California Air Resources Board

Appendix H
ACC II LEV Technology Appendix

Date of Release: April 12, 2022
Date of Hearing: June 9, 2022

Table of Contents

List of Figures

List of Tables

I. Introduction

For the air in California to meet the health-based national and state ambient air quality standards for criteria pollutants under the federal Clean Air Act, especially by the 2031 and 2037 deadlines for the national ozone standards, and other public health goals, emissions of harmful air pollutants from motor vehicle engines must be reduced. In particular, motor vehicle engines are a significant share of the State's nitrogen oxide (NOx) emissions that cause excessive ground-level ozone, or smog, and inhalable fine particulate matter, or soot. Reducing emissions of fine particulate matter (PM) from motor vehicles will also help attain the ambient air quality standards in the San Joaquin Valley and other areas of California. Considering that motor vehicles can stay on the road for a long time, early action on this front is critical for maximizing reductions to harmful pollutants like NOx and PM to reach and maintain the air quality standards. Reducing emissions are critical as early action will save more lives and result in fewer premature deaths and hospitalizations.

Reducing these emissions is of great importance because of the serious nature and magnitude of California's air quality challenges. California is one of the most climate and air pollution challenged areas on the continent. It has some of the country's hottest and driest areas and suffers record-breaking heat waves and extensive wildfires. As these problems are exacerbated by climate change, it become more challenging to meet the health-based air quality standards for ozone and particulate matter. Thus, it becomes more important to reduce emissions of these pollutants as soon as possible. As a result, the State is diligently moving ahead with reducing these harmful pollutants through various programs, including Advanced Clean Cars II for light- and medium-duty vehicles and engines.

As ACC II moves ahead with electrification of the light-duty fleet at a rapid pace, this might be the last time that staff will work on new criteria emission regulations for light-duty combustion engine vehicles. Therefore, for these vehicles with combustion engines, the main objectives are to reduce criteria emissions by further increasing the stringency of existing emission standards, and to focus on reductions that will translate to real-world emission benefits, rather than rules that solely produce good results in a lab environment.

Additional stringency measures being proposed include changes to the aggressive driving standards on the US06 test cycle for NMOG+NOx and particulate matter emissions for light-duty and medium-duty vehicles and tightening the running loss evaporative emission standard. In addition to stronger standards, ACC II will also propose new regulations to ensure the resulting emission reductions occur in actual on-road driving, especially to improve control of cold-start emissions that continue to be the major source of criteria emissions from light-duty vehicles. Therefore, ACC II includes proposals for new regulations to control cold-start emissions following partial soaks, during quick drive-aways, and for plug-in hybrid electric vehicle high-power cold-starts. For medium-duty vehicles, staff is also proposing to introduce a new moving average window in-use standard to improve emission control during towing operation.

The following sections of this appendix present emission test data and certification data to support the ACC II criteria emission proposals for light-duty and medium-duty vehicles. The analysis shows that the improved standards in the proposed regulation are eminently feasible and cost effective. They are already being met by many vehicles on the road today. Ensuring all vehicles meet them will incur marginal costs and deliver significant public health and environmental benefits.

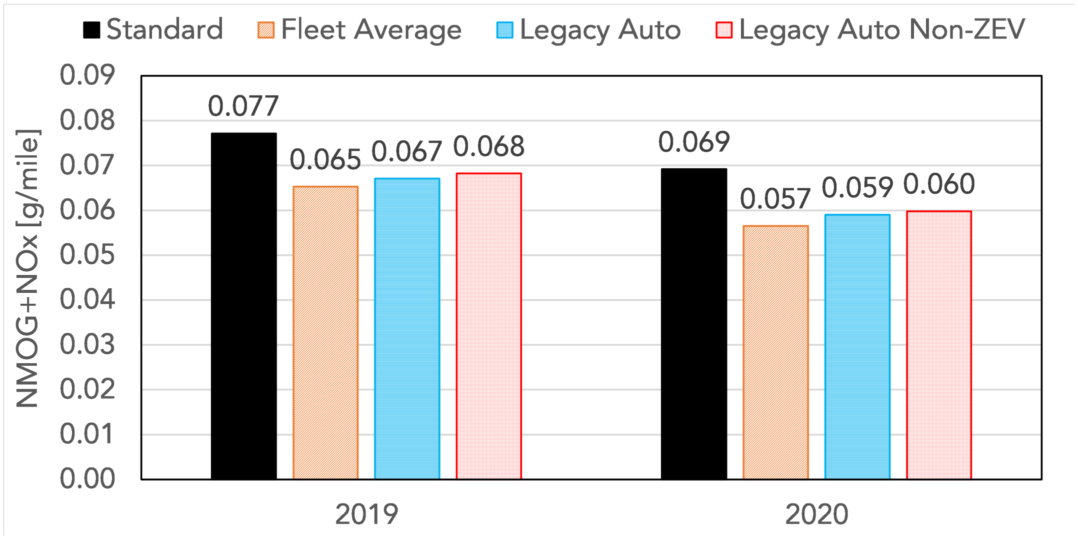
II. Emission Testing for Light-Duty Vehicle Exhaust Emission Proposals

A. Phase-Out of ZEVs from the NMOG+NOx Fleet Average

Current rules allow automakers to utilize ZEVs to meet the NMOG+NOx fleet average requirements. However, as ZEV sales are expected to substantially increase in the future, action is necessary to avoid emission backsliding of the non-ZEV portion of the fleet since automakers can offset ICE vehicle emissions by selling more ZEVs. For example, to meet the fleet average requirement of 0.030 g/mile in 2025, an automaker that has 10% ZEVs in its fleet will have to ensure the 90% of non-ZEVs in its fleet are below 0.033 g/mile. However, if thereafter the automaker increases ZEVs sales to 50%, then the non-ZEV portion of the fleet only has to be below 0.060 g/mile to meet a 0.030 g/mile fleet average. This would allow the automaker to substantially backslide on non-ZEV emissions and action is needed to avoid such scenarios. Therefore, to prevent non-ZEV emission backsliding, staff considered phasing-out and removing ZEVs from the NMOG+NOx fleet average compliance.

Staff analyzed 2019 and 2020 model year certification data to gain an understanding of the current effect of ZEVs on the fleet average. The analysis revealed that the industry has been complying with the current standards as shown in Figure 1. Including ZEVs in the fleet, as current rules allow, the industry-wide fleet average was 0.065 g/mile in 2019 and 0.057 g/mile in 2020, which was 0.012 g/mile below the levels required by the standards in each model year.

Figure 1: NMOG+NOx Fleet Average Certification Data



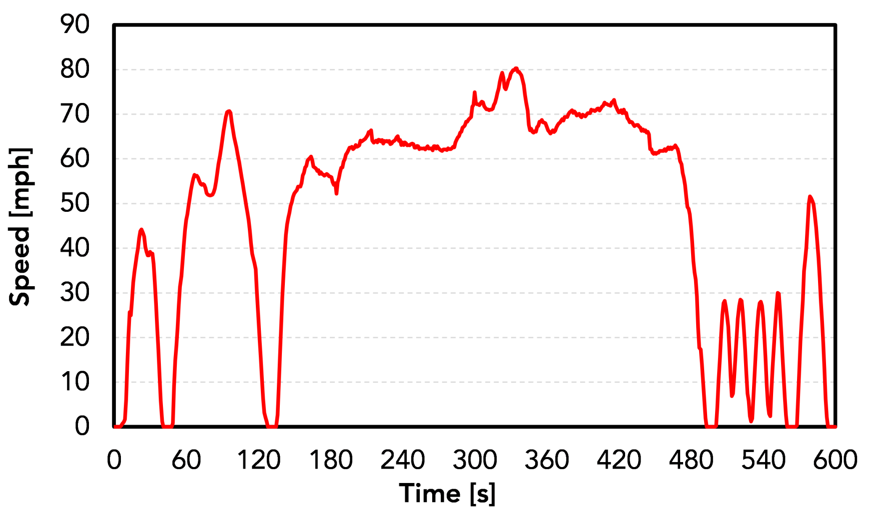
When removing pure ZEV automakers, like Tesla, from the industry fleet average, the certification data showed that the legacy automaker fleet was still 0.010 g/mile below the standard in both model years. Finally, even when taking out ZEVs from the legacy automaker fleet, the legacy automakers were still 0.009 g/mile below the fleet average in both 2019 and 2020. This not only demonstrates that automakers can meet current NMOG+NOx fleet average requirements without ZEVs, but also shows that automakers are currently generating NMOG+NOx credits that will help them comply with the fleet average standards in future model years.

Going forward to the 2025 model year, the fleet average will reduce to 0.030 g/mile and some automakers may plan to rely more on the use of ZEVs to meet the NMOG+NOx fleet average. However, this is a choice that each automaker is free to make related to their vehicle plans and is not a requirement. In fact, the LEV III rulemaking did not rely on any ZEVs in its feasibility analysis to meet the 0.030 g/mile fleet average requirement in 2025. Instead, the LEV III rulemaking considered in its analysis that all LEV and ULEV vehicles will be upgraded to SULEV30. Although there are costs associated with converting LEV and ULEV vehicles to SULEV30 vehicles, these costs were previously accounted in the LEVIII rulemaking. Some of the technologies that were included in the LEV III analysis were larger volume catalysts, greater catalyst precious metal loading, more optimized close coupled catalysts, optimized thermal management, low thermal mass turbochargers, double layer catalyst washcoat, and improved fuel injection control. As these are still the same technologies that automakers have already deployed and can continue to utilize to convert current and future vehicles to SULEV30, it indicates that a non-ZEV fleet average of 0.030 g/mile is feasible. Therefore, to prevent emission backsliding from future non-ZEVs, staff will propose to phase-out ZEVs from the fleet average and require that non-ZEVs meet a 0.030 g/mile fleet average on their own.

B. NMOG+NOx Emissions During Aggressive Driving

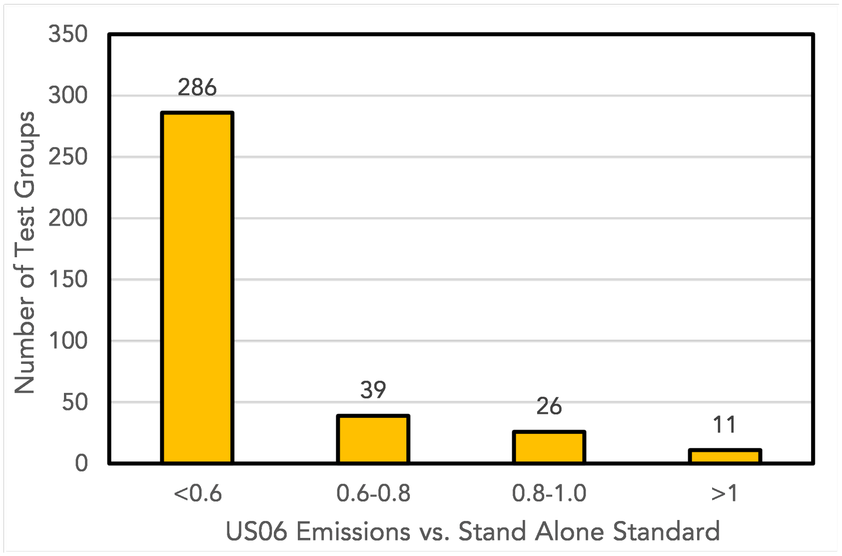
Current LEV III rules allow two different options for automakers to certify aggressive driving emissions. The stand-alone US06 standards option requires vehicles to meet a specific NMOG+NOx target on the aggressive driving US06 cycle, under high-speed and rapid acceleration conditions shown in Figure 2.

Figure 2: US06 Test Cycle.



On the other hand, the composite SFTP emission standards option allows vehicles to certify aggressive driving emissions using a composite emission value that is derived by averaging aggressive driving on the US06 cycle with less aggressive driving on the FTP cycle, which consists mostly of city driving that includes frequent stops, and the SC03 cycle. Currently, nearly all automakers have elected to certify aggressive driving emissions using the composite emission method. Analysis of certification data, shown in Figure 3, revealed that a large majority of the vehicles in the fleet have done a good job of controlling aggressive driving emissions on the US06 cycle. The figure shows that over 90% of vehicles have demonstrated US06 emissions below the US06 stand-alone standards, despite certifying to the composite SFTP method.

Figure 3: US06 NMOG+NOx Emissions Relative to the LEV III US06 Stand-Alone Standards Based on Certification Data for 2020 Model Year Vehicles.



However, the data in Figure 3 also shows that a small portion of the fleet had poor emission control during aggressive driving on the US06 cycle that resulted in emissions that exceed the LEV III stand-alone standards for the US06 cycle. Therefore, to ensure that all vehicles have good emission control during aggressive driving, staff's proposal will require all vehicles to meet stand-alone standards for the US06 cycle. To determine an appropriate emission standard for each vehicle emission category, staff conducted emission testing of numerous light-duty vehicles. A list of the test vehicles is given in Table 1. The test vehicles included three different vehicle emission categories, ranging from SUELV30 to ULEV125, various makes and models, and a wide range of engine sizes and vehicle weights.

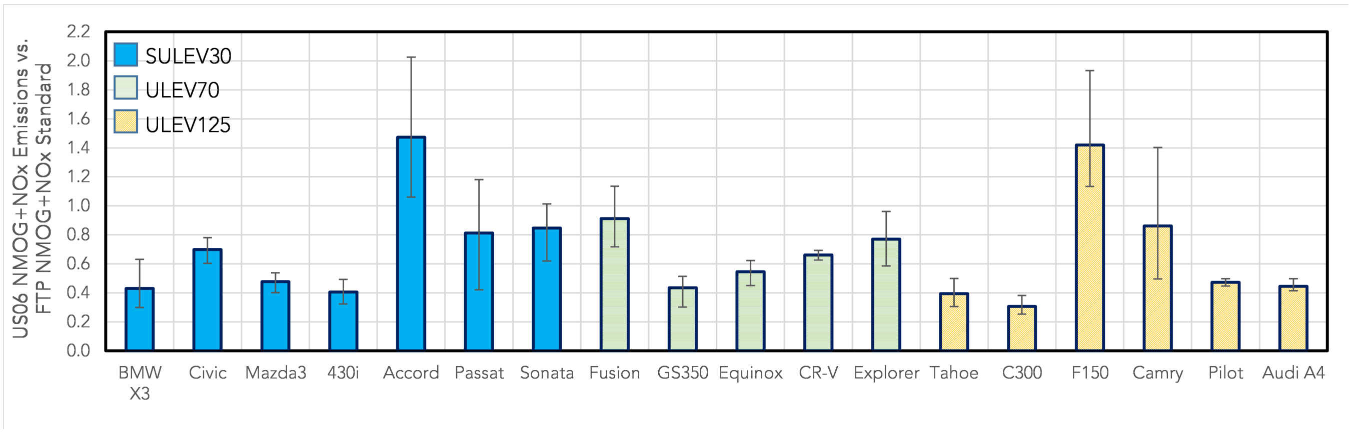
Table 1: List of Light-Duty Vehicles for US06 NMOG+NOx Emission Testing

Vehicle Make and Model	Model Year	Vehicle Emission Category	Engine Displacement [L]
BMW 430i	2018	SULEV30	2.0
BMW X3	2020	SULEV30	2.0
Honda Accord	2017	SULEV30	2.4
Honda Civic	2017	SULEV30	2.0
Hyundai Sonata	2020	SULEV30	2.5
Mazda 3	2017	SULEV30	2.0
Volkswagen Passat	2020	SULEV30	2.0
Chevrolet Equinox	2018	ULEV70	1.5
Ford Explorer	2020	ULEV70	2.3
Ford Fusion	2018	ULEV70	2.0
Honda CRV	2017	ULEV70	1.5

Lexus GS350	2017	ULEV70	3.5
Audi A4	2018	ULEV125	2.0
Chevrolet Tahoe	2018	ULEV125	5.3
Ford F150 XLT	2017	ULEV125	3.5
Honda Pilot	2017	ULEV125	3.5
Mercedes C300	2017	ULEV125	2.0
Toyota Camry	2017	ULEV125	2.5

The results of the testing are presented in Figure 4. Since three different vehicle emission categories were tested, the emission results in the figure are shown relative to the FTP certification standard of each vehicle. By dividing each vehicle's US06 NMOG+NOx emissions by its FTP standard, it enables a comparison of vehicle performance between different vehicle emission categories. The values in the graph represent the average US06 NMOG+NOx emissions, while the error bars represent the maximum and minimum values observed from multiple tests. In addition, emission durability factors were included in the results in Figure 4 to give a better representation of full useful life emissions**.**

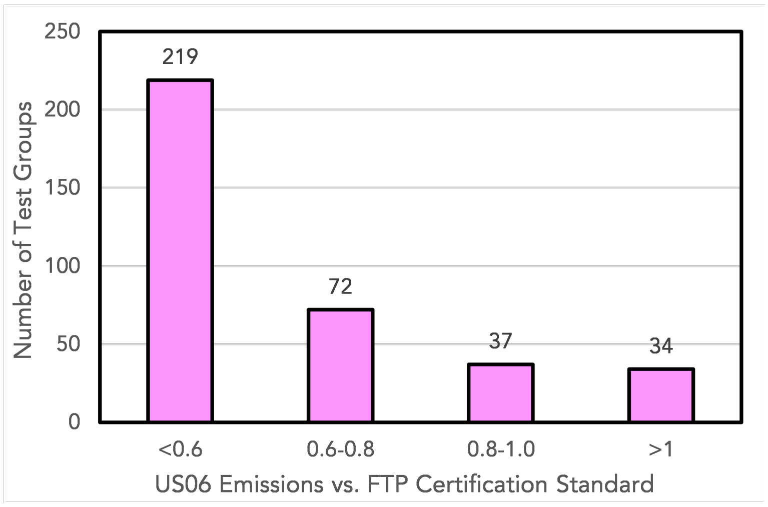
Figure 4: Ratio of US06 NMOG+NOx Emissions to FTP Certification Standard



The results in Figure 4 show that most test vehicles had good control of NMOG+NOx emissions on the US06 cycle since 16 of 18 test vehicles had average US06 emissions that were below the FTP certification standard. Even when considering test-to-test variations, as indicated by the error bars, 12 of 16 vehicles were able to demonstrate NMOG+NOx emission levels on the US06 cycle below the FTP standard. The results of these tests suggest that the FTP certification standard would be an appropriate emission target for NMOG+NOx emission compliance on the US06 cycle.

