inspection frequencies are accounted in the mathematical model and an example is shown in Figure D-9. With the proposed HD I/M regulation, the percentage of non-compliant vehicles shows similar periodic behavior as observed from light-duty Smog Check program (Figure D-7). When inspection frequency is increased from annually (every 365 days) to bi-annually (every 180 days) or quarterly (every 90 days), the percentage of mal-functioning trucks will drop and effectively reduce emissions from these non-compliant/mal-functioning vehicles, as shown in Figure D- 10.

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only due to non-durable repairs, but also new mal-functioning vehicles that are added to the mal-functioning pool. It is noteworthy to mention that California's light duty Smog Check program has been running for more than 30 years, and the saw-tooth shape of the mal-functioning vehicle percentage is due to a balance between repairs, repair failures, and introduction of new mal-functioning vehicles as they age.

[7] Vertical dashed line represents inspection due date. $\alpha(t)$ is repair rates per day as it is shown on the Y axis

Figure D-9: Periodic Behaviors of Mal-functioning Vehicle Percentage Caused by Periodic Inspection (Class 8 Tractors with MY2014 with Annual Inspection)

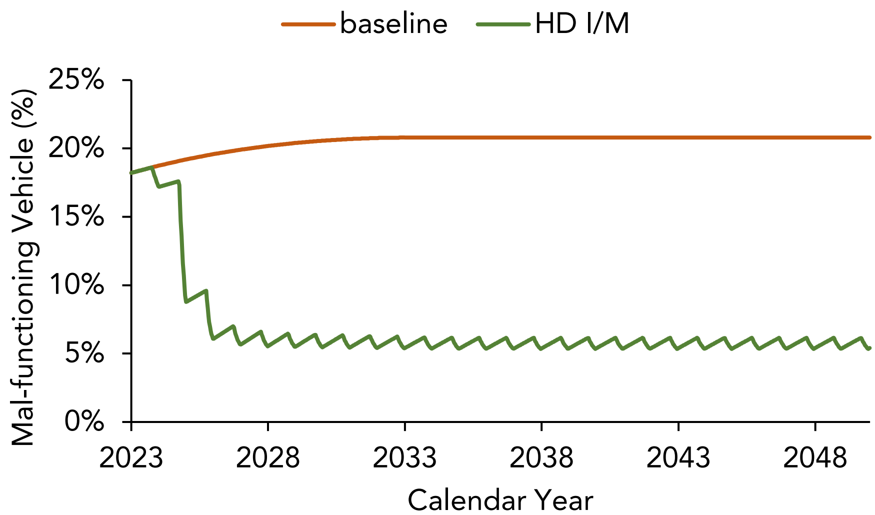
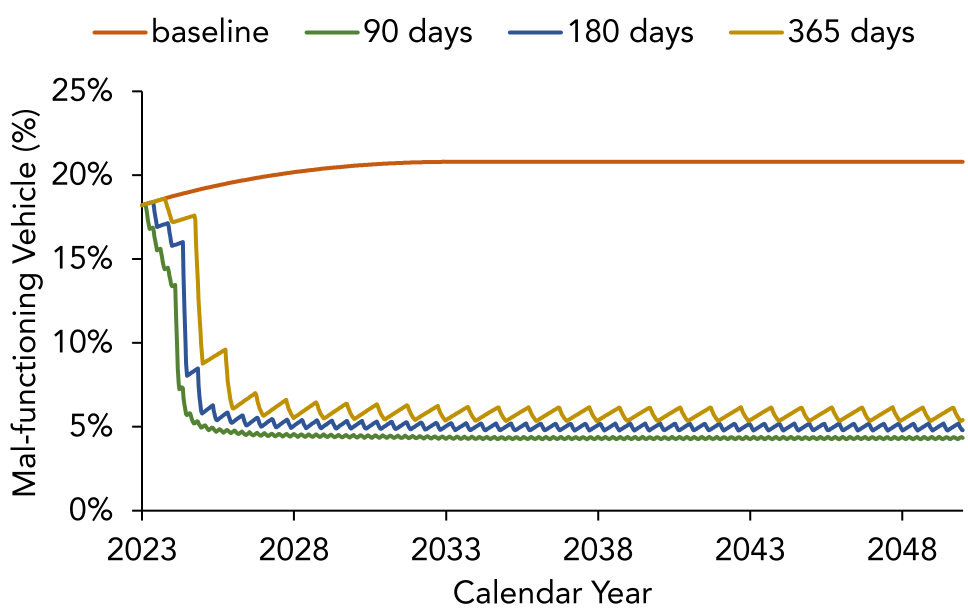


