AIR RESOURCES BOARD

FIELD EVALUATION OF HEAVY-DUTY DIESEL NOx

CONTROL STRATEGIES

January 2013

This report has been reviewed by the staff of the California Air Resources Board and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Air Resources Board, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

Table of Contents

EXECUTIVE SUMMARY

i. Background

The California Air Resources Board (ARB) and the United States Environmental Protection Agency (U.S. EPA) adopted a 0.20 gram per brake horsepower-hour (g/bhp-hr) oxides of nitrogen (NOx) emission standard for heavy-duty diesel (HDD) engines beginning with the 2010 model year (MY). The majority of engine manufacturers chose selective catalytic reduction (SCR) technology to attain this standard. All engines equipped with SCR use a liquid urea solution as the reductant, known commonly as diesel exhaust fluid (DEF). Using DEF increases the operational cost to truck operators, theoretically creating an incentive for operators to find ways to circumvent the SCR system and reduce costs by minimizing DEF usage. This could occur if DEF is not replenished with another fluid such as water, or if the DEF delivery system is disabled.

Over the past several years, industry met with ARB and the U.S. EPA to discuss strategies to assure that DEF is used properly and improper maintenance and tampering by truck operators is minimized. The U.S. EPA published guidance documents in the 2007 calendar year, in February 2009 (referred to as 2009 U.S. EPA Guidance) and again in December of 2009 (U.S. EPA reference numbers CISD-07-07 dated March 27, 2007, CISD-09-04 dated February 18, 2009 and CISD-09-04 REVISED dated December 30, 2009) to inform engine manufacturers of the steps they should take to assure DEF is used and mal-maintenance and tampering are minimized. While the guidance documents were not considered policy by the ARB, ARB provided comments during the development of the February 2009 U.S. EPA Guidance (referred to hereafter as "2010 MY Guidance") and during its 2010 engine certification reviews for California.

The 2010 MY Guidance document provided advisory information that addressed how manufacturers of SCR-equipped engines should incorporate driver warning systems, driver inducement strategies, identification of incorrect reducing agents, tamper resistant designs, and freeze protection. In addition, as a condition of certification, ARB requires manufacturers to demonstrate that all emission control systems are tamper resistant. In the case of SCR, which requires the routine addition of DEF, most manufacturers utilized driver inducements to demonstrate tamper resistance when certifying their vehicles. Consistent with the 2010 MY Guidance, these inducements first alert the driver that the DEF supply is low, and are subsequently followed by a reduction in truck performance or other inducements to encourage the driver to refill the DEF supply. Ultimately, if DEF is not refilled, or if an inappropriate fluid is added, or if hardware is tampered, the vehicle is immobilized by the engine control system. The ARB and U.S. EPA held a joint workshop in July of 2010 to update the SCR inducement strategy guidelines (referred to hereafter as "2011+ MY Guidelines") to be applied during the 2011 MY certification process. The 2010 MY Guidance and July 2010 ARB and U.S. EPA SCR Workshop expectations are outlined in the following table:

SCR Guidance and Workshop Guideline Summary

TEST CYCLE	WARNING / INDUCEMENT	**2010 MY GUIDANCE** * U.S. EPA FEBRUARY 2009 GUIDANCE	**2011+ MY GUIDELINES** * JULY 2010 CARB/U.S. EPA SCR WORKSHOP GUIDELINES
DEF DEPLETION	Initial Warnings	• Provide visual or audible alarms with escalation of warnings with adequate time to re-fill the DEF	• Same
	Inducements	• Escalation of warnings • Before tank empty or 2.5% DEF level for 2:1 or 3:1 tank sizes • At tank empty for 1:1 tank sizes • Includes engine derates, • Final Inducement: 5 MPH Limit	• Same • Similar, but clearly defined as prior to noncompliance for all tank sizes • Similar, but manufacturer discretion to propose level and combination of escalating torque derates with safety considerations: Must be approved by agencies • Similar, added no power and idle only options in addition to 5 MPH option
	Seek Safe Harbor for Final Inducement	• At 2.5% DEF Trigger or at DEF empty for 1:1 DEF/Fuel Tank Size • Mfr. used at least one trigger ✓ After Refueling ✓ After Parking ✓ After Restart	• Similar, but linked to prior to noncompliance rather than 2.5% or empty trigger • Improved: Mfr. used at least TWO triggers ✓ After Diesel Refueling ✓ After Parking/Idle ✓ After Restart
DEF CONTAMINATION	Initial Warnings	• Once detected: initiate warnings (i.e., messages, lights, alarms)	• Improved: Detect noncompliance within 1 hour; initiate warnings (i.e., messages, lights, alarms)
	Inducements	• At detection +500 miles or 10 hrs ✓ 25% torque derate ✓ Final inducement 5 MPH	• Improved: At detection • Similar, but manufacturer discretion to propose level and combination of escalating torque derates with safety considerations: Must be approved by agencies • Similar, added no power and idle only options in addition to 5 MPH option
	Seek Safe Harbor for Final Inducement	• At detection + 1,000 miles or 20 hrs – 25% torque derate continues • Mfr. used at least one trigger ✓ After Refueling ✓ After Parking ✓ After Restart	• Improved: Within 4 hours (~200 miles) of detection search for Final Inducement • Improved: Mfr. used at least TWO triggers ✓ After Diesel Refueling ✓ After Parking/Idle ✓ After Restart
DEF SYSTEM TAMPERING	Initial Warnings	• Once detected: initiate warnings (i.e., messages, lights, alarms)	• Improved: Detect noncompliance within 1 hour; initiate warnings (i.e., messages, lights, alarms)
	Inducements	• At detection +500 miles or 10 hrs ✓ 25% torque derate ✓ Final inducement 5 MPH	• Improved: At detection • Similar, but manufacturer discretion to propose level and combination of escalating torque derates with safety considerations: Must be approved by agencies • Similar, added no power and idle only options in addition to 5 MPH option
	Seek Safe Harbor for Final Inducement	• At detection + 2,000 miles or 40 hrs – 25% torque derate continues • Mfr. used at least one trigger ✓ After Refueling ✓ After Parking ✓ After Restart	• Improved: Within 4 hours (~200 miles) of detection search for Final Inducement • Improved: Mfr. used at least TWO triggers ✓ After Diesel Refueling ✓ After Parking/Idle ✓ After Restart
REPEAT OFFENSES		• Not Applicable	• Improved: SCR system should be monitored for 40 engine hours for repeat offenses and return to seek final inducement within 60 minutes for any repeat offense
SELF HEALING		• Not Applicable	• Improved: Generic scan tool cannot clear inducements.

***** Staff interpretation of documents and resulting practical application.

During the July 2010 SCR Workshop, Navistar, the one manufacturer that was not using SCR, raised concerns about the use of SCR to comply with the 2010 standards. Navistar claimed, based on their own test program that the driver SCR warning alerts and engine inducements used for the 2010 MY engines were not effective in deterring drivers from not refilling DEF or otherwise tampering with the DEF dispensing system, and that SCR was not an effective emission control strategy. (Navistar recently announced it will use SCR on most of its future engines.) In response to the expressed concerns of DEF availability, SCR tampering, and effectiveness of SCR inducement strategies, ARB initiated field investigations in 2010 to evaluate the first year implementation of SCR for the 2010 MY HDD vehicles. The investigation included:

(1) Two surveys of DEF availability within the State of California;

(2) A survey to determine whether truck operators driving 2010 MY SCR-equipped trucks on California roadways have tampered with SCR components or are not using DEF;

(3) An examination of the types and effectiveness of SCR driver inducements employed on 2010 MY HDD vehicles; and

(4) An examination of the emission impacts of HDD SCR-equipped vehicles when DEF has been depleted, diluted or the SCR system has been tampered.

The findings of this study were published in a May 2011 report entitled, "Heavy-Duty Vehicle Selective Catalytic Reduction Technology Field Evaluation" (May 2011 Report - http://www.arb.ca.gov/msprog/cihd/resources/reports/scrreport.pdf) and are summarized below:

(1) The results of the two DEF availability surveys indicated that DEF was readily available in 2010 at major diesel truck stop refueling stations, 85% and 92% respectively. In addition, both surveys indicated that 30% of retailers that normally supply parts and equipment for light-, medium-, and HDD vehicles and trucks had DEF available.

(2) Roadside inspections of 69 SCR-equipped trucks showed that all of the trucks were using proper DEF solution, no tampering was present, and no DEF-warning lights or audible alerts had been initiated. Sixty of the 69 drivers had no problem locating DEF while the remaining nine drivers indicated some problems locating DEF. However, 68 of the drivers said they never ran out of DEF while operating their vehicles and one indicated he drove only 10 miles with an empty DEF driver's gauge reading.

(3) Three 2010 MY engines (Cummins 6.7L, 14.9L, and a DDC 12.8L) were tested to evaluate how SCR inducement strategies functioned under three different scenarios: (a) when DEF is depleted under normal driving (DEF Depletion Cycle); (b) when DEF is replaced with water (DEF Contamination Cycle); and (c) when an SCR component is tampered to cause DEF to stop dosing (DEF System Tampering Cycle). The test program evaluation showed that driver inducements occurred for each vehicle based on the three SCR related inducement cycles mentioned above. There were individual vehicle issues on the Cummins' engines where the 6.7L engine experienced a problem with the DEF heater system that caused the DEF system to overheat

and stop dosing and the 14.9L engine failed to enter into the 5 mph severe vehicle speed inducement condition for each of the three test cycles. Cummins quickly addressed these issues and remedied these problems under recall and service campaigns.

(4) One test vehicle was evaluated for NOx emissions under typical baseline operation and over the three DEF test cycles listed above. Results indicated that NOx control was within control limits when operating with DEF and no tampering was present. However, when DEF was truly empty, or the delivery of DEF was tampered with, the NOx emissions were about four times higher than under normal operation.

SCR technology was first certified on 2010 MY HDD vehicles. ARB expected some initial problems to be experienced in the first few model years, and has worked diligently with manufacturers to resolve SCR inducement strategy issues on subsequent model year engine applications. In fact, some manufacturers have already issued technical service bulletins to recalibrate the 2010 MY vehicles so that the SCR inducement strategies are more in line with the July 2010 CARB/U.S. EPA SCR Workshop Guidelines for 2011+ MY engines (referred to hereafter as "2011+ MY Engines Guidelines").

ii. New Study "Field Evaluation of Heavy-Duty Diesel NOx Control Strategies"

ARB conducted a second field study in 2011/2012 similar to the first, but added Navistar's engine (non-SCR) to the lineup of engines to evaluate. The investigation included:

A. A follow up survey of DEF availability within the State of California;

B. Roadside inspections to determine whether truck operators driving SCR-equipped trucks on California roadways have tampered with SCR components or are not using DEF;

C. A re-evaluation of driver inducements on two SCR-equipped 2010 MY Cummins engines evaluated in the first study where errors in programming and part malfunctions were found;

D. A continued evaluation of 2010+ MY NOx control strategies including an examination of the types and effectiveness of SCR driver inducements employed on SCR-equipped trucks; and

E. An examination of the emission impacts of HDD vehicles when DEF has been depleted, diluted or the SCR system has been tampered, or non-SCR trucks are operated under lean cruise cycles. The lean cruise cycle was added to verify that the vehicle calibration does not adjust to optimum fuel economy efficiency settings while sacrificing NOx emissions when the vehicle is traveling at steady cruise speed conditions. All emissions were measured with a Portable Emissions Measurement System (i.e., a PEMS unit).

The results of the investigations are discussed below.

A. Summary of DEF Availability Survey

During the 2011 and 2012 calendar year, staff conducted field surveys and inspections similar to those performed in 2010. These surveys confirm that DEF has become readily available in California as DEF can now be purchased at the fuel pump at most major national truck stop fueling stations (100 percent availability of the 34 stations surveyed) and has become increasingly available at auto part retailers (90 percent availability of 79 retailers surveyed) and smaller independent HDD trucks stops (73 percent availability of 112 smaller stations surveyed). Overall, the results of the SCR surveys showed that DEF is widely and conveniently available in California.

B. Summary of DEF Quality and Tampering Survey

In regards to proper DEF usage, the ARB conducted a new survey of 243 SCR-equipped HDD trucks for DEF usage and tampering. The results of the survey were consistent with the 2010 audit showing no tampering of SCR systems and all 243 vehicles were using the proper DEF concentration. Overall, owners are on-board with providing the proper DEF concentrations for their vehicles.

C. Re-Evaluation of Driver Inducement on Two SCR-Equipped 2010 Model Year Cummins Engines (Test Vehicles 1 & 2)

In March 2011, ARB launched a test program to recheck the two Cummins 2010 MY engines that were tested in August 2010 (as mentioned in Section i(3) above) and as indicated have been corrected by Cummins.

Due to the voluntary recall and/or service campaigns that Cummins provided to their 2010 MY engine in use customers, staff expected some SCR inducement strategies may have been updated to be more consistent with the 2011+ MY Guidelines. The recalibrations were reported to update SCR related software including reduced time/mileage periods to more severe warnings and inducements, and/or additional safe harbor triggers.

The trucks were operated under similar test cycles as performed in 2010 (a) when DEF is depleted under normal driving (DEF Depletion Cycle); (b) when DEF is replaced with water (DEF Contamination Cycle); and (c) when an SCR component is tampered to cause DEF to stop dosing (DEF System Tampering Cycle).

ARB’s re-evaluation of the two Cummins SCR-equipped HDD vehicles demonstrated that the warnings and inducement strategies incorporated by the engine manufacturer were consistent with the 2010 MY Guidance as certified and rectified the issues detected in the first round of testing. In addition, the service campaigns led to the vehicles' SCR inducement management performance to be mostly consistent with the 2011+ MY engines. The issues for full consistency with the newer guidelines for 2011+ MY engines mainly dealt with timing concerns. Specifically, Test Vehicle 1 took approximately twice the suggested time as per the 2011+ MY Guidelines to search for a safe harbor event for the final inducement under the DEF Contamination and DEF System Tampering Cycles. Also, Test Vehicle 1 did not search for safe harbor event within 1 hour (this event took approximately 4 hours to accomplish) when a repeat tampering event was instituted on the vehicle (i.e., re-disconnecting the vehicle's DEF doser injector after connecting it to clear a no start condition). In May 2011 Cummins launched a voluntary service campaign on their 2010 MY 6.7L engines to address the timing parameters to search for safe harbor event for DEF contamination, SCR tampering and SCR repeat offense events that are more consistent with the 2011+ MY Guidelines.

Test Vehicle 2 almost doubled the one hour suggested 2011+ MY Guidelines for identifying contaminated DEF under the DEF Contamination Cycle and therefore was not fully consistent with the intended objectives of the 2011+ MY Guidelines. ARB staff is continuing to evaluate Cummins' control logic for DEF contamination guidance consistency with the 2011+ MY Guidelines. The following table summarizes Test Vehicles 1 and 2's performance with each of the test cycles evaluated and how each engine compared to the suggested guidance from the 2010 MY Guidance and the 2011+ MY Guidelines.

Test Vehicle Consistency With SCR Guidance

GUIDANCE	TEST CYCLE	TEST VEHICLE		
		#1 Cummins 2010MY 6.7L	#2 Cummins 2010MY 14.9L	COMMENTS
2010 MY Guidance	DEF Depletion Cycle	YES	YES	
	DEF Contamination Cycle	YES	YES	
	DEF System Tampering Cycle	YES	YES	
2011+ MY Guidelines	DEF Depletion Cycle	YES	YES	
	DEF Contamination Cycle	NO*	NO**	* When conducting a contamination, tampering and a repeat offense event, the vehicle did not search for safe harbor within 4 hours after initiating the first driver warning (1 hour guidance for the repeat offense event). **Chrysler Technical Service Bulletin (No. 18-029-11) corrected these issues.** ** The DEF Contamination Cycle took approximately 2 hours (105 miles) to launch the first driver warning; outside of the one hour guidance.
	DEF System Tampering Cycle	NO*	YES	* See explanation in the cell above.

In regards to the emission results for these vehicles, Test Vehicle 1 was not tested because emissions testing were reported on this vehicle in the previous report. Test Vehicle 2 performed as expected with the vehicle operating within its respective NOx Not-To-Exceed (NTE) standard under normal vehicle operation and under the DEF Depletion Cycle until DEF was fully depleted. Once DEF had completely depleted, the NOx emissions did increase but the driver was experiencing a significant engine power derate (approximately 40 percent less power) that would not be tolerated by any vehicle operator. The same power derate inducement conditions also occurred under the DEF Contamination and DEF System Tampering Cycles. The lack of power experienced under these test cycles with the subsequent 5 mph limited speed event will force the operator to have these issues remedied immediately.

D. Continued Evaluation of 2010+ MY NOx Control Strategies

Staff evaluated three additional HDD vehicles. The vehicles were driven over prescribed driving routes to evaluate their NOx control systems and their response to improper DEF use and tampering. The vehicles evaluated included a 2012 MY Freightliner Cascadia truck equipped with a 2011 MY 12.8 liter Detroit Diesel Corporation (DDC) DD13 engine (Test Vehicle 3) using SCR after treatment, a 2011 MY Volvo truck equipped with a 2010 MY 12.8 liter Volvo D13H engine (Test Vehicle 4) using SCR after treatment, and a 2012 MY International truck equipped with a 12.4 liter Navistar Maxxforce 13 engine (Test Vehicle 5) with no SCR after treatment.

1. SCR-Equipped Engine Evaluation – DDC (Test Vehicle 3) and Volvo (Test Vehicle 4)

ARB decided to test two additional SCR-equipped engines that were expected to comply with the 2011+ MY Guidelines. Specifically, the two engines tested were the 2011 MY 12.8 liter Detroit Diesel DD13 and the 2010 MY 12.8 liter Volvo D13H engines. The Volvo's 2010 MY engine had been updated with a SCR calibration similar, but not identical, to their 2011 MY SCR equipped engines; hence the Volvo's 2010 MY engine was expected to be consistent with the 2011+ Guidelines.

Staff ran a series of tests similar to the prior report (DEF Depletion, DEF Dilution, and DEF System Tampering Cycles) to determine if the SCR calibrations for these engines prompted driver warnings and vehicle inducements that were consistent with the vehicle owner's manuals and the 2010 MY Guidance and 2011+ MY Guidelines. For these SCR equipped engines, typically, a sequence of visual and/or audible warnings on the instrument panel (e.g. warning lights, chimes, and/or text message displays) indicating that the DEF supply is low or a problem exists with the SCR system. As additional mileage is accumulated without remedying the problem or refilling the DEF supply, further driver inducements should occur, such as power de-rates or limited vehicle speed. Ultimately, if the problem is not corrected, a severe inducement or final immobilization in the form of a no-start condition, or 5 mph maximum speed limit, or idle-only operation should be triggered once the vehicle reaches a safe harbor (e.g. when refueling the vehicle, turning off the vehicle or idling the vehicle for an extended period of time). In addition to these test cycles, staff also ran a new cycle called the DEF Dilution Cycle. The purpose of this evaluation was to determine if the SCR system is capable of detecting a diluted DEF concentration as opposed to completely filling the DEF tank with water.

Concurrently while running each test cycle, staff measured NOx emissions with a PEMS device by first establishing baseline NOx emissions for normal vehicle operation over a prescribed test route. Staff continued to measure NOx emissions for each of the SCR test cycles over the same prescribed test route to determine the effects each test cycle had on NOx emissions.

In testing the 2011 DDC engine, DDC was consistent with the 2011+ Guidelines with the exception of the DEF System Tampering Cycle. ARB staff observed that under the DEF System Tampering System Cycle, with the DEF doser injector disconnected, the vehicle did not begin its search for final inducement until well after four hours since the first driver alert occurred and therefore was not consistent with the intended objectives of the 2011+ MY Guidelines. DDC staff indicated that synergistic effects of their SCR calibration as operated under ARB's prescribed driving cycle may have prevented a timely SCR inducement strategy from searching for a safe harbor event (i.e., ARB's driving cycle did not encounter a transitional requirement like a refueling event or an extended idle time which is normal operation for these types of vehicles). ARB staff is continuing to evaluate DDC's control logic for consistency with the 2011+ MY Guidelines.

The Volvo evaluation results showed that this engine was consistent with the 2010 MY Guidance (for which this engine was certified) and the 2011+ MY Guidelines for all conducted test cycles. A summary for both the DDC and Volvo engines are shown below.

Test Vehicle Consistency With SCR Guidance

GUIDANCE	TEST CYCLE	TEST VEHICLE		
		#3 DDC 2011MY 12.8L	#4 Volvo 2010MY 12.8L	COMMENTS
2010 MY Guidance	DEF Depletion Cycle	NA[1]	YES	
	DEF Contamination Cycle	NA[1]	YES	
	DEF System Tampering Cycle	NA[1]	YES	
	DEF Dilution Cycle	NA[1]	YES	
2011+ MY Guidelines	DEF Depletion Cycle	YES	YES	
	DEF Contamination Cycle	YES	YES	
	DEF System Tampering Cycle	NO***	YES	*** Under the DEF System Tampering Cycle the engine was not fully consistent with the intended objectives of the guidelines. .
	DEF Dilution Cycle	YES	YES	

[1] – Test Vehicle 3 was a 2011 MY engine and was certified with respect to the 2010 CARB/U.S. EPA SCR Workshop Guidelines for 2011+MY. Therefore, the 2010 MY Guidance information does not apply to this engine.

2. EGR-only Equipped Engine – Navistar (Test Vehicle 5)

Navistar 2011 MY 12.4L (Test Vehicle 5): Exhaust Gas Recirculation (EGR) equipped engine NOx control is achieved by recirculating a portion of the engine's exhaust back into the engine's air intake system. In the case of EGR only equipped engines (non-SCR), drivers may desire to achieve more power and/or fuel economy by turning off or otherwise tampering with the EGR system. Staff examined the vehicle owner's manuals to determine the expected inducement strategies for each vehicle when tampering with the vehicle's EGR system. Typically, this includes a visual warning on the instrument panel (e.g., a check engine light) indicating a problem with the engine.

The test cycles performed on this vehicle included a Restricted EGR Cycle and a Lean Cruise Cycle. For the Restricted EGR Cycle staff placed an aluminum plate between the EGR cooler and the EGR transfer pipes to simulate the effects caused by a plugged EGR cooler or when an EGR valve became inoperable or stuck in the closed position.

For the Lean Cruise Cycle staff drove the vehicle at steady speeds, which required minimal throttle movement, over a prescribed test route that was reasonably flat. A Lean Cruise Cycle was added to verify that the vehicle calibration does not adjust to optimum fuel economy efficiency settings while sacrificing excessive NOx emissions while a vehicle is operated at steady cruise speed conditions. This type of calibration is considered a defeat device that led to a consent decree with several heavy-duty engine manufacturers in the late nineties for unscrupulous business practices. This test cycle was performed to simply check that this engine did not have a calibration that would create better fuel economy but at the risk for creating an excessive NOx condition.

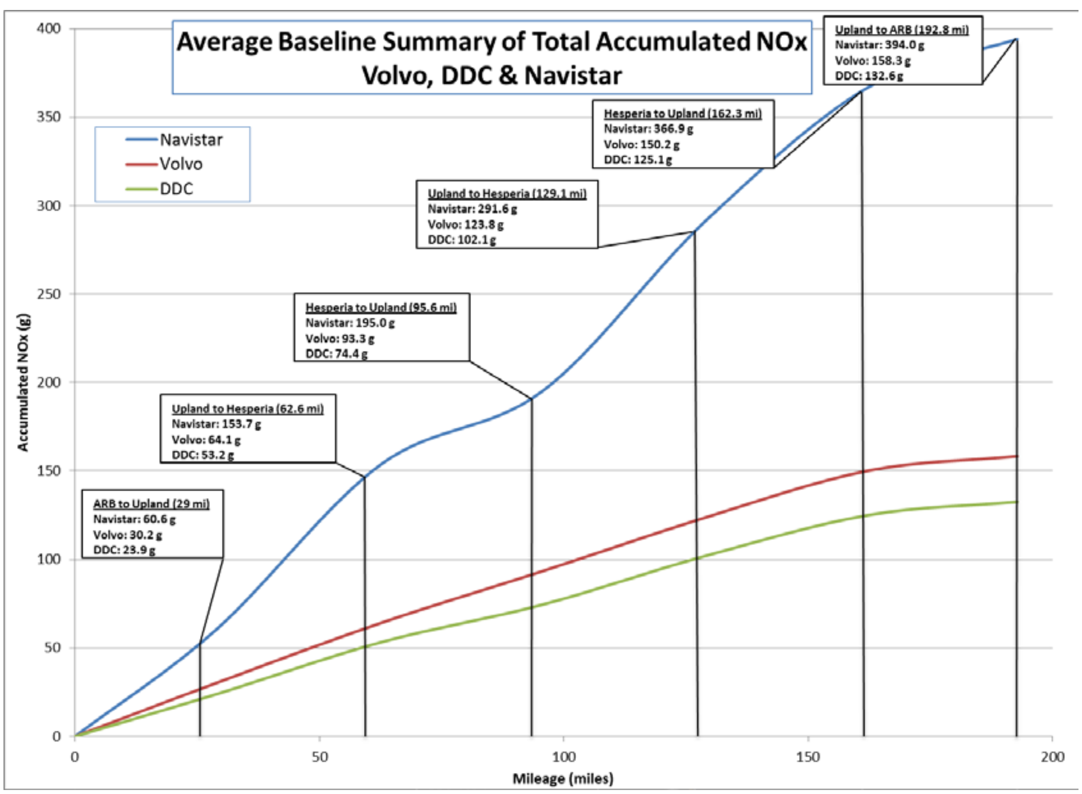
Staff operated the vehicle over the same prescribed test route as the SCR-equipped engines and also equipped these vehicles with a PEMS unit to measure NOx emissions. Staff first established the baseline emissions under normal vehicle operation over the prescribed test route and then operated the vehicle under the Restricted EGR Cycle and Lean Cruise Cycle monitoring the NOx emissions created by these test cycles.

When the Navistar 12.4L engine was performing under normal vehicle operation, the engine ran well and NOx emissions were within its applicable NOx standard (0.5 g/bhp-hr, which is higher than the other engines reported on). However, with the EGR disabled, the NOx emissions were 9.3 times above the limit, engine performance suffered, and the vehicle exhibited surging at the lower engine operating range. The driver commented that the problems created by this tampering event would not be tolerated because the surging condition and loss of power occurred at lower RPM's where the engine would normally operate. Based on the results of this test cycle, staff ascertained that plugging the EGR will lead to driver warnings in the form of a MIL, poor drivability and reduced fuel economy (9 percent less fuel economy than normal operation). In regards to the Lean Cruise Cycle evaluation, the emission data from the Lean Cruise Cycle 2 evaluation showed that although the NOx emissions increased by almost nine percent with the cruise control set as compared to the baseline data;

however, the overall results whether the vehicle was operated in the baseline mode or with the cruise control set were both within the applicable NTE standard. Therefore, operating the vehicle in a steady cruise condition did not cause excessive NOx emissions under this mode of operation.

3. NOx Emissions Evaluation for Vehicles 3, 4, & 5

In order to compare the relative NOx control of the three trucks (DDC, Volvo and Navistar), staff operated them over the same designated test route three times each and measured their NOx emissions using a PEMS measurement device. The average baseline (no tampering of the SCR or EGR systems) NOx emissions were obtained for each truck and plotted for comparison. Overall, the NOx results for these vehicles performed very well with each vehicle meeting their respective NTE NOx emission standards. It should be noted that the DDC and Volvo trucks equipped with SCR technology are certified to the 0.2 g/bhp-hr NOx standard and the Navistar truck, that mainly utilizes EGR to control NOx (i.e., no SCR), is certified to the 0.5 g/bhp-hr NOx Family Emission Limit (FEL[2]). Intriguingly, the SCR-equipped engines are certified 2.5 times lower than the non-SCR Navistar engine which is the same difference when considering the baseline NOx emissions data (i.e., the SCR-equipped engines NOx levels were approximately 2.5 times lower than the non-SCR engine). This study clearly shows that the engines with SCR technology outperformed the EGR-only equipped engine for controlling NOx.



[2] – Certification to the Family Emission Limit (FEL) is the emission level declared by the manufacturer and serves in lieu of an emission standard for certification purposes in any averaging, banking, or trading programs.

iii. Conclusion

The ARB has shown through various DEF availability surveys and DEF tampering inspections that DEF has become widely available in California and that the trucking industry is complying with the requirements to operate SCR-equipped vehicles on quality DEF. ARB's evaluation of the four SCR-equipped HDD vehicles demonstrated that the warnings and inducement strategies incorporated on these engines were consistent with the vehicle manufacturers owner's manuals, the 2010 MY Guidance and largely consistent with the 2011+ MY Guidelines.

The technology of today's HDD engines does not lend itself to be tampered with and the advancement of SCR engines has shown that the engine's management system will create intolerable engine inducement consequences when DEF is depleted to empty or the SCR system is tampered. In short, staff believes that companies and truck operators will simply not tamper with their HDD vehicle and risk costly repairs and/or possible fines especially when tampering or not using DEF will cause the engine's power to degrade and ultimately lead to no-start conditions or severely limited speed. Engine manufacturers continue to work with ARB in improving their SCR inducement strategies for current model year engine certifications and in some cases have voluntarily incorporated software enhancements to upgrade their older SCR engine management strategies that are already in commerce.

ARB's emissions testing from this evaluation demonstrated that the SCR-equipped engines when operating on quality DEF are meeting the HDD NOx NTE in-use emission requirements. Additionally, the non-SCR engine also met its NTE in-use emission standards; however, the NOx emissions from the non-SCR engine were significantly higher than the SCR-equipped engines because it is using emission credits to certify to a laxer standard.

I. Introduction

In May 2011, the California Air Resources Board (ARB) published a document titled, *Heavy-Duty Vehicle NOx Control Strategies Technology Field Evaluation* (May 2011 Report). The report discussed how most manufacturers are utilizing selective catalytic reduction (SCR) technology to attain the adopted 0.20 gram per brake horsepower-hour oxides of nitrogen (NOx) standard on heavy-duty diesel (HDD) engines beginning with the 2010 model year (MY). SCR is the after treatment technology that treats exhaust gas downstream of the engine. Small quantities of diesel exhaust fluid (DEF) are injected into the exhaust upstream of a catalyst, where it vaporizes and decomposes to form ammonia and carbon dioxide. The ammonia is the desired product which, in conjunction with the SCR catalyst, converts the NOx to harmless nitrogen and water.

Using DEF adds a nominal operational cost to businesses, theoretically creating an incentive for operators to find ways to circumvent the SCR system and reduce costs by minimizing DEF usage. This could occur if DEF is not replenished with another fluid such as water, or if the DEF delivery system is disabled. Industry raised concerns that, because SCR relies on the availability of DEF and since truck operators periodically must refill their DEF tanks, SCR could be construed as not being an effective emission reduction strategy. In addition, since the use of DEF could result in increased operational costs, truck operators may be tempted to tamper the SCR system.

To minimize the likelihood of improper maintenance and tampering, the United States Environmental Protection Agency (U.S. EPA) provided manufacturers certification guidance for SCR-equipped engines in March 2007, updated it in February 2009, and again in December of 2009. While the guidance documents were not considered policy by the agencies, these documents provided direction for employing SCR strategies to ensure that evolving SCR systems would function within the general suggested guidance so that the agencies can appropriately certify these systems and that they be properly maintained by the end user. For example, the February 2009 U.S. EPA Guidance document provided SCR advisory information (referred to hereafter as “2010 MY Guidance) that addressed SCR driver warning systems and vehicle inducement strategies that would occur if an SCR system became depleted of DEF, or if an incorrect reducing agent is used in place of DEF, or if the SCR system becomes tampered. Manufacturers utilized these guidance documents when designing the SCR systems for 2010 MY HDD engine applications. Since 2009, the ARB and U.S. EPA worked together to further define SCR inducement strategies. A workshop was held at ARB in July 2010 with the HDD industry where ARB staff provided additional SCR guidelines for 2011+MY engines (referred to hereafter as "2011+ MY Guidelines") that further enhanced SCR strategy criteria for providing feedback to the vehicle operator and triggering vehicle inducement strategies in instances when SCR systems became depleted of DEF, when incorrect reducing agents were used in place of DEF, or when the SCR system became tampered.

The May 2011 report focused on an ARB test program evaluation that was conducted in mid-2010 on three 2010 MY HDD engines equipped with SCR technology. The field evaluation demonstrated how each of the test vehicles' SCR inducement strategies functioned under specific test cycles when DEF is depleted under normal driving (DEF Depletion Cycle), when DEF is replaced with water (DEF Contamination Cycle), and when an SCR component is tampered to cause DEF to stop dosing or injecting (DEF System Tampering Cycle). Staff documented the SCR warnings/alerts and also the SCR vehicle drivability inducement events created by these cycles and compared these results to the suggested strategies identified under the U.S. EPA's guidance information and the SCR operation guide documented in each vehicle owner's manual. The test program evaluation showed that the SCR driver warnings and inducements occurred for each vehicle with a few SCR inducement design issues that were discovered during this program. Since SCR technology was first certified on 2010 MY HDD vehicles, the ARB expected some maturity issues to be experienced by industry and has worked diligently with manufacturers to resolve most SCR inducement strategy issues with subsequent MY engine applications. In fact, some manufacturers have already issued technical service campaigns, including a recall to recalibrate the 2010 MY vehicles so that the SCR inducement strategies are consistent with the 2011+ MY Guidelines discussed at the July 2010 SCR Workshop.

In March 2011, ARB staff conducted a new program that followed two separate evaluation test plans. The first evaluation was conducted on two SCR equipped 2011 MY HDD vehicles equipped with 2010 MY HDD engines. These two vehicles were originally evaluated in the 2010 calendar year and discussed in the May 2011 Report. At the time these vehicles were evaluated in 2010, the vehicles demonstrated a few SCR design issues. Since then, these vehicles received SCR inducement software updates prompting ARB to re-evaluate the vehicles' current SCR system inducement functionality. Also, staff evaluated three HDD vehicles equipped with 2010 and 2011 MY HDD engines. This program evaluated the NOx control strategies focusing on the two vehicles built with SCR as the principal NOx control strategy and another vehicle that uses EGR as the prime NOx control technology. ARB's evaluation of these trucks also examined `the SCR equipped trucks' inducement strategies and their consistencies with the 2010 MY Guidance and/or the 2011+ MY Guidelines depending on the model year of the engines. Additionally, in 2010, ARB conducted new surveys to determine the availability of DEF and to check if truck operators were adding DEF per the manufacturer's recommendations and/or tampering with their SCR systems. This report transmits ARB results from these test programs and surveys.

II. Investigation Plan

The ARB's investigation included the following: (1) a survey of the availability of DEF in California, (2) a survey to determine whether or not truck operators driving SCR-equipped trucks on California roadways have tampered with SCR components or diluted their DEF such that it would cause the SCR system to function improperly, (3) a re-examination of the types and effectiveness of SCR related driver inducements employed on two 2010 MY HDD vehicles reported on in the May 2011 report, (4) an examination of the types and effectiveness of NOx emission controls including two SCR equipped HDD vehicles and one non-SCR exhaust gas recirculation (EGR) equipped HDD vehicle, and (5) an examination of the emission impacts of the HDD SCR-equipped vehicles when DEF has been depleted, diluted or the SCR system has been tampered and in regards to the HDD non-SCR EGR equipped vehicle, when the vehicle has been tampered and driven under lean cruise conditions.

III. DEF Availability Survey

As a follow up to the DEF Availability Survey conducted in March and August 2010, ARB staff conducted a third survey to evaluate the availability of DEF throughout California (see Appendix A). The statewide survey was conducted by ARB staff and was conducted over a two week period in February 2012.

Flying J/Pilot's Billboard Located on WB I-10 near Palm Springs,

The DEF availability survey includes the results in which staff was instructed to determine if the visited facilities had DEF available to sell. Staff conducted the availability survey throughout Northern and Southern California as shown in the map below (see Figure 4).

Figure 4 - Survey Information Collection Sites

Staff focused primarily on major truck stops along freeway routes, gas stations that sell diesel, auto part stores, and some major retailers. Staff conducted the survey along some of the state's most traveled roadways, such as Interstates 5, 8, 10, and 15, California State Route 99, and U.S. Highway 101, visiting a total of 510 business establishments (see Figure 5).

Figure 5 - DEF Availability Survey Results

Location Type	YES	% YES	NO	% NO	TOTAL
Truck Stop	116	79%	30	21%	146
Gas Station selling diesel	36	15%	207	85%	243
Auto Part Retailer	79	90%	9	10%	88
Retail Business	17	52%	16	48%	33
	248	49%	**262**	51%	**510**

In conducting the survey, it was important that staff place a stronger emphasis on visiting truck stops and gas stations that sell diesel and lesser emphasis on selected retail stores. Although only 51 percent of the businesses surveyed did not sell DEF, 79 percent of the truck stops had DEF available and 90 percent of the auto part retailers sold DEF which was a significant increase for these retailers since the last survey that was conducted in August 2010. In addition, staff discovered that 17 Walmart stores (52 percent of retail businesses surveyed) now carry DEF. Since the August 2010 survey, there has been an increase in the types of businesses that sell DEF and this is expected to continue to grow with the increase of SCR equipped diesel vehicles being introduced into the California market.

Staff also focused on the major national truck stop chains including Love's Travel Stops, Truck Stop America, and Pilot Travel. These truck stops are strategically located along most major freeways and interstates throughout California. Staff visited 34 of these truck stops as shown in Figure 6 below. In total, all 34 truck stops had DEF available and all had DEF conveniently available at the pump.

Figure 6 - Locations Nation-Wide Truck Stops Surveyed

Nation-Wide Truck Stops Surveyed	YES	NO
DEF at Pump Available	34	0

When considering DEF consumption rates, it is important to note that truck operators would only be required to add DEF to their vehicles on a limited basis. DEF consumption is directly related to fuel consumption where the industry standard of DEF consumption is expected to be approximately 2 percent of fuel consumption, depending on vehicle operation, duty cycle, geography, and load ratings. An example of DEF consumption is represented in the figure below (see Figure 7).

Figure 7 – DEF Consumption Information

Annual Miles per Vehicle	Annual Total Miles	Average MPG per Truck	Average DEF Tank Size (on vehicle)	Annual Fuel Usage (gallons)	Consumption per Gallon of Fuel	Estimated Annual DEF Consumption (gallons)	DEF Fill-Ups per Year
150,000	150,000	6	20	25,000	2%	500	25

As shown above, a truck traveling 150,000 miles annually would require 25 annual stops to refill the DEF tank. Assuming a HDD vehicle carries a 200 gallon capacity diesel tank, an operator must stop 125 times to refuel and therefore, DEF would only need to be added approximately every fifth refueling event. With the limited number of DEF refill events and growing number of DEF retailers, operators will be able to locate DEF without any problems.

The price of DEF has not dramatically changed since the previous survey was conducted in August 2010. However, most retailers are only selling DEF in 2.5 gallon containers for $13.99. Heavy-duty truck stop refueling retailers are moving towards selling DEF at the pump for the convenience of their customers. The current DEF price at the pump is approximately $3.00/gallon.

A. Conclusion

The survey results show that DEF is becoming more and more available as the population of SCR equipped vehicles increases. In addition, DEF is readily available where truck operators travel along major freeway and interstate routes in California. In 2010, staff only located two truck stop locations that had DEF available at the pump. The latest survey shows that all 34 of the national chain truck stops inspected had DEF available at the pump and this number will continue to grow with more refueling stations over time. Staff even identified smaller independent truck stops that had DEF available at the pump or when questioned, owners from many of these refueling stations indicated that they would be acquiring the equipment soon. Additionally, many auto part store owners stated that not only do they carry DEF but that it is selling very well (i.e., they sell DEF because there is a demand for it). Finally, with 61 percent of the Walmarts inspected selling DEF, this again shows that the market for DEF is pushing out to at least one major retailer. As more trucks and vehicles utilize DEF, the demand will continue to increase and the availability should be plentiful.

IV. DEF Quality Tampering Survey

As a follow up to the DEF Quality Tampering Survey conducted in September 2010, ARB staff conducted another survey in November 2011 (see Appendix B). This survey's focus was to ascertain whether or not truck operators were adding non-specified fluid to their DEF tank (e.g., water) and therefore, tampering with their SCR system. This survey was performed at six California Highway Patrol commercial vehicle weigh stations in southern and northern California where ARB staff pulled over 243 identifiable SCR-equipped trucks during a two day period, November 1 - 2, 2011. As part of the survey, staff extracted a sample of DEF from each truck's DEF tank to determine whether or not the vehicle operator had tampered with the vehicle's DEF. Staff also inspected the vehicles for DEF warning indicators and engine diagnostic lights to determine if the vehicle operator had tampered with other SCR components. Shown in Figure 8 below is an illustration of the number of manufacturer vehicles that were inspected for the DEF Quality Tampering Survey.

Figure 8 – DEF Quality Tampering Survey – November 2011

CHP Weigh Station	Cummins	DDC	Ford	Fuso	Hino	Isuzu	Mack	Paccar	Volvo	Grand Total
Antelope E/B	**20**	**16**	**1**		**1**			**2**	**2**	**42**
Ford			1							1
Freightliner		16								16
Hino					1					1
Kenworth	3							1		4
Peterbilt	17							1		18
Volvo									2	2
Antelope W/B	**12**	**1**						**12**		**25**
Ford	1									1
Freightliner		1								1
Kenworth	6							7		13
Peterbilt	5							5		10
Castaic	**14**	**20**			**1**			**4**	**7**	**46**
Freightliner	2	20								22
Hino					1					1
Kenworth	4							2		6
Peterbilt	8							2		10
Volvo									7	7
Conejo	**15**	**16**	**1**		**4**		**7**	**3**	**1**	**47**
Ford			1							1
Freightliner	6	16								22
Hino					4					4
Kenworth	1							2		3
Mack							7			7
Peterbilt	8							1		9
Volvo									1	1
San Onofre S. B.	**20**	**8**		**2**	**2**	**6**		**3**	**4**	**45**
Freightliner	5	8								13
Fuso				2						2
Hino					2					2
Isuzu						6				6
Kenworth	7							3		10
Peterbilt	8									8
Volvo									4	4
Scales Rainbow N/B	**1**	**10**	**1**				**18**	**1**	**7**	**38**
Ford			1							1
Freightliner		10								10
Kenworth	1							1		2
Mack							18			18
Volvo									7	7
Grand Total	**82**	**71**	**3**	**2**	**8**	**6**	**25**	**25**	**21**	**243**

N.B. = North Bound	**S.B. = South Bound**	**W.B. = West Bound**

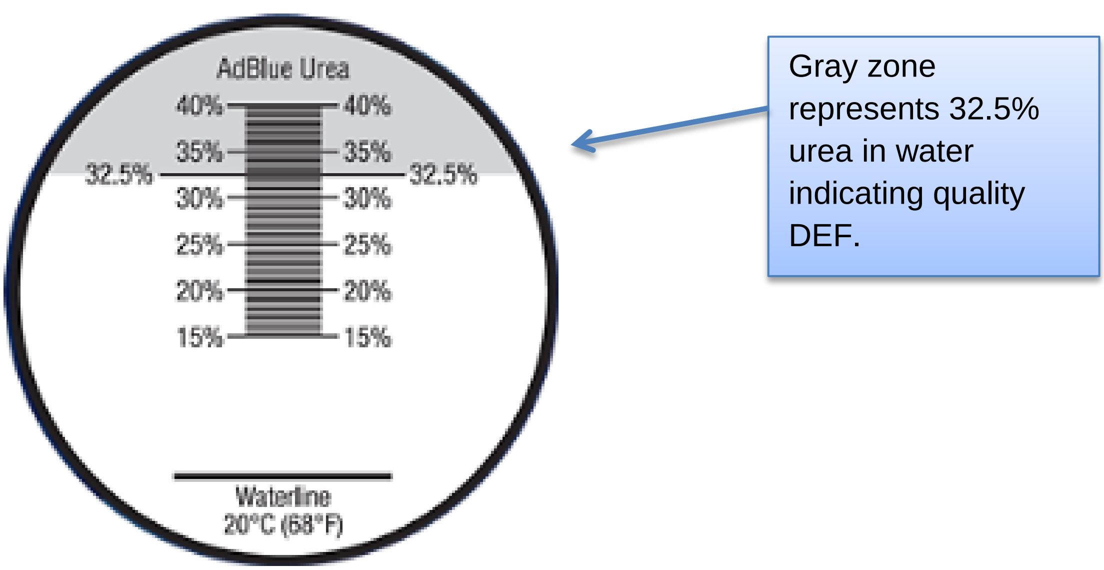
A. DEF Quality Analysis

The DEF quality analysis involved taking a sample of DEF from each vehicle and testing it with a DEF specific refractometer (see Figure 9).

Figure 9 – OTC DEF Refractometer Model 5025

A refractometer measures the refraction of light through a liquid to determine the refractive index of a sample. For this study, the refractive index of each sample taken from each inspected vehicle was compared high quality DEF (32.5 percent urea and 67.5 percent deionized water) baseline sample (see Figure 10 showing quality DEF as read on the refractometer).

Figure 10 – OTC DEF Refractometer Model 5025 Scale



Although there were 243 trucks stopped, only 239 vehicles were inspected and shown to have quality DEF. Staff was unable to obtain a sample of DEF on four vehicles due to a built-in restriction in the DEF tank, (i.e., a sample tube could not be negotiated through the DEF filler inlet due to the design of the DEF tank). Since this time, staff received information on how to obtain a DEF sample from these vehicles using an alternate method. The measured DEF readings on the 239 trucks surveyed had range of urea concentrations from 32.5 percent - 34.0 percent.

SCR- Related Driver Warnings

As part of the visual inspection, ARB staff looked for driver warnings and engine diagnostic lights. The visual inspection involved examining each vehicle's instrument panel. The inspectors were instructed to first perform a key-on event to ensure that all driver warning lights illuminated; the ARB staff discovered no problems. Subsequently, each vehicle was started to determine if any of the vehicles had DEF warning lights illuminated and/or DEF audible alerts initiated. Of the 243 vehicles inspected, 239 vehicles had no established warning alerts and four vehicles had an illuminated "check engine light" displayed. One staff member noted that the two vehicles he inspected with illuminated check engine lights could not be directly linked to the SCR system because no other DEF related warnings or messages were displayed on the dash panel.

Another inspector noted that two vehicles had the illuminated warnings, "check engine light on" and "active fault-outside temperature", but the drivers were unaware of the reasons for the warnings. As with the other two trucks with illuminated check engine lights, since there were no other DEF related warnings or messages displayed on the dash panel and the fact that the DEF quality on these trucks was within specification, the ARB concludes that the illuminated check engine lights discovered on these trucks were not related to a SCR system malfunction.