Staff analyzed 2020 certification data to further verify that setting the US06 stand-alone emission standard at FTP certification levels for NMOG+NOx would be feasible. The results of the analysis are shown in Figure 5, which shows the US06 NMOG+NOx emissions versus the FTP certification standard for each vehicle test group.

Figure 5: US06 NMOG+NOx Emissions Relative to the FTP Certification Standards Based on Certification Data for 2020 Model Year Vehicles.



The data in Figure 5 indicated that 90.6% of the 2020 fleet had US06 emissions, after factoring in the emission durability factor, that were below FTP levels. A similar analysis of 2021 certification data revealed that the percentage had increased to 93.0%. These findings were consistent with the emission test results shown in Figure 4 and provide justification for eliminating the composite SFTP certification option and setting a new stand-alone US06 NMOG+NOx emission standard at the FTP certification level.

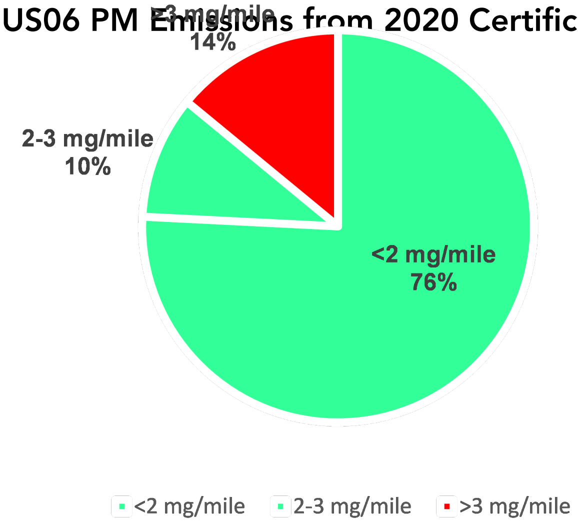
A similar analysis was done to compare CO emissions to the current US06 stand-alone standard of 9.6 grams per mile. 2020 certification data revealed that 98.1% of vehicle test groups had US06 CO emissions below 9.6 grams per mile. Therefore, staff's proposal will also eliminate the composite SFTP certification option for CO emissions and require every vehicle to meet a stand-alone US06 emission standard of 9.6 grams per mile. The stand-alone US06 standards for NMOG+NOx and CO emissions will help ensure that every vehicle will have good emission control during aggressive driving.

C. Particulate Matter Emission During Aggressive Driving

Current LEV III rules have PM standards for both the FTP cycle, which consists mostly of lower speed driving that includes frequent stops, and for the US06 cycle, which has more aggressive accelerations and higher speeds that are more typical of highway driving. The current PM standard for the FTP cycle is 3 mg/mile but phases down to 1 mg/mile from 2025 to 2028. However, the PM standard for the US06 cycle is currently set at 6 mg/mile, with no concurrent reduction in the future. Staff conducted vehicle testing and analyzed certification data to investigate the feasibility of lowering the US06 PM standard.

Analysis of 2020 certification data showed that over three quarters of vehicle test groups reported US06 PM emissions that were under 2 mg/mile and only 14% reported US06 PM emissions that were above 3 mg/mile as shown in Figure 6. This data suggested that reducing the US06 PM standard below 3 mg/mile was feasible for most vehicles in the current new vehicle fleet.

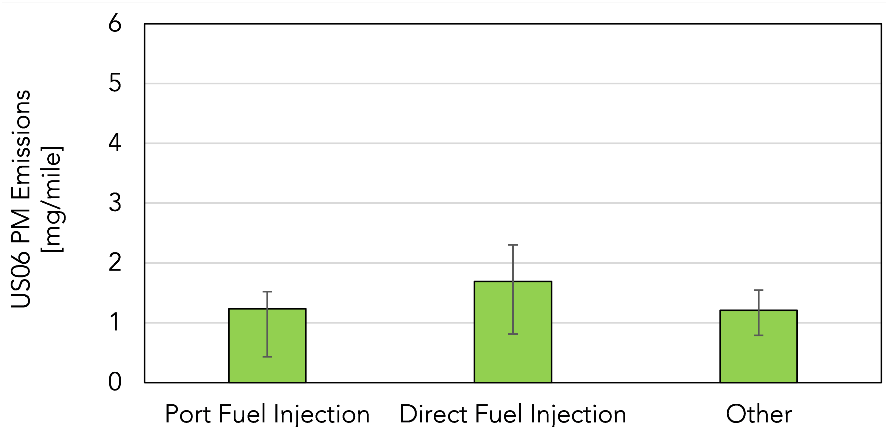
Figure 6: US06 PM Emissions from 2020 Certification Data.



Additional analysis of certification data was conducted to investigate whether fuel injection systems had a discernable effect on the US06 PM emission results. In particular, US06 PM emissions of port fuel injection vehicles were compared to those of direct fuel injection vehicles. The data in Figure 7 revealed that direct fuel injection vehicles had, on average, slightly higher US06 PM emissions than port fuel injection vehicles. However, the average US06 emissions of direct fuel injection vehicles were still below 2 mg/mile.

A similar trend was observed when comparing the 75th percentile of the US06 PM emission values for each vehicle category, as shown by the error bars in Figure 7 that show the 25th and 75th percentile range. In this instance, the 75th percentile for direct fuel injection vehicles was higher than that of the port fuel injection vehicles and it was slightly above 2 mg/mile but significantly below 3 mg/mile. Therefore, the certification data indicated that a 3 mg/mile US06 PM standard was feasible for a majority of vehicles, regardless of the vehicle's fuel injection system type.

Figure 7: US06 PM Emissions of Port Fuel vs. Direct Fuel Injection Vehicles.



Note, that the "other" category shown in Figure 7 mostly contains vehicles that had a fuel injection system that utilized both port fuel and direct fuel injection or, in some instances, the fuel injection system was not distinctly categorized as direct or port fuel injection in the certification file. The "other" category had US06 emission results that were nearly identical to the port fuel injection vehicles, both in terms of the average value and the 75th percentile. As such, a 3 mg/mile US06 PM standard would also be feasible for most vehicles in the "other" category.

Staff also conducted vehicle testing to investigate test-to-test variability of individual vehicles. A list of test vehicles is provided in Table 2. The test vehicles included a span of vehicle sizes, engine displacement, and different types of fuel injection systems. All of the test vehicles were from 2017 and 2018 model years, during which time the US06 PM standard was 10 mg/mile.

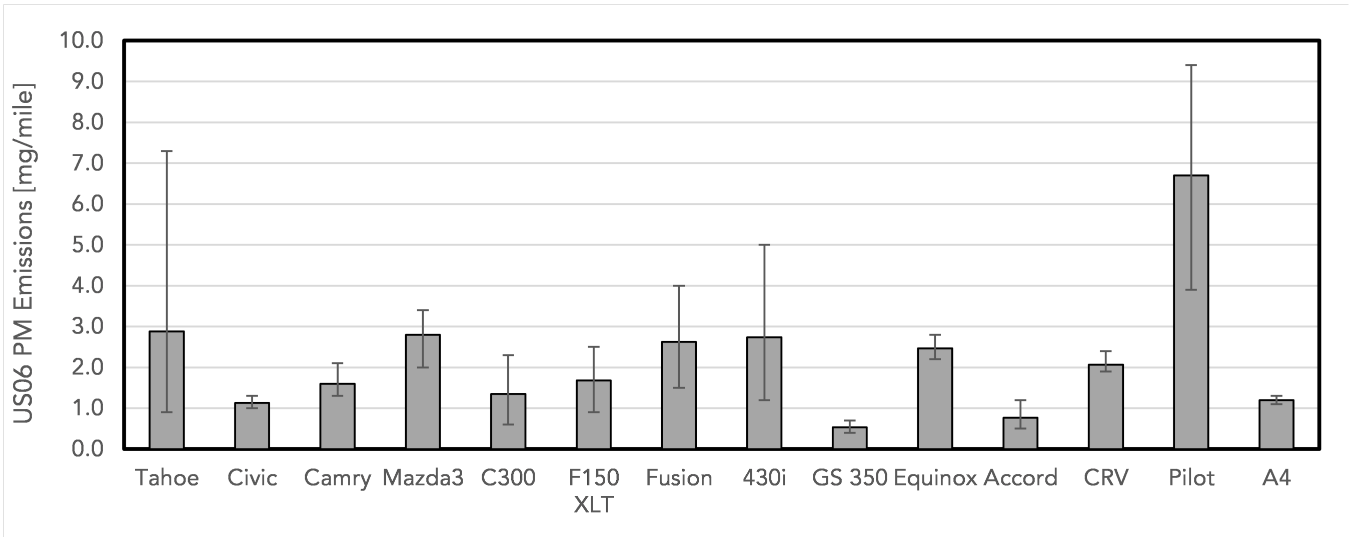
Table 2: List of Light-Duty Vehicles for US06 PM Testing

Make	Model	Model Year	Number of Cylinders	Engine Displacement [L]	Fuel Injection
Ford	F150 XLT	2017	6	3.5	PFI+DFI
Honda	Accord	2017	4	2.4	DFI
Honda	CRV	2017	4	1.5	DFI
Honda	Pilot	2017	6	3.5	DFI
Honda	Civic	2017	4	2	PFI
Lexus	GS 350	2017	6	3.6	PFI+DFI
Mazda	Mazda3	2017	4	2	DFI
Mercedes	C300	2017	4	3	DFI
Toyota	Camry	2017	4	2.5	PFI
Audi	A4	2018	4	2	DFI
BMW	430i	2018	4	2	DFI

Chevrolet	Tahoe	2018	8	5.3	DFI
Chevrolet	Equinox	2018	4	1.5	DFI
Ford	Fusion	2018	4	2	DFI

A summary of the test results is presented in Figure 8. The data showed that nearly all (13 of 14) test vehicles had average US06 PM emissions that were below 3 mg/mile. However, the data also revealed that many of the vehicles had large test-to-test variations as shown by the error bars in Figure 8 that represent the maximum and minimum values from multiple US06 PM tests. When the test variability was factored in, a majority of the test vehicles (9 of 14) still managed to achieve US06 PM emissions below 3 mg/mile, but some vehicles were considerably above the 3 mg/mile threshold.

Figure 8: US06 PM Emissions Test Results.

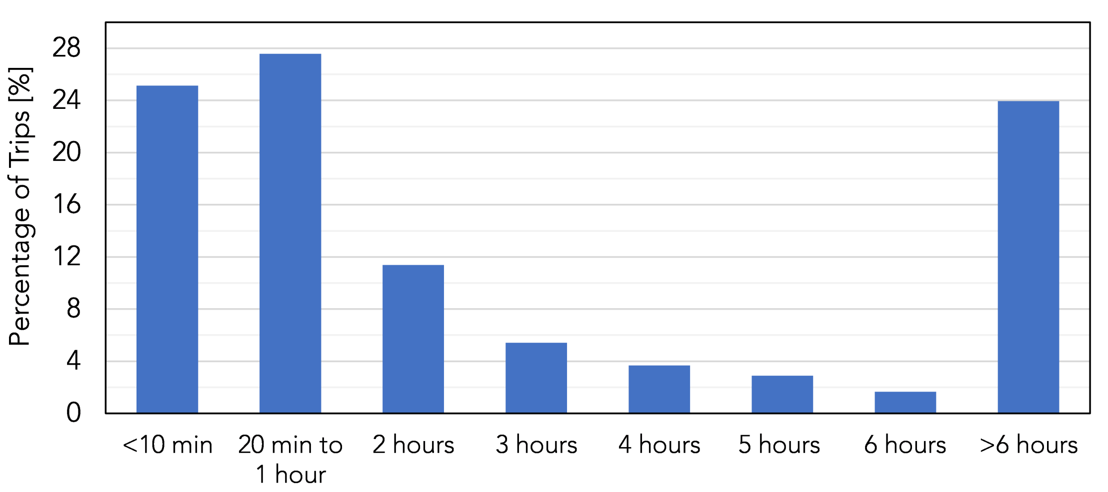


On average, the test-to-test variations resulted in emissions that were 46% higher than the average value. Considering that 76% of the 2020 new vehicle fleet had US06 PM emissions below 2 mg/mile, as indicated by the certification data in Figure 6, a 46% PM increase due to test variability would still allow most of the fleet to meet a 3 mg/mile standard. Taking this into account, staff proposal will require all vehicles to meet a 3 mg/mile US06 PM standard but will provide a 4 year phase-in period that will provide additional lead time to resolve the test-to-test variability concerns as observed on several test vehicles.

D. Partial Soak Cold-Start Emissions

Current rules only regulate cold-start emissions that follow an overnight soak where the vehicle is turned off for 12 to 36 hours, assuming that it represents the worst-case emissions with a fully cold catalyst. However, CARB's vehicle testing found that there were excess emissions for partial soaks, especially in the soak range of 30 minutes to 4 hours[1]. The excess emissions observed for partial soaks represent a substantial real-world emission effect since a large portion of in-use trips, over 40%, occur following a partial soak of 20 minutes to 4 hours as shown in Figure 9.

Figure 9: Vehicle Soak Distribution Based on CHTS Data[2].



Discussion with automakers revealed that the main cause of the emission increase for partial soaks was a different catalyst heating strategy compared to full soaks of 12 to 36 hours. As a result of CARB's discussions with automakers, most have already taken voluntary actions to reduce these excess emissions by improving the catalyst heating strategy for partial soaks. However, regulations are still needed to ensure that partial soak emissions continue to be addressed in the future and for all light-duty vehicles.

Therefore, staff conducted vehicle testing to determine appropriate emission standards for partial soak emissions. A list of test vehicles is given in Table 3**.** The vehicles selected for testing primarily included vehicles that were believed to have voluntarily addressed partial soak emissions. In addition, a 2008 Chevrolet Impala was tested as a baseline vehicle that represented an older vehicle that did not have the voluntary fix in place. The vehicles were tested on the FTP certification test cycle at various soak times ranging from 20 minute soaks to overnight soaks of more than 12 hours (720 minutes).