Figure D- 10: Effects of Inspection Interval on Mal-functioning Vehicle Percentage (Class 8 Tractors with MY2014)



IV. Emission Benefit Results

Figure D- 11 shows the statewide NOx and PM emissions under various scenarios. The numbers behind this figure are also provided in Table D- 11 and Table D-12. Note that the presented emission benefit results for all scenarios are relative to the legal baseline, which does not include the proposed Heavy-Duty Omnibus Regulation. Similarly, results for SJV and SC air basins are shown in Figure D- 12 and Figure D- 13, respectively.

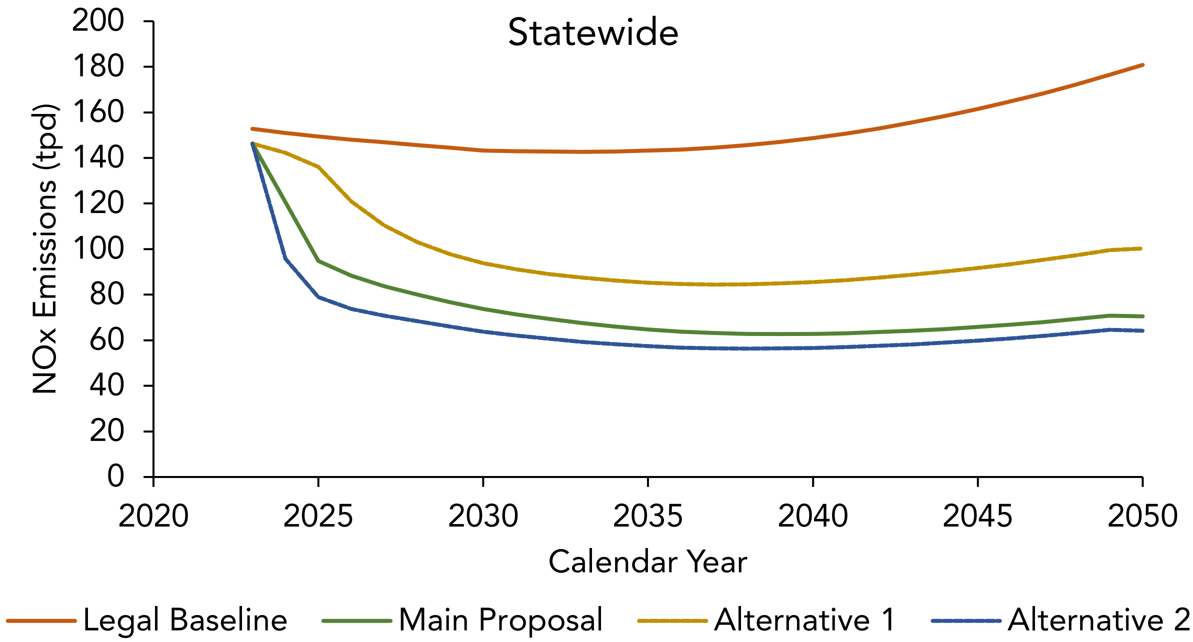
In 2023, as part of the proposed HD I/M regulation, a network of PEAQS systems will initially roll out at major state highway routes in SJV and SC air basins. As shown in Table D- 10, this action would result in about 2.7 tpd and 2.1 tpd of NOx emissions reductions in SJV and SC air basins in 2023, respectively. Despite relatively lower emission benefits, the PEAQS component of the HD I/M regulation eases the challenges to reduce PM and NOx emissions in order to achieve air quality targets in the near-term. In 2023, the statewide NOx emissions reduction is estimated to be approximately 6.4 tpd.