B. Conclusion

The results of this survey were consistent with the results of the 2010 DEF Tampering Survey with no SCR trucks showing any signs of tampering. Combining the totals of trucks sampled in the 2010 and 2011 survey, of the 308 trucks sampled (the four trucks that did not have the DEF sampled check in the 2011 survey were removed from this count) have shown no identifiable DEF contamination issues. In addition, ARB staff did not identify any DEF related visual or audible warnings that would indicate that operators are tampering with their SCR systems.

The ARB believes that truck operators will continue to add the proper DEF fluid to their vehicles to maintain optimum vehicle operation. As an additional deterrent, the ARB's Enforcement Division has incorporated a DEF quality inspection (similar to what was performed in this survey) as part of their Heavy-Duty Vehicle Inspection Program (HDVIP) procedures that started in January 2012. Any truck operator who tampers with their SCR system will be at risk of receiving a citation and monetary penalties for such actions. An additional 107 trucks have been inspected under the HDVIP program and no citations have been issued for tampered or contaminated SCR systems.

V. Re-Evaluation of Driver Inducements on Two SCR Equipped 2010 Model Year Cummins Engines

During the 2010 field study and confirmed with Cummins, two 2010 MY Cummins trucks equipped with SCR engines experienced malfunctions that impacted their SCR inducement operations. Since the completion of the 2010 field study, Cummins launched a service update and/or recall to correct SCR inducement strategies involving the engine families that were evaluated by ARB. ARB has reacquired these same vehicles to determine if the updated software corrected the issues discovered during the 2010 field study. The two vehicles included a 2011 MY Dodge Cab Chassis D5500 equipped with a 2010 MY 6.7 liter Cummins ISB engine (Test Vehicle 1) and a 2011 MY Kenworth T800 equipped with a 2010 MY 14.9 liter Cummins ISX15 engine (Test Vehicle 2). Note: the vehicles tested were the exact same vehicles that were tested in 2010 and results reported in the May 2011 report. Cummins' service campaigns for the two vehicles not only included fixes for software glitches but also were supposed to make movement towards what would be expected for SCR inducements on the Cummins' 2011 MY engines (i.e., as applicable to the 6.7L engine and the 14.9L engine).

Before testing the vehicles, ARB staff examined the vehicle owner's manuals and the February 2010 MY Guidance (see Figure 11) to ascertain the expected inducement strategies for each vehicle in the ARB evaluation program. Typically, these include a sequence of visual and/or an audible warning on the instrument panel (e.g., warning lights, chimes, and/or text message displays) indicating DEF supply was low or a problem had been identified. As additional mileage is accumulated without remedying the problem or refilling the DEF supply, further driver inducements should occur, such as power derates or speed limits (which allow continued operation of the truck). Ultimately, if the problem is not corrected a severe inducement or final immobilization in the form of a no-start condition, or a 5 mile per hour (mph) maximum speed limit, or an idle-only operation should be triggered once the vehicle reaches a safe harbor (e.g. when diesel refueling occurred, or the engine was turned off, or the vehicle was parked or idled for an extended period of time). The specific inducements for each engine evaluated are discussed below.

Each vehicle was operated under the following test conditions to determine when driver inducements were initiated, how effective they were, how they compared to what was expected from reviewing the vehicle owner's manuals, and consistency with the 2010 MY Guidance. In addition, since these 2010 engines were recalibrated with improved SCR inducement triggers, staff also reviewed the 2011+ MY Guidelines (see Figure 12) and looked for improvements expected in 2011 engines.

- **DEF Depletion Cycle** –The vehicle would be operated until the DEF tank was depleted and the vehicle experienced a no-start condition, or 5 mph maximum speed limit, or idle-only operation. According to the 2010 MY Guidance the following scenarios should occur. As DEF depletes, visual and/or audible alerts should warn the driver that the tank needed refilling. As DEF continues to deplete to empty, the driver may experience an engine power derate condition ranging between 25 percent to 40 percent depending on the vehicle type and DEF tank capacity. Typically, the first level inducement should begin at a 2.5 percent DEF level known as the DEF Trigger and should be in the form of either a 25 percent engine power derate or some maximum speed limit chosen by the manufacturer, and at that point the search for severe inducement should begin. The severe inducement or final immobilization should occur once a safe harbor event (diesel refuel, park/idle, engine restart) was reached anytime after the 2.5 percent DEF Trigger. It is important to note that vehicle gauge levels may be calibrated to read lower than actual DEF tank level to build in a reserve tank volume, e.g., 2.5 percent actual DEF level might read as 0% on the driver's gauge. Thus, in some cases the DEF is still being injected into the SCR when the DEF gauge reads empty.
- **DEF Contamination Cycle** – The vehicle would be operated with water instead of DEF until the vehicle experienced a no-start condition, or 5 mph maximum speed limit, or idle-only operation. According to the 2010 MY Guidance the following scenarios should occur. The detection of poor DEF quality should trigger initial

visual and/or audible warnings. If no remedy occurred, an engine power derate should occur at 500 miles or 10 hours after initial detection, and a severe inducement or final immobilization should occur once a safe harbor event (diesel refuel, park/idle, engine restart) was reached following 1,000 miles or 20 hours after the initial detection and warning.

- **DEF System Tampering Cycle** – Following the disabling of the DEF system by ARB staff, the vehicle would be operated until it experienced a no-start condition, or 5 mph maximum speed limit, or idle-only operation. According to the 2010 MY Guidance, the following scenarios should occur. The detection of tampering should occur quickly depending on the particular tampering event triggering visual and/or audible warnings. If no remedy is sought, an initial 25 percent engine torque power derate should occur at 500 miles or 10 hours after the initial detection, and a severe inducement or final immobilization should occur once a safe harbor event (diesel refuel, park/idle, engine restart) was reached following 2,000 miles or 40 hours after initial detection and warning.

Each vehicle underwent the three SCR test cycle evaluations described above per Test Plan #2R1102 in Appendix C. Since the vehicles are being driven on freeway routes, staff assumed a one hour threshold would be roughly equivalent to a vehicle traveling about 50 miles and the four hour threshold would be achieved after traveling approximately 200 miles. Note the ARB drivers may have not reacted as a normal truck driver would since this was an investigation into the extent the SCR inducements' operation, e.g., ARB drivers ignored warnings and initial inducements to test if final inducements worked, or intentionally triggered a safe harbor event, etc.

Additionally, Test Vehicle 2 was outfitted with a Sensors, Inc. Semtech-DS Portable Emissions Monitoring System (PEMS) unit which measured the vehicle's emissions as the vehicle was operated over the designated test route. Emissions were measured for each of the three test conditions and also a baseline condition. The baseline condition represents the average typical emissions the vehicle generates under normal vehicle operation. Since emissions data was gathered on Test Vehicle 1 in the 2010 SCR evaluation (reported in the May 2011 report), no additional exhaust emissions data was measured for Test Vehicle 1 under this test project.

Figure 11 – <u>2010 MY GUIDANCE SUMMARY</u>

DEF DEPLETION

INITIAL WARNING

- Visual or audible alarms which indicate low DEF level with escalation
- Unique symbol for DEF on dash that illuminates or message displayed
- Warnings cannot be defeated, ignored or turned off without additional DEF added

INDUCEMENTS

- Inducements begin before 2.5% DEF capacity triggering the "No-Engine Restart after Restart Countdown" or "No-Start after Refueling" or "No-Start after Parking" strategy.
- Under these conditions the DEF indicator light will flash or a message shall be indicated on the Instrument Cluster (aka, "inducement notification"). This strategy will lead to the "DEF Trigger" inducement.

SEVERE INDUCEMENT

- At "DEF Trigger" (2.5% DEF) or at DEF Empty for 1:1 DEF/Fuel Tank Size
    - 25% torque derate for DEF Trigger or 40% for 1:1 DEF/Fuel Tank Size
    - Search for Severe Inducement 5 mph speed limit (one of 3)
        - Disable after fueling
        - Disable after Parking (>1 hr or 10-20 minutes after 24 hr operation)
        - Disable after restart

DEF CONTAMINATION

INITIAL WARNING

- Once Detected: Warning message or light

INDUCEMENTS

- At detection + 500 miles or 10 hrs
    - 25% torque derate
    - Under these conditions the DEF indicator light will flash or a message shall be indicated on the Instrument Cluster

SEVERE INDUCEMENT

- At detection + 1,000 miles or 20 hrs
    - 25% torque derate continues
    - Search for Severe Inducement 5 mph speed limit (one of 3)
        - Disable after fueling
        - Disable after Parking (>1 hr or 10-20 minutes after 24 hr operation)
        - Disable after restart

Figure 11 – 2010 MY GUIDANCE SUMMARY - continued

DEF SYSTEM TAMPERING CYCLE

INITIAL WARNING

- Once Detected: Warning message or light

INDUCEMENTS

- At detection + 500 miles or 10 hrs
  - 25% torque derate
  - Under these conditions the DEF indicator light will flash or a message shall be indicated on the Instrument Cluster

SEVERE INDUCEMENT

- At detection + 2,000 miles or 40 hrs
  - 25% torque derate
- Severe Inducement 5 mph speed limit (one of 3)
  - Disable after fueling
  - Disable after Parking (>1 hr or 10-20 minutes after 24 hr operation)
  - Disable after restart

Figure 12 - 2011+ MY Guidelines

REDUCTANT LEVEL / DEF DEPLETION
GOAL • Minimum engine operation when SCR system is no longer able to dose.
KEY POINTS • Need indication of reductant level for the operator. • Initiate inducement early enough so that final inducement is engaged prior to noncompliance due to low reductant. • Any driver inducement should account for safety concerns. • Notify operator of low level at least 2 times prior to final inducement.
INDUCEMENTS • Strategy specifics – manufacturer's discretion. • Warn operator prior to any inducement. • If inducement is phased in, initiate another warning prior to final inducement. • A final inducement such as: a 5 mph limit, or no engine power, or engine idle only. • Should allow for diagnostics and restart after refill.
REDUCTANT QUALITY / DEF CONTAMINATION
GOAL • Detect poor reductant quality as quickly and accurately as possible is no longer able to dose.
KEY POINTS • Need quality or NOx sensor system capable of detecting poor reductant quality that causes noncompliance. • Be able to detect noncompliance within 1 hour and notify operator immediately. • Final inducement with driver warning initiated within 4 hours of detecting noncompliance. • Any driver inducement should account for safety concerns. • ARB – 2011
INDUCEMENTS • Strategy specifics – manufacturer's discretion. • Notify operator when noncompliance is detected. • Warn operator prior to any inducement. • If inducement is phased in, initiate another warning prior to final inducement. • A final inducement such as a 5 mph limit, or no engine power, or engine idle only • Should allow for diagnostics and restart after refill.

Figure 12 - 2011+ MY Guidelines (Continued)

DEF / SCR SYSTEM TAMPERING
GOAL • Systems should be designed to be tamper resistant to reduce the likelihood of circumvention.
KEY POINTS • Be able to detect tampering related malfunctions within 1 hour and notify operator immediately. • Final inducement with driver warning initiated within 4 hours of detecting tamper related malfunction. • Any driver inducement should account for safety concerns. • At a minimum the following tampering related malfunctions should be considered: ▪ Disconnected reductant level sensor. ▪ Blocked reductant line or dosing valve. ▪ Disconnected reductant dosing valve. ▪ Disconnected reductant pump. ▪ Disconnected SCR wiring harness. ▪ Disconnected NOx sensor (that is incorporated with the SCR system). ▪ Disconnected reductant quality sensor. ▪ Disconnected exhaust temperature sensor. ▪ Disconnected reductant temperature sensor.
INDUCEMENTS • Strategy specifics – manufacturer's discretion. • Notify operator when noncompliance is detected. • Warn operator prior to any inducement. • If inducement is phased in, initiate another warning prior to final inducement. • A final inducement such as: a 5 mph limit, or no engine power, or engine idle only • Should allow for diagnostics and restart after refill.
REPEAT TAMPERING / OFFENSES
GOAL • Discourage repeat tampering or, the repeat use of poor quality reductant.
KEY POINTS • System should monitor for repeat faults for a minimum of 40 engine hours. • Return to final inducement for repeat offense within: ▪ EPA – 30 minutes ▪ ARB – 60 minutes • Repeat offense: ▪ EPA – same offense ▪ ARB – any 2nd offense
INDUCEMENTS • Strategy specifics – manufacturer's discretion. • Warn operator prior to any inducement. • If inducement is phased in, initiate another warning prior to final inducement. • A final inducement such as: a 5 mph limit, or no engine power, or engine idle only. • Should allow for diagnostics and restart after refill.

A. Test Vehicle 1

Chassis: 2011 MY Dodge Cab Chassis D5500
Axles: 2
Engine: Cummins ISB
Engine MY: 2010 MY
Engine Family: ACEXH0408BAL
Displacement 6.7 Liter
Horsepower: 305 @ 2,900 rpm
NOx Certification FEL[1]: 0.50 g/bhp-hr

Test vehicle 1 was a Dodge Cab Chassis D5500 incomplete vehicle equipped with the 2010 MY Cummins ISB 305 engine rented from a local Southern California Dodge dealer. This was the same vehicle that had been procured (Vehicle Identification Number - 3D6WA7EL0BG501644) during the 2010 SCR Field Evaluation Study. Staff closely followed ARB's 2010 SCR field evaluation test plan (see attached ARB test plan 2R1102, Appendix C). The vehicle was received with 4,371 miles on the odometer and was again equipped with the flatbed platform and loaded with a 4,000 pound "K-rail" concrete barrier.

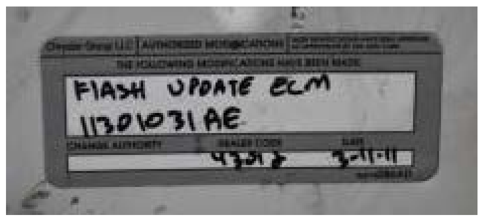
In the SCR evaluation conducted in 2010, staff reported in the May 2011 report that the SCR inducements for Test Vehicle 1 appeared to be generally consistent with the vehicle owner's manual; however, the mileage accumulation under the DEF Depletion Cycle seemed excessive for the amount of DEF consumed. Upon investigation, it was reported that a DEF heater malfunction was causing suspension of DEF dosing under certain ambient conditions, thus extending the miles driven before DEF depletion occurred. While the vehicle was, in general, consistent with the intentions of the 2010 MY Guidance, the mileage accumulation was too high for the appropriate DEF consumption rate expected. To address this problem, in September 2010, Cummins launched a service campaign under Chrysler's Technical Service Bulletin (TSB) #25-002-10 to correct the DEF heater issue. Cummins reported that this

[1] – Certification to the Family Emission Limit (FEL) is the emission level declared by the manufacturer and serves in lieu of an emission standard for certification purposes in any averaging, banking, or trading programs.

vehicle had not been repaired as a result of this service campaign but staff remembers that the vehicle was repaired when ARB returned the vehicle to the dealer after the initial 2010 SCR evaluation and prior to the launch of the service campaign. Cummins and Chrysler have no record of this repair under warranty.

Cummins reported that this vehicle had been updated with the latest emission control software (see Figure Cummins 6.7-1) as of March 11, 2011.

Figure Cummins 6.7-1: Calibration Update Performed March 11, 2011



Cummins stated to staff that the updated software is similar to the 2011 MY SCR control strategy (but not exact) and is being installed on all on-road 2010 MY 6.7L HDD engines under Chrysler's TSB #18-022-REV.B, launched in November 2010. As of late November 2011, 82 percent of the affected vehicle population received the updated calibration.

The vehicle underwent the three SCR test cycle evaluations to determine if the software fixes and updates lead to any changes or improvements in the SCR strategy designs. Before operating the vehicle, the driver reviewed the 2010 Dodge 5500 Owner's Manual to become familiar with the dashboard gauges, warning lights, vehicle controls, and SCR warning system. The driver warnings and inducements included various displays on the Electronic Vehicle Information Center (EVIC) located in the center of the instrument panel (see Figure Cummins 6.7-2) and would be accompanied by periodic audible warnings.

Since PEMS emissions data was gathered on this vehicle in the 2010 SCR evaluation, no additional exhaust emissions data was measured under this test project because the data was considered valid; the emissions data demonstrated that the SCR system operated as expected controlling NOx emissions under normal operation and in the depleted mode; NOx emissions did increase when contaminating the DEF tank (i.e., completing filling it with water) and tampering with the SCR system. Cummins stated to ARB staff that the updated SCR software provided no changes to the air/fuel emissions strategy and therefore, the emissions results would show no changes as were measured in 2010. Staff's re-evaluation of this vehicle focused on the SCR calibration improvements for detecting an SCR related problem and activating the SCR inducement strategy.

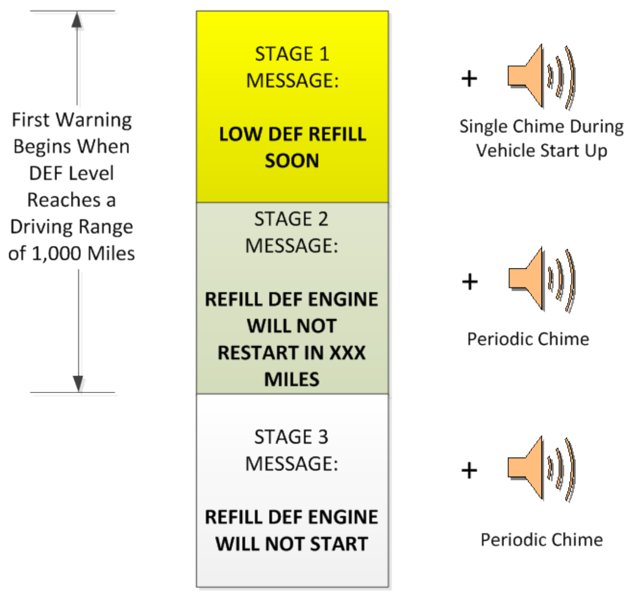
Figure Cummins 6.7-2: Electronic Vehicle Information Center

a) Vehicle 1 - DEF Depletion Cycle

Figure Cummins 6.7-3 below was created by ARB staff as an interpretation of the SCR driver warning and inducement sequences for this vehicle based on the information provided in the vehicle owner's manual and has been approved for use in this report with Cummins' permission. Under the DEF Depletion Cycle, the first inducement in the form of warning messages and chimes should occur when approximately 1,000 miles of driving remains until DEF runs out. If DEF still has not been added 500 miles after the initial warnings occurred, the vehicle should enter into a 500 mile countdown sequence as indicated on the dash mounted display. Once the display reaches zero miles and no

DEF has been added to the vehicle's DEF tank, the vehicle should not start upon its next key-off/key-on event.

Figure Cummins 6.7-3: 2010 Cummins' 6.7L SCR System DEF Depletion Warning Sequence



STAGE 1

- The EVIC message will be displayed at every startup for a short period; while driving, the message will display periodically increasing in frequency as the vehicle is continually driven on low DEF.
- The chime will accompany the EVIC message at every startup; while driving, the chime will sound periodically increasing in frequency.

STAGE 2

- The EVIC message will be displayed continuously (with actual mileage countdown from 500 miles).
- The chime will sound periodically increasing in frequency as the vehicle is continually driven.

STAGE 3

- The EVIC message will be displayed continuously.
- The chime will sound periodically.
- The DEF icon will display continuously, independent of the EVIC message.

<u>Day 1</u>

Testing began with the odometer at 4,474 miles, the DEF tank filled to 17 percent of its capacity as displayed on the EVIC, and the diesel fuel gauge at about the 25 percent mark. The vehicle was operated for 321 miles for the day and required two refueling events that took place at 4,504 miles and 4,686 miles on the odometer. The vehicle experienced no associated driver warnings or other SCR inducements and finished with the DEF level at 14 percent of its full capacity as indicated on the EVIC, and the diesel fuel gauge reading 75 percent of capacity (odometer = 4,795 miles).

Day 2

Operation began the next day with the DEF level still showing 14 percent full (odometer = 4,795 miles). The vehicle was driven 70 miles (odometer = 4,865 miles) and the vehicle was refueled with 20 gallons of diesel fuel. After accumulating 212 additional miles (odometer = 5,077 miles), the vehicle was keyed-off for another refueling event. The vehicle was filled with 21.6 gallons of diesel fuel bringing the fuel level back to 100 percent of capacity. The vehicle was restarted and after two miles of driving (odometer = 5,079) with the DEF Level Gauge reading 9 percent of full capacity, the first the first driver warning took place with the EVIC displaying the message “Low DEF Refill Soon” and then extinguished about minute later (see Figure Cummins 6.7-3, Stage 1). As the mileage accumulation continued for the day, the driver observed the same message again at an odometer reading of 5,214 miles (upon restart with an associated chime), 5,248 miles, and 5,297 miles (with an associated chime). During this time staff added 21 gallons of diesel fuel with an odometer reading of 5,252 miles. Staff returned to ARB’s El Monte facility with the DEF Level Gauge reading four percent of full capacity, and the EVIC was displaying the message “Low DEF Refill Soon” where one chime occurred upon the display of the message (odometer = 5,327 miles). With testing completed for the day, staff shutdown the vehicle.

Day 3

When staff started the vehicle on Day 3, the DEF level indicator showed 5 percent remaining, the “Low DEF Refill Soon” message appeared and one chime occurred warning the driver of low DEF. The message extinguished when the vehicle operation began, but the message and chime occurred again 20 miles after starting the test route (odometer = 5,347 miles). As mileage accumulation continued, the “Low DEF Refill

Soon" warning message appeared and extinguished within a few minutes approximately every 50 miles and upon vehicle start up. The DEF Level Gauge dropped to 0% capacity with an odometer reading of 5,545 miles. Nine miles after the DEF tank reached empty (odometer = 5,554 miles), the amber DEF light illuminated and the EVIC displayed the message "Refill DEF Engine Will Not Restart In 500 Miles" (see Figure Cummins 6.7-3, Stage 2) initiating the 500 mile countdown sequence (See Figure Cummins 6.7- 4).

Figure Cummins 6.7- 4: Example of Message Alert, 500 Mile Countdown

As the vehicle counted down from 500 miles to 0 miles, the amber DEF light continued to illuminate and was accompanied with a periodic audible alert at vehicle start-up and approximately every 50 miles for the next 100 miles decreasing to about every 25 miles as the vehicle was driven along the designated test route. Staff returned to ARB's El Monte facility with the counter showing 325 miles before the engine no-start condition was to occur (odometer = 5,733 miles).

<u>**Day 4**</u>

With the vehicle odometer at 5,733 miles, the vehicle was started the next day and the EVIC was still showing a DEF level of 0%, and also included the illumination of the DEF light. As mileage accumulation continued the amber DEF light was continuously illuminated and was accompanied with a periodic audible alert approximately every 25 miles and upon engine start up while driving the designated test route. The operator was unable to change the countdown message display while in the countdown mode (i.e., the EVIC did not show other information that could typically be accessed through the EVIC display, like outside temperature or fuel economy information). Staff returned to ARB's El Monte facility with the no-start counter showing 249 miles left before the no-start condition would occur. Testing was terminated for the day with the odometer at 5,804 miles.

Day 5

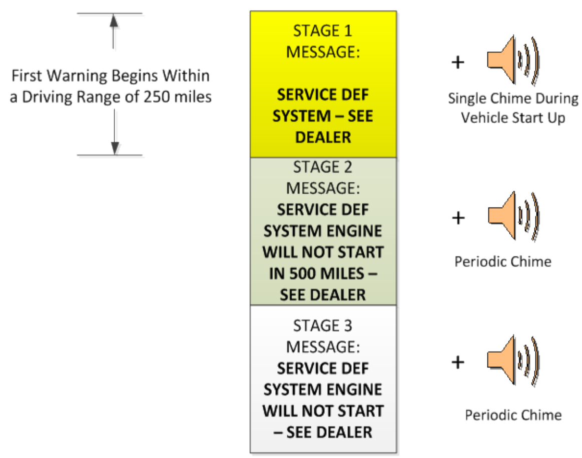
Upon restart on Day 5, the countdown to a no-start condition was still displayed and the amber DEF light continuously illuminated accompanied by a periodic audible chime that took place approximately every 25 miles and upon engine start up (i.e., the chime sounded once at designated mileage intervals and upon vehicle start up). The frequency of the audible chime increased to about every 10 miles once the countdown counter reached 100 miles. After driving a total of 497 miles (odometer = 6,051 miles) since the countdown initiated, the EVIC message displayed "Refill DEF Engine Will Not Start" (see Figure Cummins 6.7-3, Stage 3). Staff drove for nine more miles with the audible alert signaling about every two minutes. At this time, staff stopped the vehicle and then executed a key-off/key-on event but the vehicle failed to start (odometer = 6,060 miles). Staff filled the DEF tank with seven gallons of DEF and initiated a key-on event. Subsequently, all SCR related warnings extinguished and staff was able to restart the vehicle. This concluded the DEF Depletion Test Cycle.

In summary, the first driver's warning occurred at a DEF level of nine percent, well before the DEF tank level displayed empty, at odometer mileage point 5,079 miles. The countdown to no-start was reached 475 miles later when the DEF gauge level reached empty, keeping in mind that manufacturers build in reserve levels that the operator will not see. As the countdown progressed, this message was accompanied an increasing frequency of audible chimes. Once the countdown expired and the vehicle was keyed off, the no-start condition occurred rendering the vehicle unusable until DEF was added to the system. The results were consistent with the 2010 MY Guidance and there was some indication that the time between the first warning and triggering the countdown was reduced from the original 2010 calibration.

b) Vehicle 1 - DEF System Tampering Cycle

Figure Cummins 6.7- 5 below was created by ARB staff as an interpretation of the SCR driver warning and inducement sequences for this vehicle based on the information provided in the 2010 vehicle owner's manual and has been approved for use in this report with Cummins' permission. Under the DEF System Tampering Cycle, the 500 mile countdown should commence 250 miles after the initial driver warning occurs accompanied by periodic chimes. Once the display reaches zero miles and the tampered event has not been remedied, the vehicle should not start upon its next key-off/key-on event.

Figure Cummins 6.7- 5: Cummins' 2010 6.7L SCR System Tampering and Contamination Warning Sequence



STAGE 1

- Upon detection, the EVIC message "Service DEF System – See Dealer" message will appear.
- The chime will accompany the EVIC message at every startup; while driving, the chime will sound periodically increasing in frequency.

STAGE 2

- The EVIC message will be displayed continuously (with actual mileage countdown from 500 miles); the vehicle will operate under Stage 1 for 250 miles then initiate the 500 mile countdown message.
- The chime will sound periodically increasing in frequency as the vehicle is continually driven.

STAGE 3

- The EVIC message will be displayed continuously. The "Service DEF System Engine Will Not Start – See Dealer" message will appear.
- The chime will sound periodically.
- The DEF icon will display continuously, independent of the EVIC message.

Day 1

In order to initiate the DEF System Tampering Cycle, staff disconnected the DEF doser injector to represent a tampering event. The SCR inducement evaluation began with the odometer showing 6,060 miles. After driving two miles (odometer = 6,062 miles), the vehicle set a MIL (that stayed on throughout the test cycle) and the EVIC displayed the message “Service DEF System - See Dealer” (see Figure Cummins 6.7-5, Stage 1).

As the mileage accumulation continued for the day, the driver observed the same message at an odometer reading of 6,091 miles (see Figure Cummins 6.7-6) and 6,141 miles (with an associated chime) extinguishing a few minutes after it displayed.

Figure Cummins 6.7-6: Tampering Message

After an additional 50 miles driven (odometer = 6,191 miles) the SCR system prompted a new EVIC message showing “Service DEF System Engine Will Not Start In 400 Miles – See Dealer” (see Figure Cummins 6.7-5, Stage 2) along with an audible chime. Staff observed that the counter began at 400 miles instead of 500 miles, as was witnessed in the 2010 evaluation program. Once this message was displayed, the operator was not able to change the countdown message display while in the countdown mode. As staff continued to drive the vehicle, the EVIC continually displayed the miles of operation remaining until the no-start condition would occur and an audible alert sounded at 50 mile intervals for the first 100 miles of operation (odometer = 6,291 miles) and initiated upon every engine start up. The chime frequency increased to every 25 mile interval for the next 200 miles of operation and finally every 10 miles during the last 100 miles of operation. The countdown expired after accumulating 397 miles (odometer = 6,588 miles) triggering a new EVIC message, “Service DEF System Engine Will Not Start – See Dealer” (see Figure Cummins 6.7-5, Stage 3). Staff drove for two additional miles beyond the countdown expiration and executed a key-off/key-on event but the vehicle did not start (odometer = 6,590 miles).

Day 2

Staff attempted a re-tamper event to determine if the vehicle would detect a repeat tampering event and return to a no-start condition in short order. To initiate this event, staff reconnected the DEF doser injector and cleared codes with a generic scan tool and upon restart the vehicle immediately returned to normal engine operation. Staff immediately disconnected the doser injector to determine if the vehicle would seek final inducement per the 2011+ MY Guidelines (odometer = 6,590 miles) despite being a 2010 certified engine under the 2010 MY Guidance. The driver drove the designated test route and after 14 miles the EVIC displayed the message, Service DEF System – See Dealer (odometer = 6,604 miles) and illuminated the MIL. In addition, the audible chime alert occurred periodically as with the initial tampering event. The driver continued on the designated route and after 146 miles of operation since disconnecting the doser injector (odometer = 6,736 miles), with the MIL still illuminated, the EVIC displayed the message “Service DEF System Engine Will Not Start In 400 Miles – See Dealer.” After driving an additional 101 miles, staff stopped the vehicle at ARB’s El Monte facility and terminated the repeat tampering event because the vehicle did not return to search for a safe harbor event within one hour (odometer = 6,837 miles).

For the DEF Tampering Cycle, the vehicle performed similar to the original 2010 MY calibration by again instituting audible alerts, visual messages and illuminating the MIL to alert the driver of an existing DEF system issue. Staff noted that both calibration strategies quickly detected each of the test conditions but the updated calibration was able to initiate the countdown strategy almost 50 percent faster than the original 2010 MY calibration. In addition, the updated SCR inducement strategy began the countdown criterion at 400 miles as opposed to the 500 mile countdown strategy utilized for the original 2010 MY calibration. Overall, the updated SCR strategy is working as designed and closely follows the inducement strategies set forth in the vehicle owner's manual, the 2010 MY Guidance, and in some aspects, the 2011+ MY Guidelines.

Day 3

Staff reconnected the DEF doser injector and upon restart the vehicle driver warnings extinguished. Staff drove the vehicle 132 miles verifying that the vehicle returned to normal engine operation. This concluded the DEF System Tampering Cycle.

c) Vehicle 1 - DEF Contamination Cycle

As shown in Figure Cummins 6.7-4, under the DEF Contamination Cycle, the 500 mile countdown should commence 250 miles after the initial driver warning occurs accompanied by periodic chimes. Once the display reaches zero miles and the contamination event has not been remedied, the vehicle should not start upon its next key-off/key-on event.

Day 1

To initiate the DEF Contamination Cycle, the DEF tank was drained of DEF and filled with water to a capacity of 100 percent as shown on the EVIC DEF display (odometer = 6,969 miles). The vehicle was operated for 12 miles (odometer = 6,981 miles) over the designated test route when the SCR system detected contaminated DEF and displayed the EVIC message "Service DEF System – See Dealer", and was accompanied by an audible chime (see Figure Cummins 6.7-5, Stage 1). Additionally, although not prescribed in the owner's manual, the MIL also illuminated at this time. The message was present for about a minute and then extinguished but the MIL stayed on continuously. The EVIC message would re-appear periodically throughout the day occurring at 7,024 miles (restart event included an audible chime), 7,033 miles and 7,056 miles. Staff returned to ARB's El Monte facility with the same EVIC message displayed and the MIL light still illuminated (odometer = 7,057 miles).

Day 2

As soon as the engine was started the next day, the EVIC displayed the message "Service DEF System – See Dealer" and illuminated the MIL (odometer = 7,057 miles). After operating the vehicle for 100 miles since the first driver warning message took place (odometer = 7,081 miles), the EVIC message changed to "Service DEF System Engine Will Not Start In 400 Miles – See Dealer" (see Figure Cummins 6.7-5, Stage 2), and continued to be accompanied by an illuminated MIL and a periodic audible chime. Staff observed that the counter began at 400 miles instead of 500 miles, as was witnessed in the 2010 evaluation program. Once this message was displayed, the operator was not able to change the countdown message display while in the countdown mode. As staff continued to drive the vehicle, an audible alert sounded at an increased frequency of about 50 miles for the first 100 miles of the countdown then 25 miles for the next 200 miles and finally every 10 miles for the last 100 miles. The MIL stayed illuminated throughout the entire countdown mode. The countdown expired after accumulating 398 miles (odometer = 7,479 miles) triggering a new EVIC message, "Service DEF System Engine Will Not Start – See Dealer" (see Figure Cummins 6.7-5, Stage 3). As the message displayed, staff was in the process of pulling into ARB's El Monte facility. Staff executed a key-off/key-on event, but the vehicle did not start (odometer = 7,479 miles). The total number of miles to reach a no-start condition from the time of detecting poor quality DEF was 498 miles. Since there was no emission measurement taken, staff could not determine where NOx emissions might have been considered out of control but based on past experience with this vehicle, the PEMS data conducted in 2010 showed that the vehicle was not able to control NOx shortly after starting the vehicle with water in place of DEF.

For the DEF Contamination Cycle, the vehicle performed similar to the original 2010 MY calibration by again instituting audible alerts, visual messages and illuminating the MIL to alert the driver of an existing DEF system issue. Staff noted that both calibration strategies quickly detected each of the test conditions but the updated calibration was able to initiate the countdown strategy almost 50 percent faster than the original 2010 MY calibration. In addition, the updated SCR inducement strategy began the countdown criterion at 400 miles as opposed to the 500 mile countdown strategy utilized for the original 2010 MY calibration. Overall, the updated SCR strategy is working as designed and closely follows the inducement strategies set forth in the vehicle owner's manual, the 2010 MY Guidance, and in some aspects, the 2011+ MY Guidelines.

Following this no-start condition, staff used a generic OBD scan tool to review the stored DTC information and then cleared the trouble codes. With the stored trouble codes removed, and all warning messages and visual/audible alerts cleared, the vehicle was started and returned to normal operation. With this last cycle completed, staff made arrangements to return the vehicle back to the local Dodge dealer from where the vehicle was rented.

d) Vehicle 1- Inducement Test Summary

The primary SCR inducement for this vehicle included the driver warning accompanied by periodic audible chimes, warning messages and finally triggering a 500 mile countdown driver message that ultimately led to a no-start condition. Keeping in mind that technically this vehicle is only required to be consistent with the 2010 MY Guidance, Figure Cummins 6.7-7, shows a direct comparison of this vehicle with the SCR calibration evaluated in 2010 and the updated calibration evaluated in 2011.

Figure Cummins 6.7-7: Cummins' SCR Calibration Evaluated in 2010 vs. 2011 for a 2010 Engine

Cummins 6.7L 2010 MY Engine	Miles Traveled After First Driver Warning to Reach Countdown Criterion		Countdown to "NO Start" Criterion		Miles Traveled During Countdown to Reach No Start Condition		Total Miles Traveled Initial Detection		Mileage Difference to Reach "No Start " Condition
CYCLES EVALUATED	2010 CY	2011 CY	2010 CY	2011 CY	2010 CY	2011 CY	2010 CY (A)	2011 CY (B)	Diff = (A) - (B)
DEF Depletion	934	475	500	500	629	497	1563	972	591
DEF Tampering	250	130	500	400	496	397	746	526	220
DEF Contamination	249	100	500	400	497	398	746	498	248

- All numbers represent miles driven.

The updated calibration software has incorporated SCR strategy enhancements and was updated on the ARB tested 2010 MY 6.7L HDD engine in March 2011. During the 2010 SCR evaluation program, staff experienced problems when conducting the DEF Depletion Cycle due to a DEF heater problem. This problem in conjunction with the 500 mile counter resetting in the midst of counting down allowed additional mileage to accumulate beyond Cummins' SCR strategy criteria. These problems were corrected with service updates through Chrysler's Dodge dealer network. Under the DEF Depletion Cycle, this vehicle was consistent with both the 2010 MY Guidance and the 2011+ MY Guidelines.

For the DEF Contamination and DEF System Tampering Cycles, the updated SCR inducement strategy performed similar to the original 2010 MY calibration by again instituting audible alerts, visual messages and illuminating the MIL to alert the driver of an existing DEF system issue. Staff noted that both calibration strategies quickly detected each of the test conditions but the updated calibration was able to initiate the countdown strategy almost 50 percent faster than the 2010 MY calibration. In addition, the updated SCR inducement strategy began the countdown criterion at 400 miles for each of these cycles as opposed to the 500 mile countdown strategy utilized for the original 2010 MY calibration. Overall, the updated SCR strategy is working as designed and closely follows the inducement strategies set forth in the vehicle owner's manual, the 2010 MY Guidance but was not fully consistent with the intended 2011+ MY Guidelines when operating in a contaminated or tampered mode .

Staff demonstrated during the DEF Contamination Cycle that the generic scan tool can reset the vehicle when the no-start condition occurred; thus, allowing staff to reset the trouble codes and allow the driver to restart the vehicle. Staff contacted Cummins regarding this issue after completing the 2011 evaluation. Cummins responded that since updating the SCR calibration in November 2010, Cummins launched a new service campaign in May 2011, installing a further enhanced SCR calibration update on all 6.7L engines built before January 1, 2011. The new software update enhances the SCR inducement strategy by lowering the countdown of contamination or tampering detection from 400 miles to 200 miles. If a re-tampered event is detected, the countdown mileage counter will reinitiate in less than 200 miles. Although a generic scan tool will be able to clear a no-start condition, the SCR system will retain a tampered event in its memory for 40 hours and should the vehicle be re-tampered, the counter may restart at the value where it stopped when a previous fault was temporarily remedied, or at a minimum of 50 miles. The most recent campaign would more closely align with the 2011+ MY Guidelines. At this time, the effort by Cummins to update their 2010 in use engines to the 2011+ MY Guidelines is totally voluntary on their part.

B. Test Vehicle 2

Chassis: 2011 MY Kenworth T800
Axles: 3
Engine: Cummins ISX15
Engine MY: 2010 MY
Engine Family: ACEXH0912XAP
Displacement: 14.9 Liter
Horsepower: 450 HP @ 1800 RPM
Trailer: 48-foot flatbed
NOx Certification FEL: 0.35 g/bhp-hr

Test Vehicle 2 was a Kenworth T800 equipped with a 2010 MY Cummins ISX15 450 engine (Vehicle Identification Number - 1XKDD49X5BJ278732). This was the same truck that was tested in the August 2010 SCR field evaluation under ARB's test plan (see attached test plan #2R1102, Appendix C). Staff received the vehicle with 7,531 miles showing on the odometer and prior to starting the SCR test program, Cummins updated the ECU on March 16, 2011 (recall campaign # 1036). The vehicle towed a 48-foot flatbed trailer that was loaded with five 20-foot "K-rail" concrete barriers that weighed about 40,000 pounds. In order to determine the impact on NOx emissions, this truck was outfitted with a Sensors, Inc. Semtech-DS PEMS unit allowing for real-time emissions readings.

This vehicle utilizes the SCR system and therefore, uses DEF as part of its after treatment system for controlling NOx emissions. When needed, the SCR system is expected to alert the driver through a sequence of warning lights in conjunction with vehicle inducements designed to draw the driver's attention to the following conditions: low levels of DEF, contaminated DEF, or if certain components of the SCR system are disabled as per the 2010 MY Guidance. Before operating the vehicle, the driver reviewed the vehicle owner's manual to become familiar with the dashboard gauges, warning lights, vehicle controls, and SCR warning system. Figure Cummins 14.9-1 shows the various driver warning lights used when the SCR system requires attention. This information has been reproduced with Cummins' permission and is referenced in-part from the 2010 MY Kenworth T800's Owner's Manual.

Figure Cummins 14.9-1: Driver Warning Lights/Information used by SCR System

Diesel Level Gauge: Red Lamp Indicates Problem With SCR System

Check Engine Light: Secondary Lamp Notification That SCR Has Problem

Malfunction Indicator Light: The MIL illuminates when the On Board Diagnostics (OBD) detects a malfunction related to the emissions control system. The illuminated MIL indicates that the engine needs to be serviced at the first available opportunity and can be illuminated along with any of the engine indicator lamps.

Driver Information Display: Displays Messages to the Driver Including Problems with the SCR System

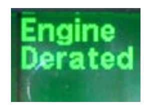
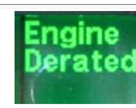
Stop Engine Light: The illumination of this lamp indicates that the vehicle is experiencing a major problem; e.g., a 5 mph limited speed event

Although this engine was certified as a 2010 MY engine, because the ECU was updated, the vehicle was evaluated to determine if the SCR related warnings and inducements closely followed the 2011+ MY Guidelines (see Figure 12) and the 2010 MY Guidance (see Figure 11).

a) Vehicle 2 - DEF Depletion Cycle

The chart below, Figure Cummins 14.9-2, was created by ARB staff with Cummins' permission as an interpretation of the 2010 MY Kenworth T800 Owner's Manual depicting the stages of escalating driver warnings and alerts expected for the DEF Depletion Cycle.

Figure Cummins 14.9-2: 2010 MY Cummins' Driver Warnings and Inducements for Depletion

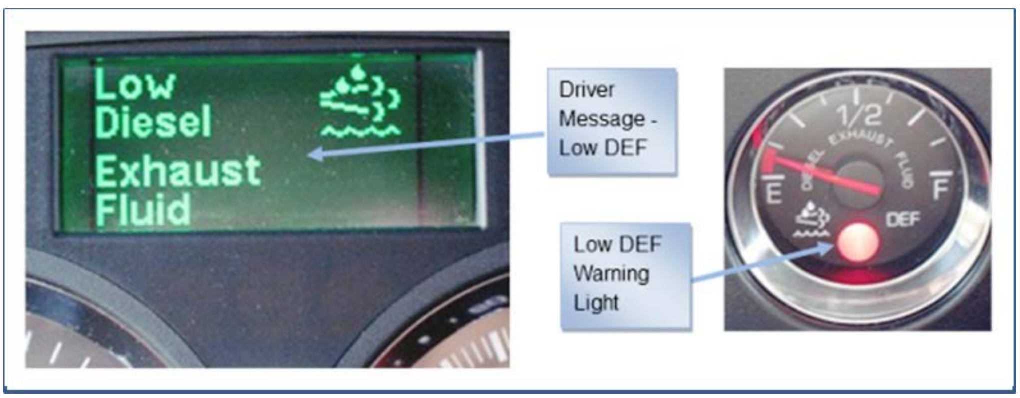
DEF DEPLETION	NOTIFICATION – LAMP	NOTIFICATION – INDUCEMENT
DEF TANK LEVEL **STAGE 1** ~10% DEF or 1/8TH of TANK	 SOLID	
STAGE 2 Below 1/8th tank but above empty	 FLASHING	
STAGE 3 Tank close to empty	  FLASHING	
STAGE 4 Tank is empty After the engine has been turned off or prolong idle.	   FLASHING	

The first driver warning was expected to be triggered when the truck's DEF level drops below 1/8 of tank capacity (see Stage 1). As DEF was depleted, the driver should be subjected to additional warnings as indicated in Stage 2 (below 1/8 tank but above empty - DEF level). When the DEF level is close to empty, the additional inducements should include a check engine light illumination and an engine torque derate (see Stage 3). Ultimately, when the DEF gauge reads empty and the vehicle is turned off or idled for 20 hours, the vehicle should enter a 5 mph speed limited condition and now accompanied by a stop engine light (see Stage 4).

Day 1

Staff began the test cycle with the DEF tank reading just above an 1/8th of a tank as indicated by the DEF Level Gauge on the vehicle's instrument dash panel (odometer = 9,061 miles) and the diesel fuel gauge reading just below 75 percent full. After driving 18 miles (odometer = 9,079 miles), the first driver warning occurred (see Figure Cummins 14.9-2, Stage 1), the red DEF gauge light illuminated and the Low DEF warning message displayed on the Driver Information Display (DID) (see Figure Cummins 14.9-3).

Figure Cummins 14.9-3: Driver Information Display Message and Low DEF Warning Light



The driver drove an additional 13 miles (odometer = 9,092 miles) since the first driver warning occurred and stopped to refuel, adding 33.6 gallons of diesel fuel. Upon restart the diesel fuel gauge was showing 100 percent fuel with the same driver warnings previously displayed on the DID. The driver continued to drive an additional 92 miles and noticed that the red DEF gauge light began to flash (odometer = 9,184 miles) indicating that Stage 2 had been reached per Figure Cummins 14.9-2. Staff returned to ARB's El Monte facility with no changes to the SCR warning system indicators and shut down the vehicle for the day (odometer = 9,226 miles).

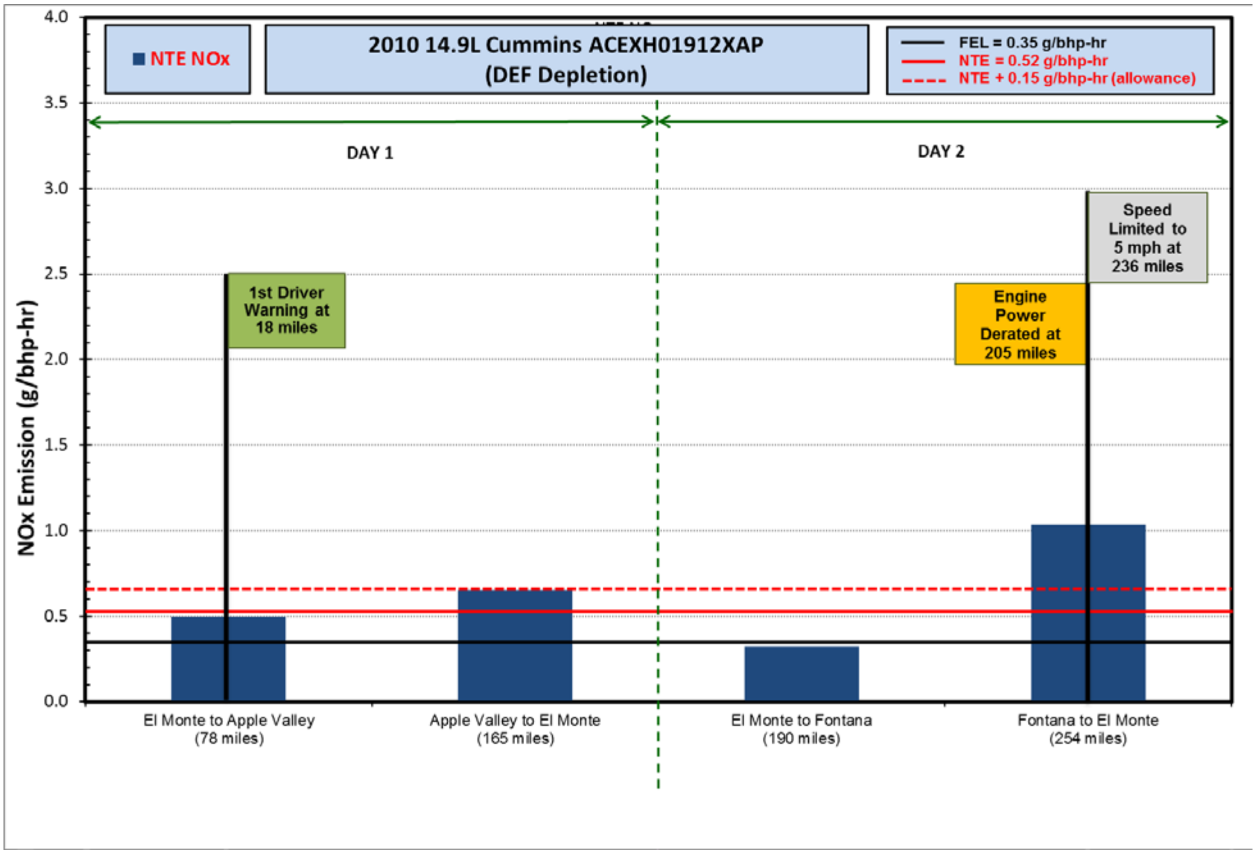
Day 2

Upon vehicle start, the red DEF gauge light began to flash and the DEF gauge showed empty. After driving 29 miles (odometer = 9,255 miles), and with the DEF gauge light still flashing, the check engine light illuminated, and the Low DEF warning message displayed on the DID. Eleven miles later (odometer = 9,266 miles), the driver noticed that the vehicle had a lack of power especially when trying to accelerate, indicating that the truck was experiencing an engine derate condition (see Figure Cummins 14.9-2, Stage 3). Traveling 16 additional miles, staff stopped to refuel adding 36.8 gallons of diesel fuel bringing the diesel fuel level back up to 100 percent full (odometer = 9,282 miles). Staff returned to ARB's El Monte facility and shut down the vehicle (odometer = 9,315 miles). Upon restart, the red stop engine light illuminated (see Figure Cummins 14.9-4) along with the other pre-established warnings (see Figure Cummins 14.9-2, Stage 4).