---

[1] California Air Resources Board, "EMFAC 2017 Volume III - Technical Documentation", Published July 20, 2018, https://ww3.arb.ca.gov/msei/downloads/emfac2017-volume-iii-technical-documentation.pdf

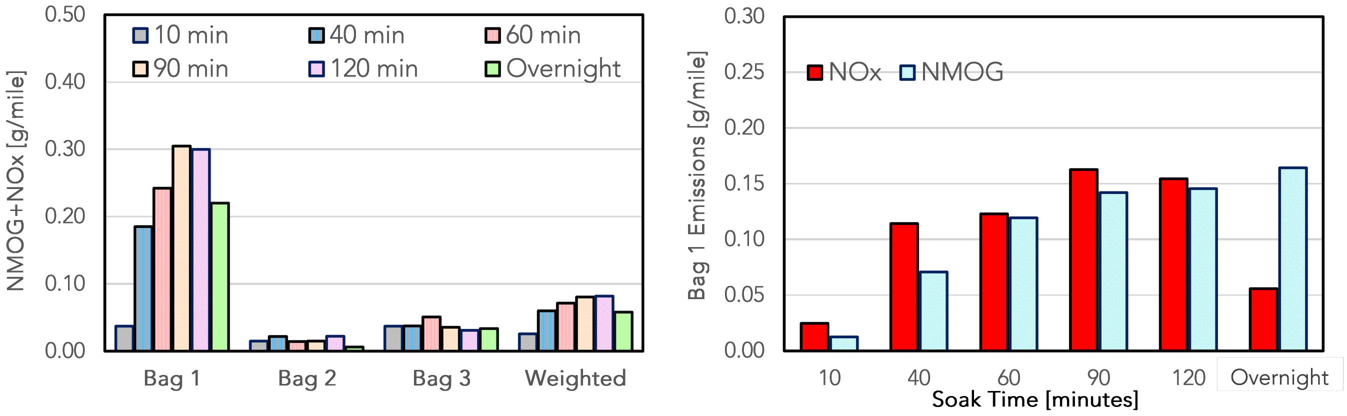
[2] National Renewable Energy Laboratory, "2010-2012 California Household Travel Survey", Accessed March 2, 2022, https://www.nrel.gov/transportation/secure-transportation-data/tsdc-california-travel-survey.html

Table 3: List of Light-Duty Vehicles for Partial Soak Testing

Make	Model	Model Year	FTP Bin	Fuel Injection and Air Intake	Engine [L]
Chevrolet	Impala	2008	LEVII LEV	PFI	3.5
BMW	X3	2020	SULEV30	Turbo, DFI	2.0
Hyundai	Sonata	2020	SULEV30	PFI+DFI	2.5
Toyota	Camry	2020	SULEV30	PFI+DFI	2.5
Volkswagen	Passat	2020	SULEV30	Turbo, DFI	2.0
Ford	Explorer	2020	ULEV70	Turbo, DFI	2.3

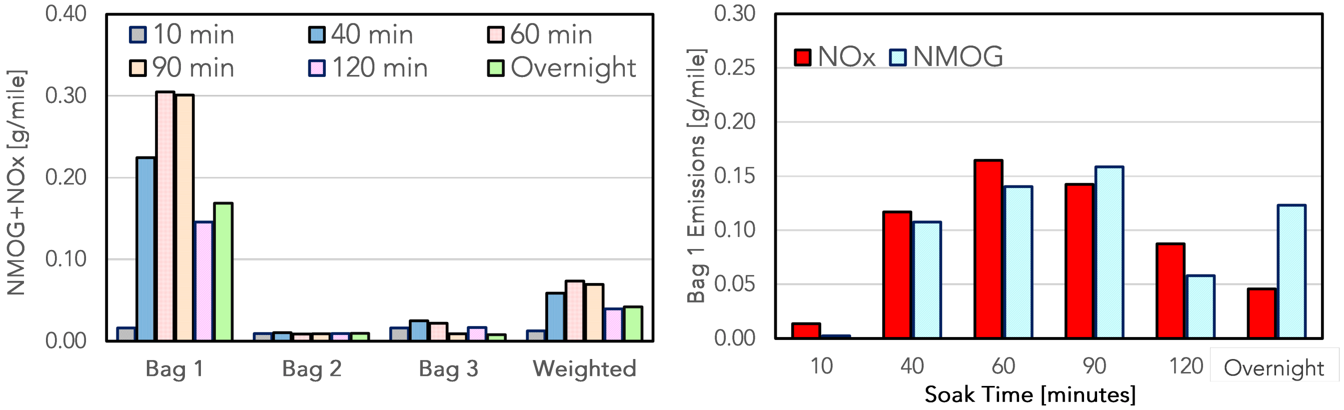
Figure 10 shows the emission test results of the Chevrolet Impala. As expected, the vehicle exhibited an increase in partial soak emissions compared to the overnight soak emissions. This was most evident in Bag 1 of the FTP test since Bag 1 represents the cold-start portion of the test whereas Bag 2 and Bag 3 represent the hot-running and hot-start phases. The increased cold-start emissions in Bag 1 also led to higher weighted emissions for partial soaks of 1 to 2 hours. Figure 10 also illustrates that the increased partial soak emissions were mostly caused by a substantial increase in NOx emissions compared to the overnight soak.

Figure 10: Partial Soak Emission Results for 2008 Chevrolet Impala.



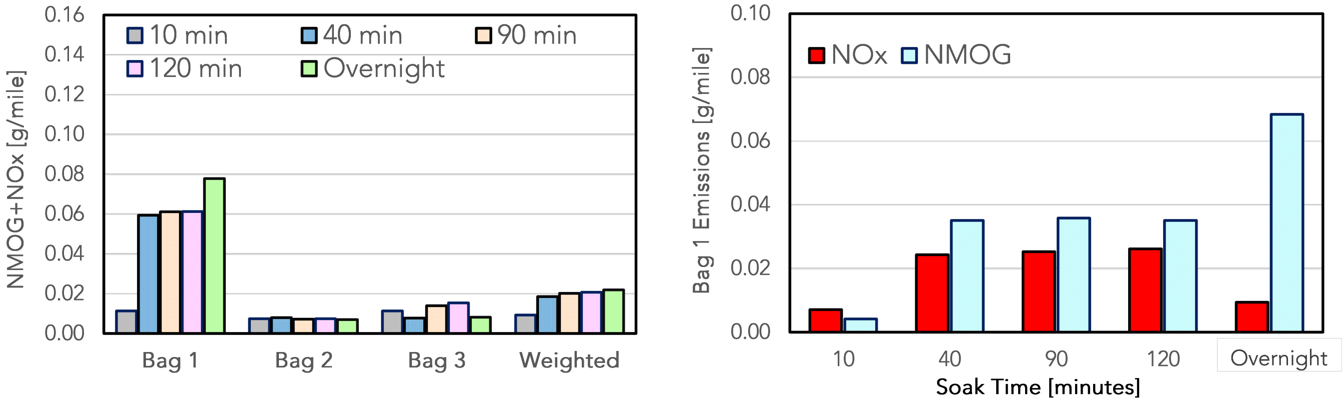
A similar trend was observed for a 2020 Ford Explorer. Although the Explorer was a new vehicle, it did not get the new calibration upgrade to reduce partial soak emissions. As a result, the data shown in Figure 11 illustrates the Explorer had higher partial soak emissions in Bag 1 of the FTP test. The increased emissions were most evident for partial soak in the range of 40 to 90 minutes. Similar to the Impala, the Explorer exhibited a substantial increase in NOx emissions for all partial soak tests.

Figure 11: Partial Soak Emission Results for 2020 Ford Explorer.



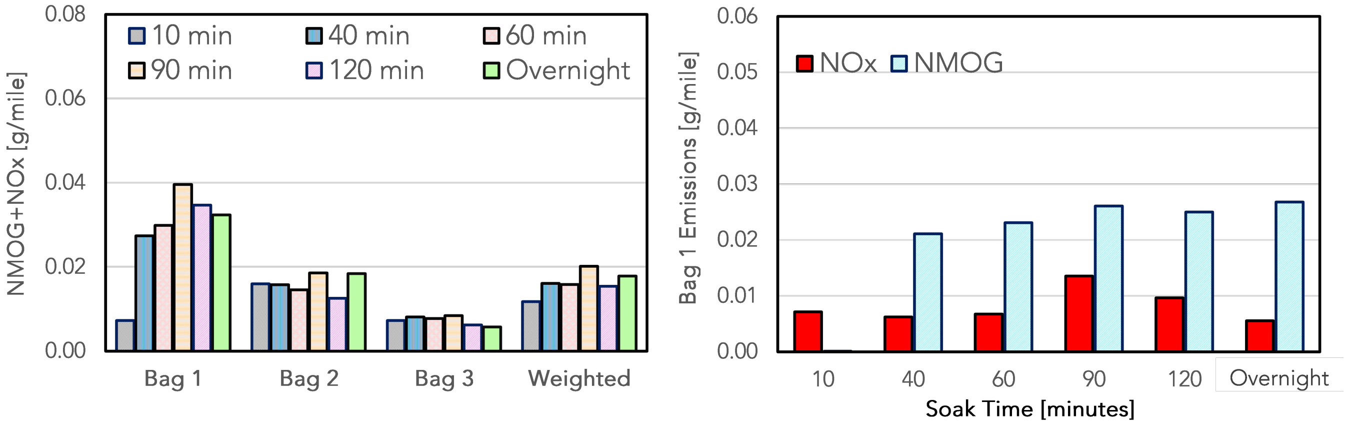
The 2020 Toyota Camry represents a vehicle that was recently recalibrated to improve emission control for partial soaks. The data in Figure 12 confirmed that the Camry had relatively good emission control for partial soaks compared to the Impala and Explorer. Bag 1 emission data indicated that partial soak emissions did not exceed the overnight soak emission levels. However, the improved emission control for partial soaks was only observed for NMOG emissions, whereas partial soaks still caused a substantial increase in NOx emissions as shown in Figure 12.

Figure 12: Partial Soak Emission Results for 2020 Toyota Camry.



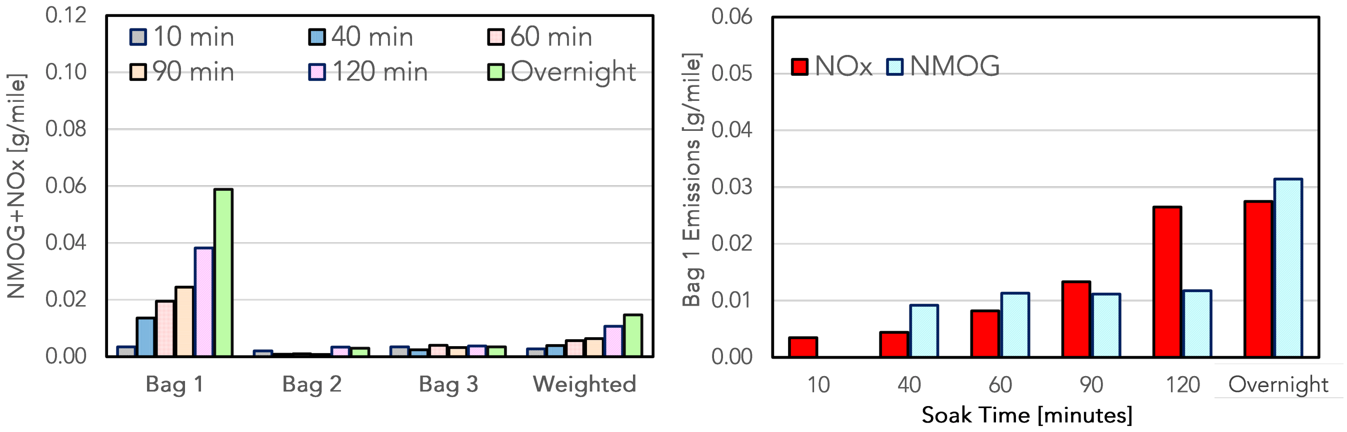
The 2020 Hyundai Sonata was another vehicle that demonstrated improved emission control for partial soak emissions compared to older vehicles. The results in Figure 13 show that the Sonata had relatively constant cold-start emissions (Bag 1) for partial soaks compared to the overnight soak. This trend was similar to the Toyota Camry. However, the data in Figure 13 also shows that the Sonata had relatively constant NOx and NMOG emissions compared to the Camry, which showed a significant impact of vehicle soak time on NOx and NMOG. Overall, both the Camry and the Sonata represent an improved cold-start calibration that ensured partial soak emissions of NMOG+NOx did not exceed overnight soak emission levels. However, these results left something more to be desired, as shorter soaks, especially in the range of 20 to 60 minutes, should have a more favorable environment for emission control, considering that the engine and after-treatment catalyst are partially warm during the initial vehicle start.

Figure 13: Partial Soak Emission Results for 2020 Hyundai Sonata.



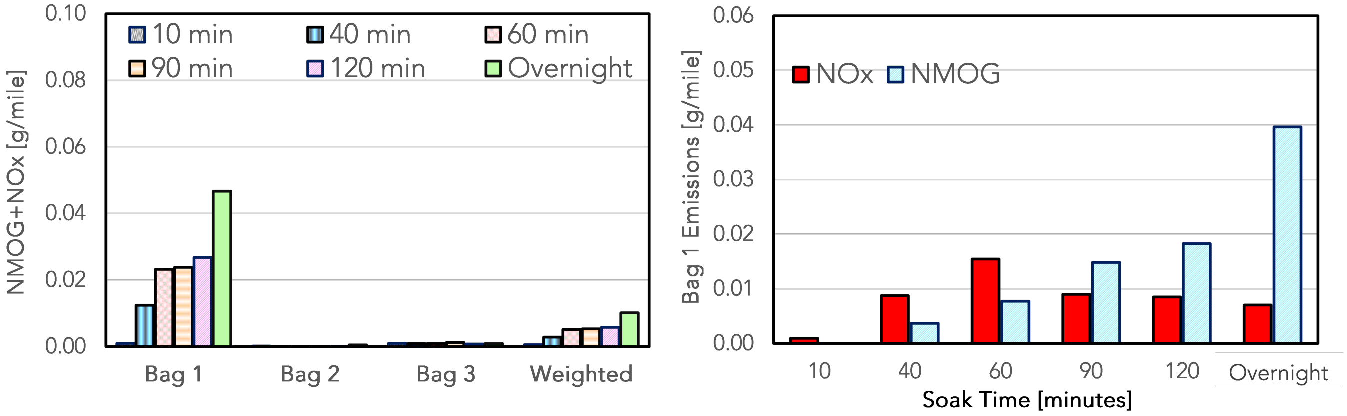
Additional vehicle tests revealed that emission reductions could be achieved for partial soaks compared to overnight soaks. The 2020 BMW X3 demonstrated consistent emission reduction as the soak time was reduced, as shown in Figure 14. Cold-start data in Bag 1 of the FTP test revealed that the cold-start emissions were well controlled for all soaks and that the vehicle utilized the advantageous engine and catalyst conditions of partial soaks to reduce both NOx and NMOG emission compared to overnight soaks. Overall, the 2020 BMW X3 represents a more ideal, and expected, emission profile for partial soaks compared to the Camry and Sonata.

Figure 14: Partial Soak Emission Results for 2020 BMW X3.



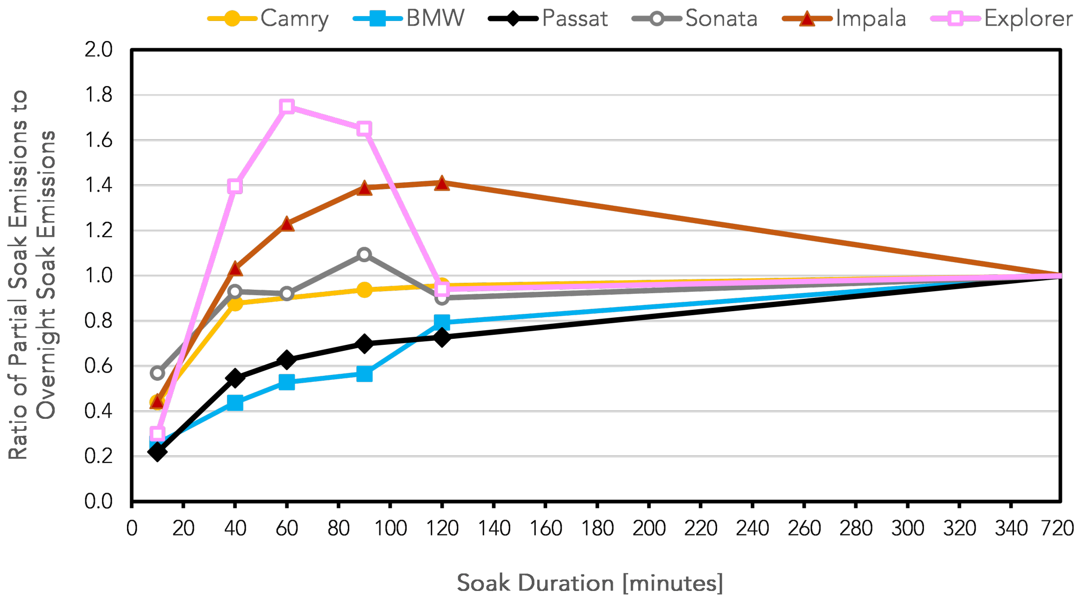
The 2020 Volkswagen Passat showed a similar emission trend as the BMW X3. Figure 15 shows that the Passat had substantially lower emissions for the partial soak tests compared to the overnight soak tests, especially during the cold-start phase in Bag 1 of the FTP. Similar to the BMW, the NMOG emissions were considerably lower for the partial soak tests. Although the NOx emissions did not reduce as the soak time was reduced, as was the case with the BMW, this was mostly because the Passat had lower NOx emissions for the overnight soak test than the BMW. Comparing the g/mile values, the Passat had lower NOx emissions than the BMW X3 for partial soaks of 90 to 120 minutes and slightly higher NOx emissions for partial soaks of 40 to 60 minutes. In summary, the Passat and BMW X3 demonstrated that NMOG+NOx emissions could be reduced for partial soaks relative to overnight soak tests.

Figure 15: Partial Soak Emission Results for 2020 Volkswagen Passat.