After 2024, with the full implementation of periodic testing, improvement of fraud detection of the submitted test data, as well as the expansion of PEAQS/RSD network throughout the State, more mal-functioning vehicles are expected to be identified and repaired, which would result in higher emission benefits for those years. In 2037, the proposed HD I/M would result in 22.1 tpd NOx emissions reduction in SC, and 21.5 tpd in SJV, and in total 81.3 tpd statewide. In 2050, the statewide NOx emissions reduction is expected to be approximately 110 tpd.

Table D- 10: Emission Benefits under the Proposed HD I/M Regulation in Key SIP Years

	Statewide	Statewide	SC	SC	SJV	SJV
Calendar Year	NOx (tpd)	PM (tpd)	NOx (tpd)	PM (tpd)	NOx (tpd)	PM (tpd)
2023	6.4	0.072	2.1	0.023	2.7	0.030
2024	30.3	0.324	8.4	0.083	8.6	0.089
2025	54.5	0.604	14.5	0.149	14.3	0.152
2031	71.6	0.658	19.5	0.165	18.7	0.169
2037	81.3	0.698	22.1	0.171	21.5	0.184

Figure D- 11: Statewide NOx and PM Emissions (tpd) under the Legal Baseline, Proposed Regulation, and Alternatives



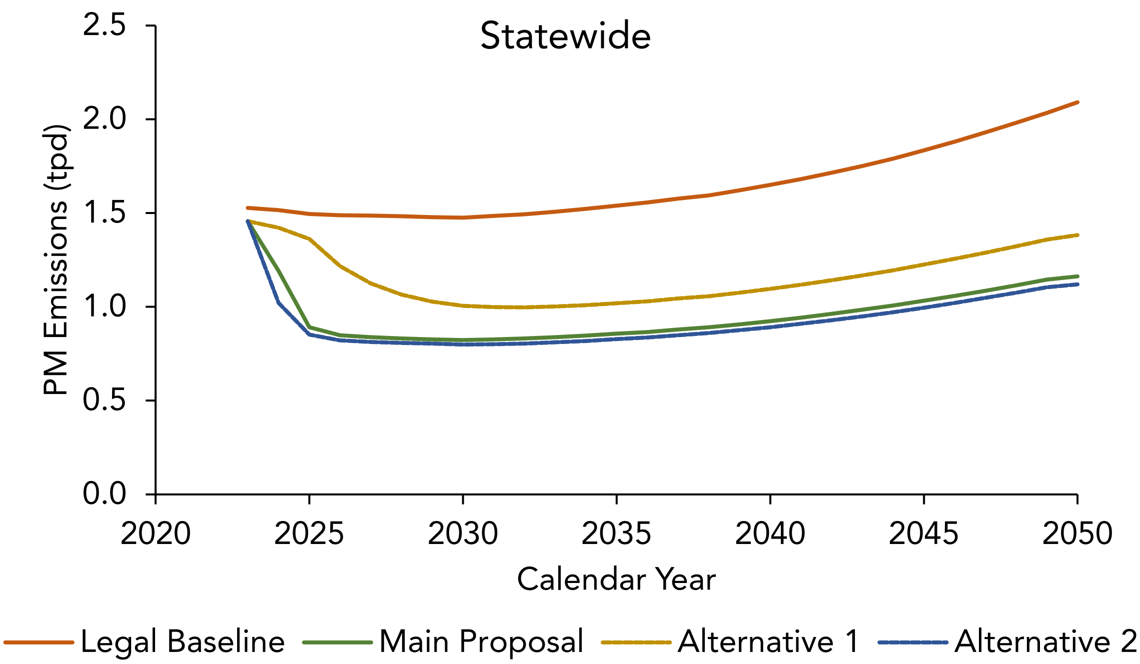
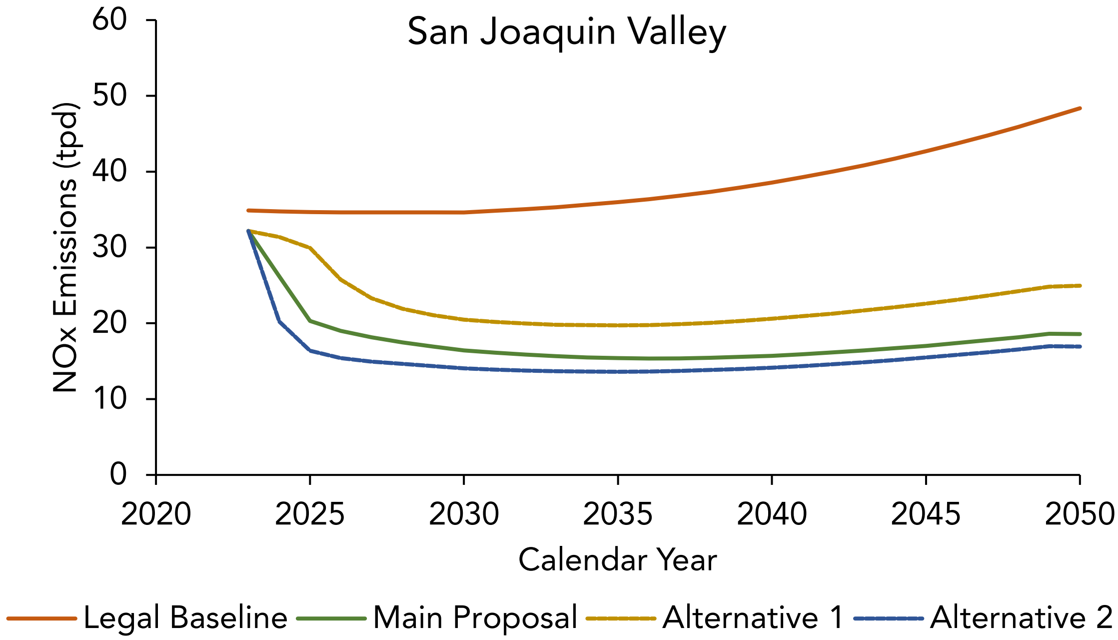