Figure Cummins 14.9-4: Stop Engine Lamp and Check Engine Light

When attempting to drive the vehicle, the vehicle speed was limited to 5 mph. In total, the vehicle was driven 236 miles since the first driver warning was displayed. After turning off the engine, staff added 5 gallons of DEF assuming this would return the engine to normal operation. Subsequently, staff restarted the vehicle and all driver warnings and vehicle inducements immediately extinguished and the vehicle returned to normal operation. The figure below represents the daily DEF Depletion Cycle emissions and includes markers where certain SCR inducement events occurred along the test route (see Figure Cummins 14.9-5 below). The events represented in the figure include the first driver warning, the onset of the engine derate, and the initiation of the vehicle's SCR strategy to seek the final inducement event.

Figure Cummins 14.9-5: Daily DEF Depletion Cycle Emissions Data



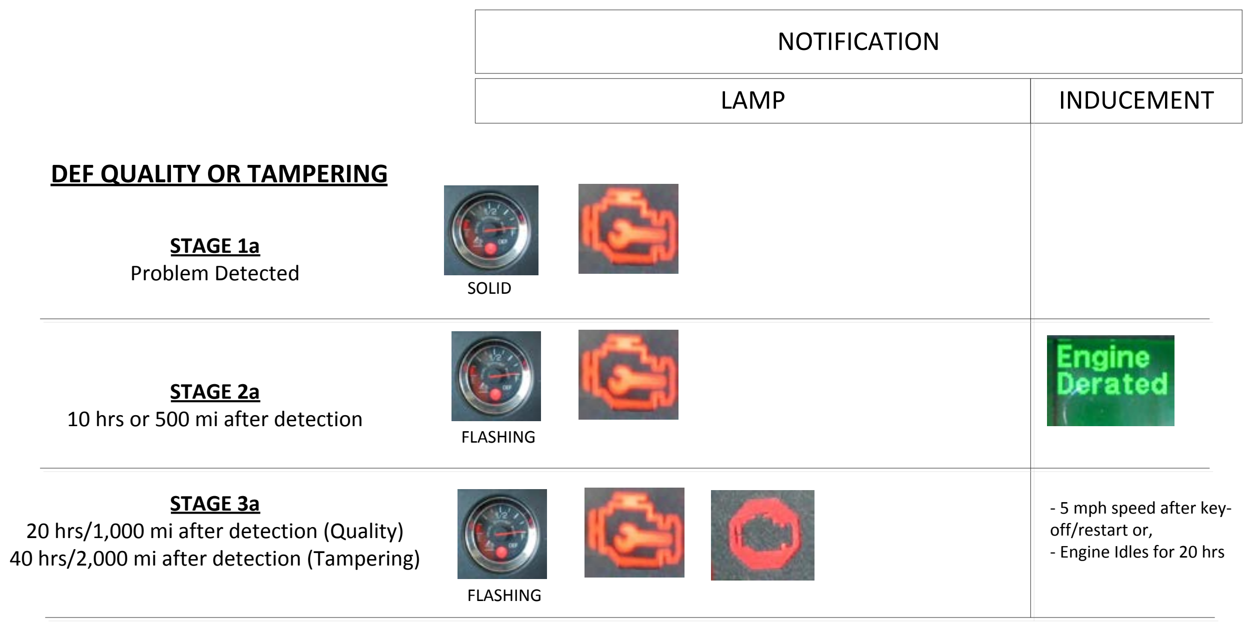
Note: The PEMS values in this figure were measured values taken during this test program while the vehicle was operated under on-road conditions. The NTE NOx is the on-road measurement of NOx emissions that requires specific engine operation and other criterion for attaining this measurement. The NOx family emission limit (FEL) of 0.35 g/bhp-hr requires emission measurements under laboratory conditions and the Not to Exceed (NTE) 0.52 g/bhp-hr standard requires specific on-road operation for attaining emission measurements. This standard, in addition to the NTE + 0.15 g/bhp-hr measurement allowance, was provided for general reference only. The PEMS unit used for this operation meets the U.S. EPA requirements per 40 CFR 1065.

In regards to the Depletion Cycle, the emission results of this vehicle showed that under the Depletion Cycle, the vehicle has the capability to control NOx emissions within the NTE standard but once the DEF gauge reads empty, the vehicle will only stay in control for about an hour and then NOx will increase significantly. However, the vehicle is flashing continuous warning signs to the driver and the vehicle is experiencing an engine derate that would not be an acceptable condition to endure when the driver can easily stop, add DEF, and return to normal vehicle operation. All prescribed inducement strategies for this cycle appeared to be consistent with the vehicle owner's manual information, the 2010 MY Guidance and the suggested SCR 2011+ MY Guidelines.

b) Vehicle 2 - DEF System Tampering Cycle

Figure Cummins 14.9-6 was created by ARB staff with Cummins' permission as an interpretation of the 2010 MY Kenworth T800 Owner's Manual depicting the stages of escalating driver warnings and alerts expected for the DEF System Tampering Cycle and the DEF Contamination Cycle.

Figure Cummins 14.9-6: 2010 MY Cummins' Driver Warnings & Inducements for DEF Quality or Tampering



When disabled or tampered, the SCR system is expected to trigger driver warnings and vehicle inducements upon the detection of a non-functioning SCR system. As the vehicle continues to operate with the disabled or tampered component, the SCR system is designed to increase the warnings and inducements up to activating a limited speed condition of 5 mph.

(1) Doser Valve Disconnected

Day 1

Before starting the next test cycle, staff filled the DEF tank to 50 percent capacity with quality DEF. Staff began the DEF System Tampering Cycle by disabling Test Vehicle 2's doser valve (odometer = 9,315 miles). The first driver warning occurred after accumulating nine miles (odometer = 9,324 miles) when the red DEF gauge light began to flash (see Figure Cummins 14.9-6, Stage 1a). After driving 16 additional miles (odometer = 9,340 miles), with the red DEF gauge light still flashing, the check engine light illuminated, the Low DEF warning message displayed on the DID and the vehicle experienced an engine power derate (see Figure Cummins 14.9-6, Step 2a). The driver stated that the engine derate was significant, especially when traveling up a grade (odometer = 9,352 miles) and that the engine power seemed to be reduced by 50 percent. The vehicle was returned to ARB's El Monte facility with the same active driver warnings and inducements (odometer = 9,388 miles).

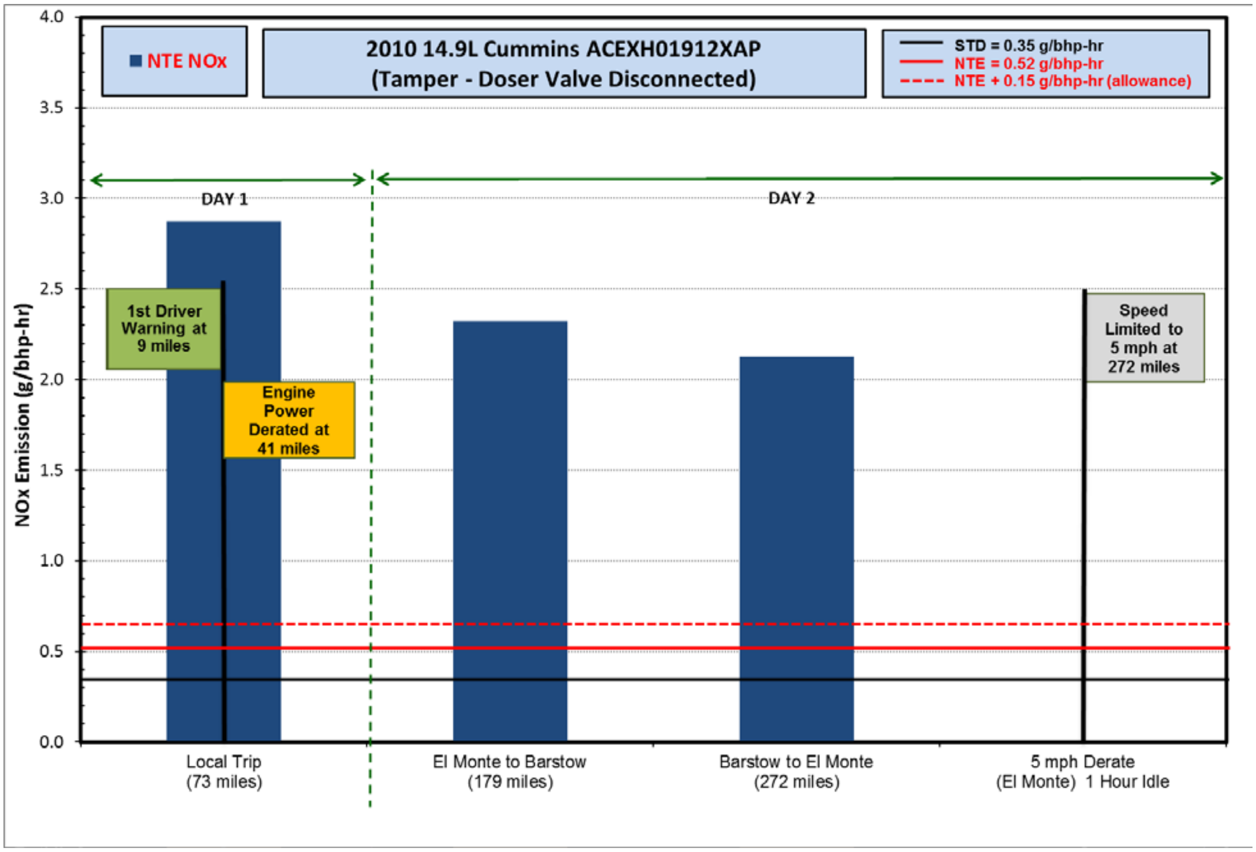
Day 2

The driver commenced his route the next morning with the check engine light still illuminated and the previous warnings and inducements still active. While in route, staff stopped to re-fuel adding 33.3 gallons of diesel fuel bringing the diesel fuel level back up to 100 percent full (odometer = 9,487 miles). The driver continued to drive the designated route and returned to the ARB El Monte facility (odometer = 9,587 miles). Staff allowed the vehicle to idle for just over an hour and a half and performed a key-off/key-on event. Upon completion of the key-of/key on event, staff observed the red stop engine light was illuminated and the vehicle went into a 5 mph derate. Additionally, the MIL was still illuminated and the previous warnings and inducements were still active. When attempting to drive, the vehicle was limited to 5 mph (see Figure Cummins 14.9-6, Stage 3a). The vehicle was clearly ahead of the 2010 MY Guidance and obviously much closer to the 2011+ MY Guidelines due to the software updates that occurred after the original testing of this vehicle in 2010.

The driver reconnected the doser valve and attempted to clear the codes but was unsuccessful. Subsequently, the vehicle was taken to the Kenworth dealer who cleared the associated codes and the vehicle returned to normal operation (odometer = 9,611 miles). The work was covered under the vehicle warranty and therefore, ARB did not incur any costs.

The figure below represents the daily DEF System Tampering Cycle emissions with a disconnected doser and includes markers where certain SCR inducement events occurred along the test route (see Figure Cummins 14.9-7 below). The events represented in the figure include the first driver warning, the onset of the engine derate, and the presumed initiation of the vehicle's SCR strategy to seek a safe harbor event.

Figure Cummins 14.9-7: Daily DEF System Tampering Cycle (Disconnected Doser) Emissions Data



Note: The PEMS values in this figure were measured values taken during this test program while the vehicle was operated under on-road conditions. The NTE NOx is the on-road measurement of NOx emissions that requires specific engine operation and other criterion for attaining this measurement. The NOx family emission limit (FEL) of 0.35 g/bhp-hr requires emission measurements under laboratory conditions and the Not to Exceed (NTE) 0.52 g/bhp-hr standard requires specific on-road operation for attaining emission measurements. This standard, in addition to the NTE + 0.15 g/bhp-hr measurement allowance, was provided for general reference only. The PEMS unit used for this operation meets the U.S. EPA requirements per 40 CFR 1065.

The NOx emissions, as expected increased dramatically with the tampering event and remained high throughout. However, it is clear the initial warnings and especially the derate condition caught the attention of the driver and would have likely resulted in more immediate attention than the ARB driver paid here trying to control the final inducement trigger by delaying the safe harbor event to a more convenient time and place. Cummins initiative to update in use 2010 engines to be more in line with the 2011+ MY Guidelines will result in an even greater reduction in tampering emission impacts by giving strong and immediate driver inducements.

(2) Thermocouple Disconnected

<u>Day 1</u>

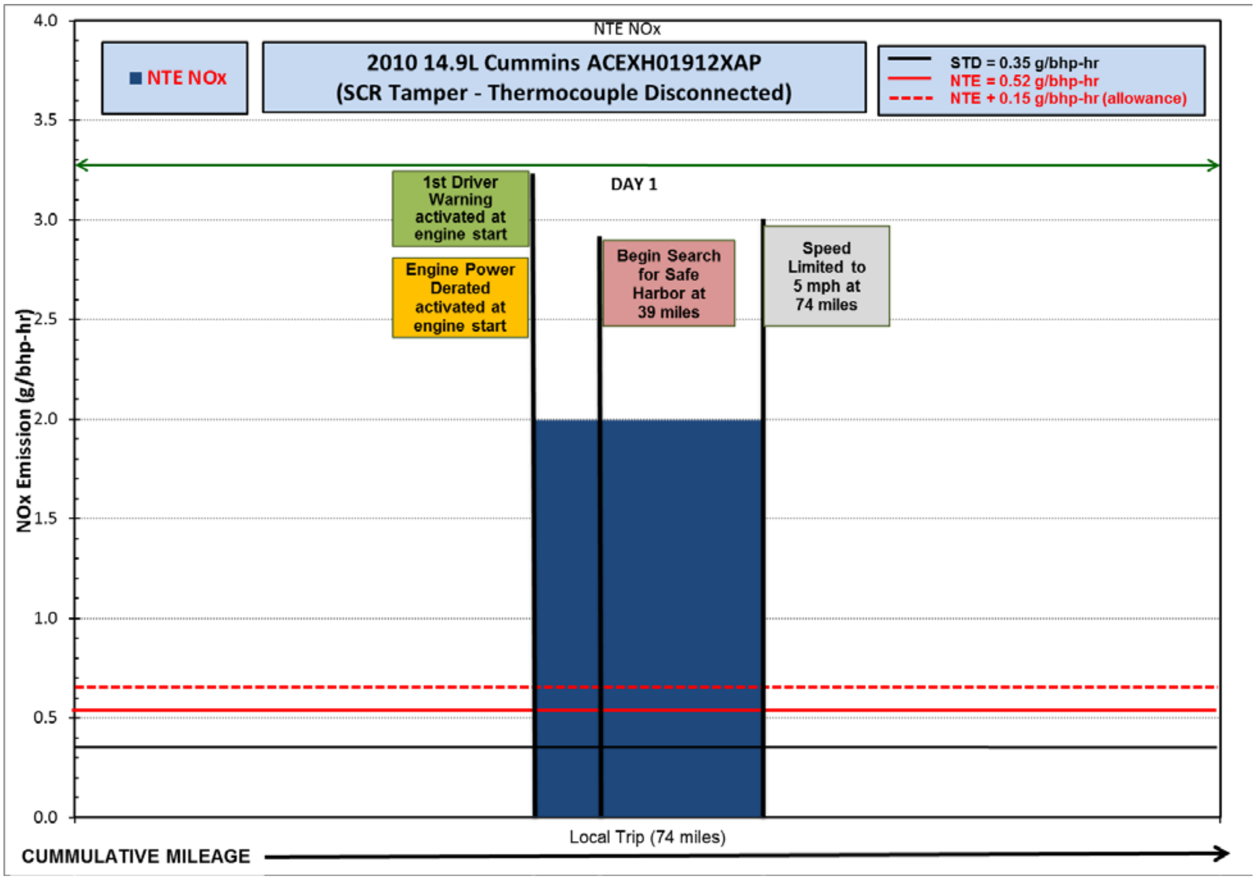
Staff attempted a second SCR tampering method by disconnecting the thermocouple on the outlet side of the SCR catalyst (odometer = 9,620 miles). Immediately after starting the vehicle, the check engine light illuminated and the "Engine De-rate, See Operator Manual" warning message displayed on the DID. After driving 39 miles (odometer = 9,659 miles), the driver observed that the vehicle sustained a severe power loss, similar to what was experienced in the first tampering cycle. The driver noted that the vehicle could not achieve speeds greater than 50 mph and based on his experience with the first tampering cycle, the vehicle was probably searching for a safe harbor event to initiate the final inducement. After driving an additional 35 miles (odometer = 9,694 miles) the DID display changed to "Exhaust (SCR/DEF) Service Required" (see Figure Cummins 14.9-8). Staff performed a key off/key-on event and the red stop engine light illuminated (see Figure Cummins 14.9-6, Stage 3a). Subsequently, the vehicle went into a 5 mph limited speed event..

Figure Cummins 14.9-8: DIC Message – Exhaust (SCR/DEF) Service Required

The drive time to reach the final inducement since the first driver warning was triggered took approximately two hours or 74 miles. Staff drove the vehicle with the 5 mph inducement for two miles, back to the ARB El Monte facility, shut off the engine and reconnected the thermocouple (odometer = 9,696 miles). Staff restarted the engine, apparently triggering the SCR system into a “self-healing” reset which extinguished the SCR-related driver warnings and inducements. With the warning lights cleared, staff noted that the message “Check Engine History” was displayed on the DID. Staff drove the vehicle and experienced an engine power derate within 12 miles (odometer = 9,708 miles). Staff continued to drive and after completing 62 additional miles of operation, the vehicle’s power was restored to normal and only the message “Check Engine History” was displayed (odometer = 9,770 miles). This concluded the DEF System Tampering Cycle.

The figure below represents the DEF System Tampering Cycle emissions with a disconnected thermocouple and includes markers where certain SCR inducement events occurred along the test route (see Figure Cummins 14.9-9 below). The events represented in the figure include the first driver warning, the onset of the engine derate, and the assumed initiation of the vehicle’s SCR strategy to seek a safe harbor.

Figure Cummins 14.9-9: Daily DEF System Tampering Cycle (Disconnected Thermocouple) Emissions Data



Note: The PEMS values in this figure were measured values taken during this test program while the vehicle was operated under on-road conditions. The NTE NOx is the on-road measurement of NOx emissions that requires specific engine operation and other criterion for attaining this measurement. The NOx family emission limit (FEL) of 0.35 g/bhp-hr requires emission measurements under laboratory conditions and the Not to Exceed (NTE) 0.52 g/bhp-hr standard requires specific on-road operation for attaining emission measurements. This standard, in addition to the NTE + 0.15 g/bhp-hr measurement allowance, was provided for general reference only. The PEMS unit used for this operation meets the U.S. EPA requirements per 40 CFR 1065.

Under the DEF System Tampering Cycle, the emissions also increased significantly when disconnecting SCR related components. Staff performed two types of tampering events where the DEF doser injector was disconnected and later disconnected the SCR thermocouple. With regards to the initial alert for both tampering events, the SCR system triggered the first SCR driver warning within one hour and are consistent with suggested 2011+ MY Guidelines. In regards to seeking final inducement within four hours (approximately 200 miles), both tampering cases were consistent with the 2011+ MY Guidelines. Keep in mind that this vehicle was a 2010 MY certified engine and was only required to meet the 2010 MY Guidance, so Cummins' voluntary calibration update significantly improved the time/mileage points for warnings and inducements.

c) Vehicle 2 - DEF Contamination Cycle

In the case of DEF contamination, the SCR system is expected to detect NOx noncompliance and trigger driver warnings and vehicle inducements. As the vehicle continues to operate with poor quality DEF, the SCR system is designed to increase the warnings and inducements up to activating a limited speed condition of 5 mph. The SCR system should follow the same stages of escalating driver warnings and inducements shown in Figure Cummins 14.9-6.

Day 1

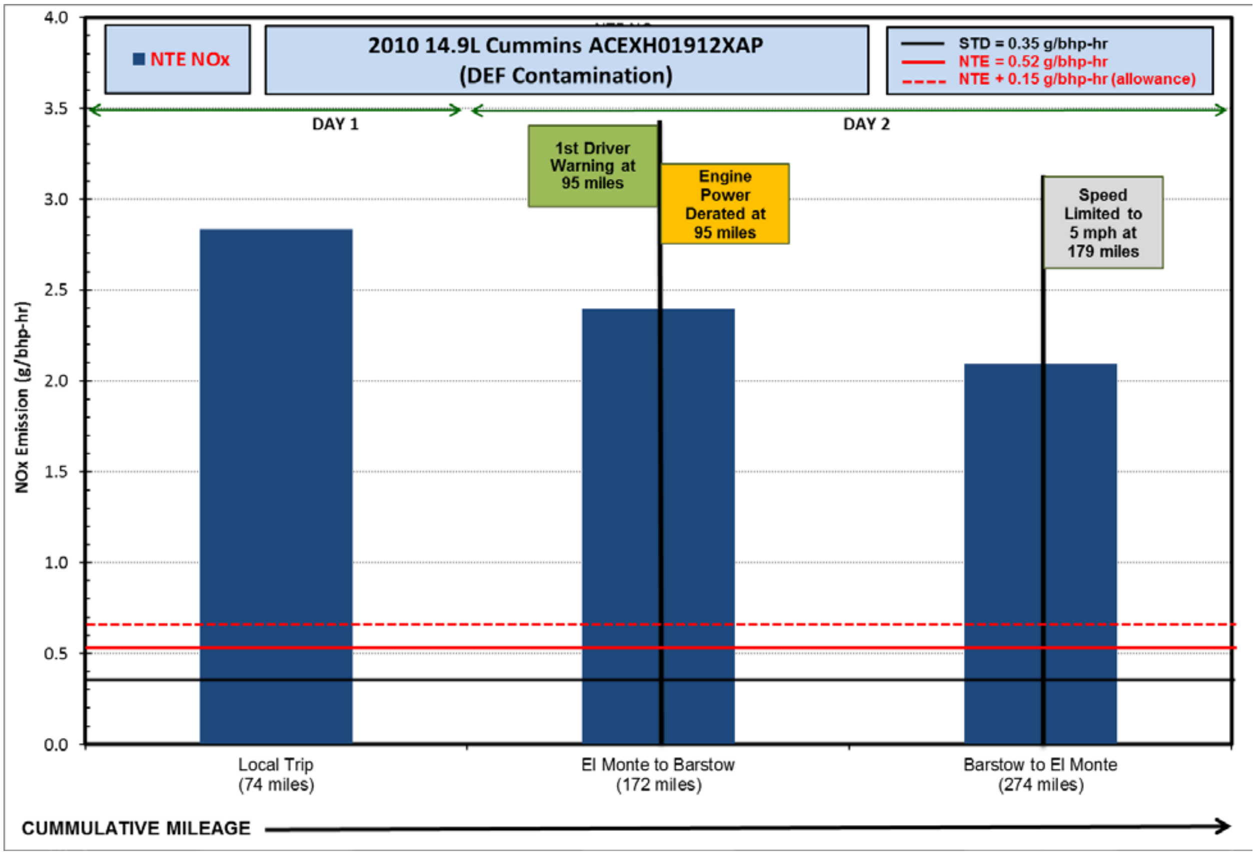
Staff prepared for this test cycle by draining the DEF tank and filling it approximately half full with deionized water. The vehicle's diesel fuel tank was also filled to approximately half of its capacity as indicated on the fuel gauge. Staff began operating the vehicle over the designated test route (odometer = 9,770 miles) and drove for just over an hour and a half before returning to ARB's El Monte facility for the evening (odometer = 9,844 miles). No driver warnings or inducements were experienced during this time of operation.

Day 2

Staff began driving the test route the next day and within a half an hour (odometer = 9,865 miles) the driver experienced a power derate and the first driver warning occurred with the DID displaying the message "Exhaust (SCR/DEF) Service Required" (see Figure Cummins 14.9-6, Stage 2a). Traveling 11 additional miles, staff stopped to refuel adding 72.9 gallons of diesel fuel (odometer = 9,876 miles). The driver continued to drive the vehicle stopping to top off the fuel tank, adding 13.0 gallons of diesel fuel (odometer = 9,944 miles). The driver decided to test if the vehicle would be in a safe harbor seeking mode based on the refuel event, then continued the test route and returned to ARB's El Monte facility (odometer = 10,044 miles) with the same SCR driver warning alerts displayed. Staff performed a key-off/key-on event and the red Stop Engine light illuminated (see Figure Cummins 14.9-6, Stage 3a) and the vehicle was immediately restricted to a 5 mph speed limit. The drive time to reach the final inducement since the first driver warning was triggered took approximately four hours (179 miles traveled). Staff drained the water from the DEF tank and filled it with five gallons of quality DEF and then cleared the codes using Cummins' software (this software was purchased by ARB from Cummins) which cleared all associated SCR warnings and inducements. The vehicle returned to normal vehicle operation. This concluded the DEF Contamination Cycle.

The figure below represents the DEF Contamination Cycle emissions and includes markers where certain SCR inducement events occurred along the test route (see Figure Cummins 14.9-10 below). The events represented in the figure include the first driver warning, the onset of the engine derate, and the presumed initiation of the vehicle's SCR strategy to seek the final inducement event.

Figure Cummins 14.9-10: Daily DEF Contamination Cycle Emissions Data



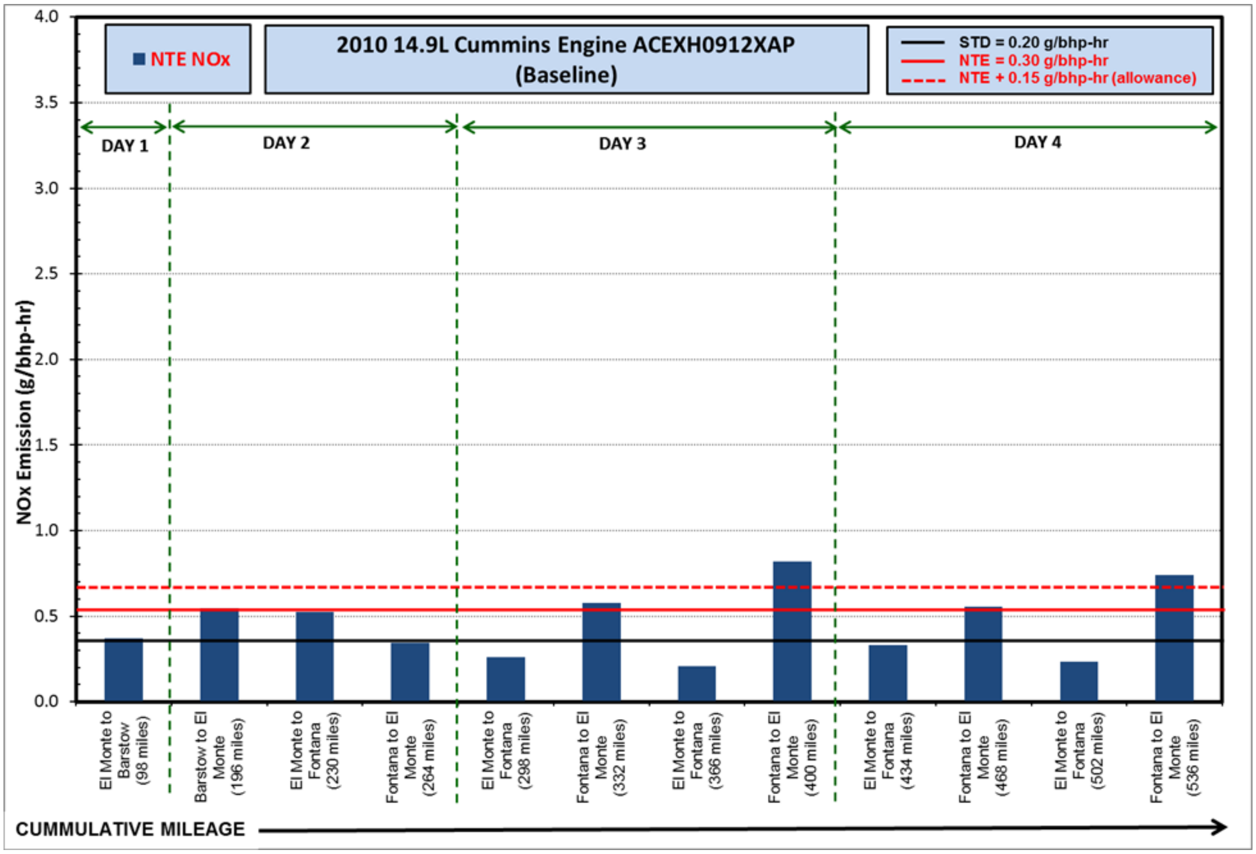
Note: The PEMS values in this figure were measured values taken during this test program while the vehicle was operated under on-road conditions. The NTE NOx is the on-road measurement of NOx emissions that requires specific engine operation and other criterion for attaining this measurement. The NOx family emission limit (FEL) of 0.35 g/bhp-hr requires emission measurements under laboratory conditions and the Not to Exceed (NTE) 0.52 g/bhp-hr standard requires specific on-road operation for attaining emission measurements. This standard, in addition to the NTE + 0.15 g/bhp-hr measurement allowance, was provided for general reference only. The PEMS unit used for this operation meets the U.S. EPA requirements per 40 CFR 1065.

As expected, under the DEF Contamination Cycle, the emissions increased significantly when adding water in place of DEF. During the DEF Contamination Cycle the initial detection for triggering the first SCR driver warning took just over two hours (95 miles traveled) and was accompanied by a derate. ARB believes that this first warning is not fully consistent with the 2011+ MY Guidelines which suggested a one hour (approximately 50 miles) detection of noncompliance and notification to the operator. However, this engine was a certified 2010 MY engine and was consistent with the applicable 2010 MY Guidance information for this engine. ARB is currently in discussions with the manufacturer to determine if the results for initiating the first driver warning for identifying contaminated DEF met Cummins' design criteria of their calibration update. Additionally, the vehicle did seek final inducement within four hours or 200 miles after triggering the first driver warning which is consistent with the 2011+ MY Guidelines.

d) Vehicle 2 - Baseline Test Cycle

Baseline testing began with the DEF tank filled to 40 percent capacity with quality DEF and the diesel fuel tank filled to about 90 percent capacity (odometer=10,044 miles). The baseline portion of this test program represents the average typical emissions the vehicle generates under normal vehicle operation. Staff drove this vehicle for four days and accumulated 557 miles establishing baseline NOx emissions data (odometer = 10,601 miles). The daily baseline emissions are represented in Figure Cummins 14.9-11 below. As you can see, this vehicle maintained very good NOx control throughout most of the test route, relative to its 0.52 g/bhp-hr NTE certified level, and never exceeded 1.0 g/bhp-hr for any of the segments. The legitimate NTE points, accounting for the measurement allowance, were minimally exceeded on only two of the driving segments.

Figure Cummins 14.9-11: Daily Baseline Emissions Data



Note: The PEMS values in this figure were measured values taken during this test program while the vehicle was operated under on-road conditions. The NTE NOx is the on-road measurement of NOx emissions that requires specific engine operation and other criterion for attaining this measurement. The NOx family emission limit (FEL) of 0.35 g/bhp-hr requires emission measurements under laboratory conditions and the Not to Exceed (NTE) 0.52 g/bhp-hr standard requires specific on-road operation for attaining emission measurements. This standard, in addition to the NTE + 0.15 g/bhp-hr measurement allowance, was provided for general reference only. The PEMS unit used for this operation meets the U.S. EPA requirements per 40 CFR 1065.

e) Vehicle 2 - Emission Measurements

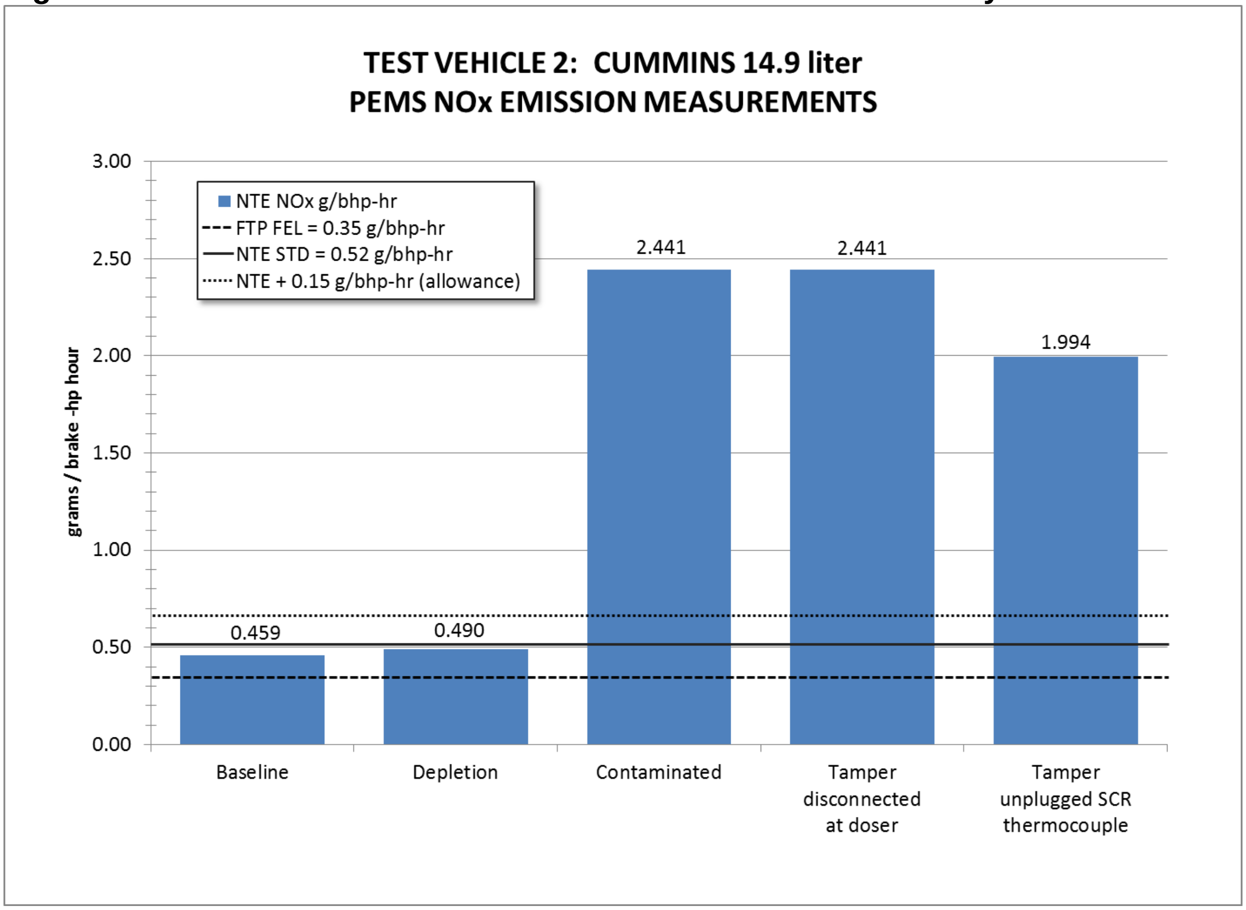
Test Vehicle 2 was outfitted with a PEMS unit which measured the vehicles emissions as the vehicle was operated over the designated test route. Emissions were measured under each of the prescribed test cycles: the Baseline Cycle, the DEF System Tampering Cycles (disconnection of the doser injector and SCR catalyst thermocouple) and the DEF Contamination Cycle.

Figure Cummins 14.9-12 is a summary of the average NTE NOx emissions measured for each of these test cycles. It should be noted that staff utilized NTE zone emission measurements to compare the emission results for each test cycle. The Family Emissions Limit (FEL) is also shown on the chart but the test requirement to conduct a certification type test requires an engine dynamometer under laboratory conditions. This standard was only included on the chart for informational purposes.

The Baseline Cycle NOx emissions were 0.459 g/bhp-hr and met the NTE NOx standard of 0.52 g/bhp-hr. The DEF Depletion Cycle's PEMS measurements were taken over two days from the time the vehicle began the DEF Depletion Cycle until the vehicle went into a 5 mph limited speed derate. Under this cycle the NTE NOx emissions averaged 0.490 g/bhp-hr. Just prior to the vehicle experiencing a 5 mph limited speed inducement and with the DEF tank completely empty, NOx emissions increased to 1.033 g/bhp-hr indicating that while the driver thought the DEF tank was empty, there was DEF in the reserve which allowed the vehicle to remain in compliance for some time.

The NTE NOx emissions for the DEF Contamination and DEF System Tampering Cycles were about five times higher than the baseline NTE results ranging from 1.994 to 2.441 g/bhp-hr, respectively.

Figure Cummins 14.9-12: Vehicle 2: NOx Emission Data Summary



Note: The PEMS values in this figure are the average NOx NTE emissions taken during this test program while the vehicle was operated under on-road conditions. The NOx family emission limit (FEL) of 0.35 g/bhp-hr requires emission measurements under laboratory conditions. This standard, in addition to the NTE standard of 0.52 g/bhp-hr measurement allowance, was provided for general reference only. The PEMS unit used for this operation meets the U.S. EPA requirements as per 40 CFR 1065.

f) Vehicle 2 - Inducement Test Summary

ARB staff operated this Test Vehicle 2 under various test cycles comparing the vehicle's SCR-related driver warnings and inducements to those supplied in the vehicle owner's manual and their consistency with the 2010 MY Guidance and/or the 2011+ MY Guidelines. ARB staff checked the driver warnings and inducements under the following cycles: DEF Depletion Cycle, DEF System Tampering Cycle, and DEF Contamination Cycle.

Comparing the SCR warnings and inducements strategies with the vehicle owner's manual showed many consistencies with one slight difference with the DEF System

Tampering and DEF Contamination Cycles. Under these cycles, the driver noted that the time to reach the limited speed severe inducement event was reduced by 50 percent.

It is important to note that this was a follow up to the test program conducted on this same vehicle in mid-2010, and technically, this vehicle is only required to be consistent with the 2010 MY Guidance. In the May 2011 SCR evaluation report, ARB staff stated that this vehicle (equipped with the 2010 MY calibration) experienced issues in reaching the 5 mph final inducement for all three evaluated test cycles. In November 2010, Cummins recalled the affected vehicles recalibrating the ECU to correct various SCR inducement strategies (Recall # C1036). Based on ARB's new study after completion of the test cycles, it was disclosed that the new calibration did in fact resolve the problems identified in the 2010 study. Cummins' voluntarily revised software that enhanced the SCR strategy by triggering driver warnings and engine-derate events sooner and also allowed each of the evaluated test cycles to reach the final 5 mph severe inducement. The problems experienced would be intolerable for any driver on their daily route.

In conclusion, the new calibration was consistent with the 2010 MY Guidance and closely followed the suggested SCR 2011+ MY Guidelines presented at ARB's July 2010 SCR Workshop, although as mentioned previously, this engine only needed to be consistent with the 2010 MY Guidance.

VI. Continued Evaluation of 2010+ NOx Control Strategies

ARB staff evaluated three heavy-duty vehicles equipped with a 2010 or 2011 MY HDD engine (two vehicles using engines with SCR-equipped technology and one vehicle utilizing an engine with EGR but no SCR emission control technology). The SCR equipped vehicles evaluated included a 2011 MY Freightliner Cascadia Class 8 truck, equipped with a 2011 MY Detroit Diesel (DDC) 12.8L engine (Test Vehicle 3), a 2010 MY Volvo Class 8 truck, equipped with a 2010 MY Volvo 12.8L engine (ECU recalibrated with some 2011 MY SCR attributes (Test Vehicle 4), and the non-SCR vehicle was a 2012 MY International Class 8 truck, equipped with a 2011 MY Navistar MaxxForce 13 engine (Test Vehicle 5).

Test Vehicles 3 and 4 underwent these four SCR test cycle evaluations as followed in ARB's Test Plan #1Q1102 (see Appendix D) to monitor the manufacturers' SCR detection and inducement strategies.

- **DEF Depletion Cycle** – continued vehicle operation to deplete the DEF tank until the vehicle experiences a no-start condition, or a 5 mph maximum speed limit, or an idle-only operation.
- **DEF Contamination Cycle** – continued vehicle operation with water instead of DEF until the vehicle experiences a no-start condition, or a 5 mph maximum speed limit, or an idle-only operation.
- **DEF System Tampering Cycle** – continued operation after disabling the SCR until the vehicle experiences a no-start condition, or a 5 mph maximum speed limit, or an idle-only operation.
- **Dilution Test Cycle** – continued operation with a blend of water and DEF to check if and when a diluted DEF mixture will cause the SCR driver warnings and engine inducements to initiate. The purpose of this evaluation is to determine if the SCR system is capable of detecting a diluted DEF concentration as opposed to completely filling the DEF tank with water. The vehicles were not driven to final inducement under this test cycle.

Typically, these strategies include a sequence of visual and/or audible warnings on the instrument panel (e.g., warning lights, chimes, and/or text message displays) indicating the DEF supply was low or a problem had been identified. As additional mileage is accumulated without remedying the problem or refilling the DEF supply, further driver inducements should occur, such as power derates or speed limits (which allow continued operation of the truck). Ultimately, if the problem is not corrected, a severe inducement or final immobilization in the form of a no-start condition, or a 5 mph maximum speed limit, or an idle-only operation should be triggered once the vehicle reaches a safe harbor (e.g., when diesel refueling occurs, the engine is keyed-off, or the vehicle is parked at idle for an extended period of time). Depending on the certified MY of the engine, the vehicles were evaluated to determine if the SCR driver warnings and inducements were consistent with the vehicle owner's manuals, and/or the 2010 MY Guidance (see Figure 11), and/or the 2011+ MY Guidelines (see Figure 12). Because the vehicles are being driven on freeway routes, staff assumes a one hour threshold will be achieved after traveling about 50 miles and a four threshold will be achieved after traveling about 200 miles.

Additionally, Test Vehicles 3 and 4 were outfitted with a Sensors, Inc. Semtech-DS PEMS unit which measured the vehicles' emissions as the vehicle was operated over the designated test route. Emissions were measured for each of the four test conditions described above and a baseline condition. The baseline condition represents the average typical emissions the vehicles generated under normal vehicle operation.

The non-SCR equipped vehicle (Test Vehicle 5) was operated under separate test conditions (shown below) to determine if any driver alerts or vehicle inducements were created following ARB's Test Plan #1Q1102 (see Appendix D).

- **EGR Tampering Cycle** – continued operation with a tampered EGR system observing and documenting all (if any) driver warnings, vehicle performance issues caused by this tampering event and fuel economy impacts.

- **Lean Cruise Cycle** – continued operation to identify if any indication of engine management strategy exists to achieve better fuel economy but might cause an increase in NOx emissions when maintaining steady state freeway speeds on a level roadway.

Test Vehicle 5 was also outfitted with a Sensors, Inc. Semtech-DS PEMS unit and the vehicle operated over the designated test route while continuously measuring NOx emissions.

A. *Test Vehicle 3*

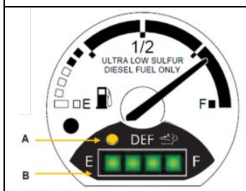
Chassis:	2012 MY Freightliner Cascadia
Axles:	3
Engine:	Detroit Diesel Corporation
Engine MY:	2011 MY
Engine Family:	BDDXH12.8FED
Displacement:	12.8 Liter
Horsepower:	500 HP @ 1800 RPM
Trailer:	48-foot flatbed

NOx Certification Standard: 0.20 g/bhp-hr

Test Vehicle 3 was a 2012 MY Freightliner Cascadia equipped with a 2011 MY Detroit Diesel Corporation (DDC) DD13 engine rented from Penske Truck Rental (Vehicle Identification Number - 1FUJGEDVXCSBD2735). When ARB took possession of the vehicle, the odometer displayed 3,859 miles. The vehicle towed a 48-foot flatbed trailer that was loaded with five 20-foot “K-rail” concrete barriers that weighed about 40,000 pounds. In order to determine the impact on NOx emissions, this truck was outfitted with a Sensors, Inc. Semtech-DS PEMS unit allowing for real-time emissions readings.

This vehicle utilizes the SCR system and therefore uses DEF as part of its after treatment system for controlling NOx emissions. When needed, the SCR system is expected to alert the driver through a sequence of warning lights in conjunction with vehicle inducements designed to draw the driver’s attention to the following conditions: low levels of DEF, contaminated DEF, or a tampered SCR system. This vehicle was expected to have attributes related to the SCR warning and inducement strategies that closely follow the 2011+ MY Guidelines (see Figure 12). Before operating the vehicle, the driver reviewed the vehicle driver’s manual to become familiar with the dashboard gauges, warning lights, vehicle controls, and SCR-related warning system. Figure DDC-1, shown on the next page, describes the various driver warning lights used when the SCR system requires attention. This information has been reproduced with DDC’s permission and is referenced in-part from the 2012 Freightliner Cascadia Driver’s Manual.