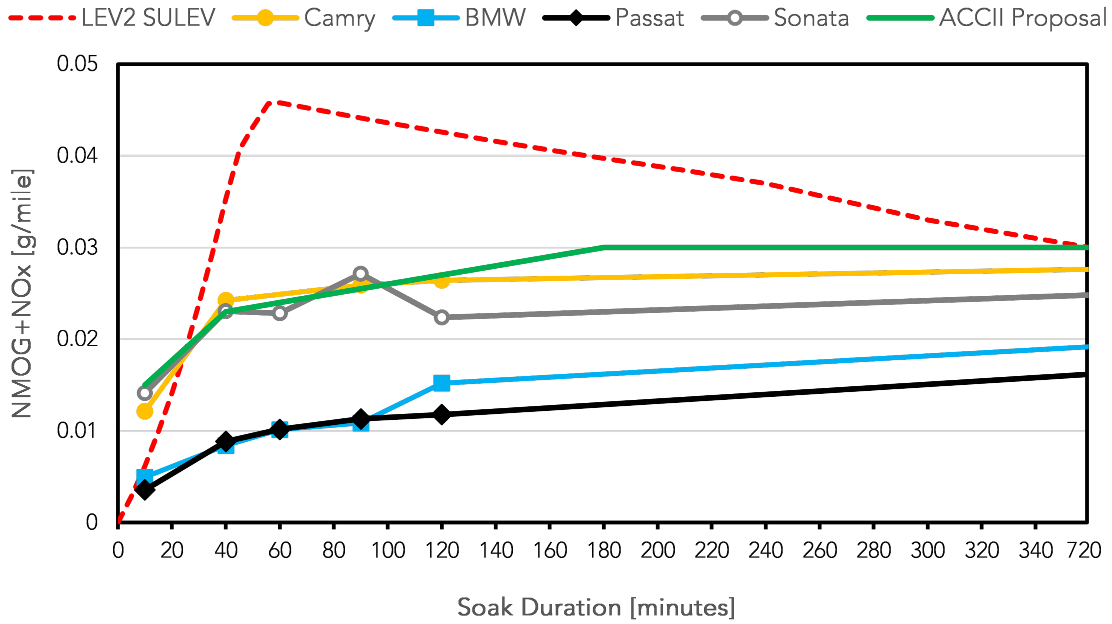
A direct comparison of all the vehicles is shown in Figure 16. The figure illustrates the emission levels at each soak time relative to the vehicles' emissions on the overnight soak test. The data in the figure clearly indicates that the BMW and Passat demonstrated the best emission control for the partial soak tests. Therefore, staff will propose a new emission standard for partial soaks that will strive to achieve an emission profile representative of the emission performance achieved by at least two vehicles already in production, the BMW X3 and Volkswagen Passat.

Figure 16: Summary of Partial Soak Emission Results for NMOG+NOx.



Staff's proposal for partial soak emissions is illustrated in Figure 17 for a SULEV30 vehicle. The ACC II proposal curve in the figure represents the maximum partial soak emissions allowed for a soaks between 10 minutes to 12 hours. As shown in the figure, the standard for soaks of 3 hours or more is a constant value that is set to match the FTP certification standard.

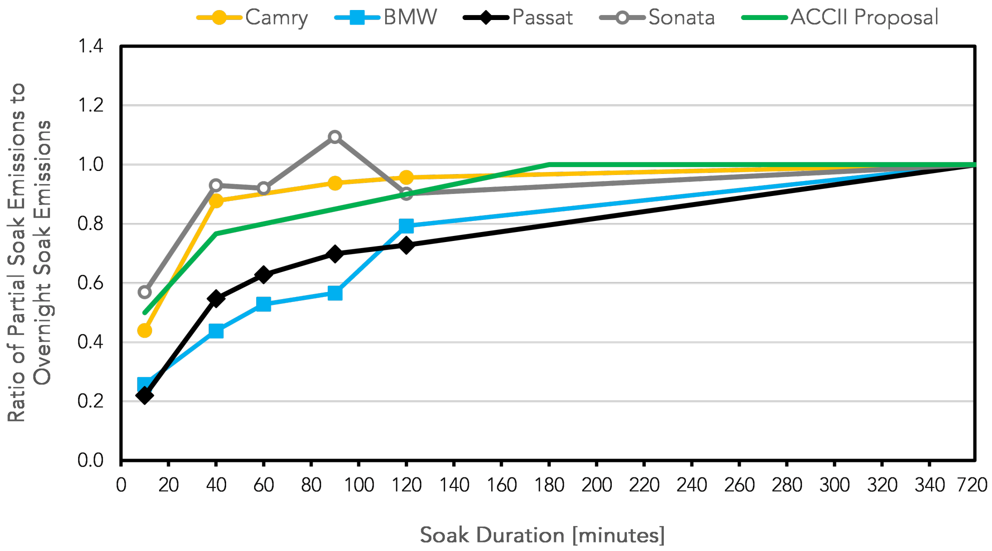
Figure 17: ACC II Proposal for Partial Soak Emissions for SULEV30 Vehicles.



In addition, the ACC II proposal will also require vehicles to meet more stringent standards for soaks of 10 minutes to 3 hours to match the emission profile of the BMW X3 and Passat, which is reflected by the slight emission reduction for soak in the region of 40 minutes to 3 hours, followed by a steeper emission reduction for soaks in the region of 10 to 40 minutes. Although the ACC II proposal curve in Figure 17 appears to overlap with the Camry and Sonata data in the region of 10 minute to 2 hour soaks, the shape of the proposal curve more closely resembles the BMW and Passat curves, as discussed in more detail below. Nevertheless, the overlap of the ACC II proposal curve with the Camry and Sonata in Figure 17 is an indication that although both vehicles need to improve partial soak emission control, they are not far from the proposed requirement, and this indicates that the proposed partial soak targets are feasible since all four vehicles shown in Figure 17 are either already complying with the proposed standards or are overlapping with the requirement but need to improve slightly to ensure that the partial soak emissions are below the proposed standards for all soaks.

When partial soak emissions are adjusted relative to the overnight soak emission values of each vehicle, Figure 18 illustrates more clearly that the ACC II proposal curve has a shape and profile that matches better with the BMW X3 and Passat. It also shows that there is a constant gap/margin (safety factor) built into the ACC II proposal curve relative to the BMW and Passat to represent the fact that automakers typically apply a safety factor by certifying vehicles at a modest margin below the standard to ensure compliance. Although the ACC II proposal was developed from SULEV30 vehicles, the ACC II proposal curve in Figure 18, which is normalized with respect to the overnight soak emission standard, can be applied to any other FTP certification bin.

Figure 18: Ratio of Partial Soak to Overnight Soak Emissions ACC II Proposal.



E. Quick Drive-Away Cold-Start Emissions

Another cold-start issue that CARB has been investigating concerns excess emissions that can occur when a real-world drive-away is quicker than those on lab test cycles. For reference, the cold-start FTP test has an initial idle of 20 seconds. CARB analyzed real-world data that indicated in-use driving tends to have much shorter initial idles as shown in Figure 19. A large share, over 60%, of in-use trips have a faster drive-away than the FTP cycle, with the median time being around 14 seconds, and with 24% of trips having a drive-away of 5 seconds or less. Therefore, staff conducted vehicle testing to investigate the emission impacts of quick drive-aways that have a shorter initial idle. A list of test vehicles is given in Table 4. The test vehicles included various FTP certification bins, ranging from SULEV30 to ULEV125, and vehicles from 2016 to 2020 model years.

Figure 19: Distribution of Initial Idle Times from Real-World Trips.

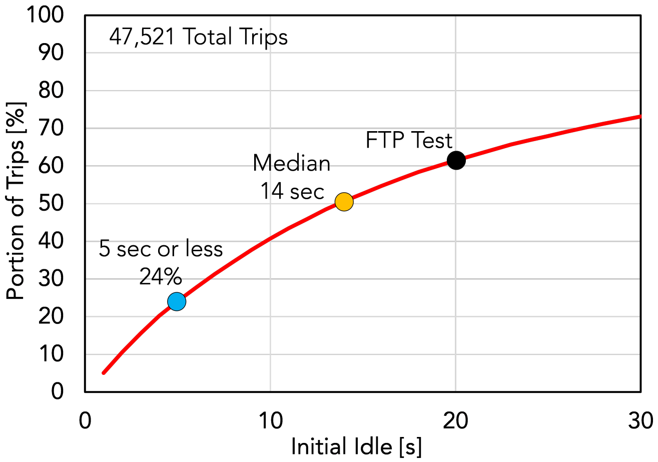


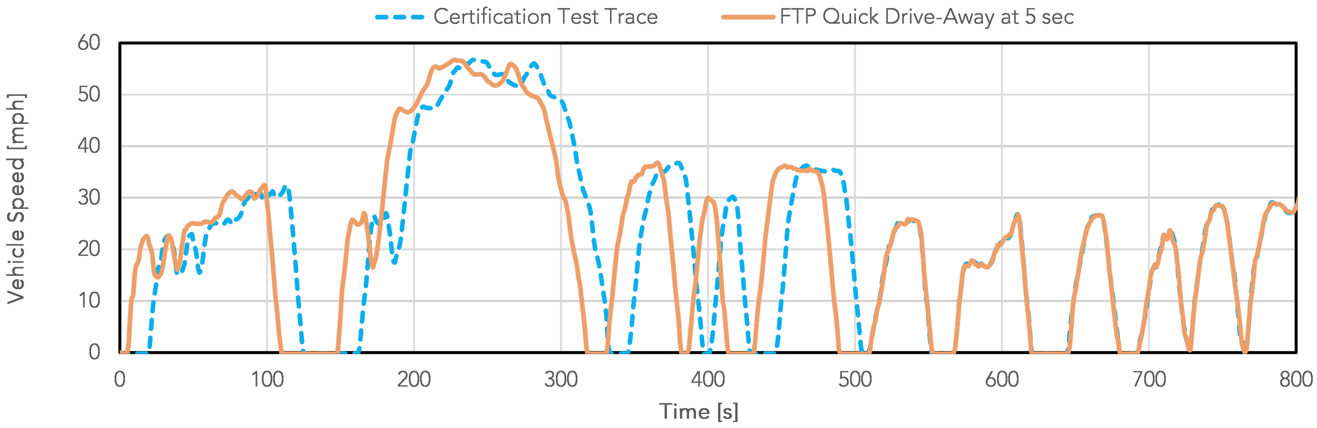
Table 4: List of Light-Duty Vehicles for Quick Drive-Away Testing.

Make	Model	Model Year	Vehicle Emission Category	Engine [L]
BMW	430i	2018	SULEV30	2
BMW	X3	2020	SULEV30	2
Dodge	Dart	2016	SULEV30	2.4
Hyundai	Elantra	2018	SULEV30	2
Hyundai	Sonata	2020	SULEV30	2.5
Mazda	3	2017	SULEV30	2
Nissan	Altima	2018	SULEV30	2.5
Toyota	Camry	2020	SULEV30	2.5
Volkswagen	Passat	2020	SULEV30	2
Ford	Fusion	2018	ULEV70	2
Ford	Explorer	2020	ULEV70	2.3
Mercedes	C300	2017	ULEV70	2

Chevrolet	Tahoe	2018	ULEV125	5.3
Jeep	Wrangler	2018	ULEV125	3.6
Toyota	Camry	2017	ULEV125	2.5

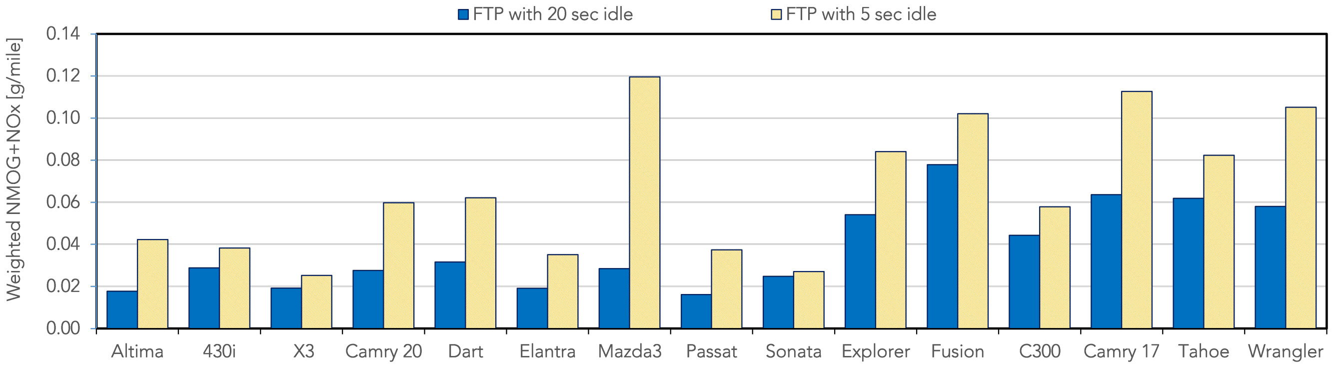
All the test vehicles were tested on a standard FTP certification test, which has a 20 second initial idle, and a quick drive-away FTP test, which has a shorter initial idle of 5 seconds. A comparison of the two test is shown in Figure 20. As shown in the figure, Bag 1 of the FTP test, which represents cold-start operation and includes only the first 505 seconds, is shifted 15 seconds earlier for the quick drive-away FTP test due to the shorter initial idle. Starting at 505 seconds, Bag 2 of the test, which represents hot-running operation, is identical for both tests. Although not shown, Bag 3, which represents hot-start operation, is identical to Bag 1.

Figure 20: Quick Drive-Away FTP Speed Trace.



The test results are provided in Figure 21. The data revealed that a quick drive-away had an emission impact for every test vehicle, which was expected. However, some vehicles did a better job of controlling quick drive-away emissions than others as shown in Figure 21. For example, for the Mazda3, the NMOG+NOx emissions increased by 400%, as shown in Figure 21, when the initial idle was reduced from 20 to 5 seconds. On the other end, the Hyundai Sonata only had an emission increase of 8%. Therefore, to ensure good emission control for all vehicles, staff will propose a new regulation to control quick drive-away emissions.

Figure 21: Impact of Quick Drive-Away on Exhaust Emissions.



The proposed emission targets are based on the average emissions for each FTP bin as shown in Table 5. The values in Table 5 were calculated based on full useful life emissions by adding the emission durability factor to each vehicle's raw emission test results. It should also be noted that the Mazda3 was excluded from the averaging since it had a disproportional impact on the calculation of the SULEV30 average. Based on the data in Table 5, an emission standard of 0.042 g/mile was selected for the SULEV30 bin, 0.082 g/mile for the ULEV70 bin, and 0.125 for the ULEV125 bin.

Table 5: Average Quick Drive-Away Emissions for Each FTP Bin.

Vehicle Emission Category	FTP 20s NMOG+NOx [g/mile]	FTP 5s NMOG+NOx [g/mile]
SULEV30	0.0237	0.0409
ULEV70	0.0588	0.0813
ULEV125	0.0612	0.1001

Since vehicles in other bins (SULEV20, ULEV50) were not tested, the quick drive-away standard for these bins was also set to be 0.012 g/mile above their FTP certification standard (0.032 g/mile for SULEV20 and 0.062 g/mile for ULEV50) to follow the trend observed for the SULEV30 and ULEV70 bins. Accordingly, the new bins proposed in ACCII (SULEV15, SULEV25, ULEV40, ULEV60) will also have a quick drive-away standard that is 0.012 g/mile above their FTP certification standard. For the ULEV125 bin, it was not necessary to add 0.012 g/mile to the FTP standard as the test data in Figure 21 shows that all three ULEV125 vehicles (Camry 17, Tahoe, and Wrangler) would already be able to comply with a 0.125 g/mile quick drive-away standard.

F. PHEV High-Power Cold-Start Emissions

There are also cold start issues that are unique to plug-in hybrid vehicles. PHEVs can start out driving in pure electric mode, then when they get to the freeway and accelerate hard, the

ICE can turn on, at the worst possible time, during the high-power demand, and there will be a huge spike in emissions. So to get an idea of the emission impacts this high-power cold-start can cause, staff tested various PHEVs to compare emissions from the urban emission certification cycle with emissions from various high-power cold-start cycles.