Figure D- 12: NOx and PM Emissions (tpd) in SJV Air Basin under the Legal Baseline, Proposed Regulation, and Alternatives



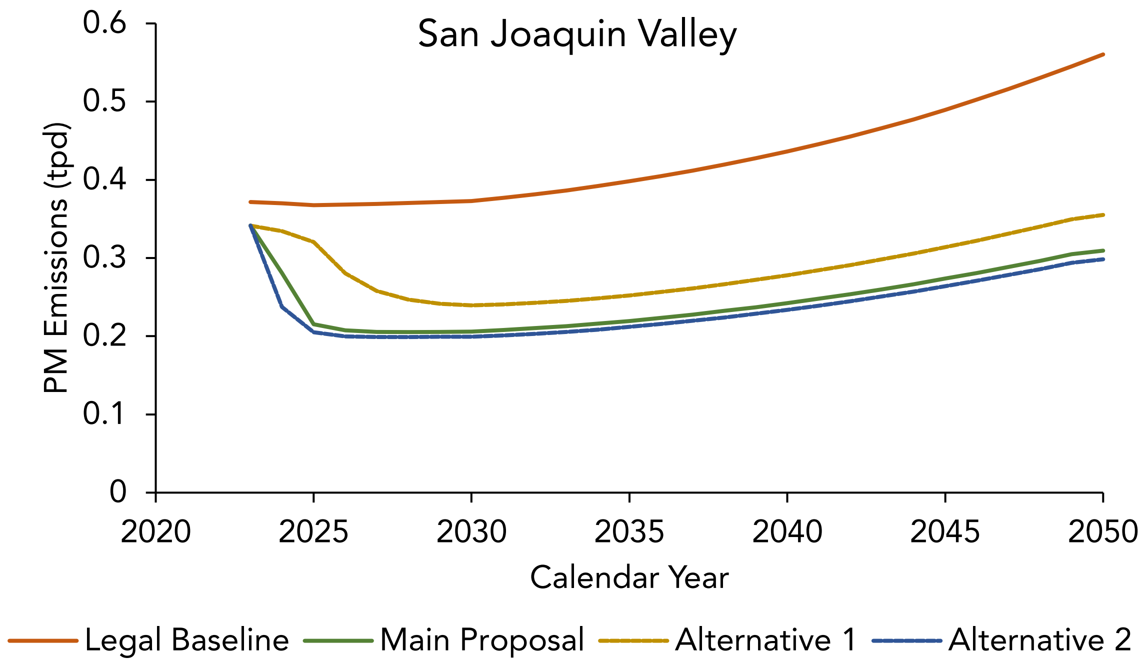


Figure D- 13: NOx and PM Emissions (tpd) in SC Air Basin under the Legal Baseline, Proposed Regulation, and Alternatives