Figure DDC-1: DDC's SCR System Driver Warning Lights

Referenced from: **2012 FREIGHTLINER CASCADIA DRIVER'S MANUAL** www.freightliner.com	
	**Fuel/DEF Level Gauge** – pages 4.26 and 11.7 The fuel and DEF levels are measured in a dual purpose fuel/DEF gauge. The lower portion of the gauge is the **DEF Level Lightbar (see item B)**, where each illuminated green bar equals ¼ of the DEF tank capacity. The **Low DEF Level Warning Lamp (see item A)**, that illuminates amber when the DEF level reaches 10% of capacity.
	**Malfunction Indicator Lamp (amber color)** – page 4.24 Indicates an engine emissions-related fault, including, but not limited to the after treatment system. See the engine operation manual for details.
	**Stop Engine Lamp (red color)** – page 4.23 Indicates a serious fault which requires the engine shut down immediately.
	**Check Engine Lamp (amber color)** – page 4.23 Indicates an undesirable engine condition is detected or recorded.

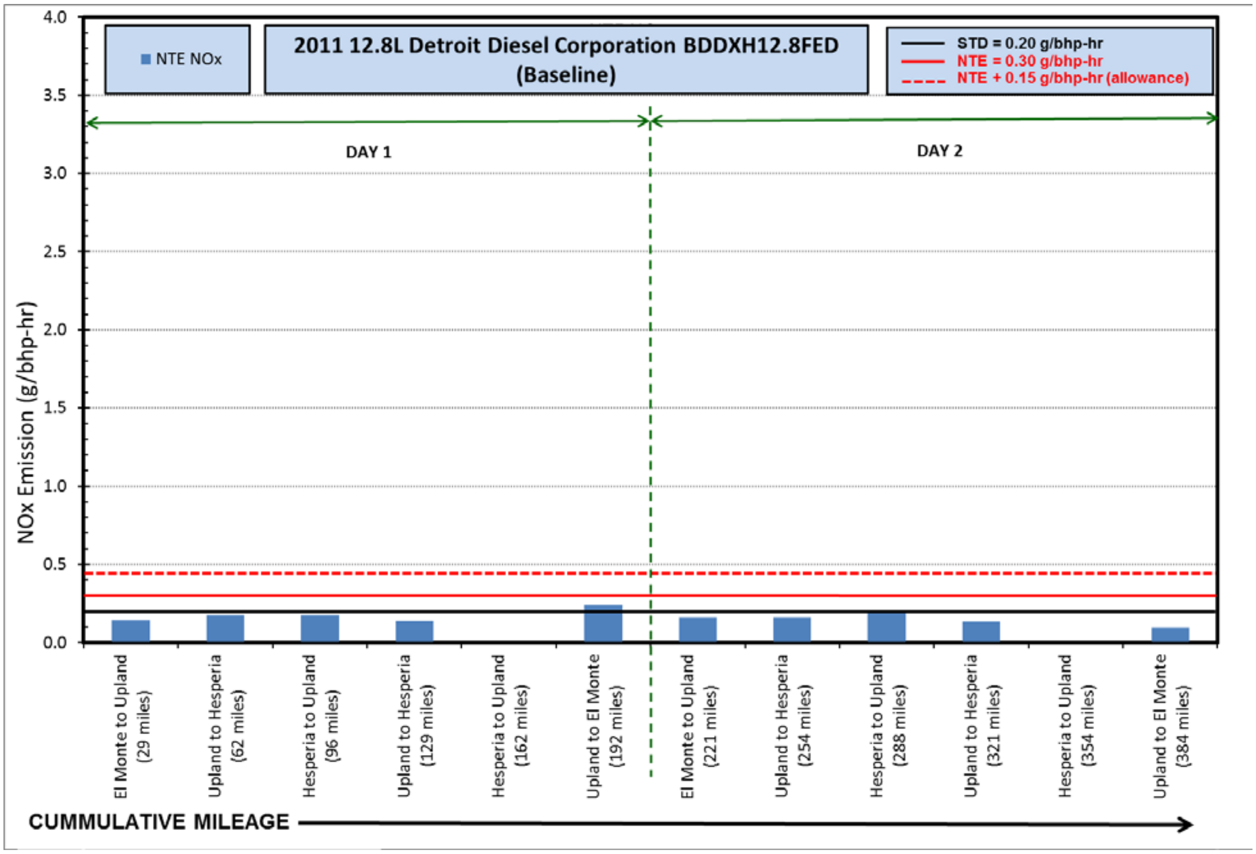
a) Vehicle 3 - Baseline Testing

To begin the SCR system evaluation, staff operated the "as received" test vehicle, over the designated test route while sampling the vehicle's exhaust to establish a baseline profile utilizing the PEMS (see Figure DDC-2).

Figure DDC-2: Portable Emissions Monitoring System and K-Rails

This baseline profile represents the average emissions the vehicle generated during typical operation and will later be compared to the DEF Depletion Cycle, DEF Contamination Cycle, and DEF System Tampering Cycle. The vehicle's average baseline emissions are shown in driving segments in Figure DDC-3. Note: the NTE NOx data is not shown in some of the traveled routes because some ambient conditions were outside of the required NTE measurement zones. This vehicle maintained excellent NOx control throughout the driving route for both total and NTE NOx emissions relative to its 0.30 g/bhp-hr NTE certified level. None of the average emission levels ever reached or exceeded the NTE measurement allowance level and the NTE segments were well below the non-measurement allowance level of 0.30 NOx.

Figure DDC-3: Daily Baseline Emissions Data

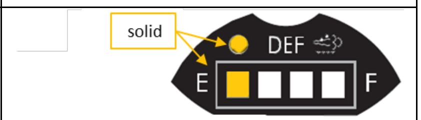
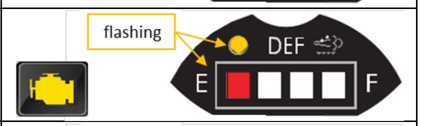
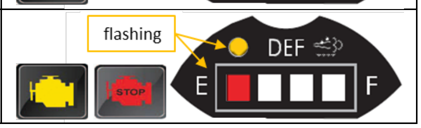


Note: The PEMS values in this figure were measured values taken during this test program while the vehicle was operated under on-road conditions. The NTE NOx is the on-road measurement of NOx emissions that requires specific engine operation and other criterion for attaining this measurement. The NOx certification emission standard of 0.20 g/bhp-hr requires emission measurements under laboratory conditions. This standard, in addition to the NTE standard of 0.30 g/bhp-hr and the NTE + 0.15 g/bhp-hr measurement allowance, was provided for general reference only. The PEMS unit used for this operation meets the U.S. EPA requirements per 40 CFR 1065.

b) Vehicle 3 - DEF Depletion Cycle

Figure DDC-4, reproduced with DDC's permission, from the 2012 Freightliner Cascadia Driver's Manual shows the different steps of gauge/lamp combinations and associated SCR system responses expected for the DEF Depletion Cycle. These different steps represent the escalating driver warnings and vehicle inducements; as the steps increase, so will the level of driver warnings and the severity of vehicle inducements.

Figure DDC-4: DDC's SCR System Sequence of Steps for DEF Depletion

Referenced from: **2012 FREIGHTLINER CASCADIA DRIVER'S MANUAL** www.freightliner.com		
	SCR SYSTEM RESPONCE	**GAUGE / LAMP COMBINATION**
Step 1	DEF level... Between 10% to 25% of tank capacity.	
Step 2	DEF level is **LOW**... Less than 10% of tank capacity.	
Step 3	DEF level is **VERY LOW / Initial Warning**.	
Step 4	DEF level is **EMPTY**. Vehicle power limited. Vehicle speed limited to 55 mph.	
Step 5	DEF level is **EMPTY** and **IGNORED**. Vehicle power limited. Vehicle speed limited to 5 mph.	

As shown in Figure DDC-4, Step 1, the DEF Level Lightbar lamp (the light that is shaped like a square) will illuminate 1 green square as the DEF depletes from 25 to 10 percent capacity. Once the DEF level drops below 10 percent, the DEF Level Lightbar lamp should change from green to amber as shown in Step 2. As the DEF level continues to deplete below 10 percent, the DEF Level Lightbar lamp should continue to illuminate amber accompanied by a solid amber Low DEF Level Warning Lamp (the light that shaped like a circle) as shown in Step 3. Once the DEF level depletes to empty, the DEF Level Lightbar lamp and the Low DEF Level Warning Lamp should begin to flash and the Malfunction Indicator Lamp (MIL) will illuminate as shown in Step 4. Additionally, during this time the engine power should be derated and the vehicle speed limited to 55 mph. Per Step 5, if the empty DEF tank is ignored, the DEF Level Lightbar lamp should illuminate red and flash along with the amber Low DEF Level Warning Lamp; the MIL should continue to illuminate; the red Stop Engine Lamp should illuminate; and the vehicle speed should be limited to 5 mph (assuming the vehicle is brought to a safe harbor event).

Day 1

In preparation for the DEF Depletion Cycle, staff adjusted the truck's DEF level so that one green bar (see Figure DDC-4, Step 1) was illuminated on the DEF Level Lightbar (odometer = 4,778 miles), and the fuel level gauge indicated the diesel fuel tank at nearly full. After traveling 53 miles (odometer = 4,832 miles) the first driver warning took place with the green bar changing to amber on the DEF Level Lightbar (see Figure DDC-4, Step 2); but then after two miles the DEF Level Lightbar lamp reverted back to a green bar. It took an additional 52 miles to permanently activate the second driver warning sequence (odometer = 4,884 miles), with the illumination of the solid Low DEF Level Warning Lamp and one amber bar on the DEF Level Lightbar (see Figure DDC-4, Step 3). Fourteen miles later, the driver stopped to add 37.5 gallons of diesel fuel and then returned to ARB's El Monte facility terminating the route with the odometer showing 4,961 miles.

Day 2

The next day upon vehicle start, the driver noted that the Low DEF Level Warning Lamp on the DEF gauge was flashing, the DEF Level Lightbar lamp changed to red and was flashing and the MIL was also illuminated. However, after driving less than a mile (odometer = 4,961 miles) the MIL extinguished and the flashing Low DEF Level Warning Lamp and DEF Level Lightbar lamp reverted back to a solid amber color. The vehicle's SCR system escalated the driver warning sequence 54 miles later (odometer = 5,015 miles) with a flashing amber Low DEF Level Warning Lamp, a single flashing red bar on the DEF Level Lightbar, and again illuminating the MIL. In conjunction with these driver warnings, the driver noticed a power loss indicating that the vehicle was experiencing an engine power derate condition (see Figure DDC-4, Step 4). The driver stated there was a noticeable loss of power when accelerating or when climbing a steep grade; however, the driver did not attempt to surpass the 55 mph speed limit because he was not comfortable with accelerating beyond the speed limit.

After driving 73 miles since the engine power derated, the driver stopped to add 34.2 gallons of diesel fuel. During this stop, the engine remained on and at idle (odometer = 5,088 miles). Returning to the driver's seat, the driver discovered that the Stop Engine Lamp had illuminated, adding to the already illuminated MIL, a flashing Low DEF Level Warning Lamp, and a single flashing red bar on the DEF Level Lightbar (see Figure DDC-4, Step 5). By reaching Step 5 of the sequence, staff presumed that the vehicle would begin searching for a safe harbor condition to activate the final inducement.

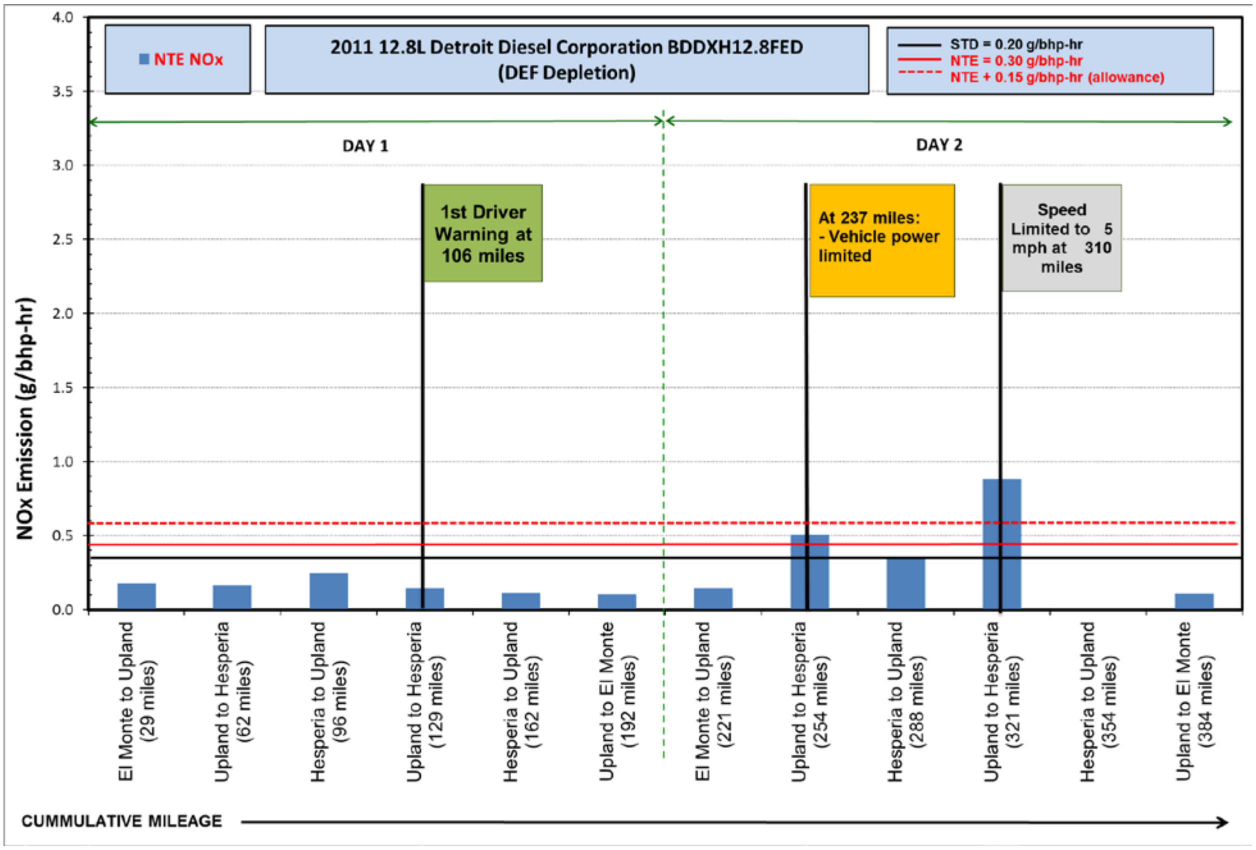
As the driver attempted to leave the diesel refueling station, staff discovered that the final inducement had been triggered limiting the vehicle speed to 5 mph. Staff drove the vehicle away from the fueling station at 5 mph to avoid blocking traffic and parked (odometer = 5,089 miles).

After turning off the engine, staff added 2.5 gallons of DEF and then restarted the engine allowing the SCR system to do a "self-healing" reset. After a few minutes, the SCR-related driver warnings cleared on the dashboard. Staff confirmed that the vehicle inducements of derated power and/or speed limiters were also cleared as they continued driving the test route. With the vehicle having returned back to normal operation and the DEF gauge showing one green bar on the DEF Level Lightbar, the driver returned to ARB's El Monte facility (odometer = 5,152 miles) ending the day and the DEF Depletion Cycle. In total, the vehicle had traveled 205 miles, assumed to be roughly four hours of operation, from when the first continuous SCR-related low DEF driver warning activated to when the SCR system was confirmed to search for and reached the final inducement of 5 mph.

Figure DDC-5, represents the average segment emissions measured using the PEMS during the DEF Depletion Cycle. The figure also includes the sequence of the SCR inducements occurring as the vehicle was operated along the test route. The figure shows the activation of the SCR-related first driver warning, when the engine was derated or vehicle speed limited, as well as the SCR activated final inducement. Note: the NTE NOx data is not shown in some of the traveled routes because some ambient conditions were outside of the required NTE measurement zones.

The DDC truck was able to maintain good NOx control throughout the DEF Depletion Cycle indicating that warnings and inducements were initiated well before DEF was truly empty or the vehicle used other mechanisms to control NOx. The 2011+ MY Guidelines expected detection of noncompliance within one hour and within four hours after detection of noncompliance a search for final inducement. In the DDC case, the emissions levels were compliant for almost the entire duration of this cycle and therefore initiated its warnings and inducements well before noncompliance took place which is consistent with and an improvement over the 2011+ MY Guidelines.

Figure DDC-5: Daily DEF Depletion Cycle Emissions Data



Note: The PEMS values in this figure were measured values taken during this test program while the vehicle was operated under on-road conditions. The NTE NOx is the on-road measurement of NOx emissions that requires specific engine operation and other criterion for attaining this measurement. The NOx certification emission standard of 0.20 g/bhp-hr requires emission measurements under laboratory conditions. This standard, in addition to the NTE standard of 0.30 g/bhp-hr and the NTE + 0.15 g/bhp-hr measurement allowance, was provided for general reference only. The PEMS unit used for this operation meets the U.S. EPA requirements per 40 CFR 1065.

c) Vehicle 3 - DEF Contamination Cycle

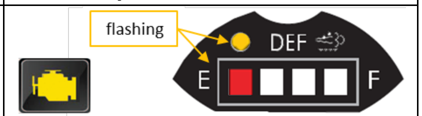
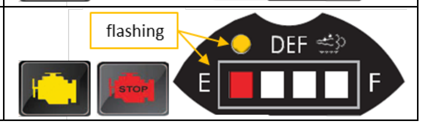
Figure DDC-6, reproduced with DDC's permission, is from the 2012 Freightliner Cascadia Driver's Manual and shows the different steps of gauge/lamp combinations and associated SCR system responses when operating the vehicle with contaminated DEF.

Figure DDC-6: DDC's SCR System Sequence of Steps for DEF Contamination

Referenced from:

2012 FREIGHTLINER CASCADIA DRIVER'S MANUAL

www.freightliner.com

	SCR SYSTEM RESPONCE	GAUGE / LAMP COMBINATION
Step 1	**CONTAMINATED** DEF in SCR System. Vehicle power limited. Vehicle speed limited to 55 mph.	
Step 2	**CONTAMINATED** DEF in SCR System. Vehicle power limited. Vehicle speed limited to 5 mph.	

As shown in Figure DDC-6, Step 1, when the SCR system is detected with contaminated DEF, the DEF Level Lightbar lamp will illuminate and flash one red bar along with a flashing amber Low DEF Level Warning Lamp and the MIL should illuminate. Additionally, the engine power should be derated and vehicle speed limited to 55 mph. Per Step 2, if the vehicle is continually driven with a contaminated SCR system, the DEF gauge lights should continue to flash; the MIL should continue to illuminate, the red Stop Engine Lamp should illuminate; and the vehicle speed should be limited to 5 mph (assuming the vehicle is brought to a safe harbor event).

Per DDC owner's manual, once contaminated DEF has been detected in the SCR system, the vehicle must be taken to an authorized service center to check the SCR system for damage and to deactivate the driver warning lights and vehicle inducement limits.

Day 1

Prior to operating the vehicle, staff drained the DEF tank and filled it with 10 gallons of deionized water. The DEF Level Gauge immediately illuminated three solid green lamps on the DEF Level Lightbar. Staff began driving the test route (odometer = 5,152 miles) with the diesel fuel gauge indicating 100 percent full capacity.

In less than one hour (odometer = 5,191 miles) the first driver warning occurred when the Low DEF Level Warning Lamp flashed, the MIL illuminated, and the message

“Code EEC 61” appeared on the liquid crystal display (LCD) (see Figure DDC-6, Step 1) on the instrument panel. The three green lamps remained illuminated. Additionally, although not noted in DDC’s owner manual as specified in Figure DDC-6, the Check Engine Lamp also illuminated at this point indicating an undesirable engine condition. Concurrently, with the dashboard warnings, the driver also noticed a loss of engine power but the driver did not exceed 55 mph so it is not certain if the vehicle was limited to 55 mph. The vehicle returned to ARB’s El Monte facility (odometer = 5,342 miles and diesel fuel gauge = 65 percent full) with the same visual warnings noted above. In preparation for the next day, staff added approximately 60 gallons of diesel fuel at ARB’s El Monte facility.

Day 2

After starting the vehicle, staff noticed the same active SCR driver dashboard warnings from the previous day. With 5,342 miles on the odometer and the diesel fuel tank full, the driver headed out along the designated test route and experienced a 55 mph limited speed condition along with the engine power derate. The driver continued along the test route before returning to ARB’s El Monte facility (odometer = 5,600 miles) with the diesel fuel level showing 62 percent of full capacity. The dashboard warnings of a flashing Low DEF Level Warning Lamp and MIL and an illuminated Check Engine Lamp remained unchanged throughout the test route. The day ended having traveled 409 miles since the first SCR-related warning.

Note: Due to PEMS equipment issues, the PEMS unit was not used for this day of testing.

Day 3

The PEMS equipment problem from Day 2 was resolved and PEMS measurements were resumed. After starting the vehicle, staff noticed the same active SCR driver warnings from the previous day. Staff drove along the designated test route for 191 miles and returned to ARB’s El Monte facility with no changes in the active driver warnings and inducements (odometer = 5,791 miles). Immediately after executing a key-off/key-on event the vehicle immediately illuminated the red Stop Engine Lamp adding to the already flashing Low DEF Level Warning Lamp and the illuminated MIL and Check Engine Lamp (see Figure DDC-6, Step 2). Staff expected that the vehicle speed would be limited to 5 mph, which was confirmed as they attempted to drive away (odometer = 5,792 miles). This concluded the DEF Contamination Cycle evaluation.

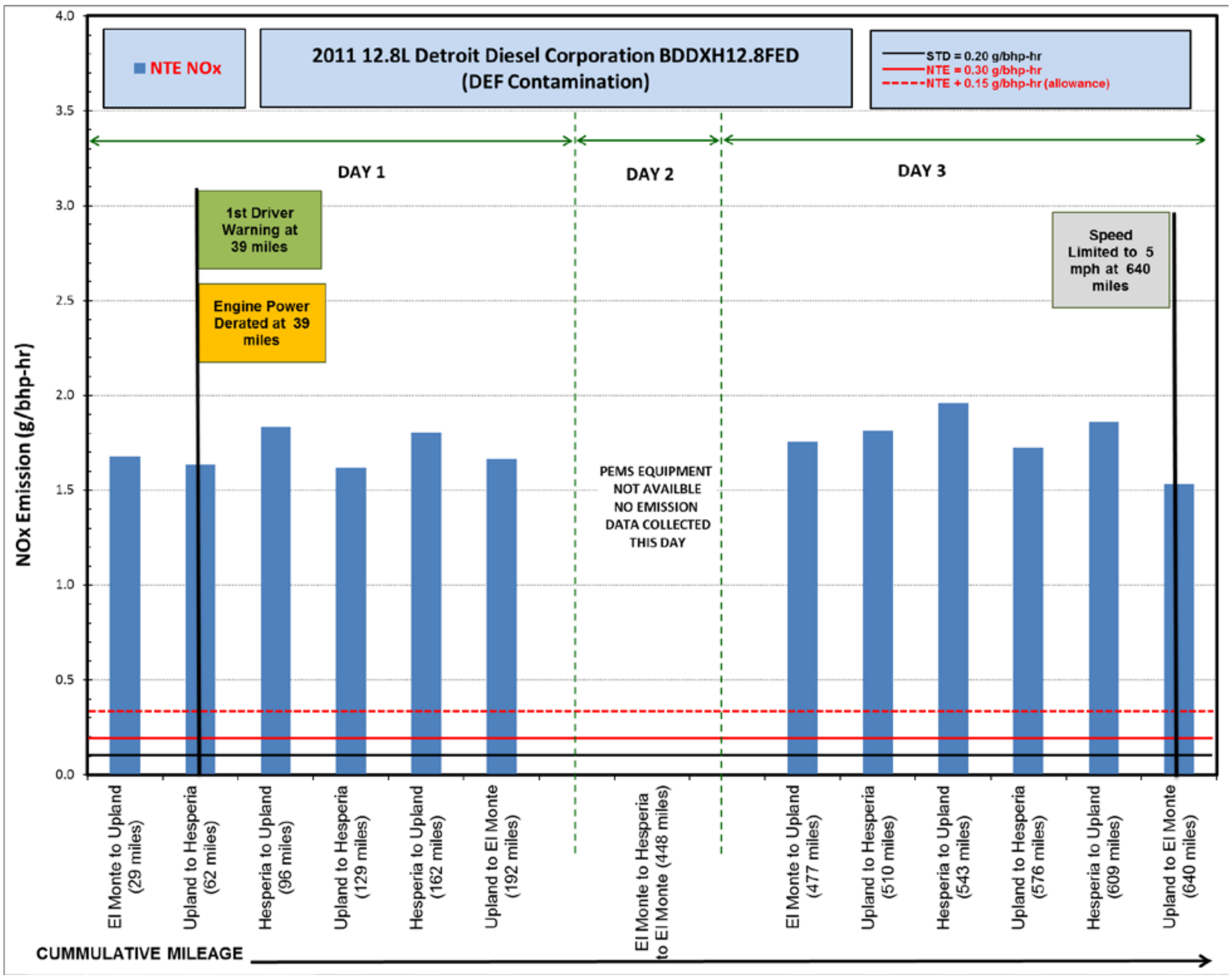
Day 4

To clear the 5 mph vehicle speed limit, staff added five gallons of quality DEF after draining the water from the DEF tank. Next, staff deactivated all SCR-related driver warnings and vehicle inducements using DDC's pc-based proprietary engine software connected to the truck's engine control computer. The vehicle was filled with 83.4 gallons of diesel fuel, then driven 71 miles to confirm that all SCR-related warnings and inducements issues were cleared before moving on to the next test cycle (odometer = 5,863 miles).

From Figure DDC-7, shown on the following page, represents the emissions sampled using the PEMS during the DEF Contamination Cycle. The figure also includes the sequence of the SCR inducements occurring as the vehicle was operated along the test route. The figure shows the activation of the SCR-related first driver warning, when the engine was derated or vehicle speed limited, as well as the SCR activated final inducement.

As expected, the NOx emissions measured during the DEF Contamination Cycle were much greater than the baseline emissions. The SCR system successfully triggered the initial driver warning within one hour after the contamination was detected; consistent with the suggested SCR 2011+ MY Guidelines. Staff would have expected that the vehicle would be seeking a safe harbor event (refuel, restart, idle) within four hours (or approximately 200 miles traveled) from the initial detection. However, it appears the search for final inducement had not been initiated by the time staff refueled with diesel fuel despite having traveled 151 miles since the first driver warning. The next day, the truck was driven 191 miles before again reaching a safe harbor event, in this case an engine restart, before activating the 5 mph final inducement. Staff understands that manufacturers may institute transition criteria while the vehicle is searching for a safe harbor event and then initiate the final inducement. Based on the driving conditions of this test cycle, staff believes the SCR system was consistent with specifics of the 2011+ MY Guidelines, but inconsistent with its intentions to limit high NOx operation for extended periods of time.

Figure DDC-7: Daily DEF Contamination Cycle Emissions Data

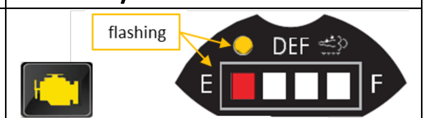
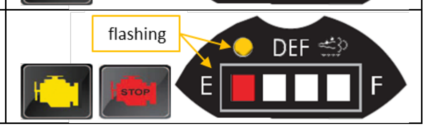


Note: The PEMS values in this figure were measured values taken during this test program while the vehicle was operated under on-road conditions. The NTE NOx is the on-road measurement of NOx emissions that requires specific engine operation and other criterion for attaining this measurement. The NOx certification emission standard of 0.20 g/bhp-hr requires emission measurements under laboratory conditions. This standard, in addition to the NTE standard of 0.30 g/bhp-hr and the NTE + 0.15 g/bhp-hr measurement allowance, was provided for general reference only. The PEMS unit used for this operation meets the U.S. EPA requirements per 40 CFR 1065.

d) Vehicle 3 - DEF System Tampering Cycle

Figure DDC-8, reproduced with DDC's permission, from the 2012 Freightliner Cascadia Driver's Manual shows the different steps of gauge/lamp combinations and associated SCR system responses when operating the vehicle with a non-functioning SCR system.

Figure DDC-8: DDC's SCR Sequence of Events for SCR System Tampering

Referenced from: **2012 FREIGHTLINER CASCADIA DRIVER'S MANUAL** www.freightliner.com		
	SCR SYSTEM RESPONCE	**GAUGE / LAMP COMBINATION**
Step 1	SCR SYSTEM is **DISABLED**, or **TAMPERED.** Vehicle power limited. Vehicle speed limited to 55 mph.	
Step 2	SCR SYSTEM is **DISABLED**, or **TAMPERED.** Vehicle power limited. Vehicle speed limited to 5 mph.	

As shown in Figure DDC-8, Step 1, when the SCR system is detected with a tampered SCR system, the DEF Level Lightbar lamp will illuminate and flash one red bar along with a flashing amber Low DEF Level Warning Lamp and the MIL should illuminate. Additionally, the engine power should be derated and vehicle speed limited to 55 mph. Per Step 2, if the vehicle is continually driven with a tampered SCR system, the DEF gauge lights should continue to flash; the MIL should continue to illuminate, the red Stop Engine Lamp should illuminate; and the vehicle speed should be limited to 5 mph (assuming the vehicle is brought to a safe harbor event).

Per DDC owner's manual, once detected by the SCR system, the vehicle must be taken to an authorized service center to check the SCR system for damage and to deactivate the warning lights and engine limits.

Day 1

Test Vehicle 3 was prepared for the DEF System Tampering Cycle by disconnecting the DEF doser injector (odometer = 5,863 miles). As staff started the engine, the SCR system immediately triggered the first driver warnings by illuminating the MIL and the Check Engine Lamp along with the message "Code EEC 61" displayed on the LCD on the instrument panel. The DEF Level Gauge showed one green lamp on the DEF Level Lightbar indicating that the DEF level was between 10 to 25 percent tank capacity and the diesel fuel gauge indicated 100 percent tank capacity. After driving 31 miles, with the first set of warning lights still illuminated, the Low DEF Level Warning Lamp illuminated and started flashing (odometer = 5,894 miles) (see Figure DDC-8, Step 1). Additionally, although not noted in DDC's owner manual as specified in Figure DDC-8, the Check Engine Lamp also illuminated at this point indicating an undesirable engine condition.

Continuing to drive, the driver commented about the engine power derate being noticeable during accelerations, however the driver did not verify if the vehicle speed was limited to 55 mph. After driving for approximately five hours, staff returned to the ARB's El Monte facility and executed a key-off/key-on event (odometer = 6,054 miles). After the engine started there was no change to the active SCR warnings. After restarting the vehicle, staff departed the El Monte facility, drove a 62 mile round trip route, ending back at El Monte and executed another key-off/key-on event with no changes to the SCR active visual warnings or engine inducements (odometer = 6,116 miles).

Day 2

After starting the engine, staff noticed the same active driver warnings from the previous day. As driving began, staff observed the vehicle was still experiencing an engine derate condition. Staff executed key-off/key-on events at different points along the test route (odometer = 6,178 miles and 6,244 miles), but neither attempt activated any additional SCR warnings or inducements. Staff returned to ARB's El Monte facility after driving 191 miles and again executed a key-off/key-on event (odometer = 6,307 miles). Upon engine restart the SCR system activated the Stop Engine Lamp, along with the MIL, and the Check Engine Lamp (see Figure DDC-8, Step 2). When attempting to drive the vehicle, the vehicle speed was limited to 5 mph (odometer = 6,307 miles). In total, the vehicle traveled 444 miles from the first SCR driver warning for this test cycle. Staff shut down the vehicle and reconnected the DEF injector. Upon restart, all SCR warning lights extinguished except the Check Engine Lamp. Staff shut down the vehicle and ended testing for the day.

Day 3

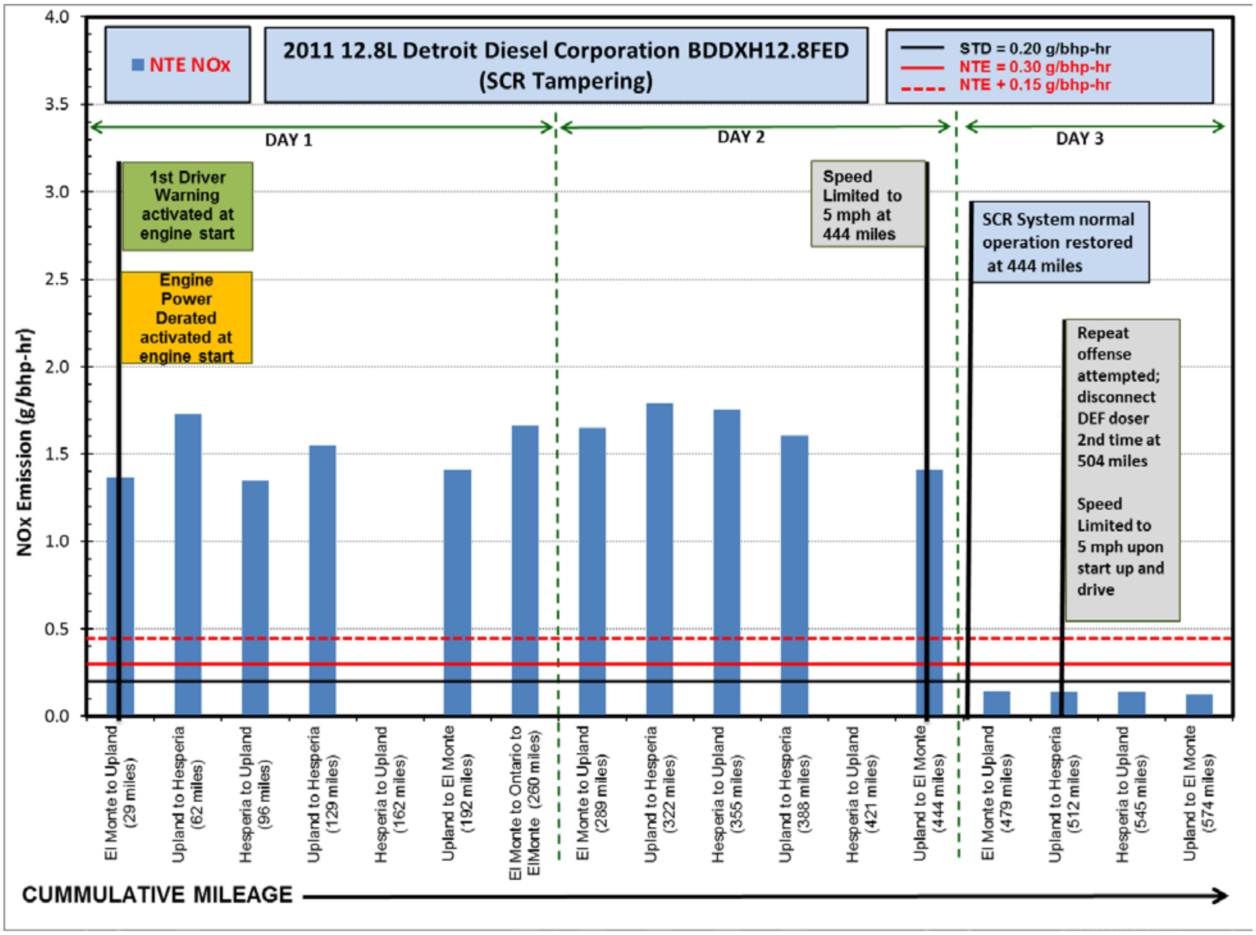
The next day (odometer = 6,307 miles), staff drove the designated test route to verify all SCR warnings and inducements would be cleared. The driver quickly discovered the return of full engine power, and after accumulating 62 miles since reconnecting the DEF doser, the Check Engine Lamp extinguished after a key-off/key-on event (odometer = 6,369 miles).

At this point, staff decided to again disconnect the DEF doser injector (a repeat offense) to see how long it would take the vehicle to re-enter the 5 mph limited speed condition. With the engine off and after adding 102.8 gallons of diesel fuel, staff started the engine and the SCR system immediately activated the Stop Engine Lamp, the flashing Low DEF Level Warning Lamp, the MIL, the Check Engine Lamp, and a newly added audible alert. When attempting to drive the vehicle, staff found the vehicle speed was limited to 5 mph (odometer = 6,369 miles). Staff turned off the vehicle and reconnected the DEF doser injector. Staff restarted the engine and all SCR warning lights, except the Check Engine Lamp were extinguished. Staff resumed driving along the designated test route and drove back to the ARB's El Monte facility experiencing no engine inducement issues and the Check Engine Lamp extinguished en route back to ARB's El Monte facility at (odometer = 6,432 miles) and this completed the DEF Tampering Cycle.

The SCR system did trigger an initial driver warning within one hour upon detecting a problem with the SCR system, consistent with the suggested 2011+ MY Guidelines. However, staff would have expected the vehicle to be searching for a safe harbor condition within approximately 200 miles or four hours from the first warning. Staff attempted key-on/key-off events on two separate occasions after accumulating more than 200 miles, yet the final inducement was not activated until a total of 444 miles had been driven after initial detection. Based on the outcome of this part of the tampering sequence, it was inconsistent with the July 2010 SCR Workshop's suggested 2011+ MY Guidelines. Staff believes that under this cycle, the vehicle did not reach the final inducement within the anticipated time frame after the initial detection. However, the repeat tampering event immediately triggered all warnings and the final inducement well ahead of the 2011+ MY Guidelines.

Figure DDC-9 represents the emissions measured during the DEF Tampering Cycle. The figure also includes the sequence of the SCR inducements that occurred as the vehicle was operated along the test route. The figure shows the activation of the SCR-related first driver warning, when the engine was derated or vehicle speed limited, as well as the SCR activated final inducement. It should be noted that the fourth day emissions are prominently low because the DEF injector is connected and only momentarily disconnected for a short period when verifying the repeat tampering event. Also, the NTE NOx data is not shown in some of the traveled routes because some ambient conditions were outside of the required NTE measurement zones. It is clear that a tampering event can lead to NOx emissions three times higher than typical compliant operations.

Figure DDC-9: Daily DEF System Tampering Cycle Emissions Data



Note: The PEMS values in this figure were measured values taken during this test program while the vehicle was operated under on-road conditions. The NTE NOx is the on-road measurement of NOx emissions that requires specific engine operation and other criterion for attaining this measurement. The NOx certification emission standard of 0.20 g/bhp-hr requires emission measurements under laboratory conditions. This standard, in addition to the NTE standard of 0.30 g/bhp-hr and the NTE + 0.15 g/bhp-hr measurement allowance, was provided for general reference only. The PEMS unit used for this operation meets the U.S. EPA requirements per 40 CFR 1065.

e) Vehicle 3 - DEF Dilution Cycle

As an experiment to determine at what percentage of diluted DEF would likely result in increased NOx emissions, staff decided to check three different blended mixtures of DEF, with 25 percent water (resulting urea concentration in mixture of ~24.4 percent), 50 percent water (resulting urea concentration in mixture of ~16.2 percent), and 75 percent water (resulting urea concentration in mixture of ~8.1% percent). Staff operated the vehicle using each of the different DEF diluted concentrations to determine the DEF threshold for the SCR system to trigger driver warnings and SCR inducements while measuring the emissions with each dilution cycle. This cycle was not intended to drive these vehicles to trigger the 5 mph final inducement event, only to determine if different diluted blends of DEF would cause the SCR inducement system to activate.

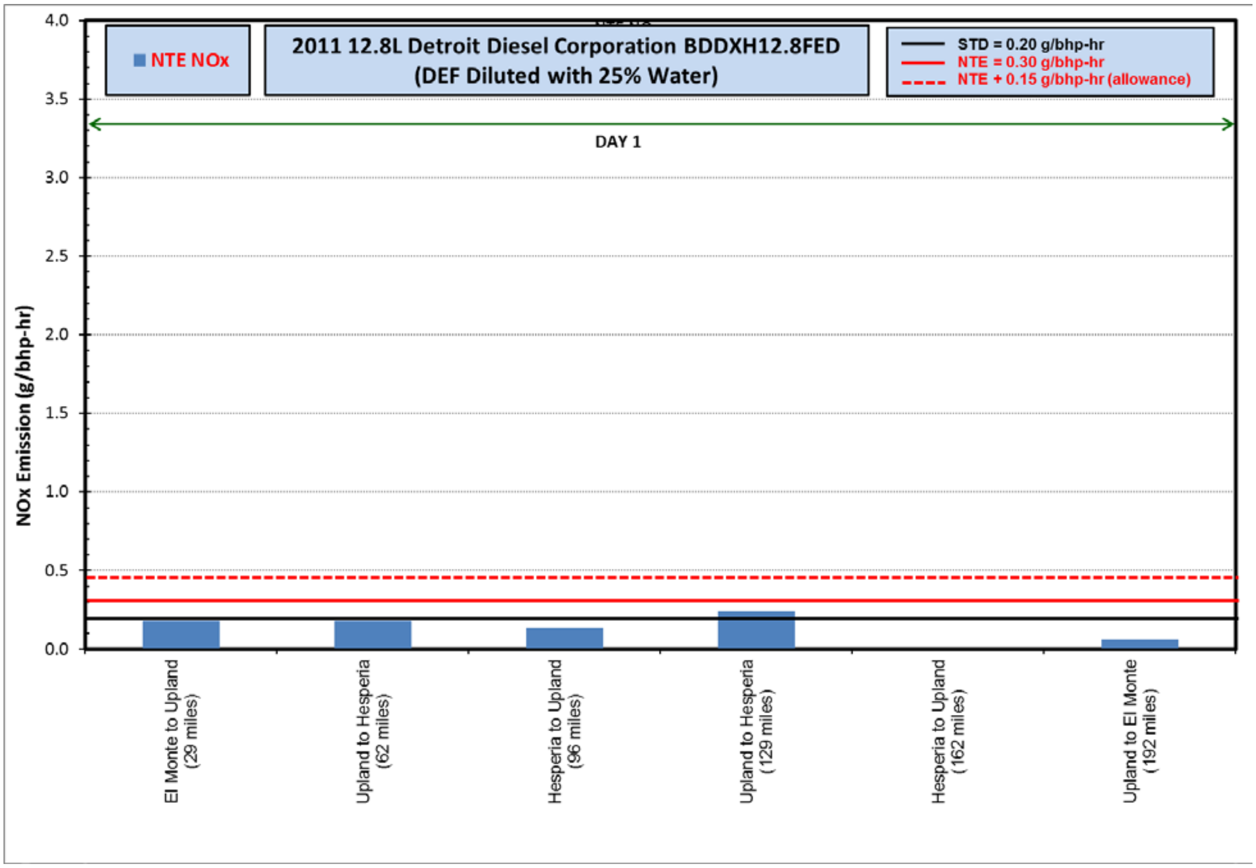
(1) DEF Diluted with 25 Percent Water

Day 1

To begin the 25 percent DEF Dilution segment, staff first drained the DEF tank and then refilled it (odometer = 6,432 miles) with a five gallon mixture of DEF/water (concentration verified with a DEF Refractometer). After starting the engine, staff observed the DEF gauge showed two green lamps on the DEF Level Lightbar and no other SCR-related driver warnings or vehicle inducements; also, the diesel fuel gauge showed the tank level at 100 percent capacity. After driving 145 miles (odometer = 6,577 miles) on the 25 percent DEF Dilution Cycle, staff observed the DEF gauge now showed only one green lamp. Following the test route, staff traveled 191 miles with no observations of any SCR-related driver warnings or vehicle inducements (odometer = 6,623 miles). This concluded the 25 percent DEF Dilution Cycle.

Figure DDC-10 represents the emissions measured for the 25 percent DEF Dilution Cycle. Note: the NTE NOx data is not shown in some of the traveled routes because some ambient conditions were outside of the required NTE measurement zones. As can be seen, despite the DEF being diluted with 25 percent water, the vehicle maintained good NOx control throughout the test route.

Figure DDC-10: Daily DEF Dilution Cycle (25 Percent Water) Emissions Data



Note: The PEMS values in this figure were measured values taken during this test program while the vehicle was operated under on-road conditions. The NTE NOx is the on-road measurement of NOx emissions that requires specific engine operation and other criterion for attaining this measurement. The NOx certification emission standard of 0.20 g/bhp-hr requires emission measurements under laboratory conditions. This standard, in addition to the NTE standard of 0.30 g/bhp-hr and the NTE + 0.15 g/bhp-hr measurement allowance, was provided for general reference only. The PEMS unit used for this operation meets the U.S. EPA requirements per 40 CFR 1065.