Table 6: List of Plug-In Hybrid Electric Vehicles for High-Power Cold-Start Emission Tests

Make	Model	Model Year	Vehicle Emission Category	Label Range [miles]	Battery Capacity [kWh]
Honda	Clarity PHEV	2018	LEV3 SULEV20	48	17
Ford	Fusion Energi PHEV	2013	LEV2 SULEV	20	7.6
Toyota	Prius PHEV	2013	LEV2 SULEV	11	4.4
Hyundai	Sonata PHEV	2016	LEV3 SULEV30	27	9.8
Audi	A3 e-Tron	2017	LEV3 SULEV30	16	8.8
Toyota	Prius Prime	2017	LEV3 SULEV30	25	8.8
Mitsubishi	Outlander PHEV	2018	LEV3 SULEV30	22	12
Volvo	XC90 PHEV	2018	LEV3 SULEV30	19	10.4
Chrysler	Pacifica Hybrid	2019	LEV3 SULEV30	32	16
Porsche	Cayanne S E-Hybrid	2016	LEV2 ULEV	14	10.8

A list of PHEV test vehicles is given in Table 6. The test vehicles mostly include SULEV30 PHEVs since there were very few PHEV offerings in other FTP bin categories. A SULEV20 PHEV and a LEV2 ULEV (certified at 0.125 g/mile) were tested to represent the full range of certification bins of currently available PHEVs. As shown in Table 6, the PHEV test vehicles included a wide variety of battery capacity and all-electric range.

All PHEVs were tested on the Urban Charge-Sustaining Emission Test, a US06 Charge-Depleting Emission Test, and 8 different high-power cycles. The high-power cycles were developed by actually driving the PHEVs on the road and identifying driving conditions that triggered a high-power cold-start. Based on the on-road driving, 8 different high-power cycles were developed and the speed traces of these cycles are shown in Figure 22 to Figure 25. The high-power cycles include speeds and accelerations that represent driving maneuvers like freeway on-ramp acceleration, merging into fast-moving traffic, and passing other vehicles.

Figure 22: PHEV High-Power Cold-Start Cycles 1 to 3

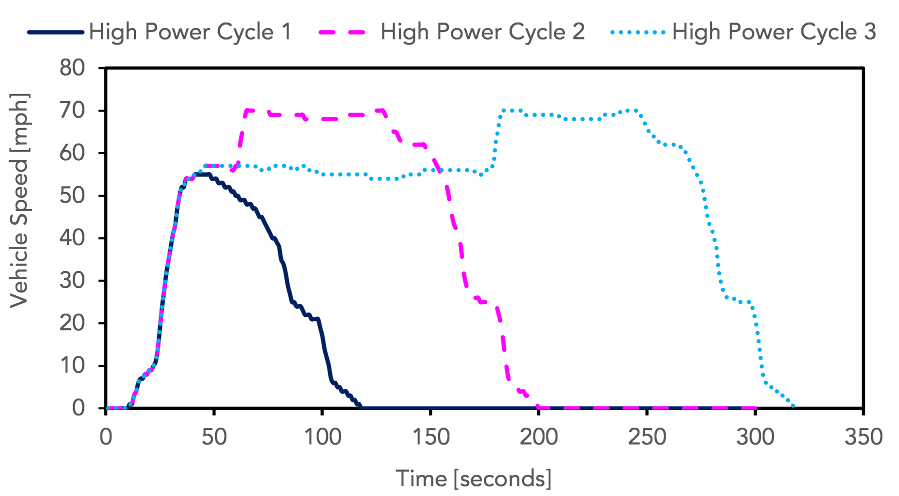


Figure 23: PHEV High-Power Cold-Start Cycles 4 to 6

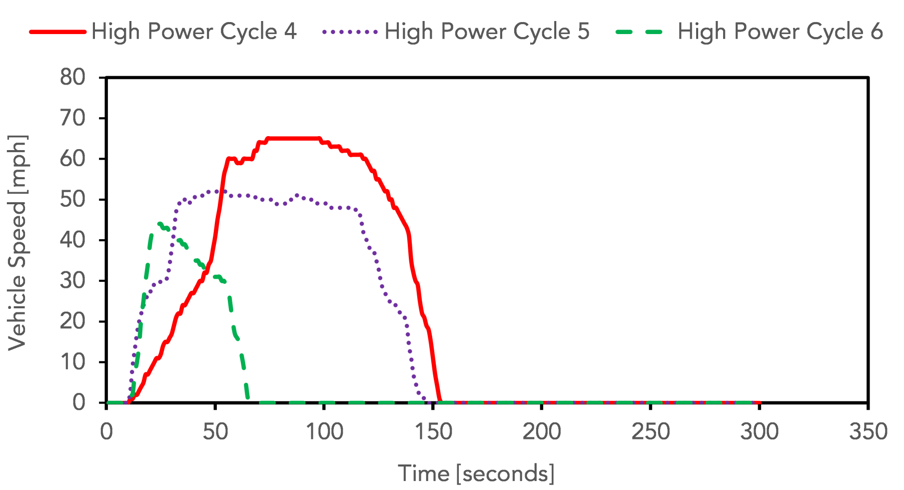


Figure 24: PHEV High-Power Cold-Start Cycle 7

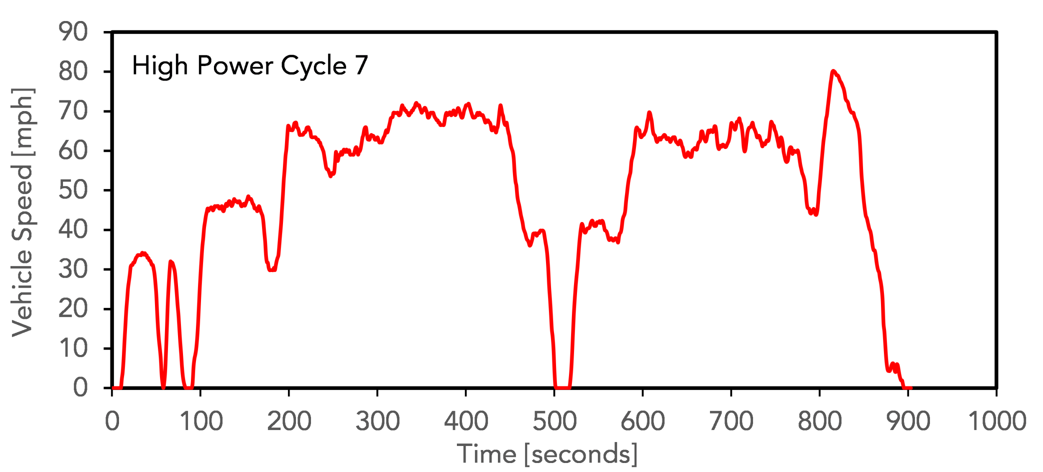
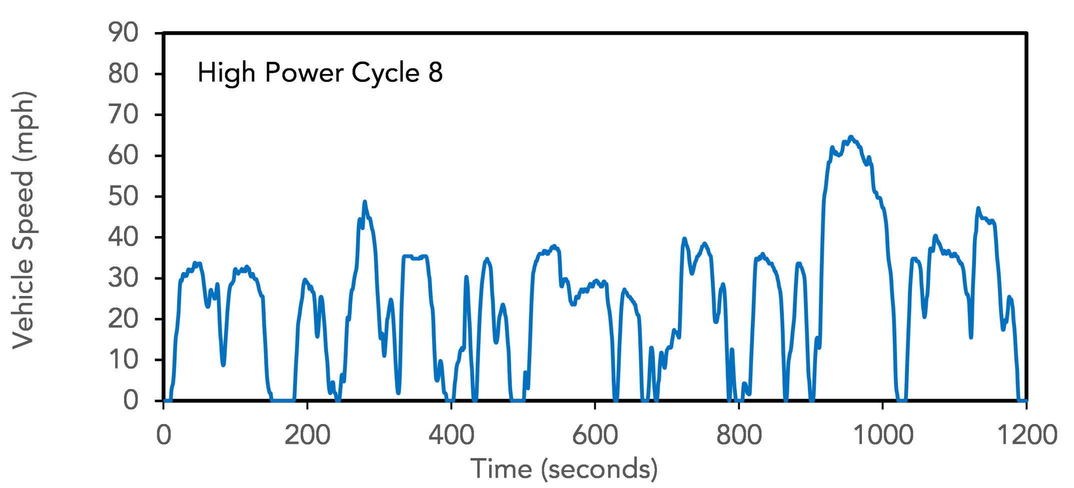
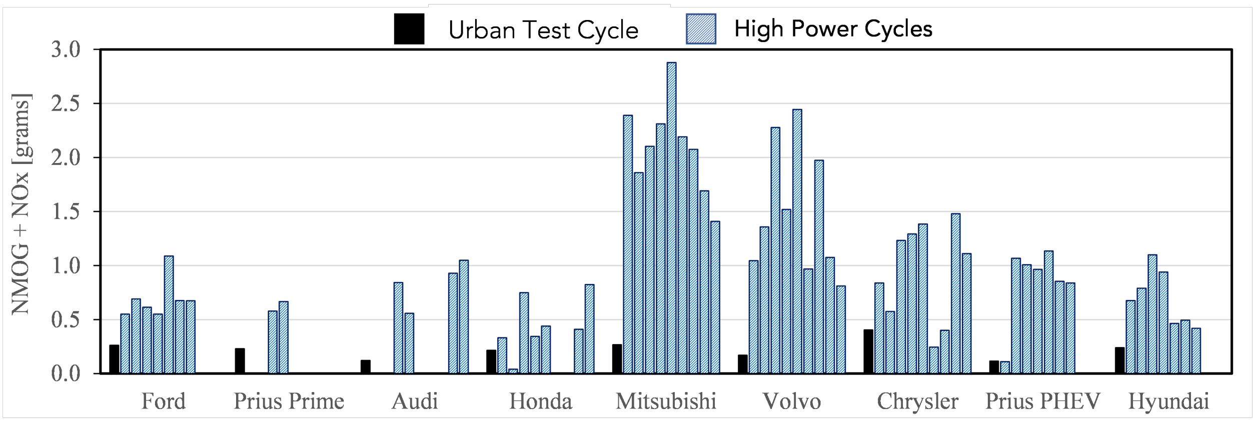


Figure 25: PHEV High-Power Cold-Start Cycle 8



The emission test results in Figure 26 showed that high-power starts had a substantial impact on exhaust emissions compared to the charge-sustaining urban test cycle, although some PHEVs performed much better than others. For example, the Toyota Prius Prime was able to complete most of the high-power cycles without generating any emissions by driving under electric power alone. This represents a real-world emission benefit since a vehicle like the Prius Prime would be able to avoid many cold-starts during in-use driving. The Prius Prime only produced high-power start emissions under the most demanding high-power cycles, which are not likely to occur very frequently in real-world driving. When averaging all of the high-power cycle emissions, including the non-starts, the average high-power cold-start emissions of the Prius Prime were similar to the emissions observed on the urban test cycle.

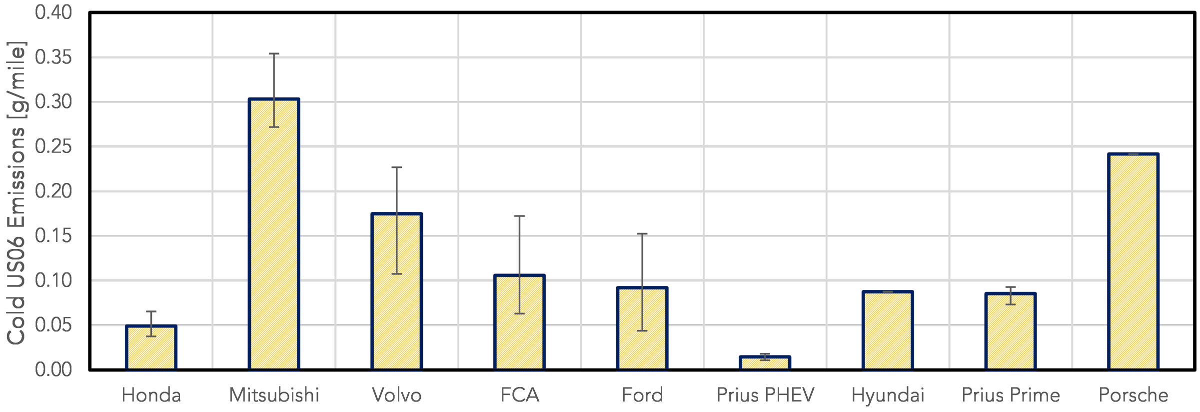
Figure 26: Emission Results for PHEV High-Power Cold-Starts.



Another vehicle that performed well was the Honda Clarity PHEV. Although the Clarity PHEV had more frequent high-power starts than the Prius Prime, the Clarity generally had well-controlled emissions during the high-power starts, which were not much different, on average, than its urban test emissions. On the other end, some of the worse performing PHEVs required the use of the combustion engine on every high-power cycle and the emissions were not well controlled. For instance, some of the heavier SUV PHEVs, like the Mitsubishi and Volvo models, had emissions that were almost 10 times higher on some of the high-power cycles compared to the FTP certification test. These test results highlight the need to regulate PHEV high-power cold start emissions to prevent the substantial emission impacts that were observed on some of the test vehicles. Therefore, staff's proposal will include a new high-power cold-start standard to ensure that PHEVs will have good emission control during high-power starts.

Staff's proposal will require PHEVs to meet an emission target, which is based on the best performing PHEVs, on the US06 charge-depleting emission test. The US06 cycle was selected as it is an existing test cycle that is familiar to stakeholders and since it represents aggressive driving. Emission results for the US06 charge-depleting emission test are shown in Figure 27. All the PHEVs were tested in their normal or default driver-selectable mode as it is the mode most commonly used in real-world driving. The only exception was the Prius Prime, which was tested in a non-default mode since the default mode resulted in no emissions.

Figure 27: PHEV US06 Charge-Depleting Emission Test Results.



The results in Figure 27 indicated that a 0.100 g/mile emission standard would be suitable for SULEV30 PHEVs since 4 of 7 had average US06 emissions below 0.100 g/mile. Similarly, a SULEV20 standard of 0.67 g/mile is proposed for the SULEV20 category based on the emission data of the Honda Clarity in Figure 27. The proposed emission standard for ULEV125 PHEVs is 0.250 g/mile based on the Porsche PHEV data in Figure 27. The emission standards for other vehicle emission categories were distributed between the SULEV20, SULEV30, and ULEV125 categories.

The proposed standards are feasible as existing PHEVs can already meet the proposed targets, but they will also ensure that the dirtiest PHEVs will improve control of high-power cold-start emissions. Finally, since high-power cold start emissions are primarily a concern for blended PHEVs that require the use of an engine to supply power during high-power demand, the proposal will include an exemption for US06 cold-start emission testing for any PHEV that is non-blended on the US06 cycle, meaning a PHEV that can drive the US06 cycle using only electric power with zero exhaust emissions. This exemption will avoid unnecessary testing and reduce the test burden for automakers while at the same time encouraging PHEVs to target non-blended operation for aggressive driving, like on the US06 cycle, that will reduce the frequency of high-power starts and provide real-world emission benefits.

III. Evaporative Emission Proposals

A. Development of Proposed Puff Equation: Minimum Canister Size

Applicability: For vehicles that have a tank pressure which exceeds 10 inches of water during the running loss test.

I. The equation:

Minimum canister nominal WC = $1.2 \times 1.3 \times [5.8 \times 14.7/P_{tvs} \times ((P_{tvs} \times V_{tvs})/14.7 - V_{tvs}) + G_{refuel} \times 0.88 \times V_{fuelcap}]$

Where:

- Gives the working capacity (WC) in grams
- V_{tvs} is tank vapor space (Gallons)
  - This is 90% of the total geometric volume of the fuel tank. Geometric volume is the sum of the fuel tank capacity and vapor space. This is used as a reasonable approximation of a near worst case refueling condition.
- $V_{fuelcap}$ is the nominal fuel tank capacity which means the volume of the fuel tank(s), specified by the manufacturer to the nearest tenth of a U.S. gallon, which may be filled with fuel from the fuel tank filler inlet.
- G_{refuel} is the vapor generation during refueling in grams/gallon
  - Use 5 grams/gallon as default
  - Alternate value can be used, per subsection IV.
- P_{tvs} is fuel tank's maximum pressure in-use (absolute pressure in psi)
  - See section III. for guidance on what value to use for Ptvs for a particular vehicle

II. How the equation was developed:

- Minimum Canister nominal WC = 1.2 x 1.3 x (Mass HC Puff + Mass HC Refuel)

- Nominal WC = working capacity, grams, defined per California Evaporative Emission Test Procedure[3] III.D.3.3.4
  - Uses a load rate of 15 g/hour butane
- 1.2 compensates for the fact that butane working capacity, which is a bench standard to indicate the canister's ability to adsorb vapors, decreases on a gasoline aged canister. This decrease in working capacity is expected to be the result of a heel accumulating, which is gasoline vapors becoming lodged into a portion of the canister. And since gasoline vapors decrease the butane working capacity, it is expected that this will also likely reduce the canister's ability to adsorb vapors during real world refueling. Therefore, this added 1.2 factor has been added to compensate for this uncertainty.
- 1.3 accounts for needing larger WC to accommodate refueling vapor loading rate

Loading:	Adsorption performance:
15 g/hour butane (nominal)	6.2 [a]
Refueling (ORVR)	4.8 [b]

[a] g/100cc 15 BWC carbon, per guidance from automakers and Manufacturers of Emission Controls Association (MECA)
[b] g/100cc 15 BWC carbon, per Evap Manual[2] pg. 108.