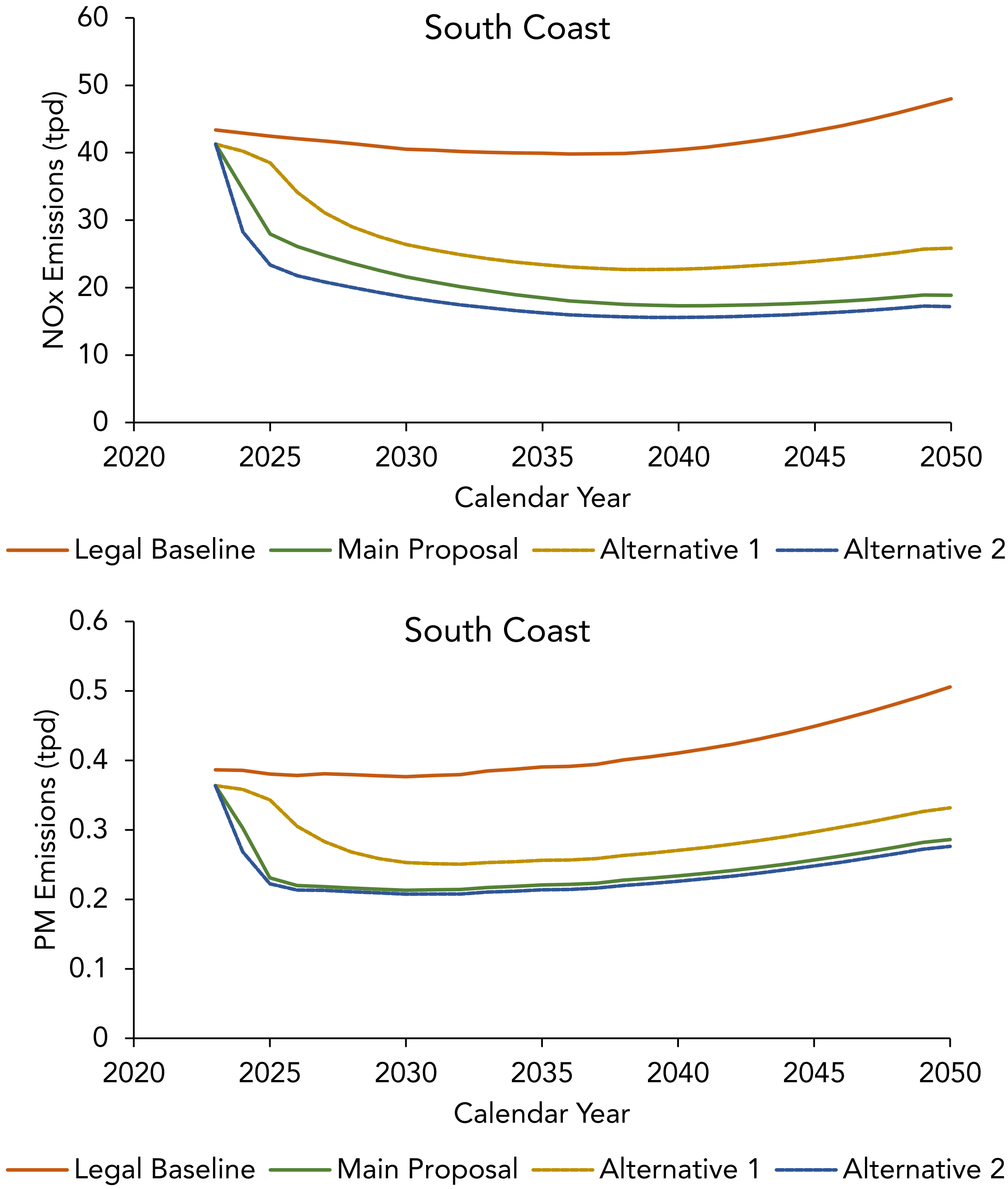


Table D- 11: Statewide NOx Emissions (tpd) under the Legal Baseline, Proposed HD I/M Regulation and Alternatives

Calendar Year	Legal Baseline	Proposed Regulation	Alternative 1	Alternative 2
2023	152.7	146.3	146.3	146.3
2024	151.0	120.7	142.3	95.8
2025	149.4	94.9	136.1	78.9
2026	148.0	88.3	120.9	73.8
2027	146.8	83.8	110.4	70.8
2028	145.7	80.0	103.0	68.4
2029	144.5	76.7	97.8	66.0
2030	143.3	73.7	93.8	63.8
2031	143.0	71.4	91.2	62.1
2032	142.8	69.4	89.1	60.6
2033	142.7	67.6	87.4	59.3
2034	142.8	66.0	86.2	58.3
2035	143.2	64.8	85.3	57.5
2036	143.6	63.8	84.6	56.8
2037	144.5	63.2	84.4	56.5
2038	145.6	62.8	84.5	56.3
2039	147.0	62.7	84.9	56.4
2040	148.7	62.8	85.6	56.6
2041	150.7	63.1	86.4	57.0
2042	153.0	63.6	87.5	57.5
2043	155.6	64.2	88.8	58.2
2044	158.4	64.9	90.2	58.9
2045	161.5	65.8	91.7	59.8
2046	164.8	66.8	93.4	60.8
2047	168.4	68.0	95.3	61.9
2048	172.3	69.3	97.4	63.2
2049	176.5	70.8	99.6	64.5
2050	180.8	70.6	100.216	64.2