(2) DEF Diluted with 50 Percent Water

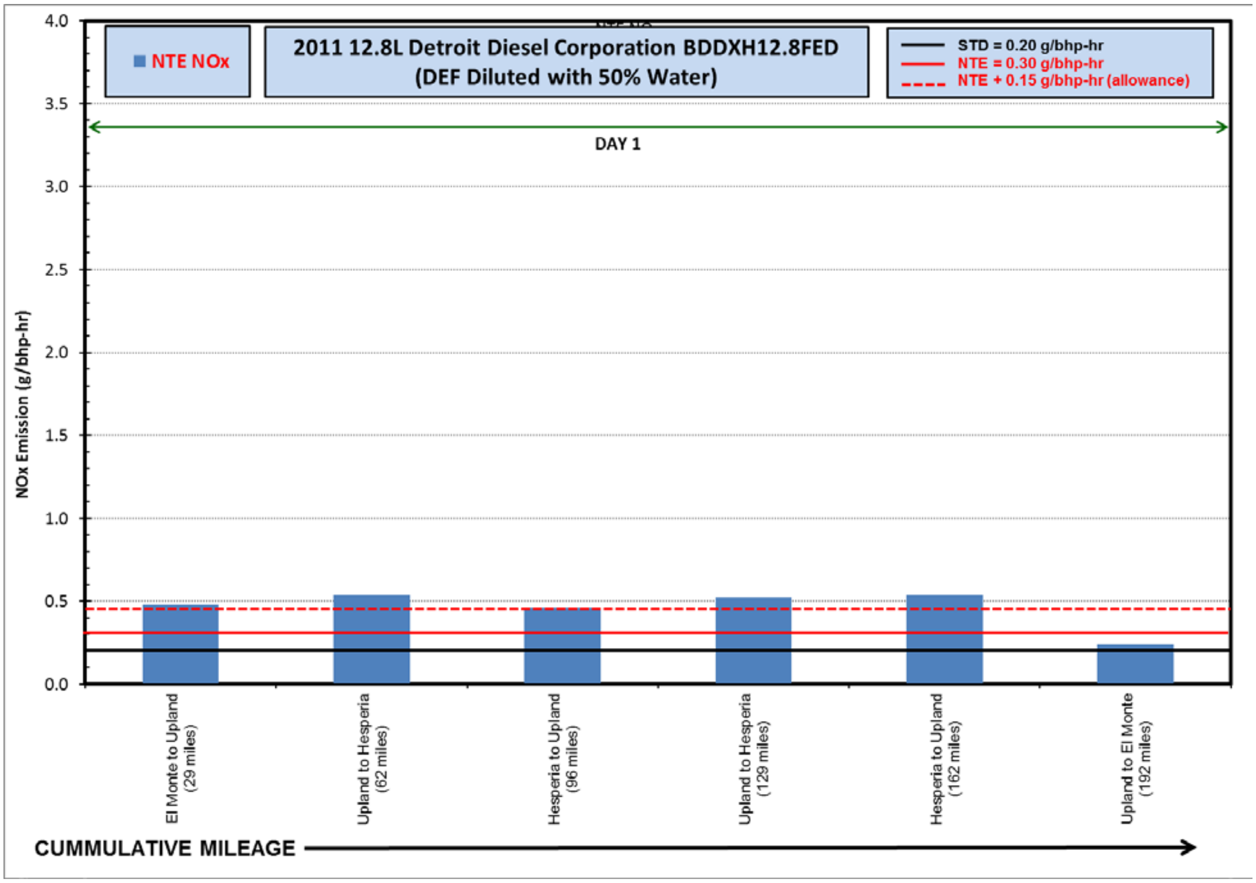
Day 1

To begin the 50 percent DEF Dilution segment, staff first drained the DEF tank and then refilled the DEF tank (odometer = 6,623 miles) with a five gallon mixture of DEF/water (concentration verified with a DEF Refractometer). After starting the engine staff observed the DEF gauge showed one green lamp on the DEF Level Lightbar and no other SCR-related driver warnings or vehicle inducements. At an odometer reading of 6,751 miles, staff stopped and added 70.7 gallons of diesel fuel that filled the tank to

100 percent capacity. After traveling a total of 191 miles on the test route with the 50 percent diluted DEF, staff returned to ARB's El Monte facility without any SCR-related driver warnings or vehicle inducements triggered throughout the route (odometer = 6,814 miles). This concluded the 50 percent DEF Dilution Cycle.

Figure DDC-11, shown below, represents the emissions measured during the 50 percent DEF Dilution Cycle. Despite operating on 50 percent diluted DEF, the vehicle maintained reasonable control of NOx emissions, rarely exceeding the NTE measurement allowance limit of 0.45 g/bhp-hr NOx. This indicates manufacturers are either using other control strategies to control NOx or increasing dosing to compensate for the poor quality DEF. It is also speculated that the NOx either ran below compliance levels or right at compliance levels based on NOx sensor measurements, not triggering a detection event.

Figure DDC-11: Daily DEF Dilution Cycle (50 Percent Water) Emissions Data



Note: The PEMS values in this figure were measured values taken during this test program while the vehicle was operated under on-road conditions. The NTE NOx is the on-road measurement of NOx emissions that requires specific engine operation and other criterion for attaining this measurement. The NOx certification emission standard of 0.20 g/bhp-hr requires emission measurements under laboratory conditions. This standard, in addition to the NTE standard of 0.30 g/bhp-hr and the NTE + 0.15 g/bhp-hr measurement allowance, was provided for general reference only. The PEMS unit used for this operation meets the U.S. EPA requirements per 40 CFR 1065.

(3) DEF Diluted with 75 Percent Water

Day 1

To begin the 75 percent DEF Dilution segment, staff first drained the DEF tank and then refilled it (odometer = 6,814 miles) with a five gallon mixture of DEF/water (concentration verified with a DEF Refractometer). After starting the engine, staff observed that the DEF gauge showed one green bar illuminated on the DEF Level Lightbar and no other SCR-related driver warnings or vehicle inducements were noted. Staff operated the vehicle for 38 miles (odometer = 6,852 miles) when the driver noticed the loss of engine power and a vehicle speed limit of 55 mph. Additionally, the first driver visual warnings occurred with an illuminated MIL and Check Engine Lamp and a flashing Low DEF Level Warning Lamp. Staff operated the vehicle for 152 miles with no change to the already active driver warnings and vehicle inducements when turning off the engine at ARB's El Monte facility (odometer = 7,004 miles). This concluded the 75 percent Diluted DEF Cycle.

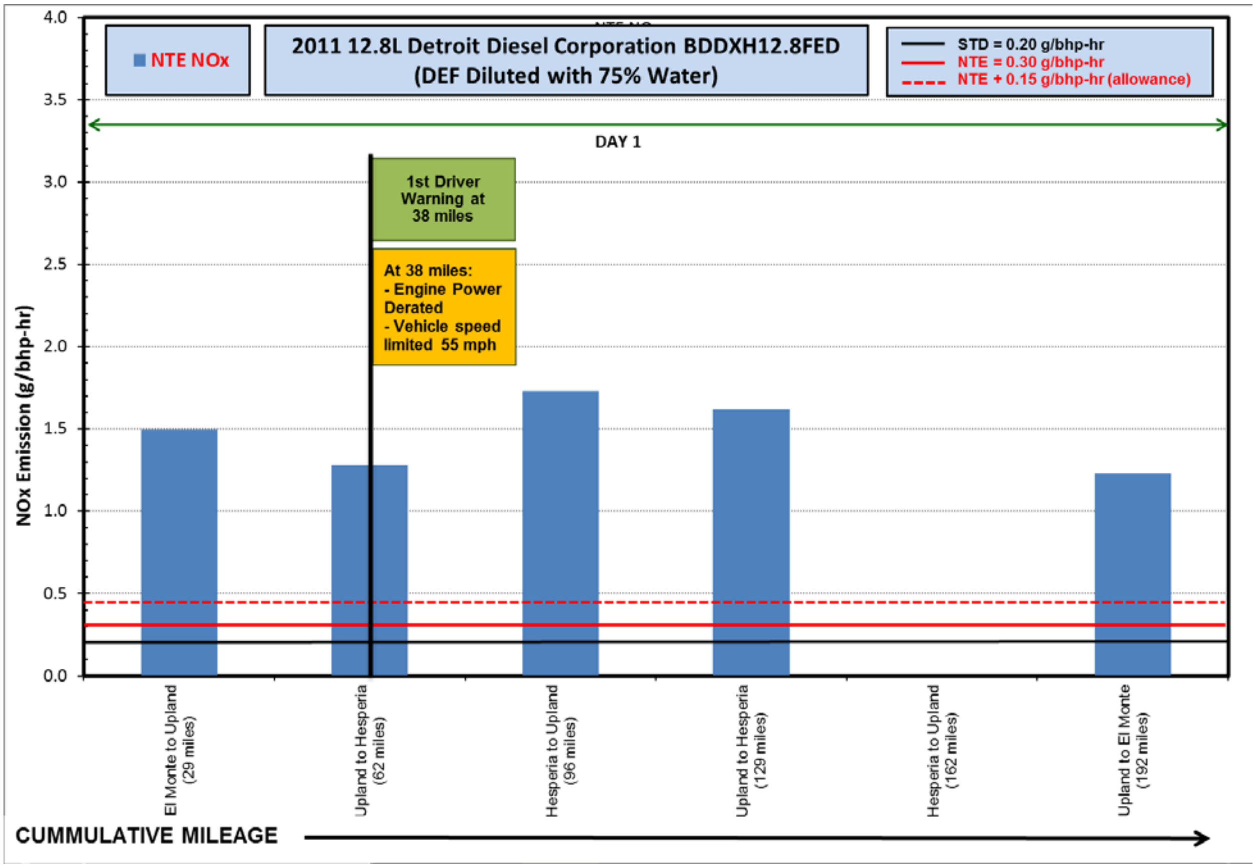
Day 2

Staff drained the DEF tank and then refilled it with five gallons of quality DEF. Staff borrowed DDC pc-based proprietary engine software and deactivated all SCR-related driver warnings and vehicle inducements on this vehicle. The vehicle was refueled with 53.3 gallons of diesel fuel and returned to the Penske Truck Rental facility.

Figure DDC-12, represents the emissions measured during the 75 percent DEF Dilution Cycle. The figure also includes the sequence of the SCR inducements occurring as the vehicle was operated along the test route. The figure shows the activation of the SCR-related first driver warnings and the engine power derate or vehicle speed limit. Note: the NTE NOx data is not shown in some of the traveled routes because some ambient conditions were outside of the required NTE measurement zones.

The DEF Dilution Cycles were used to determine if and when the SCR system would detect poor quality DEF and how various levels of diluted DEF would affect NOx emissions. After using the three different diluted DEF mixtures, ARB staff found that the SCR system activated no warnings or inducements when DEF was diluted with 25 percent water and 50 percent water; however the SCR system was able to activate a driver warning when using DEF diluted with 75 percent water. Staff believes the SCR did not activate when DEF was diluted with 25 percent water because NOx emissions were in compliance. Although the 50 percent DEF/water blend showed an increase, the amount of the increase was marginal and may not have been enough to detect NOx noncompliance. In fact, ARB staff monitoring the PEMS data in the truck stated that the vehicle's emissions patterns were constantly searching for proper NOx control (i.e., attempting to reduce NOx with the amount of DEF available with the emissions constantly increasing and reducing) while the vehicle was being driven. When DEF was diluted with 75 percent water, the NOx emissions significantly increased and the SCR system identified reductant contamination, prompting the SCR driver warnings and also initiating an engine derate and a 55 mph limited speed condition within 38 miles or one hour of driving. Based on the driving conditions of this test cycle, staff believes the SCR system was consistent with the suggested 2011+ MY Guidelines.

Figure DDC-12 - Daily DEF Dilution Cycle (75 Percent Water) Emissions Data



Note: The PEMS values in this figure were measured values taken during this test program while the vehicle was operated under on-road conditions. The NTE NOx is the on-road measurement of NOx emissions that requires specific engine operation and other criterion for attaining this measurement. The NOx certification emission standard of 0.20 g/bhp-hr requires emission measurements under laboratory conditions. This standard, in addition to the NTE standard of 0.30 g/bhp-hr and the NTE + 0.15 g/bhp-hr measurement allowance, was provided for general reference only. The PEMS unit used for this operation meets the U.S. EPA requirements per 40 CFR 1065.

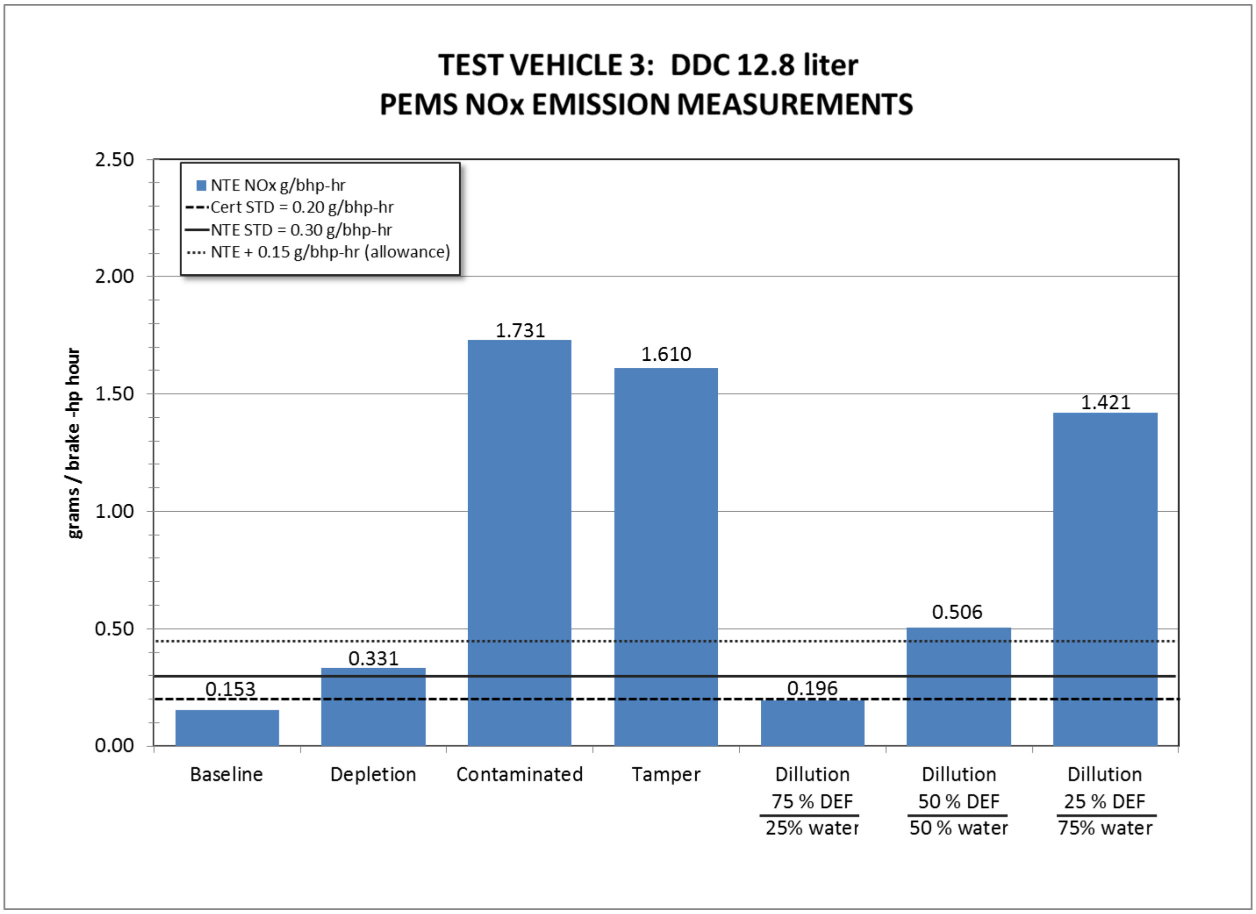
f) Vehicle 3 - Emissions Measurements Summary

Figure DDC-13 shows the average NOx emissions measured for the Baseline Cycle, the DEF Contamination Cycle, the DEF System Tampering Cycle and the DEF Dilution Cycle. It should be noted that staff utilized NTE zone emission measurements to compare the emission results for each test cycle. The certification standard is also shown on the chart but the test requirements to conduct certification type tests require an engine dynamometer in laboratory conditions. This standard was only included on the chart for informational purposes.

The Baseline Cycle NOx emissions of 0.15 g/bhp-hr easily met the NTE NOx standards of 0.3 g/bhp-hr without consideration of the measurement allowance. The DEF Depletion Cycle PEMS measurements were taken over a two day period from the time the vehicle began the DEF Depletion Cycle until the vehicle went into a 5 mph limited speed event. As DEF was depleting to empty, the overall NTE NOx emissions were 0.331 g/bhp-hr, slightly above the NTE allowance (see Figure DDC-13).

The DEF Contamination and DEF System Tampering Cycles NOx emissions were ten times higher than the baseline NTE results. The 25 percent DEF dilution results were below and the 50 percent diluted DEF results were marginally over the NTE allowance indicating the engine management system's ability to overcompensate for poor quality DEF to some degree. However, as the 75 percent Diluted DEF results show, somewhere between 50 percent and 75 percent DEF dilution, the vehicle loses its ability to compensate for poor quality DEF and loses NOx control by more than three times the NTE NOx allowance limit.

Figure DDC-13: Vehicle 3 - NOx Emission Data Summary



Note: The PEMS values in this figure are the average NOx NTE emissions taken during this test program while the vehicle was operated under on-road conditions. The NOx certification emission standard of 0.20 g/bhp-hr requires emission measurements under laboratory conditions. This standard, in addition to the NTE standard of 0.30 g/bhp-hr and the NTE + 0.15 g/bhp-hr measurement allowance, was provided for general reference. The PEMS unit used for this operation meets the U.S. EPA requirements per 40 CFR 1065.

g) Vehicle 3 - Inducement Test Summary

ARB staff operated Test Vehicle 3 under various test cycles comparing the vehicle's SCR-related driver warnings and inducements to those supplied in the driver's manual and their consistency with the 2011+ MY Guidelines. ARB staff checked the driver warnings and inducements under the following cycles: DEF Depletion, DEF Contamination, DEF System Tampering, and DEF Dilution.

Comparing the SCR warnings and inducement strategies with the vehicle owner's manual showed much consistency with some slight differences with the DEF

Contamination and DEF System Tampering Cycles. Under these cycles the DEF Level Light Bar did not illuminate nor flash as predicated in the vehicle owner's manual but instead the Check Engine Lamp illuminated and also the message "Code EEC 61" displayed on the LCD located on the instrument panel which added a significant visual warning to the driver that a problem existed. In addition, the vehicle owner's manual indicated that if the vehicle encountered a 5 mph inducement event for contamination or tampering, the 5 mph event could only be cleared by an authorized dealer. In the case of contamination this was correct but staff discovered that by simply reconnecting the doser injector (i.e., under the tampered condition) the vehicle self-healed itself back to normal power. It should be noted when trying to re-tamper the SCR system, the vehicle immediately returned to a 5 mph limited speed condition.

DDC's SCR system showed consistency with the 2011+ MY Guidelines with the exception of the tampering event where 444 miles were traveled after the first driver warning occurred. Staff believes that the vehicle should have been searching for a safe harbor event within 200 miles (approximately four hours) after the first SCR driver's warning occurred. In fact, staff performed two safe harbor stops after achieving the first SCR driver's warning but the vehicle did not experience a 5 mph limited speed condition until a third safe harbor event was achieved. Staff spoke with DDC who stated that the reason the vehicle did not reach a 5 mph inducement is because the vehicle had not achieved its transition criteria (i.e., some manufacturers use transition criteria, such as a refueling event, to prompt the 5 mph inducement) and therefore it took a little longer for the vehicle to search for a safe harbor event and institute the 5 mph severe inducement. Based on this discussion, DDC projects that ARB's driving cycle may have created a scenario which caused the DDC's engine management system to take longer in triggering the vehicle to search for a safe harbor and institute the final 5 mph inducement strategy.

The ARB driver stated that the SCR warning light strategy was very effective in getting his attention to show that the vehicle was experiencing a problem. Additionally, the coinciding engine derates and limited speed events were intolerable and would simply not be endured by a truck driver on a day-to-day basis. Finally, the ARB driver indicated that the 5 mph severe inducement is a significant deterrent that would keep truck operators from continually running their vehicles out of DEF or tampering with their SCR systems.

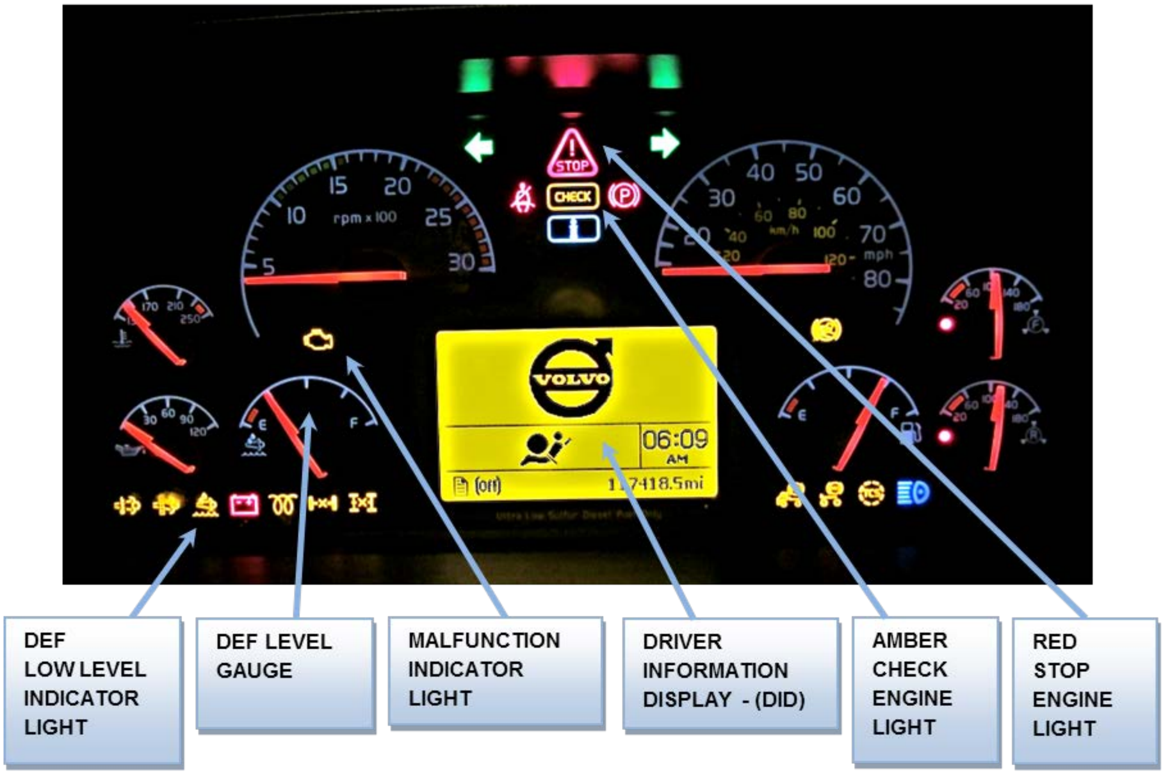
B. Test Vehicle 4

Chassis: 2011 MY Volvo Sleeper Cab
Axles: 3
Engine: Volvo Corporation
Engine MY: 2010 MY
Engine Family: AVPTH12.8SO1
Displacement: 12.8 Liter
Horsepower: 435 @ 1,700 rpm
Trailer: 48-foot flatbed
NOx Certification Standard: 0.20 g/bhp-hr

Test Vehicle 4 was a 2011 MY Volvo Sleeper Cab equipped with a 2010 MY Volvo Corporation D13H435 engine rented from Penske Truck Rental (Vehicle Identification Number - 4V4NC9EH4BN294402 and odometer = 114,777 miles). The vehicle was outfitted with a 48-foot flatbed trailer carrying five 20-foot “K-rail” concrete barriers that weighed in total about 40,000 pounds. In order to determine the impact on NOx emissions, this truck was outfitted with a Sensors, Inc. Semtech-DS PEMS unit allowing for real-time emissions readings. ARB followed the prescribed test plan for evaluating this vehicle (see Appendix D). In January 2011, Volvo recalibrated the ECU on this test vehicle with the latest SCR strategy software upgrading strategies to their SCR system. Volvo stated to staff that the software reflash was provided as a field action in response to the July 2010 SCR Workshop. Although the software upgrade addresses many of the suggested guidance, it is not fully consistent with the guidance. On February 10, 2012, Volvo has reported a nationwide capture rate of 52 percent for the recalibration campaign on all 2010 MY engines.

This vehicle utilizes the SCR system and therefore uses DEF as part of its after treatment system for controlling NOx emissions. When needed, the SCR system is expected to alert the driver through a sequence of warning lights in conjunction with vehicle inducements designed to draw the driver’s attention to the following conditions: low levels of DEF, contaminated DEF, or if the SCR system is disabled. Before operating the vehicle, the driver reviewed the vehicle owner’s manual to become familiar with the dashboard gauges, warning lights, vehicle controls, and SCR warning system. Figure Volvo-1 displays the various driver warning lights used when the SCR system requires attention.

Figure Volvo-1: Volvo's SCR System Driver Warning Lights/Information



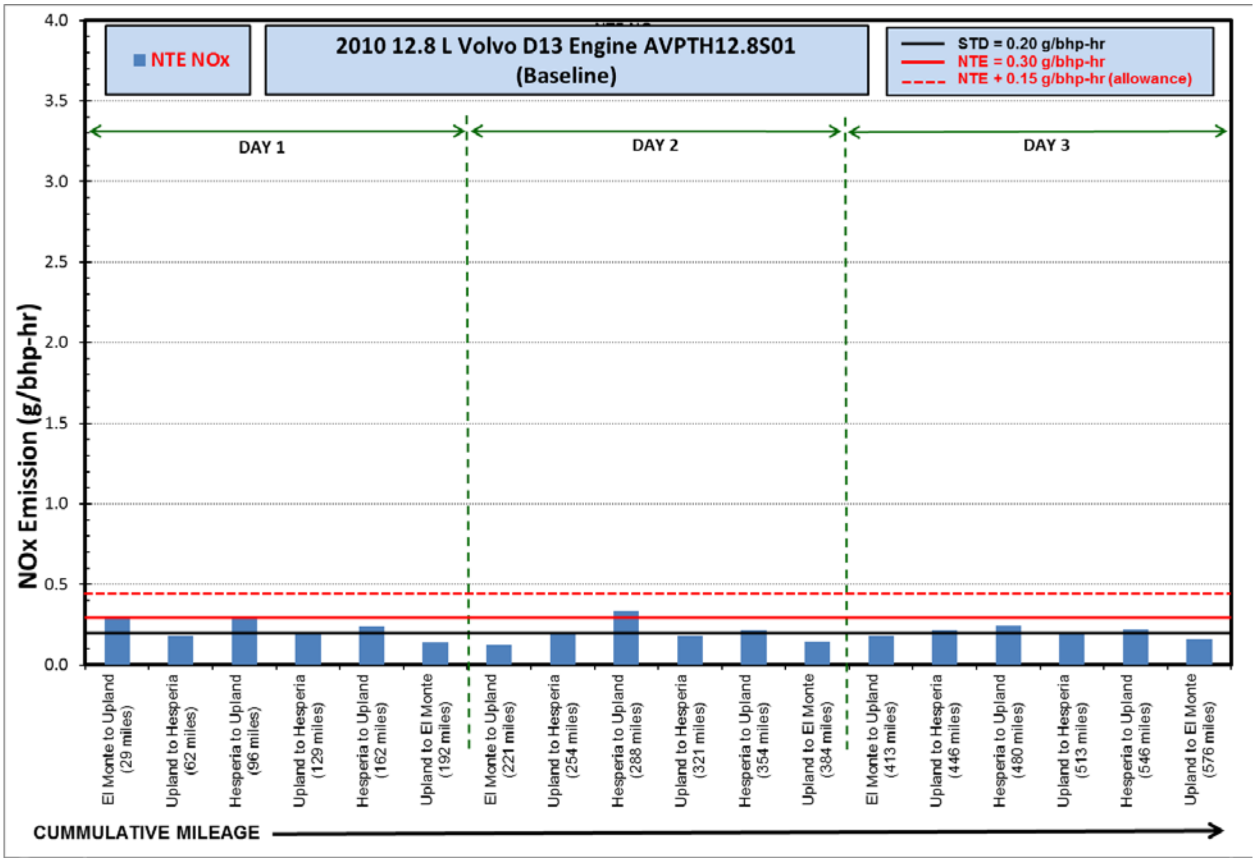
a) Vehicle 4 - Baseline Testing

Staff operated the "as received" 2011 MY Volvo over the designated test route while sampling the vehicle's exhaust to establish a baseline profile. A PEMS unit was attached to the weight laden (five concrete K-rails) 48-foot flatbed trailer (see Figure Volvo-2).

Figure Volvo-2: Portable Emissions Monitoring System and K-Rails

The baseline portion of this test program represents the average typical emissions the vehicle generates under normal vehicle operation. Staff began this test cycle with 114,806 miles on the odometer, adding 61 gallons of fuel at 115,128 miles, and over the course of three days accumulated 577 miles (odometer = 115,383 miles). The daily baseline emissions are represented in Figure Volvo-3 below.

Figure Volvo-3: Daily Baseline Emissions Data



Note: The PEMS values in this figure were measured values taken during this test program while the vehicle was operated under on-road conditions. The NTE NOx is the on-road measurement of NOx emissions that requires specific engine operation and other criterion for attaining this measurement. The NOx certification emission standard of 0.20 g/bhp-hr requires emission measurements under laboratory conditions. This standard, in addition to the NTE standard of 0.30 g/bhp-hr and the NTE + 0.15 g/bhp-hr measurement allowance, was provided for general reference only. The PEMS unit used for this operation meets the U.S. EPA requirements per 40 CFR 1065.

This engine was certified to a 0.30 g/bhp-hr NTE standard with a measurement allowance of 0.15 g/bhp-hr. As you can see the emissions for NTE NOx were within the NTE allowance limit in all cases over multiple days. This vehicle exhibited the expected NOx control based on its certification levels.

b) Vehicle 4 - DEF Depletion Cycle

The chart below, Figure Volvo-4, contains information from the Volvo Owner's Manual that came with the vehicle and was reproduced with Volvo's permission. It displays the stages of escalating driver warnings and alerts expected for the DEF Depletion Cycle.

Figure Volvo-4: Volvo's SCR Driver Warning Sequence for DEF Depletion

Steps	Triggers	Aftertreatment DEF Tank Low Level Indicator	Driver Information Display Screen
Step 0	100% to 12 % Aftertreatment DEF Tank Level Gauge	None	None
Step 1	<=12 % Aftertreatment DEF Tank Level Gauge		**DEF Low**
Step 2	0% Aftertreatment DEF Tank Level Gauge (~1% DEF Remaining)		**DEF Tank Near Empty Engine in Derate Add DEF**
Step 3a	0 % Aftertreatment DEF Tank Level Gauge, Insufficient DEF Pump Pressure, Diesel Fuel Refueling >15%		**DEF Tank Empty Refill DEF to avoid 5 Mph Limit Engine in Derate**
Step 3b	DEF tank empty and refueling event with parking brake applied **Note:** To avoid the Back Stop feature, the DEF tank must be filled to more than 18% of capacity.		**Veh Speed Limited to 5 Mph Add DEF**

The engine was certified to 2010 standards and SCR requirements so we expected it to be consistent with the 2010 MY Guidance. Step 1 is expected to occur when the DEF level falls below 12 percent on the vehicle's gauge initiating a DEF tank low level indicator and a Driver Information Display (DID) message "DEF Low". If no DEF is added and the DEF Level Gauge reads 0%, Step 2 occurs initiating an audible chime with a flashing DEF tank low level indicator, and the DID message changes to "DEF Tank Near Empty, Engine in Derate, Add DEF". Step 2 messages are expected to be accompanied by an engine derate per Figure Volvo-4. Step 3a is interpreted to mean that the DEF tank falls to true empty, causing loss of DEF pump pressure, then the DID changes to “DEF Tank Empty Refill DEF to Avoid 5 Mph Limit Engine in Derate”. When Step 3a is reached, it is presumed the search for safe harbor would be initiated and triggered by a refueling event of greater than 15 percent fuel capacity. Step 3b indicates that the vehicle should experience a 5 mph severe inducement event when the vehicle is refueled with the parking brake applied. However, as mentioned above, the engine was upgraded with software that was supposed to make the vehicle more consistent with the SCR warnings and inducements in the 2011+ MY Guidelines.

Day 1

In preparation for the DEF Depletion Cycle, staff adjusted the truck’s DEF level to approximately 15 percent on the DEF Level Gauge (odometer = 115,383 miles). After driving 140 miles, the first driver warning occurred (odometer = 115,523 miles) with the illumination of the DEF tank low level indicator light, the sounding of an audible alert, and the DID displayed the message “DEF Low” (see Figure Volvo-4, Step 1). The driver continued along the designated route and after driving 22 additional miles, the warnings extinguished (odometer=115,545 miles). Staff operated the vehicle for another 31 miles in route to ARB’s El Monte facility and observed the truck’s DEF level had dropped to 12 percent (odometer = 115,516 miles).

Day 2

Staff continued to drive the test route and after 50 miles, the vehicle began to sound an audible alert every few minutes (odometer = 115,626 miles). According to the owner’s manual, the DEF tank low level indicator light should have flashed; however, based on the driver’s observations, the DEF tank low level indicator light only illuminated but did not flash. Staff noted that the DEF Level Gauge indicated that the DEF tank was near empty (i.e., the DEF gauge needle was reading slightly above bottom of the ‘E’ mark on the DEF level gauge - see Figure Volvo-4, Step 2) and drove for two additional hours noticing that the audible alerts continued to sound periodically, approximately 20 times during this period. The DEF gauge level was at the bottom of the red mark on the DEF gauge level, which led staff to assume that the DEF tank was empty. The driver then stopped to add 95 gallons of diesel fuel (odometer = 115,705 miles). The audible alerts continued as staff drove along the test route then returned to ARB's El Monte facility (odometer=115,768 miles).

Day 3

The following week, staff started the vehicle (odometer = 115,767 miles), the diesel fuel tank was over ¾ full. Staff noted that the DEF tank low level indicator light was illuminated and the DID displayed the message "Low DEF". Next, two miles later, audible alerts occurred with the message extinguishing. After driving 70 additional miles, the driver noticed the audible alerts reoccurred (odometer = 115,839 miles). After accumulating 194 miles, since starting the vehicle, staff returned to ARB's El Monte facility with no changes to the SCR driver warning alert system (odometer = 115,962 miles) and executed a key-off/key-on event but the vehicle did not experience a 5 mph limited speed inducement. The driver observed that the DID displayed the message "DEF Tank Empty, Refill DEF to Avoid 5 Mph Limit Engine in Derate" warning (see Figure Volvo-4, Step 3a). The DEF light illuminated and flashed after stopping the truck but the vehicle did not experience a 5 mph limited speed inducement. After this trial, with no additional miles driven, staff shut down the vehicle for the weekend.

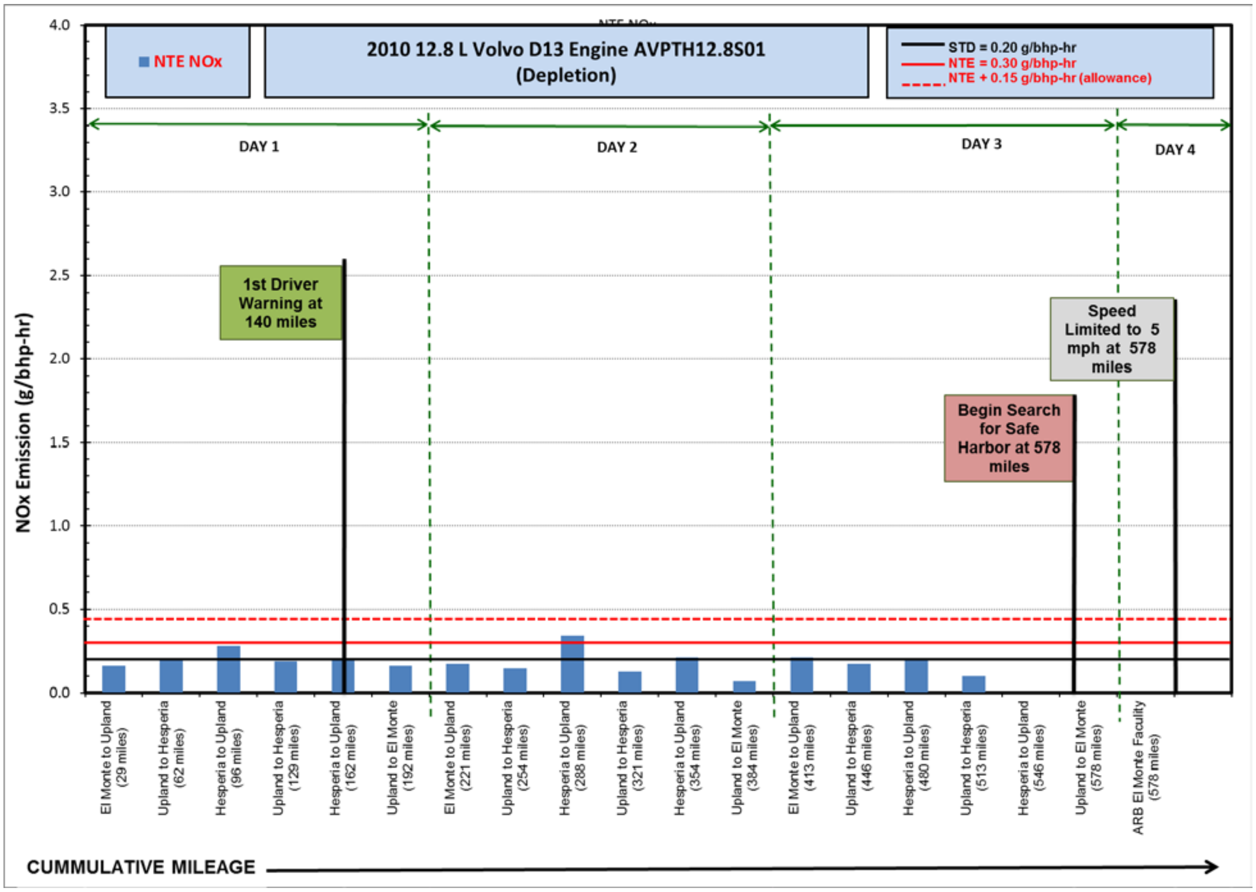
Day 4

On Day 4 as staff attempted to drive the vehicle, it immediately experienced the 5 mph severe inducement condition (odometer = 115,961 miles) the DEF light started to flash, an audible alert beeped and the DID displayed the message "Vehicle Speed Limited to 5 Mph Add DEF" (see Figure Volvo-5) indicating that severe inducement sequence had been reached. Staff shut down the vehicle and added two and a half gallons of DEF and the DEF gauge level was at 15 percent capacity. Upon restart, the vehicle triggered the SCR system into a "self-healing" reset and all the warning lights, chimes and messages were cleared. This SCR reset was designed to deactivate the previously active SCR-related driver warnings and remove any vehicle SCR inducements. Staff drove the vehicle and verified that the vehicle was back to normal operation and returned to ARB's El Monte facility (odometer = 115,962 miles) concluding the DEF Depletion Cycle.

Figure Volvo-5: Volvo Driver Information Display Indicating 5 Mph Derate

The figure below represents the daily DEF Depletion Cycle emissions over various driving segments and includes markers where certain SCR warnings and inducement events occurred along the test route (see Figure Volvo-6). The events represented in the figure include the first driver warning, and the presumed initiation of the vehicle's SCR strategy to seek the final inducement event based on the vehicle owner's manual. Note: the NTE NOx data is not shown in some of the traveled routes because some ambient conditions were outside of the required NTE measurement zones.

Figure Volvo-6: Daily DEF Depletion Cycle Emissions Data



Note: The PEMS values in this figure were measured values taken during this test program while the vehicle was operated under on-road conditions. The NTE NOx is the on-road measurement of NOx emissions that requires specific engine operation and other criterion for attaining this measurement. The NOx certification emission standard of 0.20 g/bhp-hr requires emission measurements under laboratory conditions. This standard, in addition to the NTE standard of 0.30 g/bhp-hr and the NTE + 0.15 g/bhp-hr measurement allowance, was provided for general reference only. The PEMS unit used for this operation meets the U.S. EPA requirements per 40 CFR 1065.

Despite DEF being depleted, as you can see, the Volvo truck maintained NOx control throughout the entire testing sequence indicating the strategy used by Volvo was to trigger warnings and inducements well ahead of NOx noncompliance which would likely occur at true DEF depletion, unless significant other NOx control strategies were employed.

Under the DEF Depletion Cycle, this vehicle performed as expected inducing driver SCR visual/audible warnings that were preceded by escalating low DEF level inducements, including an engine power derate and ultimately a 5 mph limited vehicle speed inducement. In addition, the NOx emissions measured under this cycle performed within its NTE standard. All prescribed inducement strategies for this cycle appeared to be consistent with the vehicle owner's manual information, the 2010 MY Guidance and the suggested 2011+ MY Guidelines, primarily by initiating warnings and inducements well ahead of any noncompliance detection.

c) Vehicle 4 - DEF Contamination Cycle

The chart below, Figure Volvo-7, contains information from the Volvo Owner's Manual that came with the vehicle and was reproduced with Volvo's permission. It displays the stages of escalating driver warnings and alerts expected for the DEF Contamination Cycle.

Figure Volvo-7: Volvo's SCR Driver Warning Sequence for DEF Quality/Contamination

Steps	**Triggers**	**Aftertreatment DEF Quality Indicator**	**Driver Information Display Screen**
Step **0**	Good DEF Quality	None	None
Step 1	Poor DEF Quality DTC Initial Detected		**Engine Will Derate Soon**
Step 2	Poor DEF Quality DTC Initial Detected + 1 hours		**SCR Malfunction Engine in Derate Check SCR to Avoid 5 Mph Limit**
Step 3	Poor DEF Quality DTC Initial Detected + 4 hours Diesel Fuel Refueling >15% **OR** vehicle stopped or shut down for > 20 minutes		**Service SCR System Repair needed to avoid 5 Mph Limit**
Step **4**	1 Refueling Event with Parking Brake **ON** 2 Stationary for 20 minutes with engine on or off (Back Stop)		**Service SCR System 5 Mph Limit**

Once poor quality DEF is detected, the amber check engine light is expected to illuminate, accompanied by a DID message, “Engine Will Derate Soon”. After initial detection plus 1 hour, if no remedy is sought, then the DID displays “SCR Malfunction Engine in Derate Check SCR to Avoid 5 Mph Limit”. After initial detection plus four hours, if no remedy, the search for final inducement is triggered by completing a 15 percent fuel refill, stopping the vehicle, performing a vehicle shutdown or a 20+ minute idle, all accompanied by a new series of messages in the DID (see Figure Volvo-7 for specific sequencing and messages).

Day 1

To begin the DEF Contamination Cycle, staff drained the DEF tank and added about five gallons of deionized water prior to engine startup. The DEF level was about 25 percent full and the diesel fuel level was a little above the one half mark. After starting the engine, staff observed that no SCR warning lights or alerts were active (odometer = 116,068 miles). As staff began to drive the vehicle, they also noticed the vehicle was operating normally.

The SCR system triggered the first driver warnings and inducement within the first hour of driving after accumulating 49 miles (odometer = 116,117 miles) with the illumination of the amber Check Engine light, the DEF tank low level indicator light, a continuous audible beep, and the DID showing the message "SCR Malfunction, Service SCR to Avoid Engine Derate." Driving 15 more miles, the DID changed to “Derate Check Engine Fault” and the audible alert had extinguished (odometer = 116,132 miles). Approximately 45 minutes later (odometer = 116,167 miles), the DID changed again showing “SCR Malfunction, Engine in Derate, Check SCR to Avoid 5 Mph Limit." The previously observed SCR warning lights were still illuminated and the audible warning alert began to beep continuously. Twelve miles later the driver noticed a loss of power (odometer = 116,179 miles). Staff returned to ARB’s El Monte facility after accumulating 199 miles for the day (odometer = 116,267 miles). Before shutting down the vehicle, staff noted that the amber Check Engine light was illuminated and the DID was displaying the message “SCR Malfunction, Engine in De-rate, Check SCR to Avoid

5 Mph Limit." and the DEF gauge level had decreased to 1/5 of a tank. Staff shut off the vehicle and ended testing for the day.

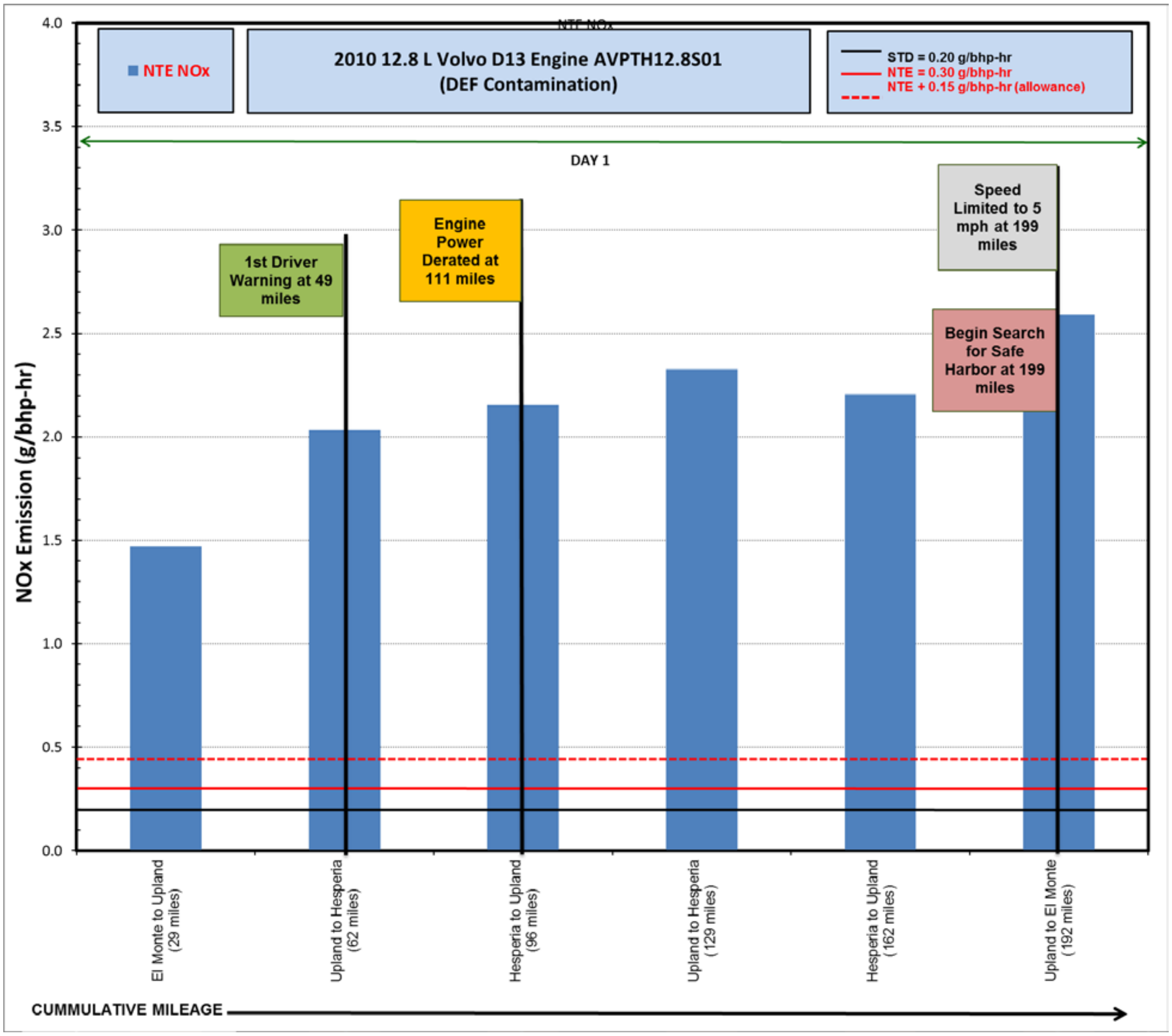
Day 2

Staff started the vehicle and immediately the amber Check Engine light and the DEF tank low level indicator light were illuminated; the audible warning alert beeped continuously; the particulate trap regeneration light was flashing; and the DID displayed the message "Check Engine Fault & Service SCR, System 5 Mph Limit." Staff attempted to drive the vehicle and immediately experienced the 5 mph severe inducement condition (odometer = 116,267 miles). The drive time to reach the final inducement since the first driver warning was triggered was approximately three hours and 15 minutes and the vehicle was driven 150 miles. The vehicle was then shut off for the day.