- Adjustment factor: 6.2/4.8 = 1.3

  - Nominal WC = 1.3 x ORVR WC

- Mass HC Puff = 5.8 x 14.7/Ptvs x ((Ptvs x Vtvs)/14.7 - Vtvs)
  - This was patterned using Evap Manual1 Practice Problem 6-4 pg. 178.
  - V_{tvs} is tank vapor space (Gallons)
    - This is defined in section I above.
  - P_{tvs} is fuel tank's maximum pressure in-use (absolute pressure in psi)

---

[3] "California Evaporative Emission Standards and Test Procedures for 2001 and Subsequent Model Motor Vehicles", Amended September 2, 2015

  - See section below for guidance on what value to use for P_{tvs} for a particular vehicle.
- Development
- $(P_{tvs} \times V_{tvs}) / T_{tvs} = (P_{atm} \times V_{atm}) / T_{atm}$ (from ideal gas law)
- Assume $T_{tvs} = T_{atm}$
- $V = (P_{tvs} \times V_{tvs}) / P_{atm}$ (eqn. 1)
- $V_{esc} = V_{atm} - V_{tvs}$ (eqn. 2)
  - V_{esc} is the volume of the HC vapors which escape from the tank vapor space

- Density HC vapor in tank = 5.8 (grams / gallon @ P_{tvs})
  - Per Evap manual[1], refueling nomograph, RVP 7 fuel, 110°F, page 82
  - This represents approximate worst case California summer refueling, with a car that has been driven on a hot day: 105 F ambient, but fuel has reached 110 F. This was determined from fuel temperature gains from fuel temperature profile data from running loss drives, with plug-in hybrid electric (PHEV) vehicles. This takes into consideration that the condition that is expected to generate the most heat to the fuel tank, namely significant engine on operation, will also likely have the tank largely purged of vapors prior to refueling and therefore less puff loading to the canister. And this considers that fuel temperature gains will likely be less dramatic for electric only trips, but still have potential to apply puff loading to the canister, since the pressure is usually stored in the fuel tank, albeit with a more modest temperature gain.

- Dens. HC vapor = 5.8 (grams / gallon @ P_{tvs}) x [V_{tvs} (gallon @ P_{tvs}) / V_{atm} (gallon @ P_{atm})] (eqn. 3)
  - This gives Dens. HC vapor once it is released from the tank: (grams / gallon @ Patm)
- Mass HC Puff = Dens. HC vapor x V_{esc}
- Mass HC Puff = $5.8 \times (V_{tvs} / V_{atm}) \times (V_{atm} - V_{tvs})$ (subbed in eqn. 2,3)
- Mass HC Puff = $5.8 \times (V_{tvs} / (P_{tvs} \times V_{tvs}) / P_{atm}) \times ((P_{tvs} \times V_{tvs}) / P_{atm} - V_{tvs})$ (subbed in eqn. 1)

- Mass HC Puff = 5.8 x (14.7 / P_{tvs}) x [(P_{tvs} x V_{tvs})/ 14.7 - V_{tvs}]

- Mass HC Refuel = G_{refuel} x 0.88 x $V_{fuelcap}$
  - $V_{fuelcap}$ is the nominal fuel tank capacity means the volume of the fuel tank(s), specified by the manufacturer to the nearest tenth of a U.S. gallon, which may be filled with fuel from the fuel tank filler inlet. (Gallons)
  - $V_{fuelcap}$ is multiplied by 0.88 to represent a reasonable proportion of the tank which would be filled up during refueling
  - G_{refuel} is the vapor generation during refueling (grams/gallon)
    - Use 5 grams/gallon as default
    - Per Evap manual[4] page 88, 80°F Tank, 67°F Dispense (5 grams/gallon vapor generation represents the ~mid-range of refueling situations with RVP 9 gasoline which can yield different results, such as top fill, bottom fill, air entrainment, for a liquid seal). Assumed that RVP 9 fuel characteristics shown in this figure would have similar characteristics to RVP 7 fuel dispensed at a higher temperature.
    - Alternate value can be used for G_{refuel}, per section IV. Some vehicles use fuel systems which have technology which reduces refueling vapor generation. And this option will enable manufacturers to account for their custom fuel system designs.

III. Pressures to use for P_{tvs} : see draft regulation language. Source of 19 psia value: it is the estimated pressure inside a sealed fuel tank, when the temperature inside the tank is 110 degrees F, assuming the tank was initially filled & sealed at 75 degrees F. This value was obtained using the method from Evap Manual[5] Practice Problem 6-3 pg. 178. This value was adjusted slightly downward to 19 psi, based upon review of manufacturer test data.

IV. Alternate value for Grefuel

---

[4] "Evaporative and Refueling Emission Control Training/Workshop Manual", Reddy, Sam R, version 3.0, January 20, 2010.

[5] "Evaporative and Refueling Emission Control Training/Workshop Manual", Reddy, Sam R, version 3.0, January 20, 2010.

a. Manufacturer has the option to use another value for Grefuel which represents the refueling vapor generation of their particular vehicle. If this option is used, the following data shall be provided in the certification application:
    i. Value of G_{refuel}
    ii. Method used to determine Grefuel and supporting data

V. Examples of calculations

a. Vehicle A: Vehicle attributes: Fuel tank nominal fuel capacity ($V_{fuelcap}$) = 10.3 gallons, fuel tank total geometric volume: 12 gallons, purges fuel tank during engine operation, and maximum in-tank pressure during engine operation is 15.7 psia.
Calculation: Will use 19 psia for P_{tvs}, per section III. above
Vt_{vs} is 0.9 * 12 = 10.8 gallons per section I. above
Default value of 5 grams / gallon for G_{refuel}
Putting these values into the equation:

Min Canister nominal WC = $1.2 \times 1.3 \times [5.8 \times 14.7/P_{tvs} \times ((P_{tvs} \times V_{tvs})/14.7 - V_{tvs}) + G_{refuel} \times 0.88 \times V_{fuelcap}]$

Min Canister nominal WC = $1.2 \times 1.3 \times [5.8 \times 14.7/19 \times ((19 \times 10.8)/14.7 – 10.8) + 5 \times 0.88 \times 10.3]$

Minimum Canister Nominal Working Capacity (for the vehicle in this example) = 93 grams

IV. Emission Testing for Medium-Duty Vehicle Exhaust Emission Proposals

A. Chassis Dynamometer Half and Full Payload Testing

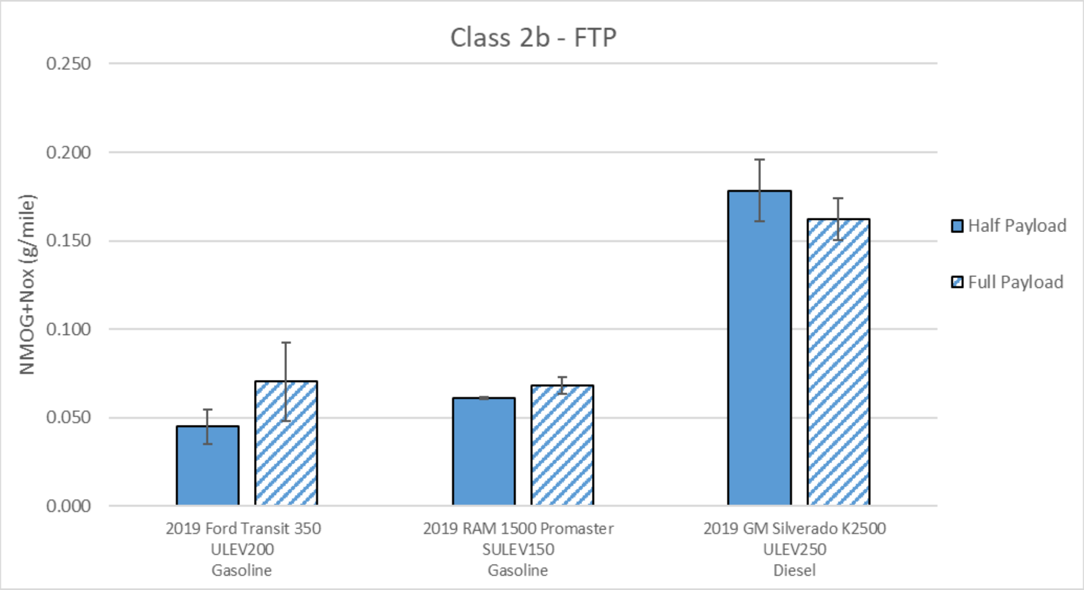
CARB conducted tests on several medium-duty vehicles (MDVs) in class 2b and 3 in the lab using the chassis dynamometers and, on the road, using a Portable Emission Measurement System (PEMS). The purpose of the test project was to evaluate current LEV III MDV emissions under different payloads and during towing. For certification, LEV III MDVs must meet the FTP and SFTP requirements at a test weight of half payload. CARB tested three MDVs at half and full payload to determine if emissions increased at heavier payloads. The other vehicles tested on the chassis dynamometer were tested at half payload only. Table 7 shows the vehicles tested by CARB and used for regulation development of the ACC II MDV proposals.

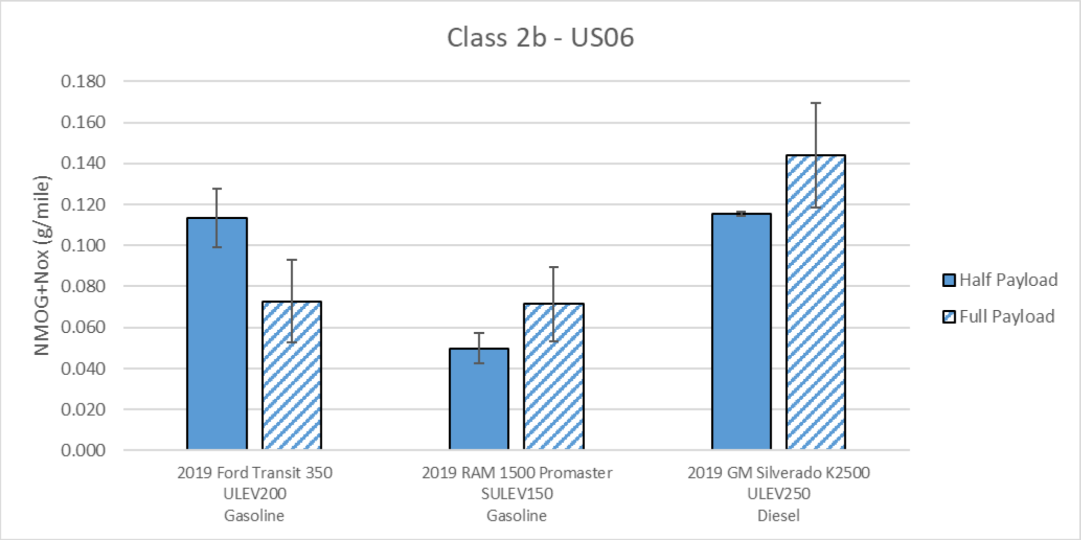
Table 7: List of MDVs Tested by CARB and Used for ACC II Regulation Development

Make	Model	Model Year	Fuel Type	Class	FTP Bin
Ford	Transit 350	2019	Gasoline	2b	ULEV200
FCA	Ram 1500 Promaster	2019	Gasoline	2b	SULEV150
GM	Silverado K2500	2019	Diesel	2b	ULEV250
Cummins	Ram 2500	2019	Diesel	2b	ULEV250
Cummins	Ram 3500	2019	Diesel	3	ULEV270
Ford	F350	2019	Gasoline	3	ULEV270
Ford	F350	2020	Diesel	2b	ULEV200
Daimler	Sprinter	2020	Diesel	2b	SULEV170
Cummins	Titan	2017	Diesel	2b	ULEV340
Cummins	Ram 2500	2018	Diesel	2b	ULEV250

The test data shown in Figure 28 is from CARB's lab testing at the Haagen-Smit Laboratory (HSL) and shows emissions for NMOG+NOx. The class 2b vehicles were tested on the FTP and US06 test cycle. The test data showed that emissions does not change much when the vehicle was loaded to full payload. Analysis of the engine loads and speeds showed engine operation does not change much either between half and full payload. Therefore, the weight increase was not enough to test the vehicle over the full range of engine operation. The only consistent change was variability was higher on the US06 for full payload across all vehicles.

Figure 28: CARB's MDV Test Data for NMOG+NOx at Half and Full Payload



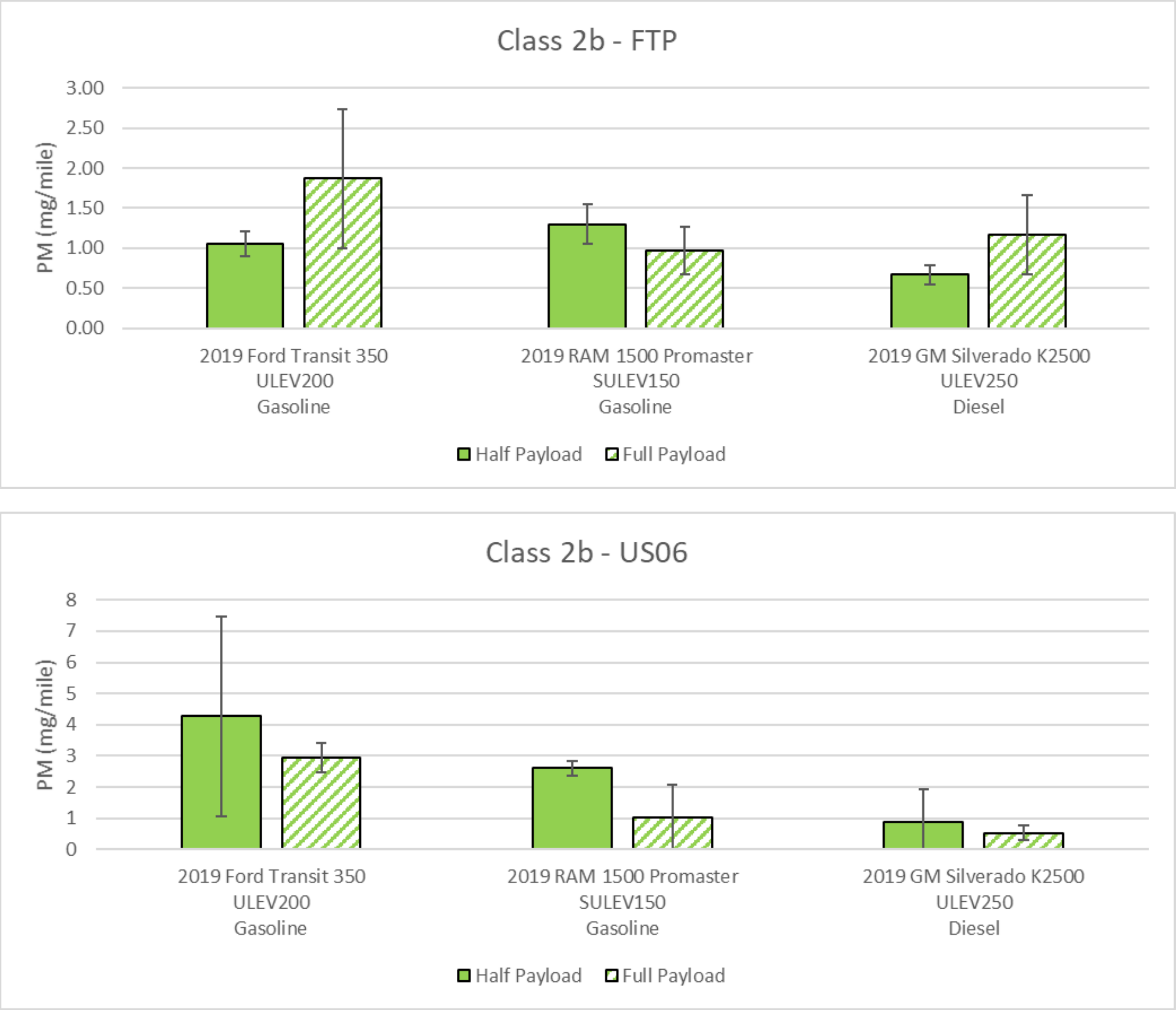

Class 2b - US06
NMOG+Nox (g/mile)
0.180
0.160
0.140
0.120
0.100
0.080
0.060
0.040
0.020
0.000
2019 Ford Transit 350
ULEV200
Gasoline
2019 RAM 1500 Promaster
SULEV150
Gasoline
2019 GM Silverado K2500
ULEV250
Diesel
Half Payload
Full Payload

Staff's analysis of the CO data for the half and full payload testing showed a significant increase in CO for the gasoline vehicles tested. The data is shown in Figure 29 for both the FTP and US06 test cycles. Staff's analysis of the OBD data collected during US06 testing had shown the gasoline vehicles to be operating under a rich air/fuel ratio mixture, which means there is more fuel in the mixture than air. This type of operation usually occurs during enrichment when more fuel is in the mixture at combustion and causes more CO to be produced, which keeps exhaust temperatures cooler to protect the emission control components, specifically the catalyst. The US06 is an aggressive test cycle with higher speeds and loads and is expected to have higher exhaust temperatures. But the use of enrichment indicates the catalyst may be undersized for operations at higher loads especially if CO rates increase more than twice the ULEV composite standard of 22 g/mile.