Table D- 12: Statewide PM Emissions (tpd) under the Legal Baseline, Proposed HD I/M Regulation and Alternatives

Calendar Year	Legal Baseline	Proposed Regulation	Alternative 1	Alternative 2
2023	1.528	1.457	1.457	1.457
2024	1.516	1.192	1.422	1.022
2025	1.495	0.892	1.363	0.852
2026	1.488	0.849	1.218	0.821
2027	1.487	0.838	1.125	0.814

Calendar Year	Legal Baseline	Proposed Regulation	Alternative 1	Alternative 2
2028	1.483	0.831	1.065	0.809
2029	1.479	0.827	1.028	0.804
2030	1.476	0.823	1.005	0.799
2031	1.485	0.827	0.999	0.801
2032	1.494	0.831	0.997	0.804
2033	1.508	0.839	1.002	0.811
2034	1.523	0.847	1.009	0.818
2035	1.540	0.857	1.020	0.828
2036	1.556	0.867	1.030	0.837
2037	1.577	0.879	1.044	0.849
2038	1.595	0.891	1.057	0.860
2039	1.621	0.907	1.076	0.875
2040	1.650	0.924	1.096	0.892
2041	1.681	0.943	1.118	0.910
2042	1.715	0.963	1.142	0.929
2043	1.751	0.985	1.168	0.950
2044	1.791	1.008	1.196	0.972
2045	1.835	1.033	1.225	0.996
2046	1.881	1.059	1.257	1.021
2047	1.930	1.086	1.289	1.048
2048	1.981	1.115	1.324	1.076
2049	2.035	1.145	1.360	1.105
2050	2.091	1.163	1.383	1.121