In preparation for the next test cycle, ARB staff removed the water from the DEF tank and replaced it with approximately five gallons of quality DEF. ARB staff cleared codes with a Volvo scan tool removing all SCR related alerts and messages (odometer = 116,267 miles). At this time, the vehicle required a diesel particulate filter (DPF) regeneration which was carried out by staff as the vehicle was parked at ARB's El Monte facility. After completion of the DPF regeneration event, staff drove the vehicle and noticed that the vehicle was still experiencing an engine power derate. Staff drove the vehicle test route to try and clear the derate condition and after driving for approximately 40 miles, staff observed that the vehicle power gradually went back to normal. Staff returned to ARB's El Monte facility and shut down the vehicle (odometer = 116,393 miles). The DEF Contamination Cycle was now complete.

The figure below, Figure Volvo-8, represents the daily DEF Contamination Cycle emissions and includes markers where certain SCR warnings and inducement events occurred along the test route. The events represented in the figure include the first driver warning, the onset of the engine derate, and the presumed initiation of the vehicle's SCR strategy to seek the final inducement event.

Figure Volvo-8: Daily DEF Contamination Cycle Emissions Data



Note: The PEMS values in this figure were measured values taken during this test program while the vehicle was operated under on-road conditions. The NTE NOx is the on-road measurement of NOx emissions that requires specific engine operation and other criterion for attaining this measurement. The NOx certification emission standard of 0.20 g/bhp-hr requires emission measurements under laboratory conditions. This standard, in addition to the NTE standard of 0.30 g/bhp-hr and the NTE + 0.15 g/bhp-hr measurement allowance, was provided for general reference only. The PEMS unit used for this operation meets the U.S. EPA requirements per 40 CFR 1065.

With water used in place of DEF, it can be seen that NOx control was lost almost immediately as the residual DEF was depleted by the water and therefore most likely initiated noncompliance detection within the first 49 miles (approximately one hour) of engine start up. NOx emissions averaged between 1.5 to 2.5 g/bhp-hr for the various driving segments.

The DEF Contamination Cycle performed similar to the DEF Depletion Cycle, prompting escalating SCR warnings/audible alerts and engine inducements including an engine power derate and a severe inducement strategy limiting vehicle speed to 5 mph. The ARB driver reported that the engine power derate was very noticeable when the truck struggled to accelerate onto a freeway or negotiating moderate freeway upgrades. The driver commented that these conditions would not be acceptable to a vehicle operator for extended periods of driving. In regards to the vehicle emissions performance under these cycles, the NOx emissions were well beyond the NOx NTE standard. When water was used in place of DEF, the vehicle's emissions results showed an immediate loss of NOx control with the NOx NTE emission results emitting between 1.5 to 2.5 g/bhp-hr for the various driving segments. Overall, the initial detection occurred within one hour by triggering driver warnings and searched for final inducement within four hours after detection. All prescribed inducement strategies appeared to be consistent with the vehicle owner's manual information and the 2010 MY Guidance. Additionally, the software upgrades apparently made them consistent with the SCR 2011+ MY Guidelines.

d) Vehicle 4 - DEF System Tampering Cycle

The chart below, Figure Volvo-9, contains information from the Volvo Owner's Manual that came with the vehicle and was reproduced with Volvo's permission. It displays the stages of escalating driver warnings and alerts expected for the DEF System Tampering Cycle.

Figure Volvo-9: Volvo's SCR Driver Warning Sequence for SCR Tampering

Aftertreatment Tampering - Driver Warning & Inducement

Triggers	Aftertreatment Tampering Indicator	Driver Information Display Screen
No Fault	None	None
Tampering Fault Detected **Note:** For examples of the various SCR sensor tampering types refer to the "SCR Sensor Disconnected Tampering Type" table below.	CHECK W2029417	**SCR System Fault Engine Will Derate Soon**
Second Drive Cycle with Active DTC	CHECK W2029417 W3031200	**SCR System Fault Engine Will Derate Soon**
Driving with Active Fault for + 1 hrs	CHECK W2029417 W3031200	**SCR System Fault Engine In Derate**
Driving with Active Fault for + 4 hrs	CHECK W2029417 W3031200	**SCR System Fault Repair needed to Avoid 5 Mph Limit**
1 Refueling Event (> 15 % fuel level increase) with stationary brake 2 Vehicle stationary for 20 minutes (vehicle speed < 1.6 Km/h (1 mph) 3 Engine shut off for 20 minutes	CHECK W2029417 W3031200	**Repair SCR System Fault 5 Mph Limit**

Once the tampering fault is detected, the amber Check Engine Light is expected to illuminate accompanied by a DID message, "SCR System Fault, Engine Will Derate Soon". After the initial detection and a second drive cycle, and no remedy is sought, the malfunction indicator light is illuminated and the DID continues to display the same message. After driving for an hour with the same active warnings, the DID will change its message to "SCR System Fault Engine in Derate". After continuing to drive for four more hours with the active warnings still illuminated, the DID will display the message "SCR System Fault Repair needed to Avoid 5 Mph Limit". If the warnings are ignored, the vehicle should display the message on the DID "Repair SCR System Fault 5 Mph Limit" and trigger the 5 mph severe inducement when a safe harbor is reached (i.e., a safe harbor would occur when the vehicle's fuel level is increased by 15 percent fuel, or the vehicle is stationary for 20 minutes, or when the vehicle is shut down for 20 minutes) (see Figure Volvo-9 for specific sequencing and messages).

Day 1

Test Vehicle 4 was prepared for testing by unplugging the DEF doser injector electrical connector (odometer = 116,393 miles). After startup, the SCR system immediately illuminated the amber Check Engine light and the message “Check Engine ECU” displayed on the DID (see Figure Volvo-10).

Figure Volvo-10: Volvo’s Driver Information Display Indicating to Check ECU

After driving 62 miles, staff stopped to put 141 gallons of diesel fuel into the vehicle and then continued the drive for another 122 miles per the designated test route back to El Monte. During this drive, the SCR system illuminated the amber Check Engine light and triggered the audible warning alert. In addition, the DID flashed warning messages that included “Check Engine ECU”, “Check Engine Fault”, “SCR System Fail, Engine Will Derate Soon” (odometer = 116,577 miles). Staff drove the vehicle ten additional miles in route back to El Monte with no perceived power loss. Staff parked the truck around the corner from ARB’s El Monte facility (odometer = 116,586 miles) and the DID displayed the following messages: “SCR System Fault”, “Engine in Derate Soon”, “Check Engine ECU”, and Check Engine Fault”. At this point, staff returned to ARB’s El Monte facility and shut down the vehicle (odometer = 116,587 miles). Subsequently, staff conducted a key-off/key-on event and upon restart the DID displayed the following messages: “SCR System Fault, Engine in Derate and 5Mph Limit Soon”, the DEF low level indicator light came on and the vehicle went into a 5 mph derate. (see Figure Volvo-11 below).

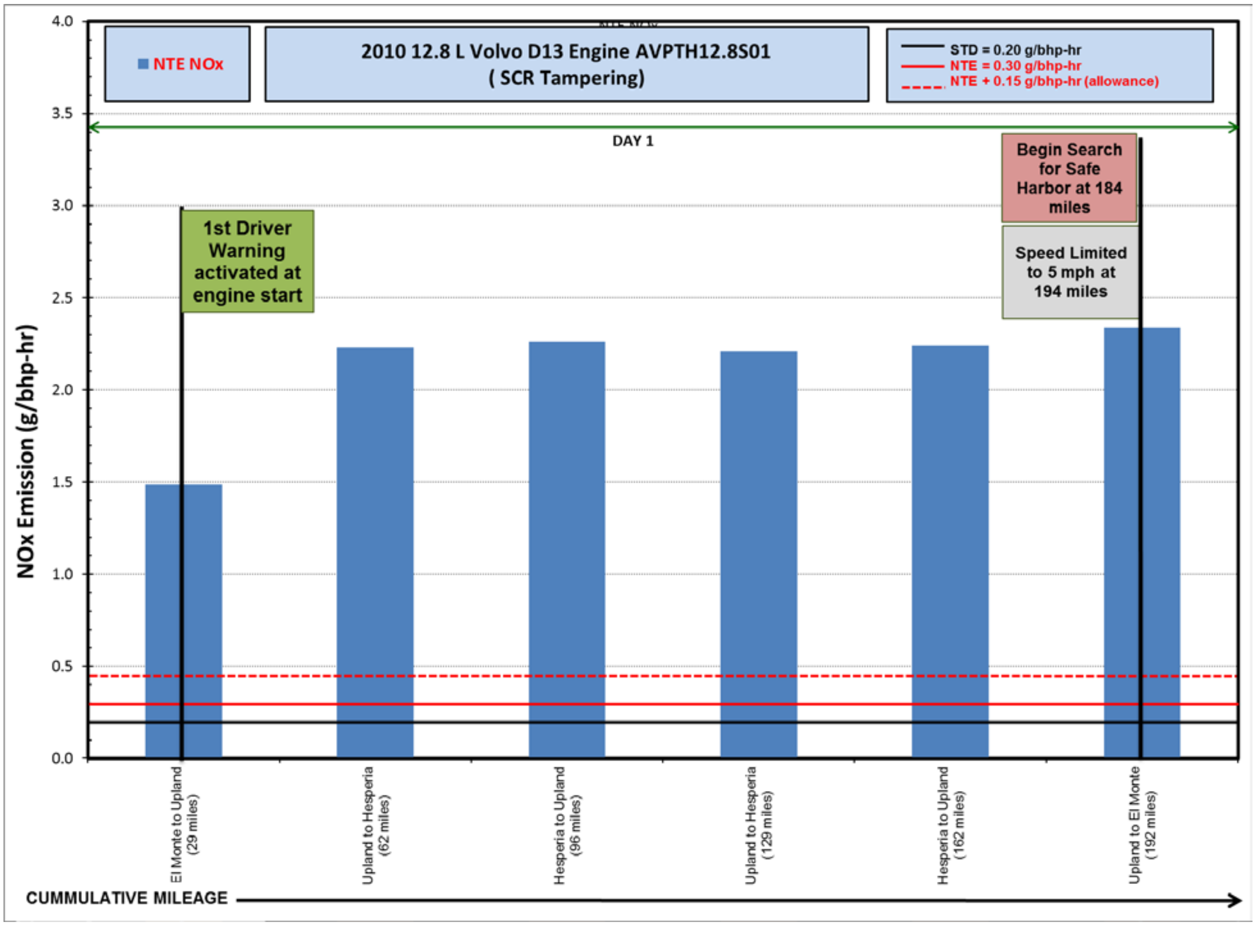
Figure Volvo-11: Volvo Driver Information Display Indicating 5 Mph Derate

<u>Day 2</u>

With the DEF doser injector still disconnected, staff again tried to drive the vehicle the following morning and confirmed that the vehicle was still limited to 5 mph. With the SCR system limiting the vehicle speed to 5 mph, the final step of the DEF System Tampering Cycle had occurred. The drive time to reach the final inducement since the first driver warning was triggered was approximately three hours and 55 minutes and 194 miles were traveled. Staff reconnected the DEF doser injector and all SCR related warning alerts and messages immediately extinguished. The driver elected to go into the next test cycle because no message displayed stating the vehicle was under a power loss condition. The DEF System Tampering Cycle was now complete.

The figure below represents the daily DEF System Tampering Cycle emissions and includes markers where certain SCR inducement events occurred along the test route (see Figure Volvo-12 below). The events represented in the figure include the first driver warning and the initiation of the vehicle's SCR strategy to seek the final inducement event.

Figure Volvo-12: Daily DEF System Tampering Cycle Emissions Data



Note: The PEMS values in this figure were measured values taken during this test program while the vehicle was operated under on-road conditions. The NTE NOx is the on-road measurement of NOx emissions that requires specific engine operation and other criterion for attaining this measurement. The NOx certification emission standard of 0.20 g/bhp-hr requires emission measurements under laboratory conditions. This standard, in addition to the NTE standard of 0.30 g/bhp-hr and the NTE + 0.15 g/bhp-hr measurement allowance, was provided for general reference only. The PEMS unit used for this operation meets the U.S. EPA requirements per 40 CFR 1065.

The DEF System Tampering Cycle performed similar to the DEF Contamination Cycle, prompting escalating SCR warnings/audible alerts and a severe engine inducement strategy limiting vehicle speed to 5 mph. However, no engine derate was noticed by the driver during any part of the test. In regards to the vehicle emissions performance under these cycles, the NOx emissions were well beyond the NOx NTE standard. Overall, the initial detection occurred within 1 hour by triggering driver warnings and reached the final inducement within four hours after detection. All prescribed inducement strategies appeared to be consistent with the vehicle owner's manual information, the 2010 MY Guidance and the software upgrades apparently made them consistent with the SCR 2011+ MY Guidelines from the July 2010 SCR Workshop as well.

e) Vehicle 4 - DEF Dilution Cycles

As with the DDC truck, staff decided to check three different blended mixtures of DEF, with 25 percent water (resulting urea concentration in mixture of ~24.4 percent), 50 percent water (resulting urea concentration in mixture of ~16.2 percent), and 75 percent water (resulting urea concentration in mixture of ~8.1% percent) to determine the percentage of diluted DEF that would likely result in increased NOx emissions. Staff operated the vehicle using each of the different DEF diluted concentrations to determine the DEF threshold for the SCR system to trigger driver warnings and SCR inducements while measuring the emissions with each dilution cycle. This cycle was not intended to drive these vehicles to trigger the 5 mph final inducement event, only to determine if different diluted blends of DEF would cause the SCR inducement system to activate.

(1) DEF Diluted with 25 Percent Water

Day 1

To begin the DEF Dilution Cycle, staff drained the DEF tank and added five gallons of a DEF/water blend (concentration verified with a DEF Refractometer) that included a blend of quality DEF and deionized water. The DEF gauge level was filled to one fifth of capacity and the diesel fuel gauge level was showing a little over three quarters of tank full. Upon engine start up, staff observed that no SCR related warning lights or audible alerts were present (odometer = 116,587 miles). As staff drove the vehicle, they confirmed the vehicle was operating normally.

The SCR system triggered the first driver warning for diluted DEF after driving 107 miles (odometer = 116,694 miles) with the illumination of the amber Check Engine light; triggered the audible warning alert; and the DID displayed the messages, "Service SCR

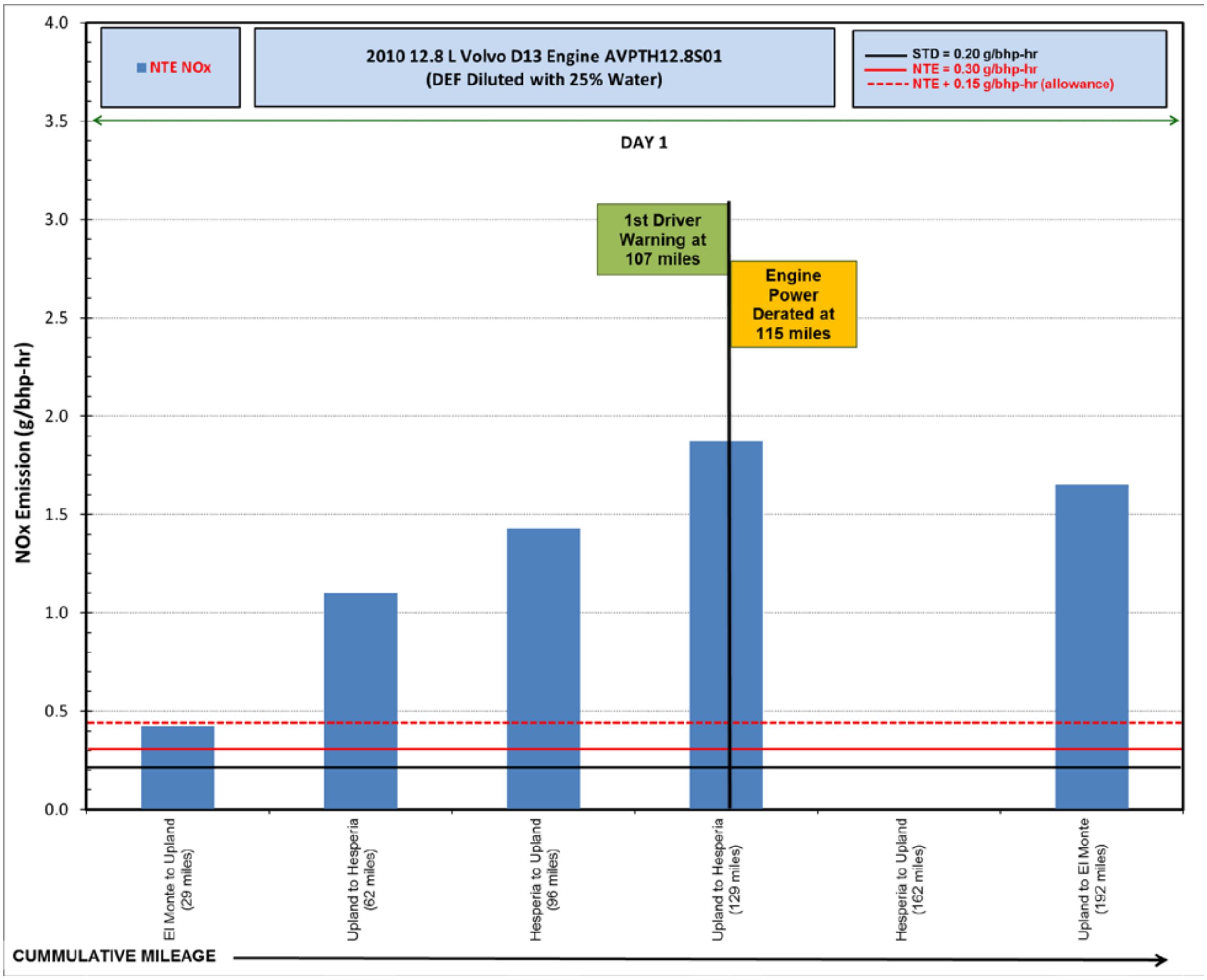
System before Refueling, to Avoid 5 Mph Derate" and "Check Engine Fault." Approximately 10 minutes later, the driver experienced an engine power loss. Staff returned to ARB's El Monte facility after accumulating 192 miles for the day with no additional SCR warnings or messages (odometer = 116,779 miles). Since running the dilution cycle was an effort to determine at what percentage dilution the SCR system could detect a diluted DEF solution blend, staff chose to discontinue testing and move on to the next dilution cycle with the DEF gauge level at 15 percent.

Day 2

To conclude the 25 percent Diluted DEF Cycle, ARB staff added 82 gallons of diesel fuel, removed the blended DEF/water mixture and filled the DEF tank with approximately five gallons of quality DEF. ARB staff cleared codes with a Volvo scan tool, removing all SCR related alerts and messages. Staff then drove the vehicle but noticed that the vehicle was initially still experiencing an engine power derate. However, after driving approximately 40 miles, staff observed that the vehicle power gradually went back to normal. Staff returned to ARB's El Monte facility and shut down the vehicle (odometer = 116,905 miles).

The figure below represents the daily 25 percent Diluted DEF Cycle emissions and includes markers where certain SCR warning and inducement events occurred along the test route (see Figure Volvo-13 below). The events represented in the figure include the first driver warning and the onset of the engine derate event.

Figure Volvo-13: Daily DEF Dilution Cycle (25 Percent Water) Emissions Data



Note: The PEMS values in this figure were measured values taken during this test program while the vehicle was operated under on-road conditions. The NTE NOx is the on-road measurement of NOx emissions that requires specific engine operation and other criterion for attaining this measurement. The NOx certification emission standard of 0.20 g/bhp-hr requires emission measurements under laboratory conditions. This standard, in addition to the NTE standard of 0.30 g/bhp-hr and the NTE + 0.15 g/bhp-hr measurement allowance, was provided for general reference only. The PEMS unit used for this operation meets the U.S. EPA requirements per 40 CFR 1065.

As shown in Figure Volvo-13, the vehicle maintained good NOx control initially during the first drive segment most likely before the diluted DEF totally infiltrated the system or the system was no longer able to dose sufficient concentration of urea despite increasing dosing amounts. Sometime between mile 30 and 107 of the drive the NOx emissions obviously increased triggering the poor quality DEF detection and first driver warning at the 107 mile point. Once NOx control was lost, emissions ranged from 1.0 to 1.5 g/bhp-hr on average. Some NTE points when averaged over a specific drive segment were slightly higher.

(2) DEF Diluted with 50 Percent Water

Day 1

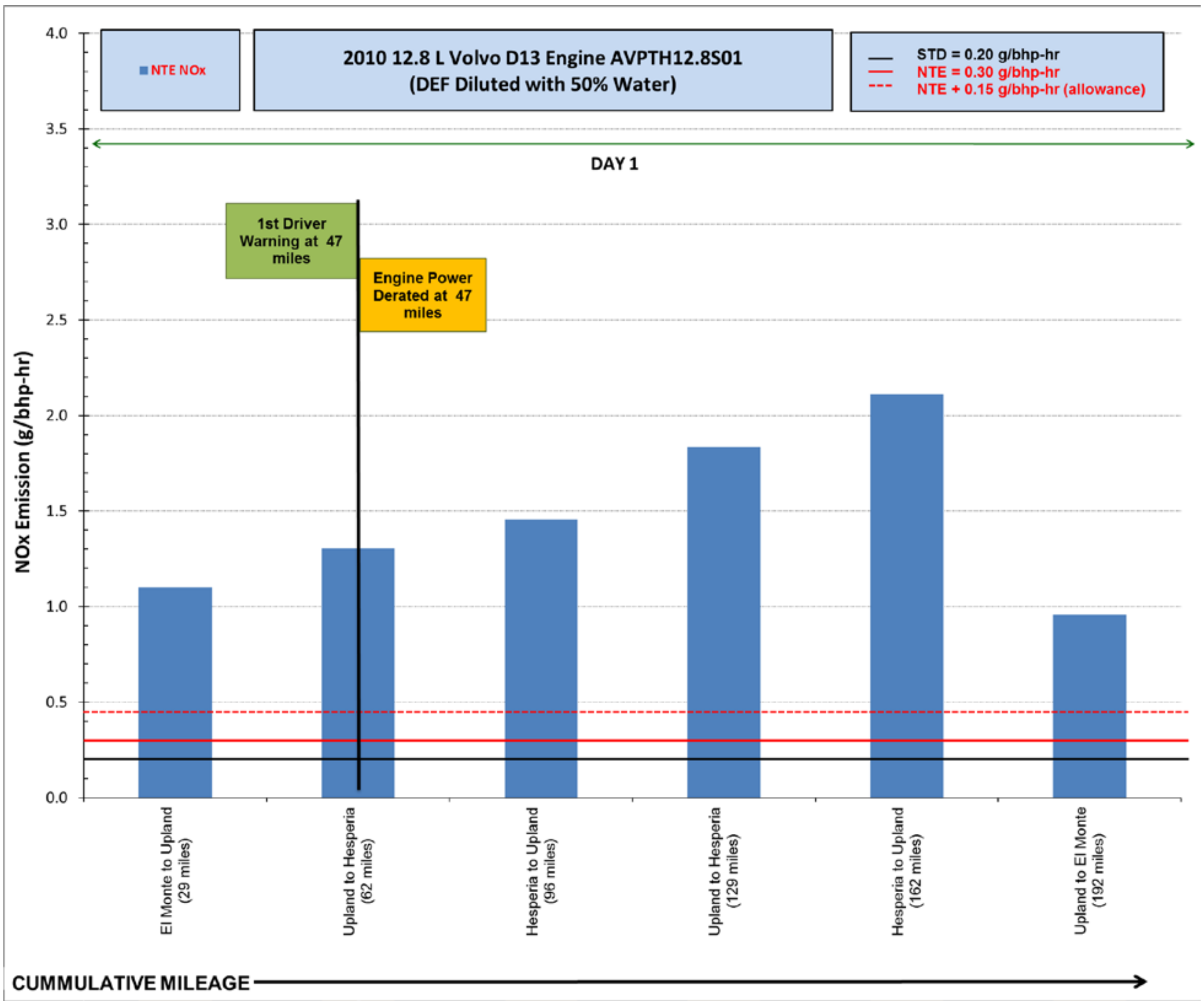
For the 50 percent DEF Dilution Cycle, staff drained the DEF tank and added about five gallons of a DEF/water blend (concentration verified with a DEF Refractometer). The DEF gauge level was at 20 percent at the start of this cycle. The test route began with` the odometer at 116,905 miles. The SCR system triggered the first driver warning and inducement for diluted DEF after driving 47 miles (odometer = 116,952 miles) with the illumination of the amber Check Engine light and the sounding of an audible warning alert. The DID displayed the messages, "Service SCR System before Refueling to Avoid 5 Mph Derate" and "Check Engine Fault." In addition to the visual and audio warnings, the driver experienced an engine power loss inducement. Staff returned to ARB’s El Monte facility after accumulating 193 miles for the day with no additional SCR warnings or messages (odometer = 117,098 miles).

Day 2

To conclude the 50 percent DEF Dilution Cycle, ARB staff added 61 gallons of diesel fuel, removed the blended DEF/water mixture and filled the DEF tank with approximately five gallons of quality DEF. ARB staff cleared codes with a Volvo scan tool removing all SCR related alerts and messages. After driving the vehicle for 40 miles, the engine power derate appeared to be gone and vehicle returned back to normal power. Staff continued to drive the vehicle for a few extra miles to verify normal vehicle operation and then returned to ARB's El Monte facility (odometer = 117,226 miles).

The figure below represents the daily 50 percent DEF Dilution Cycle (50 Percent Water) emissions and includes markers where certain SCR warning and inducement events occurred along the test route (see Figure Volvo-14 below). The events represented in the figure include the first driver warning and the onset of the engine derate event.

Figure Volvo-14: Daily DEF Dilution Cycle (50 Percent Water) Emissions Data



Note: The PEMS values in this figure were measured values taken during this test program while the vehicle was operated under on-road conditions. The NTE NOx is the on-road measurement of NOx emissions that requires specific engine operation and other criterion for attaining this measurement. The NOx certification emission standard of 0.20 g/bhp-hr requires emission measurements under laboratory conditions. This standard, in addition to the NTE *standard of 0.30 g/bhp-hr and the NTE + 0.15 g/bhp-hr measurement allowance, was provided for general reference only. The PEMS unit used for this operation meets the U.S. EPA requirements per 40 CFR 1065.*

The NOx emissions for the 50 percent DEF Dilution Cycle increased immediately in response to poor quality DEF indicating the vehicle was not able to adjust by increasing dosing amount or other NOx control means. The vehicle detected the loss of NOx control and triggered the first warning and inducement at the 47 mile test route point with emissions averaging around 1.3 g/bhp-hr NOx within the second leg of the test route. Overall, NOx emissions varied from approximately 1.0 to 2.1 g/bhp-hr NOx under the 50% DEF Dilution Cycle.

(3) DEF Diluted with 75 Percent Water

Day 1

Continuing with the third and final 75 percent DEF Dilution Cycle, staff drained the DEF tank and added a DEF/water blend (concentration verified with a DEF Refractometer). The odometer was at 117,226 miles as the test route resumed. The SCR system triggered the first driver warning and inducement for diluted DEF after driving 39 miles (odometer = 117,265 miles) with the DID displaying the messages, "Service SCR System before Refueling to Avoid 5 Mph Derate" and "Check Engine Fault." In addition, the driver experienced an engine power loss. Approximately 130 miles later, the SCR system illuminated the amber Check Engine light with no additional warning messages. Staff returned to ARB's El Monte facility after accumulating 192 miles for the day with no additional SCR warnings or messages (odometer = 117,418 miles).

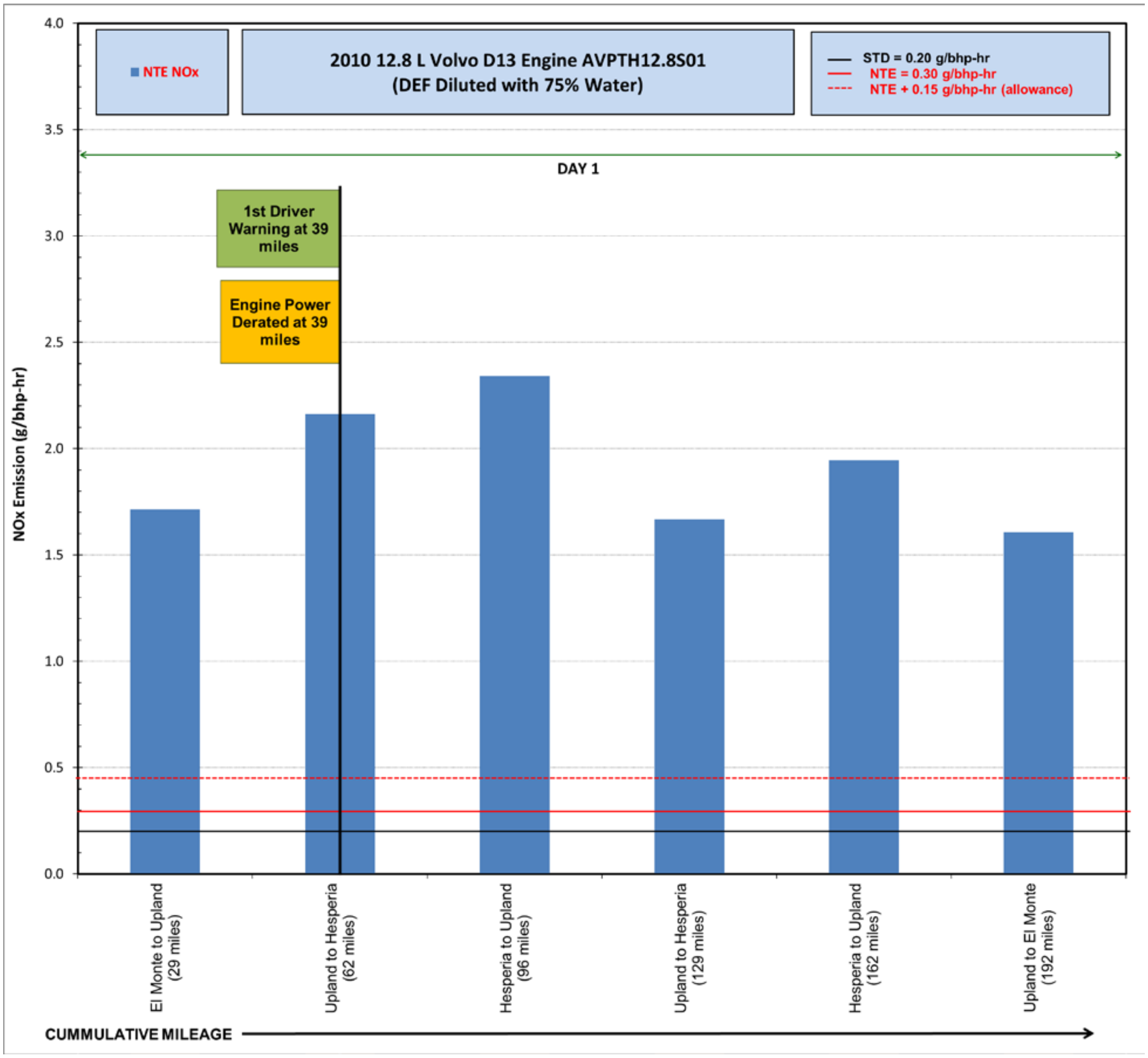
Day 2

With this last evaluation complete, staff prepared the vehicle for its return to Penske Truck Rental. ARB staff added 59 gallons of diesel fuel, removed the DEF diluted mixture, filled the DEF tank with five gallons of quality DEF, and cleared codes with a Volvo scan tool removing all SCR related alerts and messages. After all these actions were completed, staff drove the vehicle for 40 miles when the engine power derate extinguished returning the vehicle power back to normal. Staff continued to drive the vehicle to verify normal vehicle operation and returned to ARB’s El Monte facility (odometer = 117,542 miles). The following day staff added 8.7 gallons of diesel fuel and returned this vehicle to Penske Truck Rental.

The figure below represents the daily 75 percent DEF Dilution Cycle (75 Percent Water) emissions and includes markers where certain SCR warning and inducement events occurred along the test route (see Figure Volvo-15 below). The events represented in the figure include the first driver warning and the onset of the engine derate event.

In conclusion, the results showed the NOx emissions increased within the first short driving segment. The triggering of the first driver warning and inducement occurred at the 39 miles driving route marker indicating the vehicle had detected poor quality DEF. The NOx emissions varied from 1.6 to roughly 2.3 g/bhp-hr NOx during the testing route.

Figure Volvo-15: Daily DEF Dilution Cycle (75 Percent Water) Emissions Data



Note: The PEMS values in this figure were measured values taken during this test program while the vehicle was operated under on-road conditions. The NTE NOx is the on-road measurement of NOx emissions that requires specific engine operation and other criterion for attaining this measurement. The NOx certification emission standard of 0.20 g/bhp-hr requires emission measurements under laboratory conditions. This standard, in addition to the NTE standard of 0.30 g/bhp-hr and the NTE + 0.15 g/bhp-hr measurement allowance, was provided for general reference only. The PEMS unit used for this operation meets the U.S. EPA requirements per 40 CFR 1065.

The DEF Dilution Cycles were conducted to determine if a diluted DEF tank mixture would cause SCR driver warnings and inducements to employ along with increasing NOx emissions. Overall, the results disclosed that diluting the DEF tank (in all three diluted cycle evaluations) with water caused the SCR driver warnings and inducements to engage and caused NOx emissions to increase well beyond the NTE limit. As the amount of water in the DEF increased, so did the NOx emissions, as well as diminishing the time to trigger warnings and inducements. The 25 percent DEF Dilution Cycle initially maintained NOx control early in the test route (first 29 miles), but as the loss of NOx control was experienced somewhere between mileage points 30 to 62, and verified at mile 107, the first driver warning was initiated followed by the first driver inducement. The last two dilution cycles evaluated (DEF tank diluted with 50 and 75 percent water) obviously lost NOx control sooner than the 25 percent DEF Dilution Cycle and triggered their warnings and inducements at the 47 and 39 mile (roughly one hour or less) test route markers, respectively. The 2011+ MY Guidelines' goal is to detect noncompliance within an hour and notify the operatory immediately. The pattern of test results indicate that the loss of NOx control occurs sooner with higher concentrations of diluted DEF and so did the warning and inducements. The 50 percent and 75 percent DEF Dilution Cycles responses were clearly consistent with the 2011+ MY Guidelines since they detected a noncompliance within an hour and notifying the operator immediately, while the 25 percent DEF Dilution Cycle result was inconclusive due to a more gradual increase in NOx emissions as mileage was accumulated and the actual noncompliance mileage could not be pinpointed.

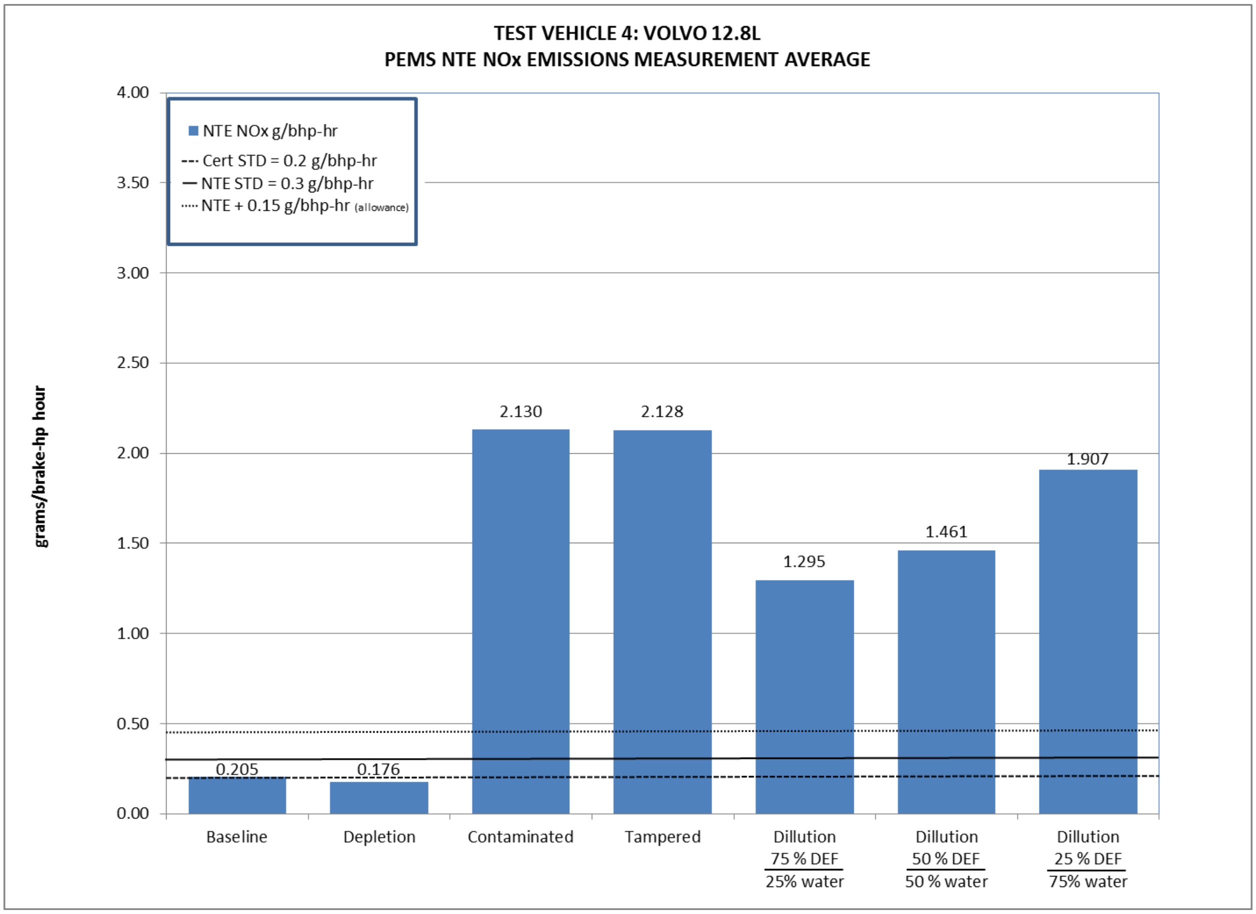
f) Vehicle 4 - Emissions Measurements

Test Vehicle 4 was outfitted with a PEMS unit which measured the vehicle's emissions as the vehicle was operated over the designated test route. The vehicle's average baseline emissions were compared to average emissions from the DEF Depletion, DEF Contamination, DEF System Tampering and the DEF Dilution Cycles. Figure Volvo-16 (see below) is a summary of the average NOx emissions measured for each of these test cycles. It should be noted that staff utilized qualifying NTE zone emission measurements to compare the emission results for each test cycle. The certification standard is also shown on the chart but the test requirements to conduct a certification type test require an engine dynamometer under laboratory conditions and cannot be directly compared to the in-use PEMS measurements. This standard was only included on the chart for informational purposes.

The average Baseline Cycle NTE NOx emissions of 0.20 g/bhp-hr were easily within the engine's NTE NOx standards of 0.3 g/bhp-hr without consideration of the NTE measurement allowance. The Depletion Cycle PEMS measurements were taken over three days from the time the vehicle began the Depletion Cycle until the vehicle went into a 5 mph limited speed derate. The overall average NOx emissions as DEF depleted to empty were 0.18 g/bhp-hr; therefore, it is presumed the vehicle had enough residual DEF or other means to maintain control of NOx emission levels leading up to the vehicle experiencing a 5 mph limited speed event.

The average NOx emissions for the DEF Contamination and DEF System Tampering Cycles were approximately seven times higher than the baseline NTE results with NOx emissions slightly above the 2.0 g/bhp-hr level. As for the DEF Dilution Cycles, the NOx emissions results were about four to seven times higher than the baseline NTE NOx emission levels dependent on the dilution level. The average NOx emissions ranged from 1.18 to 1.90 g/bhp-hr over the 25 percent to 75 percent DEF Dilution cycles, respectively. The observation indicates that Volvo's SCR system could detect poor quality diluted DEF and adjusted DEF dosing and/or other NOx control mechanisms to control NOx, but ultimately reached its ability to control NOx emissions triggering the SCR system inducement strategy.

Figure Volvo-16: Vehicle 4: NOx Emission Data Summary



Note: The PEMS values in this figure are the average NOx NTE emissions taken during this test program while the vehicle was operated under on-road conditions. The NOx certification emission standard of 0.20 g/bhp-hr requires emission measurements under laboratory conditions. This standard, in addition to the NTE standard of 0.30 g/bhp-hr and the NTE + 0.15 g/bhp-hr measurement allowance, was provided for general reference. The PEMS unit used for this operation meets the U.S. EPA requirements per 40 CFR 1065.

g) Vehicle 4 - Inducement Test Summary

ARB staff operated Test Vehicle 4 under various test cycles comparing the vehicle's SCR-related driver warnings and inducements to those supplied in the vehicle owner's manual and its consistency with the 2010 MY Guidance and/or 2011+ MY Guidelines. It was expected that it would be consistent with the 2010 MY Guidance since the engine was certified to 2010 standards and SCR requirements. ARB staff checked the driver warnings and inducements under the following cycles: DEF Depletion Cycle, DEF Contamination Cycle, DEF System Tampering Cycle, and DEF Dilution Cycles. Under the DEF Depletion Cycle, this vehicle performed as expected inducing driver SCR visual/audible warnings that were preceded by escalating low DEF level inducements, including an engine power derate and ultimately a 5 mph limited vehicle speed inducement.

With the exception of one minor difference, the SCR warnings and inducement strategies were consistent with the vehicle owner's manual, the 2010 MY Guidance and the 2011+ MY Guidelines for the DEF Contamination and DEF Tampering Cycles. During the DEF Contamination Cycle the vehicle inducements were effective in that the engine did experience a power derate and the driver noticed a power loss during the test cycle; however, the MIL wasn't illuminated as indicated in the vehicle owner's manual. The driver would not tolerate the inducement conditions while on his daily routes as it would be unbearable to be limited to a 5 mph speed limit. During the DEF System Tampering Cycle the vehicle also performed consistently in that the SCR related inducements occurred within the one hour and four hour time periods as described in the vehicle owner's manual.

At the conclusion of testing, the ARB driver stated that the SCR system's warning lights and audible alerts were effective in obtaining his attention while conducting the driving events for each test cycle. Furthermore, the occurrence of engine derates would make it difficult for the average driver to complete his daily routes. Lastly, truck drivers would be discouraged from tampering with their vehicles' SCR systems and/or allowing the DEF to run empty to avoid resulting problems, such as undergoing a 5 mph severe inducement.

C. Test Vehicle 5

Chassis:	2012 MY International Pro Star
Axles:	3
Engine:	Maxxforce 13
Engine MY:	2011 MY
Engine Family:	BNVXH07570GB
Displacement:	12.4 Liter
Horsepower:	430 HP @ 1700 RPM
Trailer:	48-foot flatbed

NOx Certification FEL: 0.50 g/bhp-hr

ARB staff procured a 2012 MY International Pro Star truck (Vehicle Identification Number - 1HSDHSJR8CJ565976). This vehicle was a three axle tractor equipped with the 2011 MY Navistar Maxxforce 13 engine rented from Idealease, a local commercial truck rental company. When ARB took possession of the vehicle from Idealease, the odometer showed 35,608 miles. The vehicle was outfitted with a 48-foot flatbed trailer loaded with five 20-foot “K-rail” concrete barriers that weighed in total about 40,000 pounds. Test plan 1Q1102 was used for this test evaluation (see Appendix D). In order to determine the impact on NOx emissions, this truck was outfitted with a Sensors, Inc. Semtech-DS PEMS unit allowing for real-time emissions readings. Because this vehicle did not utilize a SCR system for NOx control, the evaluation cycles were changed to accommodate the NOx control technology of this truck. The evaluation cycles used for this vehicle included the Baseline Test Cycle, the Lean Cruise Cycles 1 and 2, and the Restricted Exhaust Gas Recirculation (EGR) Cycle. The vehicle instrument panel was equipped with an amber Check Engine light or MIL to alert the operator of a malfunctioning engine control system (see Figure Navistar-1).

Figure Navistar-1: Navistar Instrument Panel - Check Engine Light

a) **Vehicle 5 - Baseline Test Cycle**

The baseline portion of this test program consisted of operating the vehicle over normal vehicle operation on prescribed test routes while measuring NOx emissions. Testing began with the diesel fuel tank filled to about 80 percent of its capacity and the odometer reading 35,638 miles.

Day 1

Staff drove the vehicle over the designated test route for 195 miles (odometer = 35,833 miles) collecting baseline exhaust emissions. The vehicle was observed to operate normally with no notification of any engine problems or issues.

Day 2

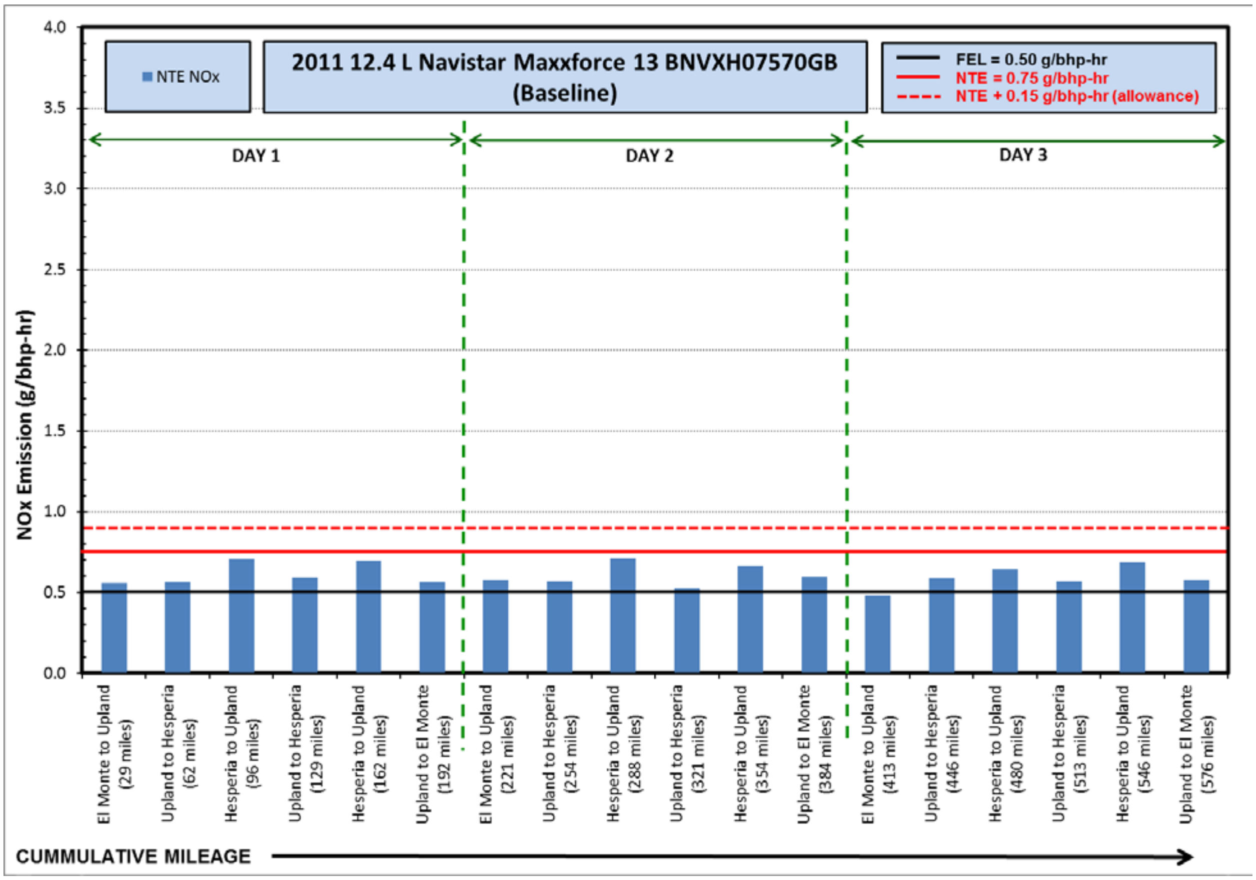
Staff drove the vehicle over the designated test route for 193 miles (odometer = 36,026 miles) collecting baseline exhaust emissions. Again, the driver noted there were no observations of any engine problems or issues.