Figure 29: CARB's MDV Test Data for CO at Half and Full Payload

Further emissions test data for half and full payload is shown in Figure 30, for the PM emissions. Emissions for PM is higher for the gasoline vehicles since the diesel vehicles are equipped with diesel particulate filters (DPF). PM emissions on the FTP was relatively low, but full payload testing did show higher variability. The most variability occurs on the US06 test cycle. In both cases, the most variability on both test cycles are from the 2019 Ford Transit. The Ford Transit had PM emissions ranging from 7.9 to 1.8 mg/mile for half payload testing on the US06. The factors that can affect PM on the US06 are usually from driver variability, which is often affected by a manufacturer's emission control strategies.

Figure 30: CARB's MDV Test Data for PM at Half and Full Payload



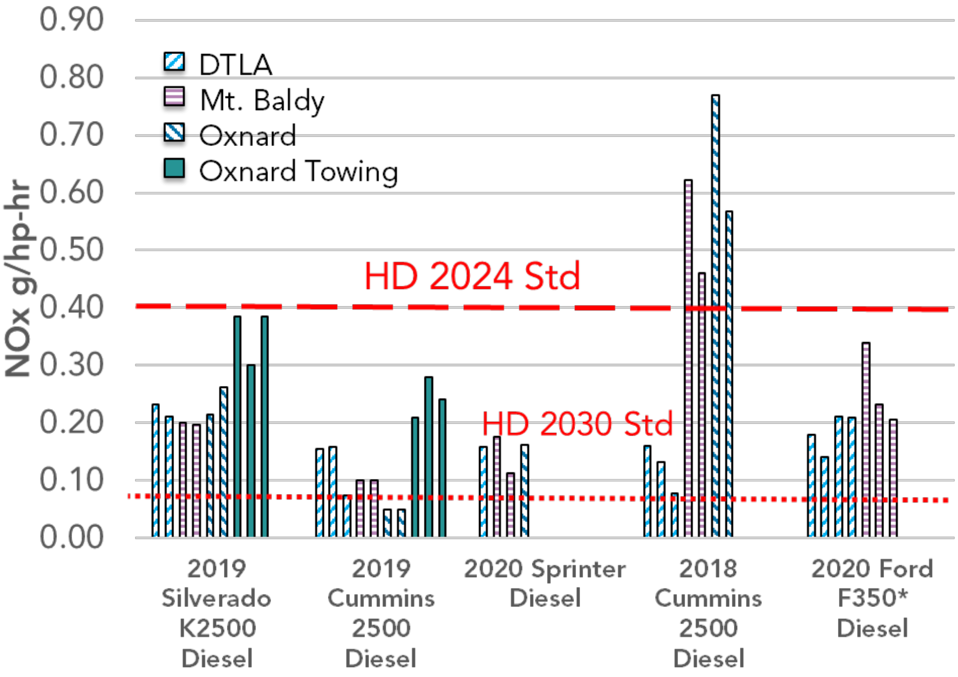
B. Moving Average Window On-Road MDV PEMS Testing

CARB chassis dynamometers at HSL are only capable of testing up to 14,000 lbs. This limits the amount of weight that these vehicles can be tested for in the lab. Diesel MDVs can have a gross combined weight rating of up to 30,000 lbs. or more. To accurately evaluate emissions under towing operation, CARB would need to test the vehicles at a minimum of 70-80% of its GCWR, which is not possible at the HSL laboratory. Therefore, CARB could only evaluate emissions for towing on the road using PEMS.

The test data collected using PEMS was performed on several different routes in Southern California. One of the routes used for testing was from CARB to Downtown Los Angeles (DTLA). It is a 50-mile route, which includes city and highway driving. All routes include a cold start at the beginning of the test and a 10-minute hot start in the middle of the test. The second route used for PEMS testing was the Mt. Baldy route (76 miles), which includes highway and some higher altitude driving during the Mt. Baldy portion of the route. The third route is the Oxnard route (138 miles), which contains mainly highway driving with uphill and downhill driving along the highway route. All routes were tested with the vehicle at half-payload, and the Oxnard route was conducted with test at both half payload and 70-80% GCWR. Currently, CARB is still conducting testing on gasoline vehicles to evaluate emissions during towing operation. Initial PEMS test data of gasoline vehicles has shown they are much cleaner than diesels during on-road operations.

The PEMS data collected was evaluated using the 3 Bin Moving Average Window (3B-MAW) test procedures and standards that were adopted as part of the Heavy Duty (HD) Low-NOx Omnibus rulemaking. The 3B-MAW analyzes data based on 5-minute intervals called “windows”. These windows are separated based on the engine load percentage of the window and binned into three different bins. Each bin represents a different area of engine operation idle, low load, and medium/high load. For otto-cycle vehicles, the windows are evaluated in one bin known as the otto bin. The emissions in each bin are calculated using the sum-over-sum equation. In Figure 31, the emissions data is calculated using the 3B-MAW test procedures, and each bar represents the total emissions for that test.

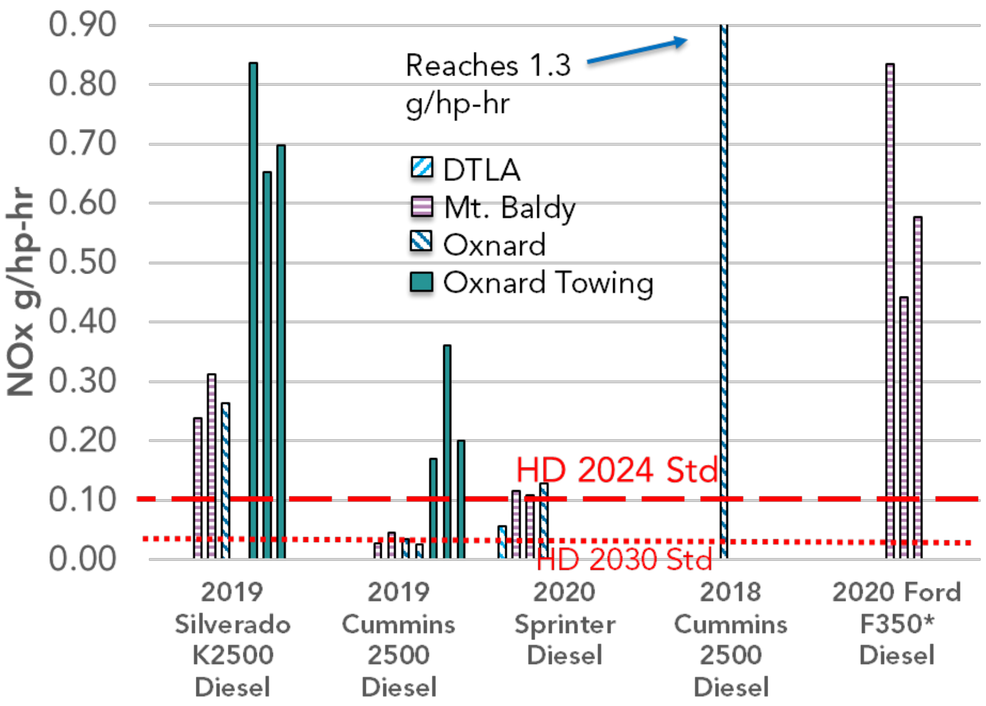
Figure 31: CARB PEMS Data analyzed using 3B-MAW – Low Load Bin (6-20% Engine Load)



LEV III vehicles are only required to calibrate and design to meet the FTP and SFTP certification requirements. Test data has shown that the FTP and SFTP test cycles operate at low loads and low speeds. Staff's analysis of the PEMS data in Figure 31 has shown that most chassis-certified MDVs can already meet the HD 2024 standard (0.4 g/hp-hr) and some MDVs are close to meeting the HD 2030 (0.075 g/hp-hr). Staff has determined this is mainly due to chassis-certified MDVs being designed to meet the FTP and SFTP requirements, which mainly operate in the low load and low engine speed range.

In Figure 32, the same MAW analysis was applied to windows that were in the medium to high engine load bin. The data revealed that with some operation into the higher loads and speeds, these vehicles had much higher emissions. This was specifically apparent when towing was included during the testing. Staff's analysis has determined that these vehicles do not have the correct hardware to handle the higher emission flow rates that occur during towing. The 2019 Cummins 2500 diesel showed significantly better performance than the Silverado. The Cummins vehicle has a much bigger selective catalytic reduction (SCR) system than the other vehicles and was subject to an emissions recalibration by CARB. The Cummins vehicle demonstrates that with better hardware and good engine/software calibration significant improvements in emission reductions are possible, and this is before any of the suggested changes that were demonstrated as part of the diesel technology package for the HD Low Nox Omnibus rulemaking.

Figure 32: CARB's PEMS Data analyzed using 3B-MAW – Medium/High Load Bin (Greater than 20% Engine Load)



C. Moving Average Window (MAW) Method for MDV In-use Testing

Applicable to MDVs certified to the chassis standards (class 2b & 3) for model year 2027 and subsequent with a GCWR>14,000 lbs.

I. PEMS on-road emissions data is divided into 5-minute windows that start at every second, and they are separated into different bins based on the engine load percentage of that window.

Table 8: MAW Engine Load Percentages for Each Emissions Bin

	Idle bin	**Low Load bin**	**Med/High Load Bin**	**Otto Bin**
Diesel	≤6% Engine Load	>6% and ≤20% Engine Load	>20% Engine Load	
Otto-Cycle				0-100% Engine Load

II. Calculating Percent Engine Load for each Window

$$Percent\ Engine\ Load_{window} = \frac{3{,}600\ sec/hr}{FCL\ \times\ HP_{max}} \times \frac{\sum_{t=1}^{300}(\dot{m}_{CO2} \times \Delta t)}{300\ sec}$$

Where:

Percent Engine Load$_{window}$ is the percent engine load calculated with the average CO_2 emission rate and the FCL
$\dot{m}_{CO2}$ mass emission rate of CO_2 [g CO_2/sec]
FCL is the family certification level on the chassis-certified FTP-75 cycle [g CO_2/bhp-hr]
HPmax is the maximum rated engine horsepower [bhp]
Δt is equal to the data sampling rate [1 second]

III. Calculating Emissions for Each Bin using the sum-over-sum (SOS) Equation

$$e_{sos\ a,b} = \frac{\sum_{k=1}^{n_b}\sum_{t=1}^{300}(\dot{m}_a \times \Delta t)}{\sum_{k=1}^{n_b}\sum_{t=1}^{300}(\dot{m}_{CO2} \times \Delta t)} \times FCL$$

Where:
$e_{sos\ a,b}$ is the SOS emissions [g/bhp-hr] of a pollutant in a bin
subscript "a" is the pollutant (NMHC, CO, NOx, and PM) and "b" refers to the low-load bin, medium/high-load bin, or otto bin
$\dot{m}_a$ is the mass emission rate of pollutant a [g/sec]
$\dot{m}_{CO2}$ is the mass emission rate of CO_2 emitted [g/sec]
n_b is the number of windows in a bin
Δt is equal to the data sampling rate [1 second]
FCL is the family certification level on the chassis certified FTP-75 cycle [g CO_2/bhp-hr]

IV. Calculating Idle Emissions for the Idle Bin

$$e_{sos\ a,idle} = \frac{\sum_{k=1}^{n_{idle}}\sum_{t=1}^{300}(\dot{m}_a \times \Delta t)}{\sum_{k=1}^{n_{idle}}\sum_{t=1}^{300}(\Delta t)} \times \frac{3{,}600sec}{1hr}$$

Where:
$e_{sos\ a,idle}$ is the SOS emission for pollutant, a, in the idle bin [g/hr]

$\dot{m}_a$ is the mass emission rate of pollutant *a* [g/sec]
n_{idle} is the number of windows in the idle bin
Δt is equal to the data sampling rate [1 second]
Since NOx is the only pollutant with an idle standard, pollutant "a", in this equation represents only NOx emissions.

V. Calculating the FCL for the MAW

$$FCL = \frac{FTP\ CO2\ [g]}{FTP\ Work\ [bhp-hr]}$$

Where:

FTP CO_2 is the weighted 3-phase chassis FTP-75 CO_2 [g/mile] × chassis FTP-75 distance traveled [miles]

$$FTP\ Work\ [bhp-hr] = \sum_{t=1}^{1874} \frac{speed[rpm] \times Torque[lb-ft]}{5252} \times \Delta t \times \frac{hr}{3600\ sec}$$

Speed [rpm] is the engine RPM (PID \$0C) from the chassis FTP-75

Torque [lb-ft] is the torque from the chassis FTP-75 calculated by subtracting Friction Torque (PID \$8E) from Indicated Torque (PID \$62) (both PIDs are percentages) and then multiplying by the reference torque (PID $63), which is in units of Nm and will be converted to lb-ft. Set torque to zero if friction torque is greater than indicated torque.

Δt is the OBD sampling rate [1 Hz]

As an alternative, the manufacturer has the option to determine an FCL for the test group using the engine test procedures in 40 CFR § 1036.108 instead of using the chassis FTP-75 cycle. This FCL is based on the FTP engine cycle

VI. Moving Average Window In-use Threshold for Chassis-Certified MDVs

Table 9: Moving Average Window Bins and In-use Threshold

Bin	Percent Engine Load	The SOS Emissions In-use Threshold
Idle	Percent Engine Load$_{window}$ ≤ 6%	$e_{sos\ a,Idle} \leq CF^{B}$ x Idle standard^{A}
Low	6% < Percent Engine Load$_{window}$ ≤ 20%	$e_{sos\ a,Low} \leq CF^{B}$ x LLC standard^{A}
Medium/High	Percent Engine Load$_{window}$ > 20%	$e_{sos\ a,MedHigh} \leq CF^{B}$ x FTP/RMC standard^{A}
Otto Bin	0%≤ Percent Engine Load$_{window}$ ≤ 100%	$e_{sos\ a,\ Otto\ Bin} \leq CF^{B}$ x FTP standard^{A}

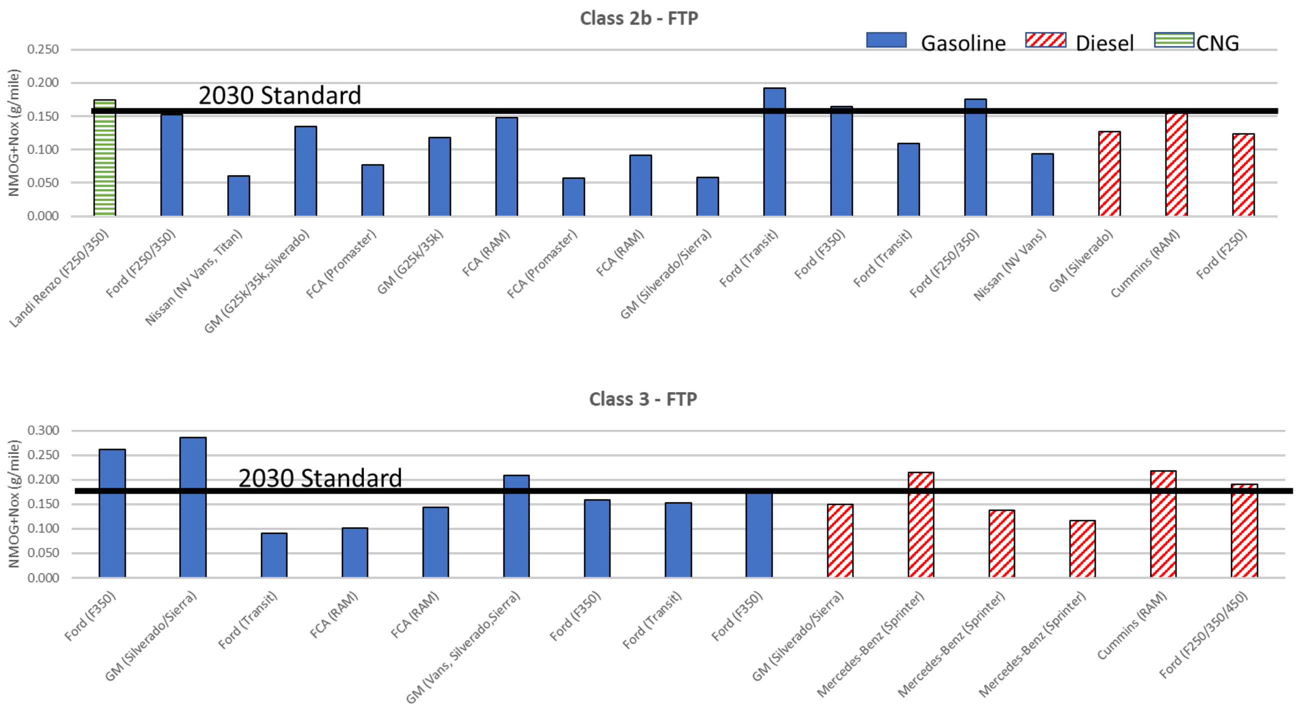
[A] For 2027 and subsequent model year MDVs, the applicable emission standards can be found in 13 CCR, §1961.4

[B] For 2027 through 2029 model year vehicles, the conformity factor, CF, is equal to 2.0. For 2030 and subsequent model year vehicles, the conformity factor, CF, is equal to 1.5.

D. MDV FTP NMOG+NOx Fleet Average

To determine the MDV ACC II fleet average standards for 2027 and subsequent model year MDVs, staff analyzed certification data for model year 2021 LEV III MDVs which are shown in Figure 33. The data shows that current class 2b and class 3 MDVs are already emitting emissions close to the proposed standards. Manufactures usually choose to maintain a certain amount of safety margin from the standards to ensure compliance during the vehicle’s full-useful life, and this will account for additional reductions in emissions beyond the proposed standard levels. The biggest reductions will come from class 3 MDVs, which have always had less stringent standards than class 2b MDVs. Based on certification data, staff has determined that class 3 vehicles are often using the same engine and emission control systems as their class 2 counterparts. The only difference is class 3 vehicles can be rated for higher payload and towing capacities, therefore the proposed ACC II fleet average standard for class 3 was marginally less stringent than class 2b.

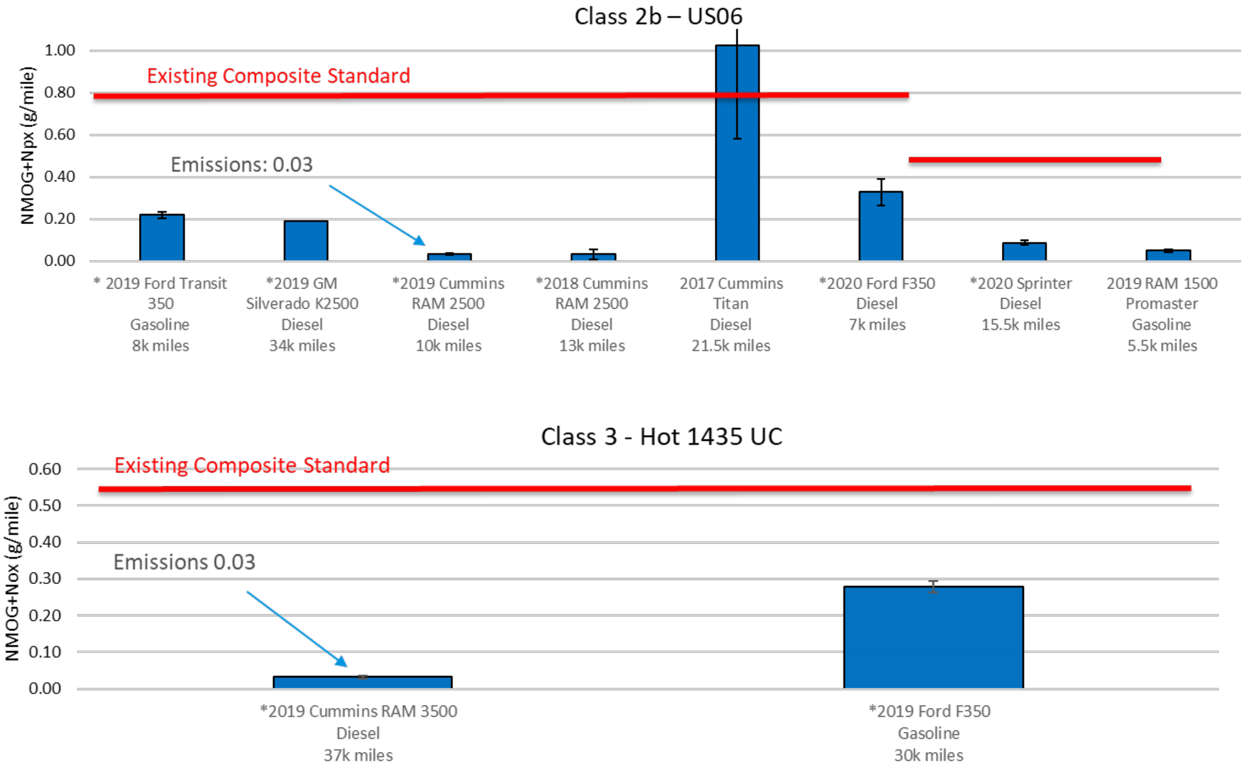
Figure 33: CARB Model Year 2021 LEV III MDV NMOG+Nox FTP Certification Data with Manufacturer Derived Deterioration Factor (DF)



E. MDV US06 and UC Cycle NMOG+NOx Emissions

CARB conducted testing on the chassis dynamometers to assess the current emission levels of LEV III MDVs in class 2b and class 3 on their SFTP test cycle. Data shown in Figure 34, is from CARB's testing. Most MDVs have shown they have well-controlled emissions on the SFTP test cycle, which are aggressive driving cycles with higher speeds and accelerations. There are some vehicles that can have very high emissions and still meet the composite standard. The Cummins Titan is shown only as an example vehicle in Figure 34 of a vehicle that could have very high emissions on its SFTP test cycle but still meet the composite standard. The Titan was certified to LEV III FTP standards but not the SFTP requirement. The 2019 Cummins Ram 2500 was certified to both the LEV III FTP and SFTP requirements. This vehicle had shown very high emissions on its SFTP test cycle in previous calibrations with emissions close to 1 g/mile like the Titan. The Ram 2500 was subject to an emissions recall by CARB for an auxiliary emission control device (AECD), and as part of the recall the vehicle was recalibrated by software changes. The Ram 2500 after the recall would demonstrate the best emissions on the SFTP test cycle. Staff's analysis of the data shows that current MDVs are capable of meeting much lower SFTP standards than they currently meet today. Additionally, a standalone standard would ensure robust emission controls under aggressive driving and prevent very high emissions like we have seen with other vehicles.

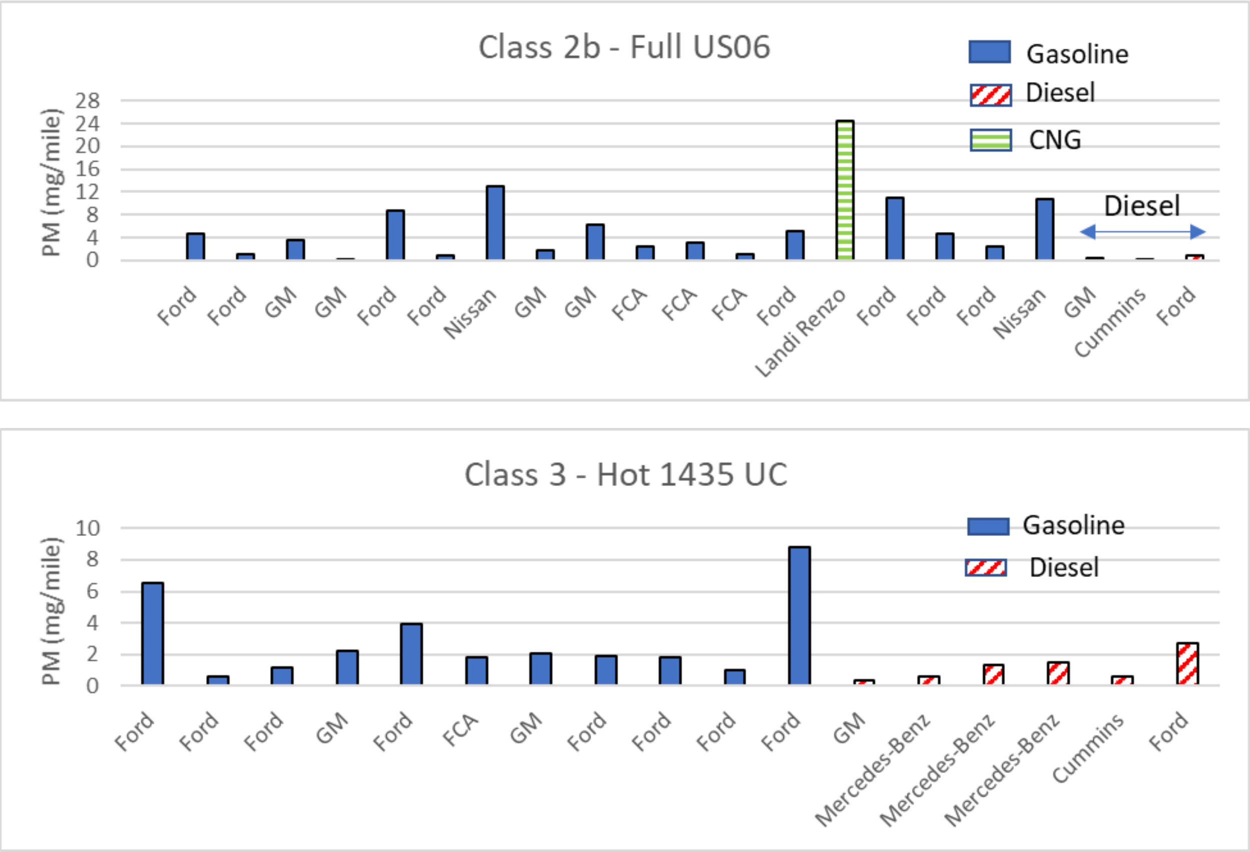
Figure 34: CARB's SFTP Test Data of LEV III MDVs for NMOG+Nox with Manufacturer Derived DF



F. MDV SFTP PM Emissions

Staff analyzed LEV III certification data for MDVs in both class 2b and 3 to propose the SFTP PM standards for ACC II. The data is shown in Figure 35 and it shows that 67% of class 2b and 89% of class 3 have PM emission levels that are well-controlled. The US06 is the most aggressive test cycle and PM variability has been known to be higher, but several test groups in class 2b are showing very poor PM control with high emitters ranging from 10-24 mg/mile. With the current technology available today and good engine/software calibration, PM emissions below 8 mg/mile should be achievable especially when more than half of the class 2b MDV test groups are achieving levels below 6 mg/mile. The proposed PM standalone standard would eliminate these high emitters for both class 2b and class 3 and help better control PM emission levels.

Figure 35: CARB Model Year 2021 LEV III MDV SFTP PM Certification Data with Manufacturer Derived DF

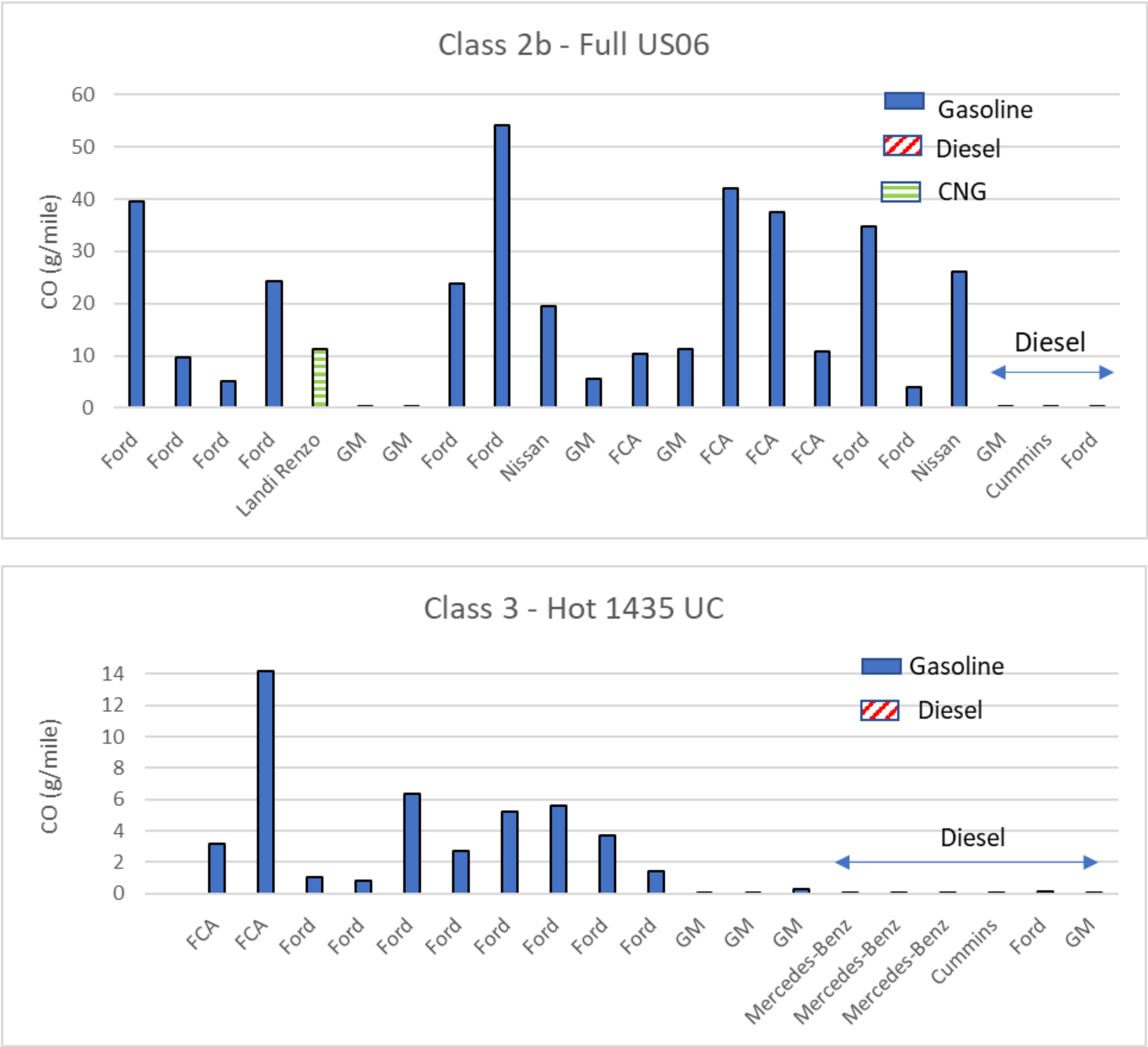


G. MDV SFTP CO Emissions

Staff analyzed model year 2021 LEV III SFTP CO certification data for class 2b and class 3 to propose the MDV SFTP CO standalone standards for ACC II. The data is shown in

Figure 36 and the figure shows variability between test groups can be very high. As stated earlier the main reason for high CO occurs when manufacturers use enrichment strategies to protect their emission control components under very high temperatures, and that is usually for protecting the catalyst. Enrichment is used only by gasoline vehicles, and on the US06 test cycle it is apparent with the high variability in CO emissions ranging from levels under 10 g/mile to higher levels of 54 g/mile. Although the US06 is an aggressive test cycle with higher speeds and accelerations, the use of enrichment is due to poor calibration or manufacturers using undersized catalyst that can overheat very quickly at higher temperatures. The current composite standard for a ULEV class 2b is 22 g/mile and current certification data shows they are emitting at levels near 2-3 times larger on the individual test cycle. The proposed ACC II standalone CO standards would limit the amount of enrichment and ensure manufacturers use better emission control technologies. The need for enrichment decreases when these vehicles are better calibrated and better emission control components are used.

Figure 36: CARB Model Year 2021 LEV III MDV SFTP CO Certification Data with Manufacturer Derived DF



V. Conclusion

As the analysis above shows, the emission control standards in the proposed regulation are necessary to ensure engine emissions from light- and medium-duty vehicles are controlled to the maximum extent feasible. Moreover, because these standards are being met by some vehicles already on the road, they are technically feasible in the time allowed. Manufacturers have several model years to ensure all their conventional vehicles that are subject to these standards meet them. The costs to do so will be reasonable and outweighed by the public health benefits they provide.

VI. References

California Air Resources Board. 2015. California Evaporative Emission Standards and Test Procedures for 2001 and Subsequent Model Motor Vehicles." Last amended September 2, 2015. *https://ww2.arb.ca.gov/sites/default/files/2020-01/evap_tps_clean_complete_10-15_accessible.pdf*

California Air Resources Board. 2018. EMFAC 2017 Volume III - Technical Documentation. Published July 20, 2018. Accessed March 10, 2022. *https://ww3.arb.ca.gov/msei/downloads/emfac2017-volume-iii-technical-documentation.pdf*.

National Renewable Energy Laboratory. 2010-2012 California Household Travel Survey. Accessed March 2, 2022. *https://www.nrel.gov/transportation/secure-transportation-data/tsdc-california-travel-survey.html*.

Reddy, Sam. 2010 "Evaporative and Refueling Emission Control Training/Workshop Manual." Version 3.0. January 20, 2010.