Day 3

Staff drove the vehicle over the designated test route for 193 miles (odometer = 36,219 miles) collecting baseline exhaust emissions and concluded the baseline test route with no observations of any engine problems or issues.

The total miles driven over the three days was 581 miles, establishing the average driving segment baseline NOx emissions data (odometer = 36,219 miles).

Figure Navistar-2: Navistar Baseline Test Cycle



Note: The PEMS values in this figure were measured values taken during this test program while the vehicle was operated under on-road conditions. The NTE NOx is the on-road measurement of NOx emissions that requires specific engine operation and other criterion for attaining this measurement. The NOx family emission limit of 0.50 g/bhp-hr requires emission measurements under laboratory conditions. This standard, in addition to the NTE standard of 0.75 g/bhp-hr and the NTE + 0.15 g/bhp-hr measurement allowance, was provided for general reference only. The PEMS unit used for this operation meets the U.S. EPA requirements per 40 CFR 1065.

The average baseline NOx emissions divided into driving segments are graphed in Figure Navistar-2. The standards at which the Navistar engine was certified are included, as well, for comparison to the PEMS results. It should be noted that the FEL standard of 0.50 g/bhp-hr is listed only for reference since a true direct comparison can only be made in the laboratory on an engine dynamometer. However, the NTE standard is expected to be met with the 0.15 allowance applied once non-qualifying data is removed per the In-Use Compliance regulations. As can be seen in the graph, this engine met the NTE standard plus measurement allowance of 0.90 g/bhp-hr over all qualifying NTE segments.

b) Vehicle 5 - Lean Cruise Cycle 1

The Lean Cruise Cycle was developed to identify if a manufacturer calibrated their engine to achieve better fuel economy when maintaining steady state freeway speeds. A lean cruise calibration will cause the air/fuel ratio to change to a lean condition when the vehicle has come to a steady cruise operation where significant power is not necessary to maintain the vehicle speed (e.g., over a stretch of road where minimal throttle movement is required to maintain a steady speed). This type of calibration provides increased fuel economy but with the risk of increased NOx emissions and considered a defeat device that led to a consent decree with several heavy-duty manufacturers in the late nineties for unscrupulous business practices. ARB utilized this test cycle to determine if an engine utilizing EGR as its primary NOx control shows a significant increase in NOx emissions when driven at steady speeds over a reasonably flat test route. Staff identified a seven mile stretch of road that was nine miles from the Hesperia turnaround point for this test cycle (see Figure Navistar-3). Staff chose this route because the road looked reasonably flat allowing for vehicle operation with minimal throttle movement. However, staff later determined that the road had too many elevation changes (creating a rolling affect) which made it difficult to modulate the vehicle's speed to 55 mph. Although the road did not offer the best surface for conducting this test cycle (see Figure Navistar- 4), staff agreed to complete the test cycle and then repeat this operation on a different highway as discussed later in the report (see Lean Cruise Cycle 2).

Figure Navistar-3: Navistar Lean Cruise Cycle 1 Drive Route

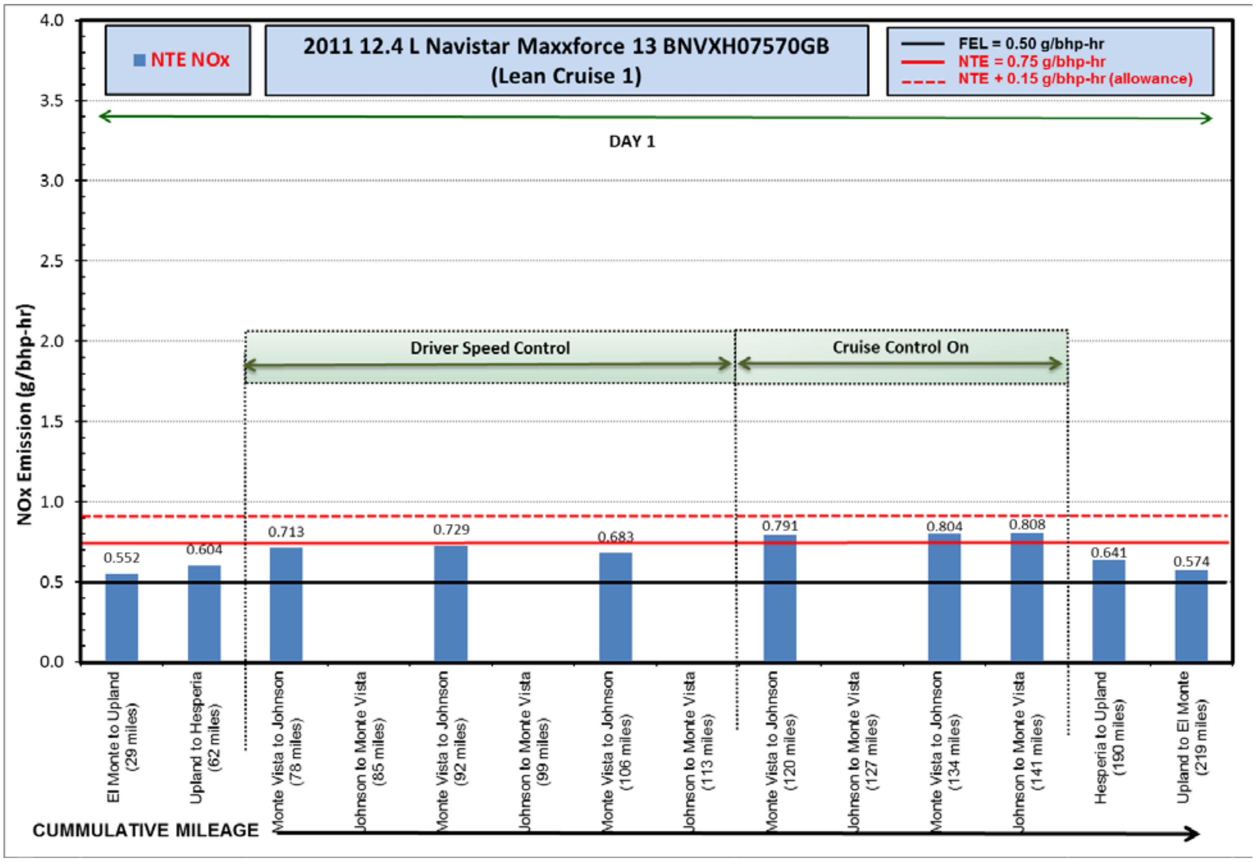
Figure Navistar-4: Uneven Road Between Johnson Rd and Monte Vista Rd

Day 1

The Lean Cruise Cycle 1 was initiated with an odometer reading of 36,219 miles. The driver completed three round trips over the designated test route; and while using the accelerator pedal, attempted to maintain an average speed of 55 mph. This was followed by two additional laps while utilizing the vehicle's cruise control set to 55 mph. Only two round trips were conducted with the cruise control on because the ambient air was cold which caused the air lines to the trailer to stiffen. While attempting to make a U-turn on the drive route the air lines were not flexible and disengaged on two occasions causing the trailer brakes to lock and preventing the driver from moving the truck. Initially, the driver did not immediately know why the truck would not move and noticed that traffic had to stop because the vehicle was blocking the road. After finally discovering the problem, the driver reconnected the air lines and moved the truck out of traffic. Due to the safety issues of losing the air lines to the trailer while making a U-turn, the driver decided to terminate the last portion of this test cycle. Overall, the vehicle drove well with no associated problems and was operated for 222 miles under this test cycle (odometer = 36,441 miles).

The results of the Lean Cruise Cycle 1 are graphed in Figure Navistar-5 with the FEL, NTE standards and the in-use measurement allowance for NTE. The instruments detected that the average NTE NOx emissions produced with the driver in control of the vehicle speed was 0.708 g/bhp-hr and increased to 0.801 g/bhp-hr when the vehicle cruise control was set. As can be seen in the graph, this engine met the NTE standard plus measurement allowance of 0.90 g/bhp-hr over all qualifying NTE segments. It is interesting to note that four of the five segments driven from Johnson Road to Monte Vista Road had no qualifying NTE points obtained. Part of this problem may be related to the uneven road surface that did not allow for steady throttle settings as discussed earlier (see Figure Navistar- 4).

Figure Navistar-5: Lean Cruise Cycle 1

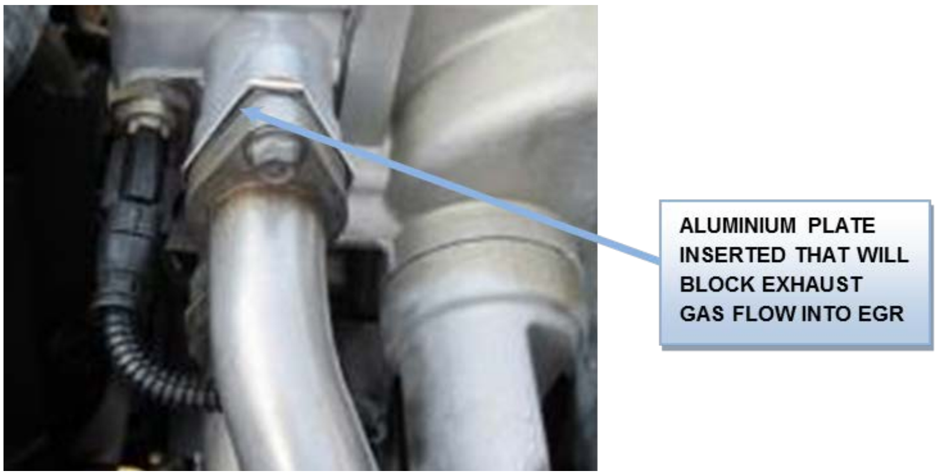


Note: The PEMS values in this figure were measured values taken during this test program while the vehicle was operated under on-road conditions. The NTE NOx is the on-road measurement of NOx emissions that requires specific engine operation and other criterion for attaining this measurement. The NOx family emission limit of 0.50 g/bhp-hr requires emission measurements under laboratory conditions. This standard, in addition to the NTE standard of 0.75 g/bhp-hr and the NTE + 0.15 g/bhp-hr measurement allowance, was provided for general reference only. The PEMS unit used for this operation meets the U.S. EPA requirements per 40 CFR 1065.

c) Vehicle 5 - Restricted EGR Cycle

For the Restricted EGR Cycle staff wanted to investigate what would occur if EGR, used as the vehicle's primary NOx control device, were modified. In the past, blocking the EGR created engine enhancements where the engine had improved power and fuel economy but caused NOx emissions to drastically increase. Staff set out to simulate the effects caused by a plugged EGR cooler or when an EGR valve becomes stuck in the closed position by placing an aluminum plate between the EGR cooler and the EGR transfer pipes (See Figure Navistar-6) to see if there would be any engine enhancement benefits to a current technology engine.

Figure Navistar-6: Restricted Exhaust Flow to EGR



Day 1

The Restricted EGR Cycle began with the odometer at 36,441 miles. As the test route commenced, the driver observed that the vehicle appeared to have sufficient power in low gears at engine revolutions per minute (rpm) levels above 1,400 rpm; however, the vehicle began to experience a surging condition when the driver increased to vehicle speeds of 55 mph and in 10th gear. The surging continued throughout the test cycle and a loss of power at lower engine rpm's was noticed. Staff refueled and filled the tank with 106.9 gallons of diesel fuel (odometer = 36,571 miles) and continued the test route. After driving two more miles (odometer = 36,573 miles) the engine MIL illuminated and the driver continued to experience loss of power and the surging condition throughout the test route. A total of 193 miles (odometer = 36,634 miles) was accumulated at the end of Day 1.

Day 2

Before beginning Day 2's drive, staff utilized a PC based Navistar specific diagnostic scan tool (loaned to ARB from Navistar) to check for engine trouble codes. The *Engine Manufacturer Diagnostic (EMD)* trouble codes were interrogated and an active code for

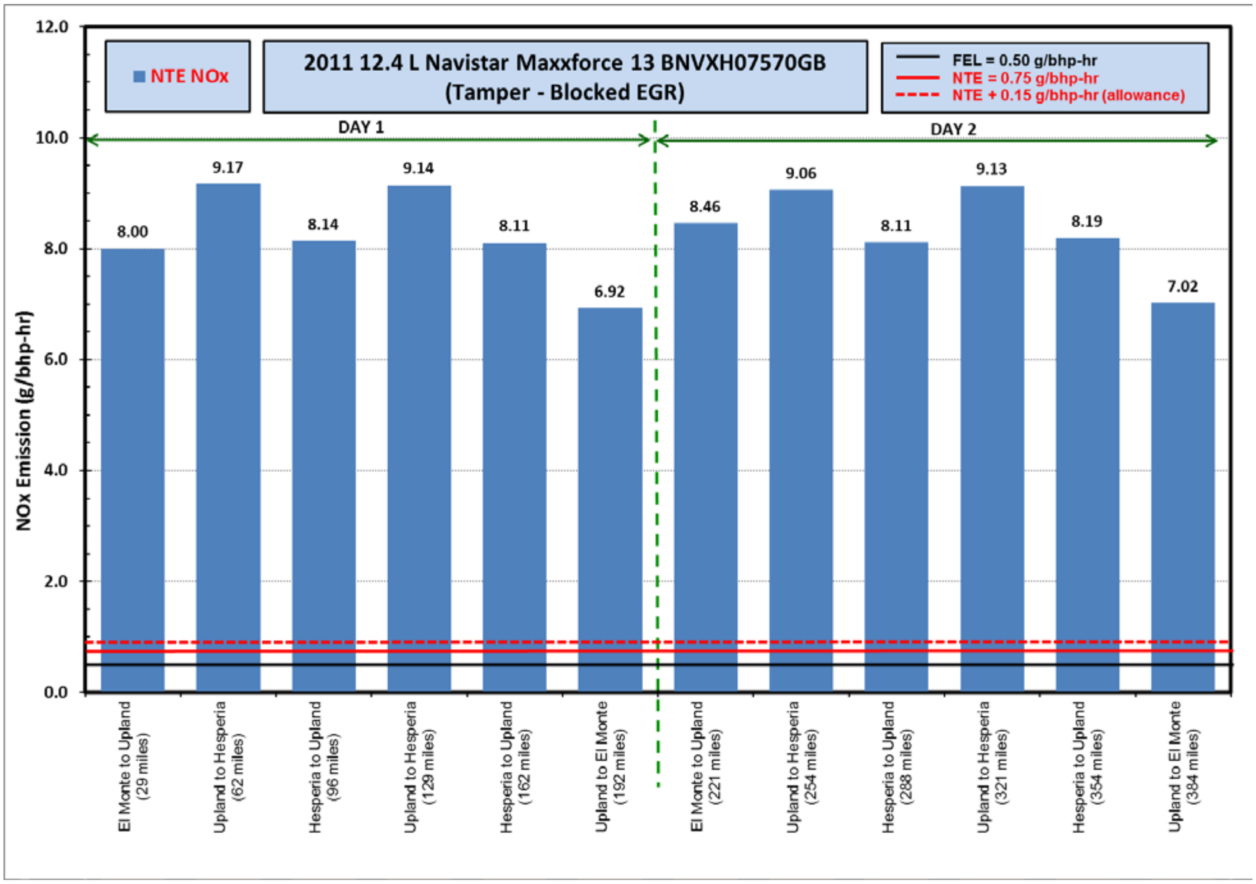
EGR Low Flow Rate Detected was present. The driver ignored the trouble codes and MIL and continued to operate the vehicle over the test route on Day 2 accumulating 194 more miles (odometer = 36,828 miles). This concluded the Restricted EGR Cycle.

Day 3

Staff removed the EGR block off plates and the vehicle was driven for an additional 162 miles (odometer = 36,990 miles) to allow for self-healing of the EGR system. During the drive, the driver performed three key-off/key-on events with the third event extinguishing the illuminated MIL. Once the self-healing had taken place, the diagnostic trouble codes were cleared with Navistar's diagnostic scan tool.

The NOx emission results of the Restricted EGR Cycle are shown in Figure Navistar-7. Keep in mind due to the poor operating conditions of the vehicle during this driving cycle, a driver is not likely to operate the vehicle for very long before seeking repair. The average segment NOx emissions were 8.29 g/bhp-hr and 9.2 times the NTE standard with the NTE allowance of 0.90 g/bhp-hr.

Figure Navistar-7: Restricted EGR Cycle



Note: The PEMS values in this figure were measured values taken during this test program while the vehicle was operated under on-road conditions. The NTE NOx is the on-road measurement of NOx emissions that requires specific engine operation and other criterion for attaining this measurement. The NOx family emission limit of 0.50 g/bhp-hr requires emission measurements under laboratory conditions. This standard, in addition to the NTE standard of 0.75 g/bhp-hr and the NTE + 0.15 g/bhp-hr measurement allowance, was provided for general reference only. The PEMS unit used for this operation meets the U.S. EPA requirements per 40 CFR 1065.

d) Vehicle 5 - Lean Cruise Cycle 2

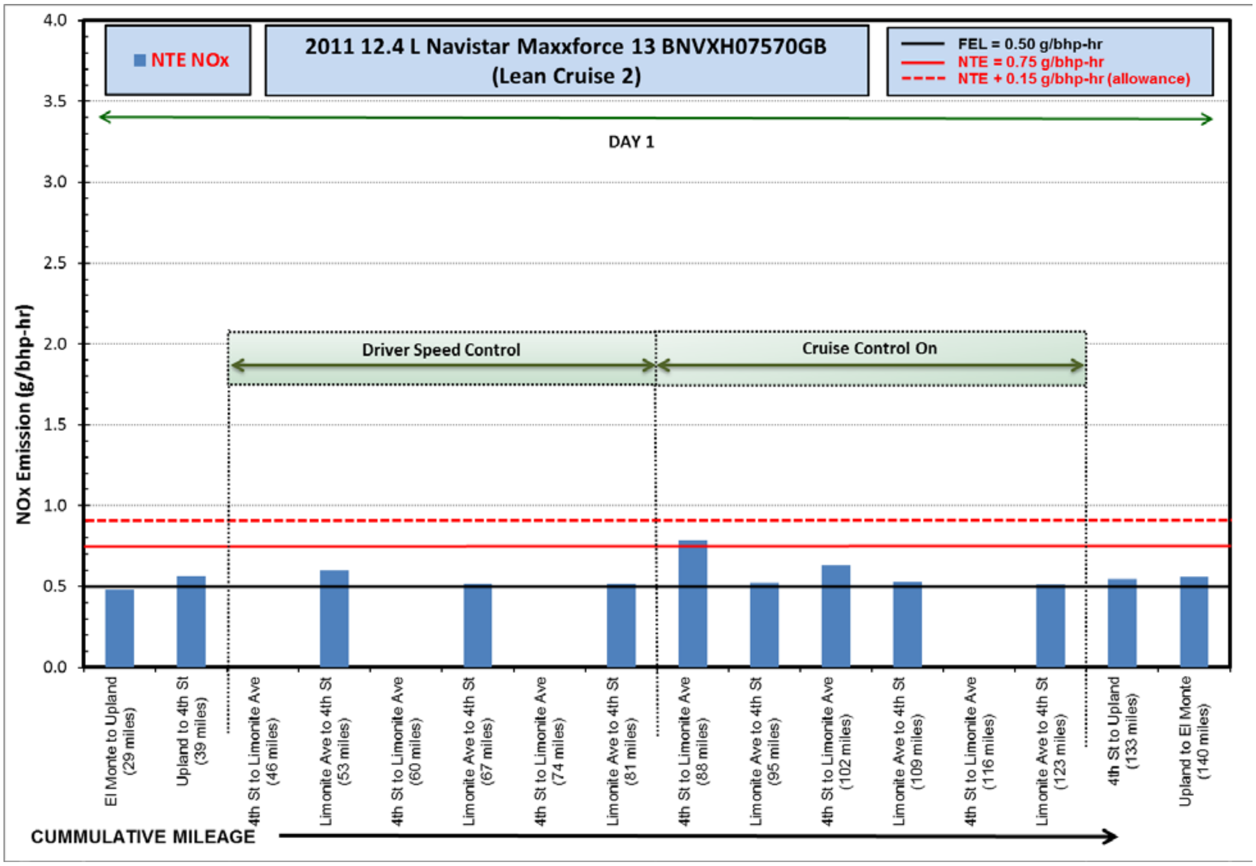
The Lean Cruise Cycle 1 was performed on a section of road that was not ideal for this type of testing. The road had frequent quick elevation changes that would require the driver to constantly adjust the throttle and ultimately would result in varying loads on the engine. Therefore, staff elected to repeat the test cycle on a more suitable route, a more commonly traveled freeway with fewer short elevation changes. The subsequent test cycle is referred to as the Lean Cruise Cycle 2, which is discussed below and shown in Attachment D as an enclosure titled “Lean Cruise Test Route”.

Day 1

The driver left El Monte to begin the Lean Cruise Cycle 2, the final test for this vehicle, with an odometer reading of 36,990 miles. Staff left El Monte, drove 39 miles towards Route 15 and immediately began the driver modulated portion of the designated test route (odometer = 37,026 miles). The constant speed part of the test route involved an approximate seven mile drive on Interstate 15 between 4^{th} street and Limonite Ave. Staff drove three round trips along the this test route, holding the vehicle speed at approximately 55 mph and then three round trips were performed with the vehicle cruise control set at 55 mph, totaling 96 accumulated miles (odometer = 37,122 miles). The driver returned to El Monte and noted that overall, the vehicle drove well with no associated problems and was operated for 174 miles under this test cycle (odometer = 37,164 miles).

The average segment results of the Lean Cruise Cycle 2 are graphed in Figure Navistar-8. Again, the trend of higher NOx emissions were seen when the vehicle was driving with the cruise control on (0.595 g/bhp-hr – cruise control vs. 0.547 g/bhp-hr – driver modulated). Additionally, in three of the six driver controlled NOx segments there were no NTE qualifying points when traveling from Limonite Ave to 4^{th} street and this occurred once with the cruise control on. Again, this may have been related to the elevation change of the road. Finally, all of the qualifying NTE NOx emissions were within the 0.90 g/bhp-hr NTE allowance level.

Figure Navistar-8: Lean Cruise Cycle 2

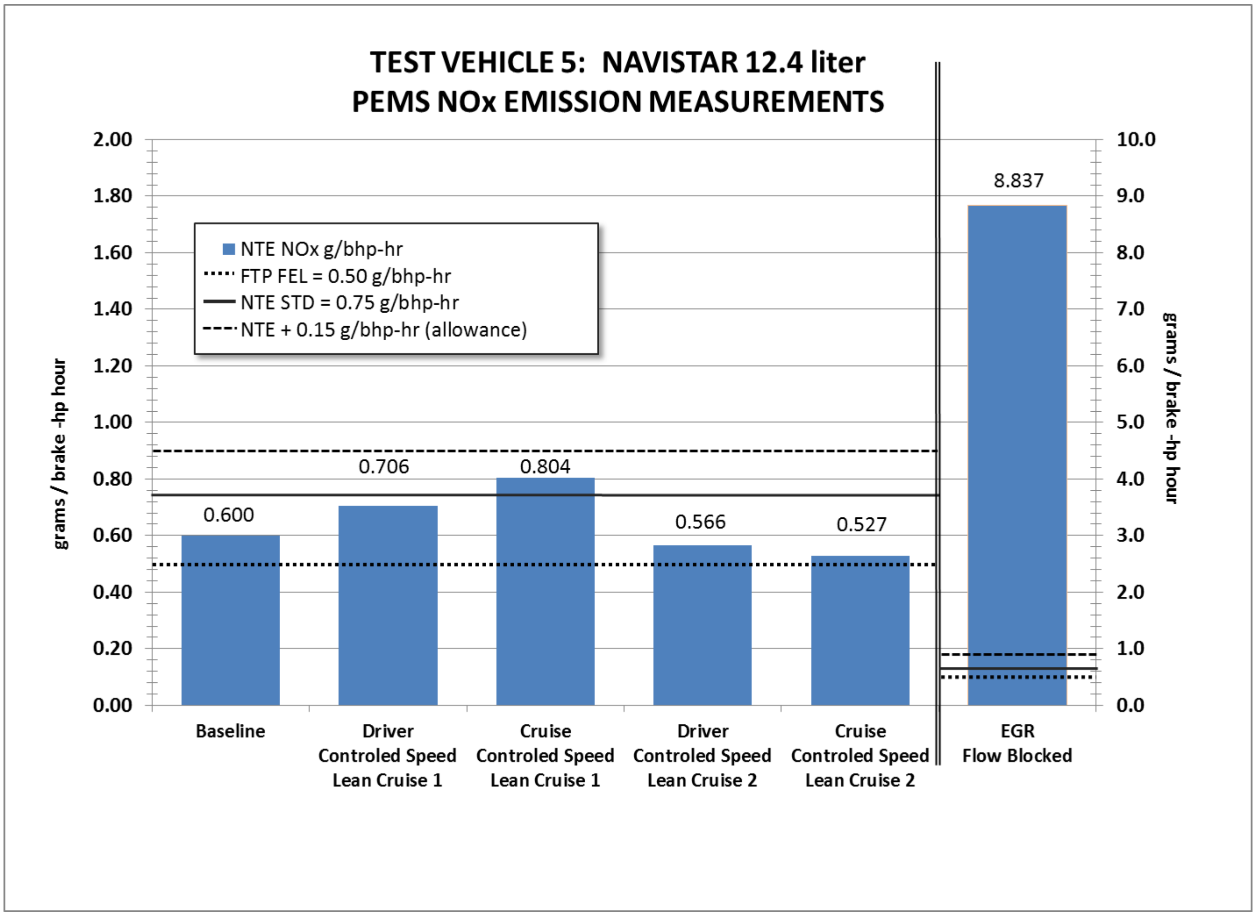


Note: The PEMS values in this figure were measured values taken during this test program while the vehicle was operated under on-road conditions. The NTE NOx is the on-road measurement of NOx emissions that requires specific engine operation and other criterion for attaining this measurement. The NOx family emission limit of 0.50 g/bhp-hr requires emission measurements under laboratory conditions. This standard, in addition to the NTE standard of 0.75 g/bhp-hr and the NTE + 0.15 g/bhp-hr measurement allowance, was provided for general reference only. The PEMS unit used for this operation meets the U.S. EPA requirements per 40 CFR 1065.

e) Vehicle 5 - Emissions Measurements

A summary of the NOx emissions that were measured for the Navistar 12.4L engine for all the test cycles is shown below (see Figure Navistar-9). As mentioned previously, the field evaluations were performed using the following cycles: the Baseline Cycle, the Lean Cruise Cycle 1, the Restricted EGR Cycle, and the Lean Cruise Cycle 2. The emissions represent the NTE zones measured for each test cycle with the corresponding NTE standard and the FEL standard indicated. The FEL of 0.5 g/bhp-hr, is the standard the engine must meet during an engine dynamometer test while operating under laboratory conditions and for reference only.

Figure Navistar-9: NOx Emission Data Summary



Note: The PEMS values in this figure were measured values taken during this test program while the vehicle was operated under on-road conditions. The Family Emission Limit (FEL) 0.5 g/bhp-hr NOx standard requires emission measurement under laboratory conditions and the Not to Exceed (NTE) 0.75 g/bhp-hr standard requires specific on-road operation for attaining emission measurements. These standards were provided for general reference only. The PEMS unit used for this operation meets the U.S. EPA requirements per 40 CFR 1065.

f) Vehicle 5 - Test Summary

When the Navistar 12.4L engine was performing under normal vehicle operation, the engine ran well and was capable of moving the load over the designated test route and NOx emissions were within the NTE. However, with the EGR disabled, the NOx emissions were 9.3 times above the NTE limit, engine performance suffered, the vehicle exhibited surging at the lower engine operating range, and reduced fuel economy by 9.1 percent. ARB does not believe that a driver would tolerate the surging condition and loss of power at lower engine RPM’s where the engine would typically operate. With the sophistication of today’s engines and the risk of costly engine repairs, owners would be reluctant to create tampering events such as blocking off the functionality of the EGR valve especially since there is no performance benefit. In regards to the Lean Cruise Cycle evaluation, the first test run was conducted on a road that was not conducive for this type of test so staff elected to use another stretch of road that had less elevation changes. The emission data from the Lean Cruise Cycle 2 evaluation showed that the NOx emissions did increase by almost nine percent when setting the cruise control but overall still met the NTE Allowance Level.

D. Emission Evaluation of NOx Control Strategies

When considering the NOx control strategies of the three trucks (DDC, Volvo and Navistar) staff evaluated them under the Evaluation of 2010+ NOx Control Strategies. Staff compared the total accumulated baseline NOx emissions for each segment driven in the designated test route (see Figure 13 – Baseline Summary of Total Accumulated NOx Per Segment Driven). Each truck was operated over the same test route for establishing three baseline cycles with driven segment intervals amounting to approximately 30 to 33 miles traveled per segment.

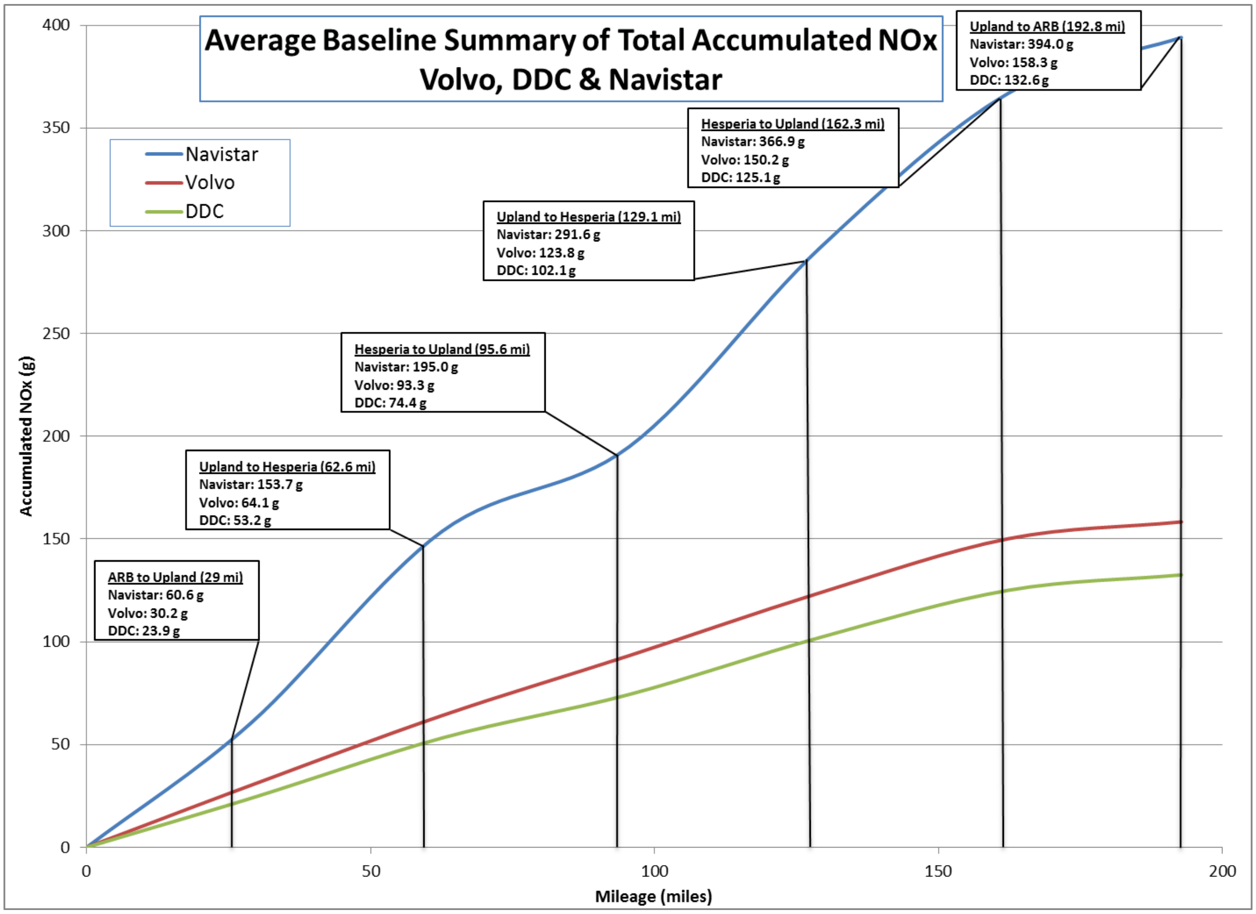
Figure 13: Baseline Summary of Total Accumulated NOx Per Segment Driven

	TOTAL NOx (grams) Per Measured Drive Segment						
	ARB to Upland	Upland to Hesperia	Hesperia to Upland	Upland to Hesperia	Hesperia to Upland	Upland to ARB	Total NOx
Volvo (Baseline 1)	42.6	28.7	33.4	26.8	31.9	5.8	169.1
Volvo (Baseline 2)	20.7	34.9	26.1	34.5	25.8	9.1	151.0
Volvo (Baseline 3)	27.4	38.1	28.2	30.1	21.5	9.6	154.9
Average	30.2	33.9	29.2	30.5	26.4	8.2	158.3
DDC (Baseline 1)	24.0	29.4	18.0	28.2	20.4	6.4	126.3
DDC (Baseline 2)	23.7	30.4	23.5	29.7	25.5	10.2	143.1
DDC (Baseline 3)	24.2	27.9	22.2	25.2	23.1	5.9	128.4
Average	23.9	29.3	21.2	27.7	23.0	7.5	132.6
Navistar (Baseline 1)	65.6	81.9	53.2	91.9	53.4	25.6	371.6
Navistar (Baseline 2)	65.5	103.9	22.2	116.2	124.4	29.9	462.0
Navistar (Baseline 3)	50.8	93.5	48.4	81.6	48.2	26.1	348.6
Average	60.6	93.1	41.3	96.5	75.3	27.2	394.0

The chart shows the total NOx emissions measured for each given segment and the final total NOx emissions measured for each measured baseline. Also shown are the average baseline total NOx emissions for each segment along with the average total NOx baseline average.

Staff graphed the total average NOx emissions for each truck's baseline emissions data (see Figure 14 – Average Baseline Summary of Total Accumulated NOx) as NOx is accumulated over the given test route. The DDC and Volvo trucks equipped with SCR technology are certified to the 0.2 g/bhp-hr NOx standard and the Navistar truck, which mainly utilizes EGR to control NOx (i.e., no SCR), is certified to the 0.5 g/bhp-hr NOx FEL. Intriguingly, the SCR-equipped engines are certified 2.5 times lower than the non-SCR Navistar engine which is the same difference when considering the baseline NOx emissions data (i.e., the SCR-equipped engines NOx levels were approximately 2.5 times lower than the non-SCR engine). When considering the NOx control strategy efficiency, this study clearly shows that the engines with SCR technology outperformed the EGR-only equipped engine for controlling NOx.

Figure 14: Average Baseline Summary of Total Accumulated NOx



VII. Overall Conclusions

The widespread availability of DEF was shown to be increasing in California based on the surveys conducted in 2010 and now even more so with the survey conducted in 2012. Based on the 2012 survey, the number and the type of retailers have vastly grown in the last year and half and DEF has become much easier to attain at the refueling pump at a growing number of truck stops. With DEF readily available, this allows truck operators to find DEF before vehicles experience disablement due to SCR related inducements. ARB also demonstrated that truck operators of SCR equipped trucks are adding DEF to their trucks and not risking SCR induced engine problems due to contaminating or tampering with their SCR systems. Based on the tampering surveys conducted in 2010 and 2012, a total of 308 trucks had no identifiable DEF contamination issues or other tampering indications. As an additional deterrent, ARB's Enforcement Division is checking for tampered SCR systems as part of the Heavy Duty Vehicle Inspection Program. With the additional risk of receiving costly citations, the ARB believes that truck operators will continue to keep their vehicles filled with quality DEF.

ARB's evaluation of the four SCR equipped HDD vehicles demonstrated that the warnings and inducement strategies incorporated by the engine manufacturers were mostly consistent with both the 2010 MY Guidance and the 2011+ MY Guidelines (see Figure 11 and 12). The main issues identified dealt with timing concerns to reach the first driver warning or seeking a safe harbor but no hardware issues were identified. Shown in the figure below is a summary of how each of the SCR vehicles performed during the 2011 evaluation as compared to the 2011+ MY Guidelines (see Figure 15).

Figure 15 – Test Vehicles Results per the 2011+ MY Guidelines

Test Vehicle	DEF Depletion Cycle	DEF Contamination Cycle	DEF System Tampering Cycle	Comments
#1 Cummins 6.7L	YES	NO*	NO*	* When conducting a contamination, tampering, and a re-tampering event, the vehicle did not search for safe harbor within 4 hours after initiating the first driver warning (1 hour guidance for the repeat offense event); however, the engine is a 2010 MY certified engine and was consistent with the 2010 MY Guidance. **Corrective action: Chrysler Technical Service Bulletin (No. 18-029-11) corrected these issues.**
#2 Cummins 14.9L	YES	NO**	YES	**The DEF Contamination Cycle took approximately 2 hours (105 miles) to launch the first driver warning; outside of the one hour guidance; however, the engine is a 2010 MY certified engine and was consistent with the 2010 MY Guidance.
#3 DDC 12.8L	YES	YES	NO***	***Under the DEF System Tampering Cycle the engine was not fully consistent with the intended objectives of the guidelines.
#4 Volvo 12.8L	YES	YES	YES	No Comments

Staff found only minor issues with two of the vehicles using SCR strategies. One problem involved the Cummins 6.7L engine where the vehicle did not search for a safe harbor after four hours of achieving the first driver warning. Cummins identified this problem in early 2011 and issued a service campaign (Chrysler Technical Service Bulletin No. 18 -29-11) in March 2011 to correct this matter. The other issue involved the Cummins 14.9L engine which did not activate the first driver warning for the DEF Contamination Cycle within one hour; the SCR system was able to activate the first driver warning after two hours. This issue may not have been fully consistent with the 2011+ MY Guidelines since the actual noncompliance point was not able to be ascertained; however, the vehicle did reach a safe harbor inside of four hours (consistent with the guidance) and the vehicle experienced severe engine derate while undergoing this cycle. The ARB believes any driver would have immediately remedied this matter because the derate condition was unacceptable and would not be tolerated. ARB is currently discussing the results of this cycle with Cummins because the SCR inducements seemed to function with expected results of the 2011+ MY Guidelines with the exception of initiating the first driver warning. Based on discussions and feedback from Cummins, ARB may consider conducting another evaluation on this vehicle to evaluate the DEF Contamination Cycle again to confirm results.

In the case of the Navistar 12.4L engine, the main NOx control for this engine is the EGR system. ARB discovered that blocking off the EGR system will cause NOx emission to increase well beyond any of the other SCR controlled trucks even if the SCR vehicles are tested with a tampered SCR condition. However, like the SCR vehicles, the Navistar's drivability problems associated with a blocked EGR valve is so significant that truck operators are not going to tamper with the EGR control system in this manner. ARB also showed that when comparing baseline NOx emissions, the Navistar total NOx emission levels were almost three times the emission levels of the SCR equipped controlled trucks. This trend indicates that the SCR technology has a far better ability to reduce NOx emissions based on the routine freeway driving as performed under this test project.

The technology of today's HDD engines does not lend itself to be tinkered with and the advancement of SCR has shown that the engine monitoring technology will create intolerable engine inducement issues when DEF depletes to empty or the SCR system is tampered. In short, staff believes that companies and truck operators will simply not tamper with their HDD vehicles and risk costly repairs and/or possible fines especially when these changes will cause the engine's power to degrade causing delivery delays and general inconvenience.

VIII. Appendices

Appendix A – DEF Availability Survey

Air Resources Board

Mary D. Nichols, Chairman
9480 Telstar Avenue, Suite 4
El Monte, California 91731 • www.arb.ca.gov

Matthew Rodriquez
Secretary for Environmental Protection

Edmund G. Brown Jr.
Governor

TO: Annette Hebert, Chief
Mobile Source Operations Division

THROUGH: Thong Sten
Lab Testing Support Section

FROM: John M. Urkov, Chief
In-Use Vehicle Programs Branch

DATE: February 15, 2012

SUBJECT: DEF AVAILABILITY SURVEY 2012
PROJECT NO. (Project Numbers No Longer Issued For Surveys)

As a follow up to the DEF Availability Survey conducted in March 2010 and August 2010, ARB staff is conducting a third survey to evaluate the availability of DEF throughout California. The survey is being conducted by MSOD's Field Operations and Warranty Section (FOWS) and Heavy-Duty Diesel Inspection and Maintenance Section (HDDIMS) and final data analysis will be performed by the In-Use Compliance Section. HDDIMS staff will begin this survey on Friday February 10, 2012, and the FOWS staff will start on February 15, 2012. This survey is estimated to take no more than two weeks to complete.

For the upcoming DEF availability survey, field staff will again visit random retailers checking for the availability to purchase DEF. The FOWS staff will survey Southern California and part of Central California and the HDDIMS staff will survey the northern areas of California. This includes routes along major freeways such as Interstate 5, Interstate 99, Interstate 10, Interstate 15, and U.S. Highway 101. It is important to have a stronger emphasis to visit the truck stop stations and a lesser emphasis on a retail store.

These truck stop facilities are typically where the California's trucking population purchase diesel fuel and other products/services that are required by a truck driver. For this reason field staff should visit as many of these truck stops as possible to check DEF availability. In addition, since the availability of DEF has been increasing, field staff will spend a portion of their time visiting retailers such as Walmart, Autozone, and O'Reilly throughout the state.

If any questions should arise during this survey, field staff should contact Tony Dickerson at (626) 459-4350 or Tom Valencia at (626) 575-6741.

Attachment

Test Plan

DEF Availability Study 2012

Project Number:

February 2012

Project Engineer:
Tony Dickerson

In-Use Compliance Section
In-Use Vehicle Programs Branch
Mobile Source Operations Division
Air Resources Board
Haagen-Smit Laboratory
9528 Telstar Avenue
El Monte, CA 91731

TEST PLAN

SCR / DEF Tampering Study

I. SCOPE

As a follow up to the DEF Availability Survey conducted in March 2010 and August 2010, ARB staff is conducting a third survey to evaluate the availability of DEF throughout California. The survey is being conducted by MSOD's Field Operations and Warranty Section (FOWS) and Heavy-Duty Diesel Inspection and Maintenance Section (HDDIMS) and final data analysis will be performed by the In-Use Compliance Section. HDDIMS staff will begin this survey on Friday February 10, 2012, and the FOWS staff will start on February 15, 2012. This survey is estimated to take no more than two weeks to complete.

For the upcoming DEF availability survey, field staff will again visit random retailers checking for the availability to purchase DEF. The FOWS staff will survey Southern California and part of Central California and the HDDIMS staff will survey the northern areas of California. This includes routes along major freeways such as Interstate 5, Interstate 99, Interstate 10, Interstate 15, and U.S. Highway 101. It is important to have a stronger emphasis to visit the truck stop stations and a lesser emphasis on a retail store.

The information contained in Table 1 below, shows the location (city and roadway) for almost all of the truck stops in California. These truck stop facilities are typically where the California's trucking population purchase diesel fuel and other products/services that are required by a truck driver. For this reason field staff should visit as many of these truck stops as possible to check DEF availability. In addition, since the availability of DEF has been increasing, field staff will spend a portion of their time visiting retailers such as Walmart, Autozone, and O'Reilly throughout the state. Field staff will take digital pictures of where DEF is available in the store or on a service island and note the prices of DEF on the shelf or from a dispenser.

II. PROGRAM MANAGEMENT

Staff from the ARB In-Use Compliance Section will be designated as the project engineer, and will be responsible for administering this test program. The project engineer will be the contact person for all issues relating to the completion of this program.

Additional MSOD staff assisting in the DEF Availability Study will come from the Field Operations & Warranty Section and the Heavy-Duty Diesel Inspection and Maintenance Development Section.

III. SURVEY LOCATIONS

Survey locations will include various locations throughout the state of California. Locations shall include but not limited to the Truck Stop Locations in California shown in Table 1.

IV. DOCUMENTATION

Completion of the survey form will be filled out for each location visited (see Figure 2). This form must be filled out completely and legibly and ARB staff should not use abbreviations or acronyms.

V. DATA MANAGEMENT

All documents and any notes taken will be provided to the project engineer.

VI. VERIFICATION OF TEST DATA

No data will be taken so there will be nothing to verify and send to VEDS.

Enclosures

TABLE 1

TRUCK STOP LOCATIONS IN CALIFORNIA

CITY	HIGHWAY	TRUCK STOP
ACAMPO	CA 99 N	JAHANT FOOD & FUEL
BAKER	I-15	BAKER SHELL
BAKER	I-15	BANDIT VALERO
BAKER	I-15	RASOR ROAD SERVICES
BAKERSFIELD	CA 58 & CA 184	24X7 TRAVEL PLAZA
BAKERSFIELD	CA 58 & CA 184	BRUCE'S TRUCK STOP
BAKERSFIELD	CA 58 & CA 184	KIMBER RENEGAD SHELL
BAKERSFIELD	HWY 99	FLYING J
BARSTOW	I-15	AMERICAN TRAVEL CENTER
BARSTOW	I-15	FLYING J
BARSTOW	I-15	PILOT
BARSTOW	I-15	TA
BLYTHE	I-10	BB TRAVEL CENTER
BORON	US 395 & CA 58	PILOT
BUTTONWILLOW	I-5	TA
CABAZON	I-10	CABAZON TRUCK STOP
CASTIC	I-5	PILOT
CASTIC	I-5	VILLAGE TRUCK STOP
CHOWCHILLA	CA 152	RED TOP TRUCK STOP
CHOWCHILLA	CA 152	RED TOP TRUCK STOP
COACHELLA	I-10	INDIO TRUCK STOP
COACHELLA	I-10	LOVES
COACHELLA	I-10	TA
COLTON	I-10	ROYAL TRUCK STOP
CORNING	I-5	FLYING J
CORNING	I-5	PETRO STOPPING CENTER
CORNING	I-5	TA
DELANO	CA 99	AKAL TRAVEL PLAZA
DUCOR	HWY 65 & 56TH AVE	A&A SHELL
DUNNIGAN	I-5	PILOT
DUNNIGAN	I-5	UNITED PETROLEUM
EL CENTRO	I-8	ON THE GO TRAVEL CENTER
EL CENTRO	I-8	TRUCK STOP 111
FENNER	I-40	HI SIERRA OASIS
FIREBAUGH	I-5	MBP TRAVEL PLAZA
FONTANA	I-10	N AMERICAN TRUCK STOP

FONTANA	I-10	THREE SISTERS TRUCK STOP
FONTANA	I-10	TRUCK TOWN TRUCK & TRAVEL PLAZA
FORTUNA	US 101 & CA 36	HANSEN TRUCK STOP
FOWLER	CA 99	BUFORD STAR MART
FRAZIER PARK	I-5	FLYING J
FRESNO	CA 99	5TH WHEEL TRUCK STOP
FRESNO	CA 99	EZ TRIP GOLDEN TRAVELCENTERS PLAZA
GILROY	CA 101 S & MONTEREY RD	GARLIC FARM CENTER
GILROY	CA 101 S & MONTEREY RD	GARLIC FARM CENTER
GOSHEN	CA 99	GOSHEN TRAVEL PLAZA
HALLELUJAH JCT	US 395/CA 70	HALLELUJAH JCT SHELL
HESPERIA	I-15	PILOT
HOLLISTER	CA 152	CASA DE FRUTA (CHEVRON)
HOLLISTER	CA 152	CASA DE FRUTA (CHEVRON)
KINGS CITY	US 101	BEACON/VALERO TRUCK STOP
KRAMER JUNCTION	US 395	PILOT TRAVEL CENTER
LAGRANDE	CA 99	MERCED TRUCK STOP
LIVE OAK SPRINGS	I-8	GOLDEN ACORN CASINO
LODI	I-5	3 B'S TRUCK/AUTO PLAZA
LODI	I-5 & HWY 12	FLYING J
LOST HILLS	I-5	LOSTHILLS TRAVEL CENTER
LOST HILLS	I-5	LOVES
LOST HILLS	I-5	PILOT
MADERA	CA 99	PILOT
MECCA	90480/66TH AVE	MECCA TRAVEL CENTER
MODESTO	CA 99	COUNRTY GIRL TRUCK STOP
NEWBERRY SPRINGS	I-40	WESCO FUEL N FOOD
NORTH PALM SPRINGS	I-10	PILOT
OCOTILLO	I-8	DESERT FUEL STOP
ONTARIO	I-10	TA
ONTARIO	I-10	TA
OTAY MESSA	AVE DE LA FUENTE	TRUCK NET
PALM SPRINGS	I-10	PILOT TRAVEL CENTER
PASO ROBLES	US 101	SAN PASO TRUCK & AUTO
PEARBLOSSOM	CA 138	CHEVERON
PEARBLOSSOM	CA 138	CHEVERON
PEARSONVILLE	US 395	PEARSONVILLE TRUCKSTOP
POLLARD FLAT	I-5	POLLARD FLAT USA
PORTERVILLE	HWY 65	TRUCKERS MINI MART

PUMPKIN CENTER	CA 99	BEAR MOUNT TRAVEL STOP
REDDING	I-5	TA
RIALTO	I-10	I-10 TRUCK STOP
RIALTO	S RIVERSIDE & AGUA MANSA	RIALTO TRAVEL CENTER
RIPON	CA 99	JIMCO TRUCK PLAZA
RIPON	CA 99	LOVES
RIPON	HWY 99	FLYING J
S SAN FRANCISCO	US 101 & GRAND	GATEWAY FLYERS
SACRAMENTO	CA 99	DHAMI TRUCK PLAZA
SACRAMENTO	I-80	SACRAMENTO 49 TRAVEL PLAZA
SACRAMENTO (WEST)	I-80	WEST SACRAMENTO TRUCK STOP
SALINAS	US 101 & S SANBORN W	PILOT
SALINAS	US 101 AIRPORT BLVD	VALLEY TRUCK STOP
SALTON SEA BEACH	CA 86	TORRES MARTINEZ TRAVEL CENTER
SAN LUIS	CA 152	PETRO 2
SAN LUIS	CA 152	PETRO 2
SANTA MARIA	US 101 & BETTERAVEIA RD	VALLEY PACIFIC PETROLEUM
SANTA NELLA	I-5	PILOT
SANTA NELLA	I-5	ROTTEN ROBBIES
SANTA NELLA/LOS BANOS	I-5	PETRO STOPPING CENTER
SANTS NELLA	I-5	TA
SELMA	CA 99	EVEREST PETROLEUM
STOCKTON	I-5	VANCO TRUCK/AUTO PLAZA
THOUSAND PALMS	I-10 RAMON EXIT	FLYING J
TRACY	I 205	TRACY TRUCK AND AUTO
TRAVER	CA 99	RJ TRAVEL CENTER
TULARE	CA 99 S	ROCHE OIL TRUCK STOP
UKIAH	US 101	JENSEN'S TRUC STOP
VICTORVILLE	US 395	HIGH DESERT TRAVEL PLAZA
WEED	I-5	TRAVELER'S TRAVEL PLAZA
WESTLEY	I-5	CHEVERON
WESTLEY	I-5	JOE'S TRAVEL PLAZA
WHEELER RIDGE	I-5	TA
WHEELER RIDGE/LEBEC	I-5	PETRO STOPPING CENTER
WILMINGTON	ALAMEDA & EU BANKS	SPEEDY FUEL
YERMO	I-15	GHOST TOWN MINI-MART
YERMO	I-15	MOHSEN OIL

FIGURE 1 – SURVEY FORM

Attach Business Card Here
or Enter Contact Information Below

STATE OF CALIFORNIA AIR RESOURCES BOARD DIESEL EXHAUST FLUID (DEF) FIELD SURVEY FORM

ARB STAFF ____________________________ SURVEY DATE ________________

FACILITY TYPE: Truck Stop ____ Auto Parts Retailer _____ Retail ______
Gas Station Selling Diesel _______ Other: _________________________________

FACILITY NAME ____

CONTACT PERSON ___________________________ PH. NO. (___) ________________________

ADDRESS ____

CITY ________________________ COUNTY _______________________ ZIP ___________________

1) How is it sold/dispensed? (check all and enter price)	
Containers: **1gal [ ] __gal [ ] __gal [ ] __gal [ ] Tote _____gal[ ]** **Price: $ ______ $ ______ $ ______ $ ______ $ __________**	**Bulk/metered pump:** **Installed? Yes[ ] No [ ]** **$ _________ per gal**
2) How Often do you run out of stock?	
If DEF on site: **Was availability of product noticeable? Yes [ ] Neutral [ ] Not at all [ ]** **Is customer assistance needed to obtain product? Yes [ ] No [ ]**	
Pictures taken? Y[ ] N [ ] Additional comments:	
END SURVEY!	

Appendix B – SCR / DEF Tamper Survey

Matthew Rodriquez
Secretary for Environmental Protection

Air Resources Board

Mary D. Nichols, Chairman
9480 Telstar Avenue, Suite 4
El Monte, California 91731 • www.arb.ca.gov

Edmund G. Brown Jr.
Governor

TO: Annette Hebert, Chief
Mobile Source Operations Division

THROUGH: Thong Sten
Lab Testing Support Section

FROM: John M. Urkov, Chief
In-Use Vehicle Programs Branch

DATE: 10-11-2011

SUBJECT: SCR / DEF TAMPERING STUDY 2011
PROJECT NO. 2R1109
(REV 9-29-2011 TEST PLAN)

In September 2010, ARB staff conducted roadside inspections of diesel exhaust fluid (DEF) on heavy-duty trucks and measured the urea concentration in their selective catalytic reduction (SCR) systems. These heavy-duty truck inspections were held at various northern and southern California Highway Patrol (CHP) commercial vehicle weigh stations and were specific to heavy-duty trucks utilizing SCR systems for oxides of nitrogen (NOx) control.

SCR was first introduced on a majority of the 2010 model year (MY) heavy-duty diesel engines to meet the 0.20 gram per brake horsepower-hour NOx emission standard. For the SCR system to operate properly, unlike most emission control systems, the driver must periodically replenish the required reductant needed to catalyze the NOx conversion. This reductant is the standardized solution of 32.5% urea in 67.5% water, commonly known as DEF.

ARB has developed a new test project that is similar to the roadside inspection conducted in September 2010. Staff will again be dispatched to CHP commercial weigh stations to survey approximately 100 SCR equipped heavy-duty trucks and measure the urea concentration of the trucks DEF tank. The survey is scheduled for early November 2011 and is expected to take approximately two weeks to complete.

The In-Use Compliance Section will coordinate the SCR / DEF Tampering Study of urea concentration in DEF from the heavy-duty truck inspections. The inspections will be conducted by ARB's Mobile Source Operations Division's Field Operations & Warranty

Section and Heavy Duty Diesel Inspection and Maintenance Development Section field staff. Also, assisting in the inspections will be ARB's Enforcement Division - Heavy Duty Diesel Enforcement Section.

Attachment

Test Plan

SCR / DEF Tampering Study 2011

Project Number:
2R1109

September 2011

Project Engineer:
Vickie Stoutingburg-Alewine

In-Use Compliance Section
In-Use Vehicle Programs Branch
Mobile Source Operations Division
Air Resources Board
Haagen-Smit Laboratory
9528 Telstar Avenue
El Monte, CA 91731

TEST PLAN

SCR / DEF Tampering Study

I. SCOPE

The primary objective of this test plan is to inspect the concentration of urea sampled from the selective catalytic reduction (SCR) system on heavy-duty trucks during roadside inspections. These heavy-duty truck inspections will be held at various northern and southern California Highway Patrol (CHP) commercial vehicle weigh stations and will be specific to heavy-duty trucks utilizing the SCR system for NOx control.

SCR was first introduced on a majority of the 2010 model year (MY) heavy-duty diesel engines to meet the 0.20 gram per brake horsepower-hour NOx emissions standard. For the SCR system to operate properly, unlike most emission control systems, the driver must periodically replenish the required reductant needed to catalyze the NOx conversion. This reductant is the standardized solution of 32.5% urea in 67.5% water, commonly known as DEF.

ARB has developed a new test project that is similar to the roadside inspection conducted in September 2010. Staff will again be dispatched to CHP commercial weigh stations to survey approximately 100 SCR equipped heavy-duty trucks and measure the urea concentration of the trucks DEF tank. The survey is scheduled for early November 2011 and is expected take approximately two weeks to complete.

II. PROGRAM MANAGEMENT

Staff from the ARB In-Use Compliance Section will be designated as the project engineer, and will be responsible for administering this test program. The project engineer will be the contact person for all issues relating to the completion of this program.

Additional MSOD staff assisting in the SCR / DEF Tampering Study will come from the Field Operations & Warranty Section and the Heavy-Duty Diesel Inspection and Maintenance Development Section. Also participating in the inspections will be staff from ARB Enforcement Division’s (ED) Heavy-Duty Diesel Enforcement Section.

III. <u>TEST EQUIPMENT</u>

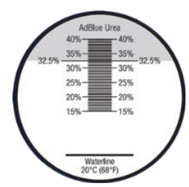
A DEF specific refractometer will be used to analyze the concentration of urea in each test sample. The refractometer will measure the bending (refraction) of light through a liquid, used to determine the refractive index of a sample.
Samples of DEF will be drawn from the DEF tank with a clean section of flexible tubing.

IV. <u>VISUAL OBSERVATION PROCEDURES</u>

a. Turn ignition to key-on/engine-off, check warning lights and document any that are not illuminated.
b. Turn on engine with all vehicle doors closed, and document any audible warnings and any illuminated warning lights on the dash or any SCR/DEF related messages in the vehicle information center.

V. <u>DEF SAMPLING TEST PROCEDURES</u>

a. Begin each test with a Zero Adjustment by applying a few drops of distilled water on the prism. If needed, turn the adjustment screw until the light / dark boundary is in-line with the waterline reference point.
b. Locate and collect a small sample of liquid from the vehicle's DEF tank being careful not to contaminate the sample.
c. Open the prism cover on the refractometer and apply a few drops of DEF sample onto the clean prism window.
d. Close the prism cover. This will allow the DEF sample to spread over the prism window, and remove any air pockets or air bubbles.
e. Observe where the light / dark boundary intersects the AdBlue Urea scale and document this value as the concentration of urea. For pure DEF the concentration of urea is 32.5%, which is indicated on the AdBlue Urea scale.



f. After the reading has been taken, wipe dry with a clean cloth (do not wash or rinse) the prism window and the prism cover.
g. If reading is ≤ 25%, obtain a sample of DEF. Sample containers will be provided and must be stored in dark containers, e.g. trunk of vehicles, to be given to the project engineer. The containers must be labeled with the label provided by the project engineer. See Enclosure 1.

VI. <u>TEST LOCATIONS</u>

Various test locations in Southern California, as well as Sacramento, will be utilized for the survey. See Enclosure 2.

VII. <u>VEHICLE SELECTION</u>

Test vehicles must be heavy-duty diesel powered trucks equipped with SCR NOx control systems strategy. To eliminate duplicates, ARB staff will issue blue colored certificates to show the heavy-duty truck has gone through ARB's inspection previously. See Enclosure 3.

VIII. DOCUMENTATION

Completion of the SCR / DEF Tamper Study Information sheet will be required for the survey. This form must be filled out completely and legibly and ARB staff should not use abbreviations or acronyms. See Enclosure 4

IX. DATA MANAGEMENT

All documents and any notes taken will be provided to the project engineer.

X. VERIFICATION OF TEST DATA

No data will be taken so there will be nothing to verify and send to VEDS.

Enclosures

Enclosure 1

Project #2R1109 Date:_______________

Last 6 Vin#:_______________ Int.:_________

DEF Distributer:__________________________

Project #2R1109 Date:_______________

Last 6 Vin#:_______________ Int.:_________

DEF Distributer:__________________________

Project #2R1109 Date:_______________

Last 6 Vin#:_______________ Int.:_________

DEF Distributer:__________________________

Project #2R1109 Date:_______________

Last 6 Vin#:_______________ Int.:_________

DEF Distributer:__________________________

Project #2R1109 Date:_______________

Last 6 Vin#:_______________ Int.:_________

DEF Distributer:__________________________

Project #2R1109 Date:_______________

Last 6 Vin#:_______________ Int.:_________

DEF Distributer:__________________________

Project #2R1109 Date:_______________

Last 6 Vin#:_______________ Int.:_________

DEF Distributer:__________________________

Project #2R1109 Date:_______________

Last 6 Vin#:_______________ Int.:_________

DEF Distributer:__________________________

Project #2R1109 Date:_______________

Last 6 Vin#:_______________ Int.:_________

DEF Distributer:__________________________

Project #2R1109 Date:_______________

Last 6 Vin#:_______________ Int.:_________

DEF Distributer:__________________________

Project #2R1109 Date:_______________

Last 6 Vin#:_______________ Int.:_________

DEF Distributer:__________________________

Project #2R1109 Date:_______________

Last 6 Vin#:_______________ Int.:_________

DEF Distributer:__________________________

Project #2R1109 Date:_______________

Last 6 Vin#:_______________ Int.:_________

DEF Distributer:__________________________

Project #2R1109 Date:_______________

Last 6 Vin#:_______________ Int.:_________

DEF Distributer:__________________________

Project #2R1109 Date:_______________

Last 6 Vin#:_______________ Int.:_________

DEF Distributer:__________________________

Project #2R1109 Date:_______________

Last 6 Vin#:_______________ Int.:_________

DEF Distributer:__________________________

Enclosure 2

CALIFORNIA COMMERCIAL VEHICLE WEIGH STATIONS				
Route	**County**	**Name**	**Direction**	**City or Nearest City**
5	Los Angeles	Castaic	NB	Santa Clarita
10	Riverside	Desert Hills	WB	Banning
80	Sacramento	Antelope	EB	Citrus Heights/ Antelope
80	Sacramento	Antelope	WB	Citrus Heights/ Antelope
15	San Diego	Rainbow	NB	Temecula
15	San Diego	Rainbow	SB	Temecula
5	San Diego	San Onofre	SB	Oceanside
101	Ventura	Conejo	SB	Thousand Oaks
15	San Bernardino	Cajon Pass	NB	San Bernardino

Revised 10/10/11.

Source: http://www.dot.ca.gov/hq/traffops/trucks/weigh-stations/locations.xls

Enclosure 3

California Environmental Protection Agency

Air Resources Board

Certificate of DEF Inspection

Last 6 Digits of VIN: ___________________

ARB Field Rep: ________________________

Weigh Station: ________________________

Date: _________________________________

Valid through November 30, 2011

California Environmental Protection Agency

Air Resources Board

Certificate of DEF Inspection

Last 6 Digits of VIN: ___________________

ARB Field Rep: ________________________

Weigh Station: ________________________

Date: _________________________________

Valid through November 30, 2011

Enclosure 4

SCR / DEF Tamper Study Information Sheet

Air Resources Board

Matthew Rodriquez
Secretary for
Environmental Protection

Mary D. Nichols, Chairman
9480 Telstar Avenue, Suite 4
El Monte, California 91731 • www.arb.ca.gov

Edmund G. Brown Jr.
Governor

DATE: _________ TIME: __________________ LOCATION: ________________________________

ARB REPRESENTATIVE(S):_____________________________, ______________________________

TRUCK MAKE: ___________________________ VIN: ______________________________________

TRUCK MODEL/YEAR: __________ ODOMETER: ____________ ENGINE MODEL YEAR : _________

ENGINE MAKE: _______________________ ENGINE FAMILY: ______________________________

ENGINE HP: ____________

From the Instrument Panel:

- List any warning indicators/lights that do no illuminate during key-on system check. Check for any audible or illuminated driver warning indicators/lights. Denote any audible warnings or list any warning indicators/lights that are observed ON.

  (Key-On) ALL WARNING INDICATORS ON ________ YES ________ NO

  Turn engine on and check AUDIBLE WARNINGS ________ YES ________ NO

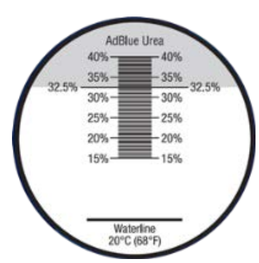
  LIST OF WARNING LIGHTS (Describe Any Warnings – Enter "None" if none exists)

  ____

  ____

  ____

From the DEF Tank - Urea Concentration:



Obtain sample of DEF (2 oz) if the % is ≤ 25%

% of Urea in DEF Sampled: ______________

Identify DEF distributer (if unknown, enter "unknown"):____________

Appendix C – Test Plan 2R1102

Linda S. Adams
Acting Secretary for Environmental Protection

Air Resources Board

Mary D. Nichols, Chairman
9480 Telstar Avenue, Suite 4
El Monte, California 91731 • www.arb.ca.gov

Edmond G. Brown Jr.
Governor

To: Annette Hebert, Chief
Mobile Source Operations Division

THROUGH: Thong Sten
Vehicle Data Services Section

FROM: John M. Urkov, Chief
In-Use Vehicle Programs Branch

DATE: 2/23/2011

SUBJECT: FIELD INVESTIGATION OF THE EFFECTIVNESS OF DRIVER INDUCEMENTS USED FOR SCR NOx CONTROLLED ENGINES

Project Number: 2R1102

INTRODUCTION

The In-Use Compliance Section (IUCS) has been assigned to investigate the effectiveness of driver inducements used by Selective Catalytic Reduction (SCR) oxide of nitrogen (NOx) controlled engines in actual field operations. For the SCR systems to function properly, the drivers are required to periodically fill their vehicle with Diesel Exhaust Fluid (DEF). Since DEF must be purchased, drivers might be motivated to operate without DEF and/or tamper with the SCR systems so they could reduce their operating costs. During the August 2010 SCR investigation ARB staff discovered deficiencies in the calibrations of the two Cummins powered vehicles. Cummins has developed calibration improvements to remedy the deficiencies.

To evaluate the calibration improvements of the driver inducements, the IUCS staff will procure two HDD trucks equipped with 2010 diesel engines using SCR technology and operate the vehicles under conditions where deficiencies were discovered in the August 2010 investigation. These conditions may include the operation with no DEF, use of water in place of DEF, and disconnection of certain SCR components.

Vehicle performance will be monitored and documented throughout specified driving routes. Staff estimates to begin this project on March 14, 2011, and will take approximately four weeks to complete this program.

Attachment

Test Plan
Evaluation of Selective Catalytic Reduction Inducement Strategies

Project Number: 2R1102

Investigation of SCR Operation
2010 Heavy Duty Diesel
Engine Family ACEXH0912XAP
Engine Family ACEXH0408BAL

March 14, 2011

Project Engineer:
John O'Cain

Test Engineer:

In-Use Compliance Section
In-Use Vehicle Programs Branch
Mobile Source Operations Division
Air Resources Board
Haagen-Smit Laboratory
9528 Telstar Avenue
El Monte, CA 9l73l

TEST PLAN

I. SCOPE

The primary objective of this program is to investigate the effectiveness of driver inducements used by Selective Catalytic Reduction (SCR) certified engines in actual field operations. For the SCR systems to effectively control oxides of nitrogen (NOx) emissions, the drivers are required to periodically fill their vehicle with Diesel Exhaust Fluid (DEF). Since DEF must be purchased, drivers might be motivated to operate without DEF and/or tamper with the SCR systems so they could reduce their operating costs. This is in contrast to ARB's certification procedures that require that vehicles be equipped with sophisticated systems to induce driver responses when drivers fail to add DEF and/or tamper with the systems through substituting water or disconnecting hardware.

The goals of this investigation are to determine the effectiveness of driver inducements improvements for driver actions or inactions relating to the use of DEF. First it will be determined how long a vehicle will operate once the DEF supply is depleted (Low DEF Test Cycle) and evaluate the vehicles' engine operation and operator alert systems as the DEF is being depleted. Second, staff will determine if the vehicle can be normally operated with water as a substitute for DEF (DEF Dilution Test Cycle). Third, staff will evaluate the case of a hardware tamper by disconnecting the DEF injector (DEF Tamper Test Cycle).

In July and August 2010, the In-Use Compliance Section (IUCS) staff conducted an investigation on SCR equipped vehicles to evaluate their inducement strategies. This investigation showed that two separate 2010 model year Cummins engines did not perform as designed. Cummins engineers have developed calibration improvements for the two engines to address the deficiencies. The IUCS staff will operate two trucks that utilize these engines in similar operating conditions from the first program to determine the effectiveness of the calibration improvements.

To evaluate the effectiveness of driver inducements, the IUCS staff will procure two Cummins powered HDD trucks equipped with 2010 diesel engines using SCR technology. One vehicle will be equipped with a 14.9L Cummins engine and the other with a 6.7L Cummins engine.

II. PROGRAM MANAGEMENT

The IUCS is charged with administering this test program. The project engineer will be the contact person for all issues relating to the completion of this program. Vehicles will be operated on California highways and no exhaust emissions will be gathered. There will be no need to verify data and no data will be entered into VTS.

III. VEHICLE PROCUREMENT

The ARB Procurement Contractor, California Environmental Engineering (CEE), will provide one test vehicle for this program, the other test vehicle will be a State owned vehicle, engine families ACEXH0912XAP, used in project number 2R1004, the previous SCR program. These vehicles will represent Cummins' engine families ACEXH0912XAP and ACEXH0408BAL and both vehicles will be operated out of ARB's Haagen-Smit Laboratory (HSL).

IV. VEHICLE DELIVERY AND CHECK-IN

Vehicles will be checked-in and all pre-existing damage will be documented and photographed upon check-in.

V. TEST FUEL REQUIREMENTS

Testing for this program will be performed on commercial diesel fuel. Diesel fuel and DEF will be purchased through a local supplier using a California Voyager Card.

VI. VEHICLE MAINTENANCE

Any necessary vehicle maintenance will be performed by the Laboratory Logistics and Test Support Section (LLTSS) staff. Maintenance that cannot be performed by staff will be performed by a local maintenance vendor. The project engineer will be notified of needed maintenance prior to being performed.

VII. TESTING

Testing of the vehicles will be performed on California highways. A Pre Drive Inspection Form is enclosed and must be completed prior to each drive. Charts 1-6 identifies the actual test cycle sequence to be performed on each vehicle for the given test cycle condition. Test cycles will be performed with highest priority on cycles where the vehicle exhibited deficiencies. If time allows each test cycle will be repeated for each vehicle. All test sequence conditions will be documented in the Vehicle Test Cycle Operation Form (enclosed). Both vehicles will have two IUCS staff on-board during all phases of testing with the exception of the driver of the Class 8 vehicle; the driver will be a staff person from the Mobile Source Control Division's Low Emission Vehicle Testing Section who possesses a Class A license. One staff person will operate the vehicle and the other will document the vehicle's operation. These vehicles will be operated for as many miles as possible during a normal shift. The IUCS staff will ballast each vehicle to near full load capacity; all safety precautions must be taken to safely operate these vehicles and drivers must adhere to all State and Federal traffic laws. In the case of an accident, the California Highway Patrol or local police authority and the project managers must be notified immediately.

Vehicle testing for engine family ACEXH0912XAP will be as follows and is listed in order of priority:

(1) Low DEF Test Cycle, (2) DEF Tamper Test Cycle, and (3) DEF Dilution Test cycle; until the vehicle is limited to 5 mph or staff determines the inducements are not functioning as designed.

Vehicle testing for engine family ACEXH0408BAL will be as follows and is listed in order of priority:

(1) Low DEF Test Cycle, (2) DEF Tamper Test Cycle, and (3) DEF Dilution Test cycle; until the vehicle becomes immobilized or staff determines the inducements are not functioning as designed.

The test route will start at HSL and proceed to Baker and return to HSL. See enclosed maps for driving route (Map 1 and Map 2). If time permits additional mileage may be accumulated during normal working shifts.

VIII. DATA HANDLING AND PROCESSING

All data will be provided to the project engineer who, together with the test engineer, will review all test data for completeness and accuracy.

IX. DOCUMENTATION

It is of the utmost importance that all forms, documents, test data sheets, etc., are accurate and complete.

X. LABORATORY VISITORS

The project engineer must be advised of any non-ARB employees that are involved with the project. No persons other that ARB employees may occupy the vehicles while they are operated on the highway without the approval of the project engineer.

XI. VEHICLE RELEASE

When a vehicle is released from the program, the project engineer will notify the procurement contract contact person (John Kim) of the vehicle's release.

Enclosures

Enclosure 1

Pre Drive Inspection Form

Project Number: ________________ Date: ______________

Vehicle License Number: ______________ Vehicle Number: __________

Driver: ____________________ Observer: ____________________

Items Checked	Ok	Comments
Fuel Level		
DMV pre drive inspection		
Oil level		
DEF level and condition		
Brakes		
Tires		
Fuel Refilled (gallons)		
DEF Refill (gallons/quarts)		
Other:		

Enclosure 2

Test Cycle Sequences

CHART 1
CUMMINS 14.9L DEF TEST PROGRAM OPERATION
(Low DEF Test Cycle)

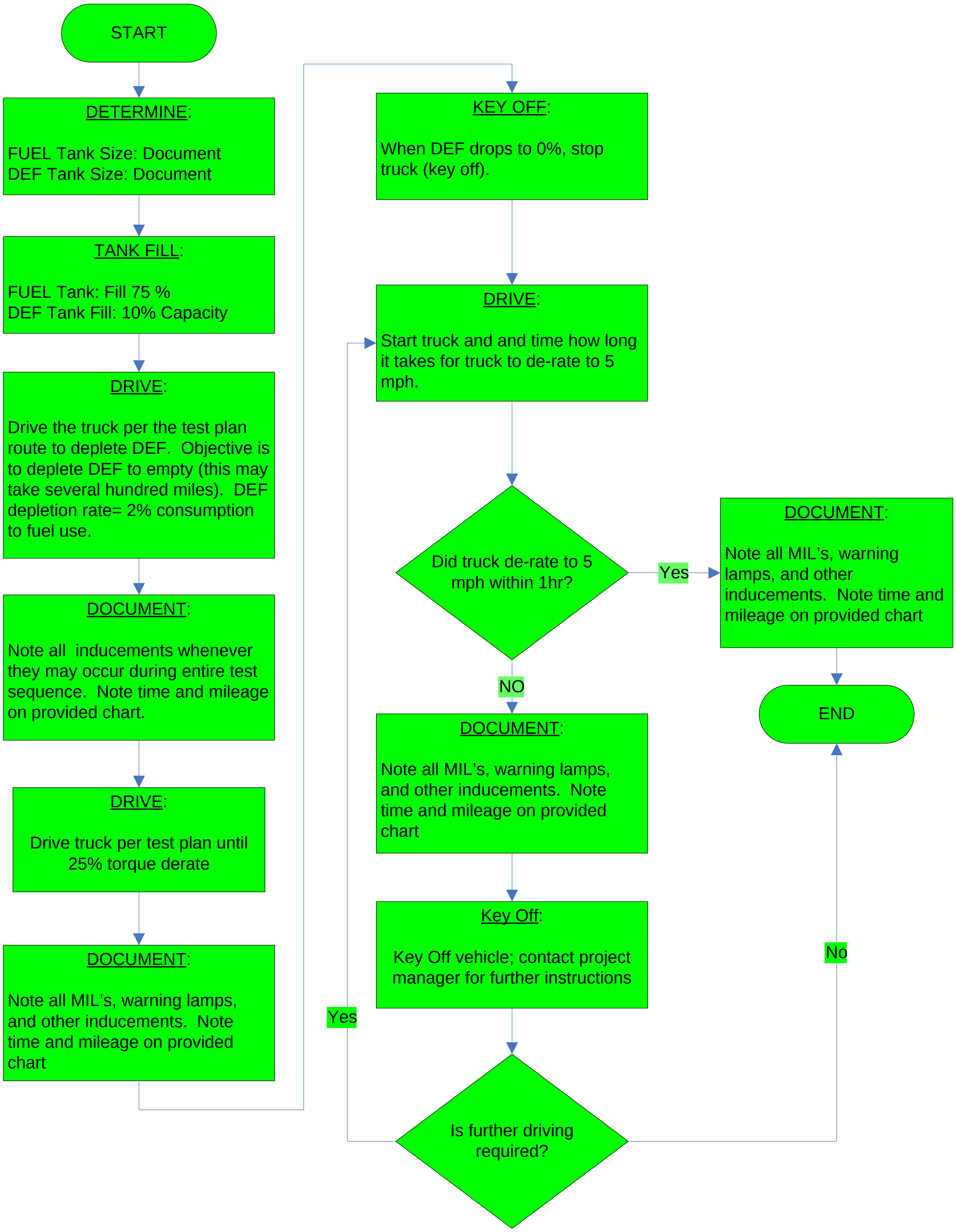


CHART 2
CUMMINS 15.0L DEF TEST PROGRAM OPERATION
(DEF Dilution Test Cycle)

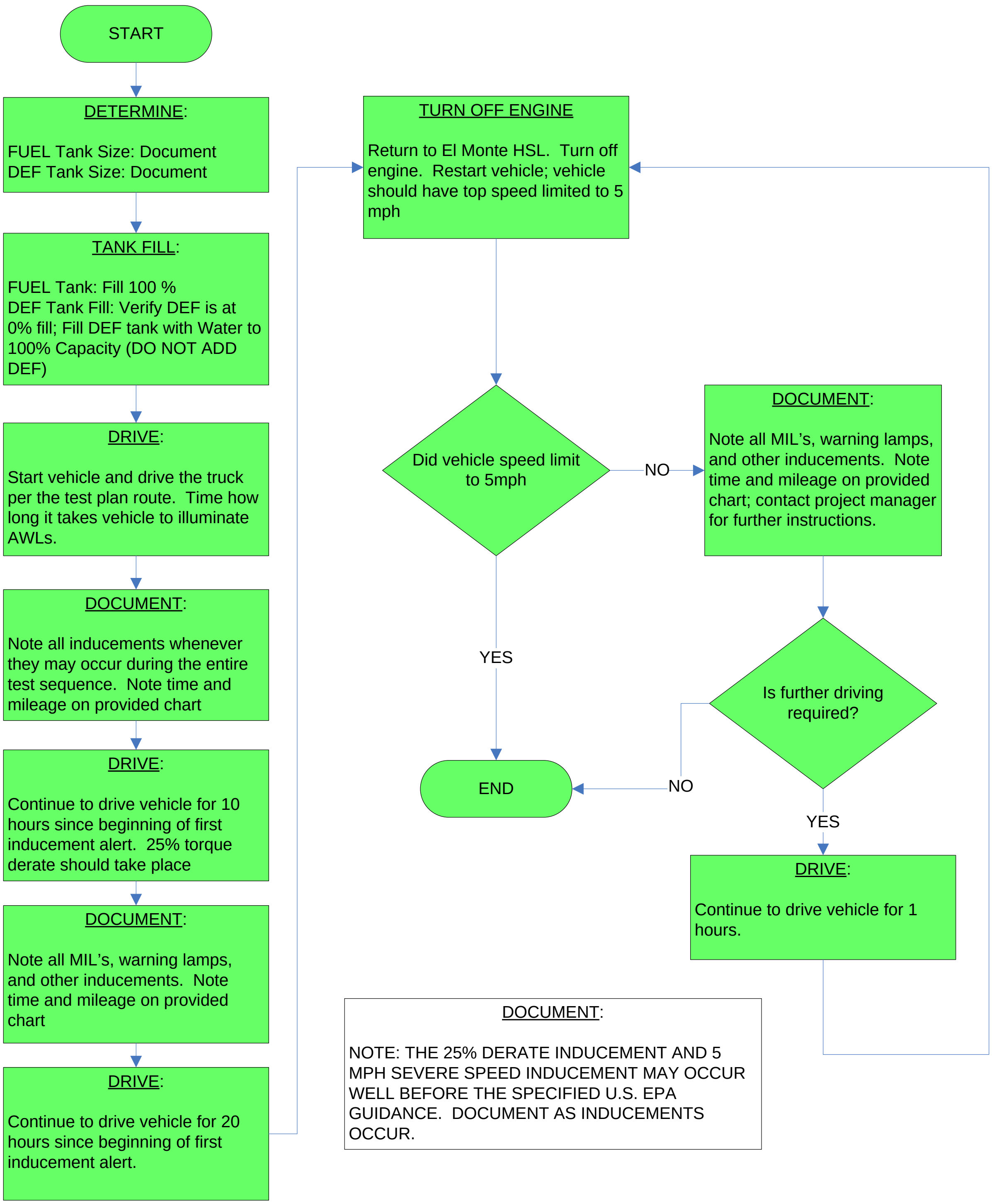


CHART 3
CUMMINS 15.0L DEF TEST PROGRAM OPERATION
(DEF Tamper Test Cycle)

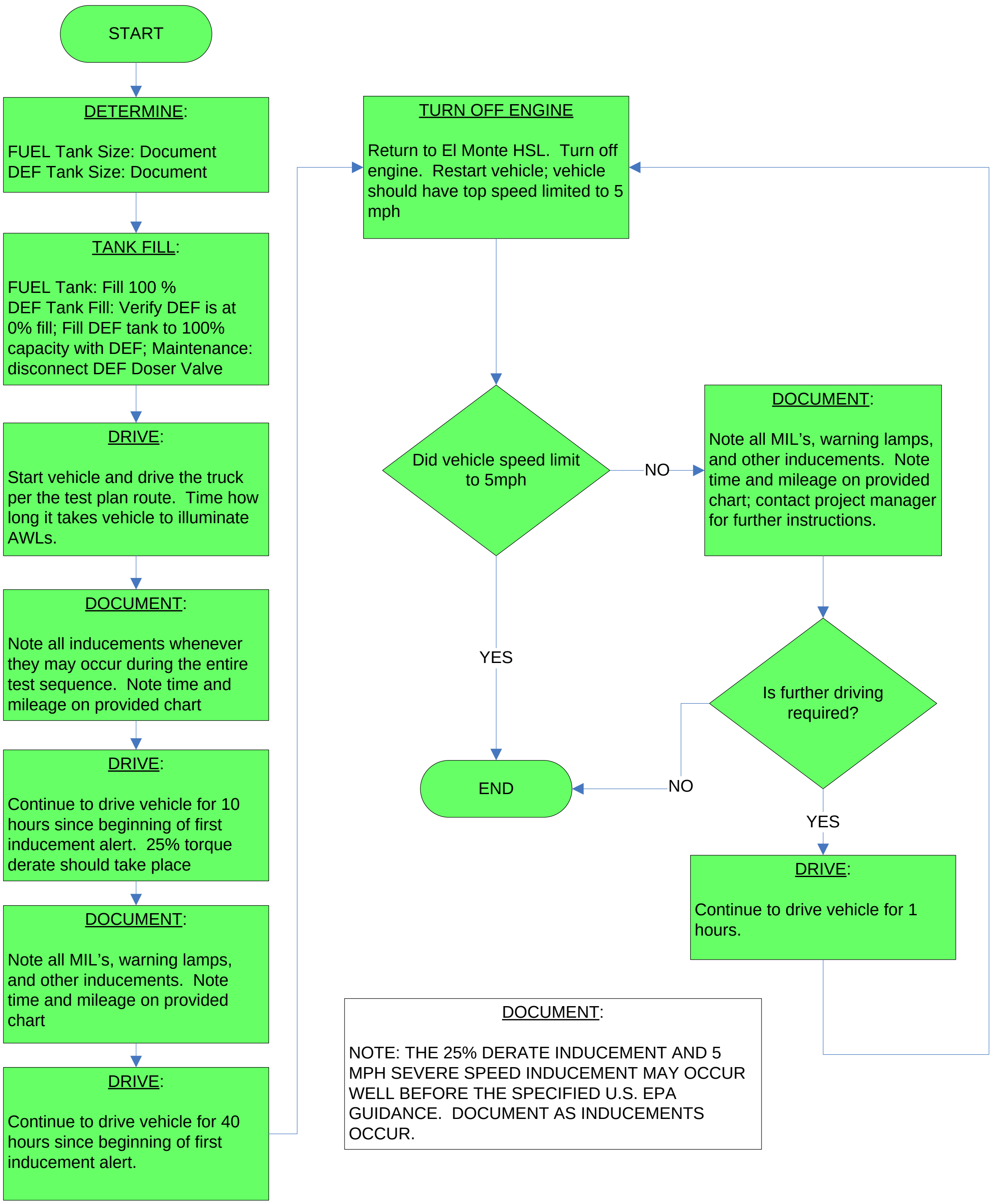


CHART 4
CUMMINS 6.7L DEF TEST PROGRAM OPERATION
(Low DEF Test Cycle)

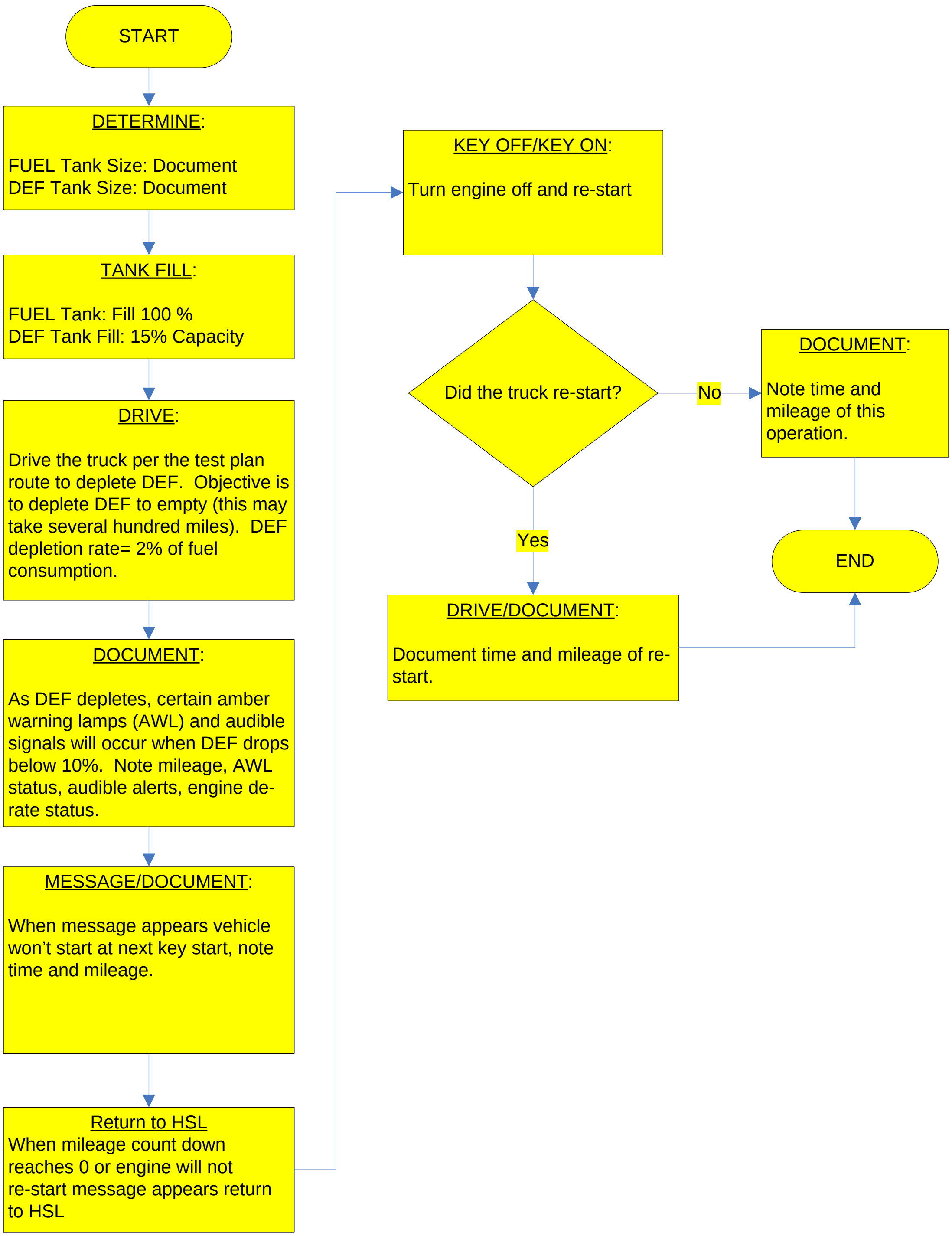


CHART 5
CUMMINS 6.7L DEF TEST PROGRAM OPERATION
(DEF Dilution Test Cycle)

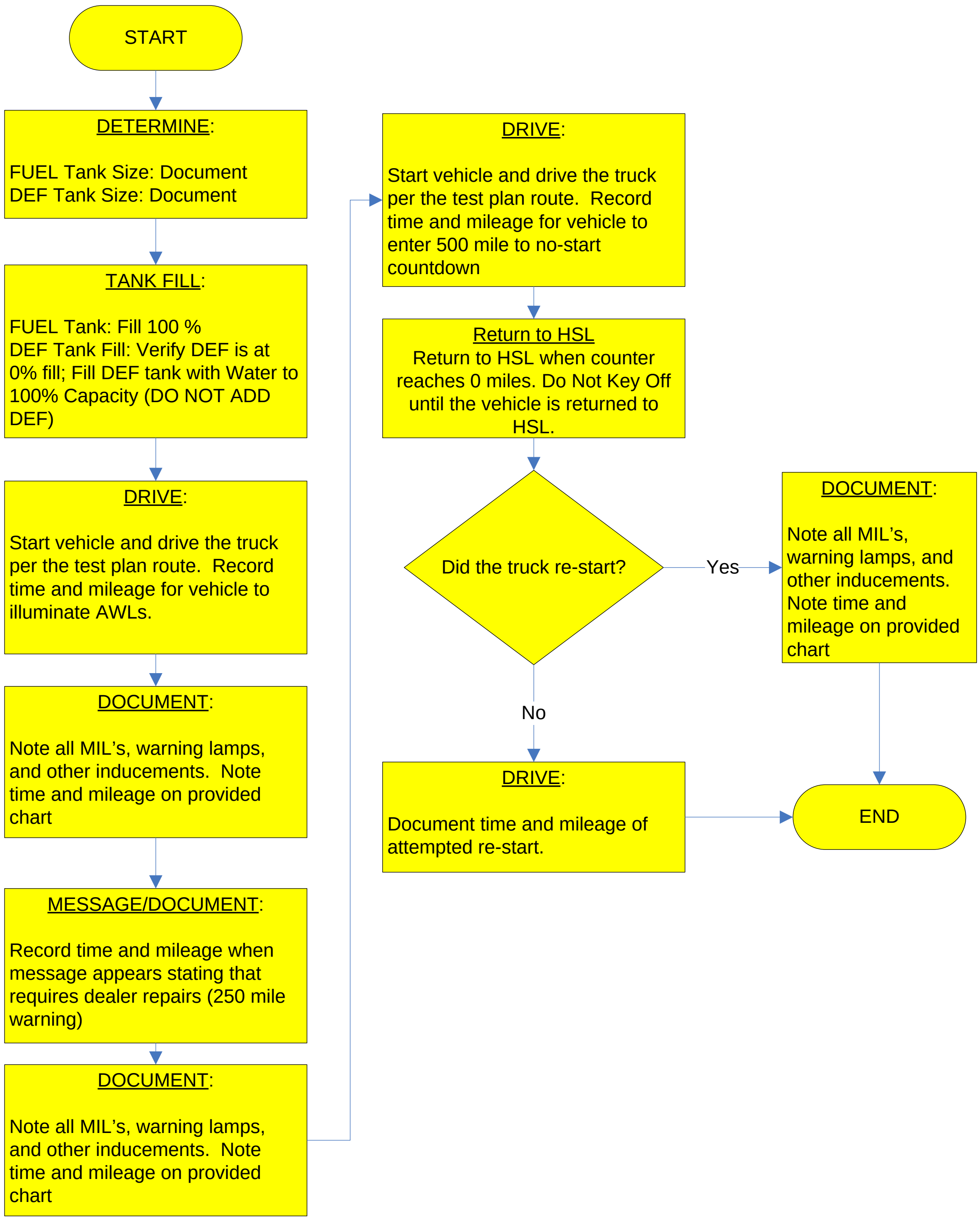
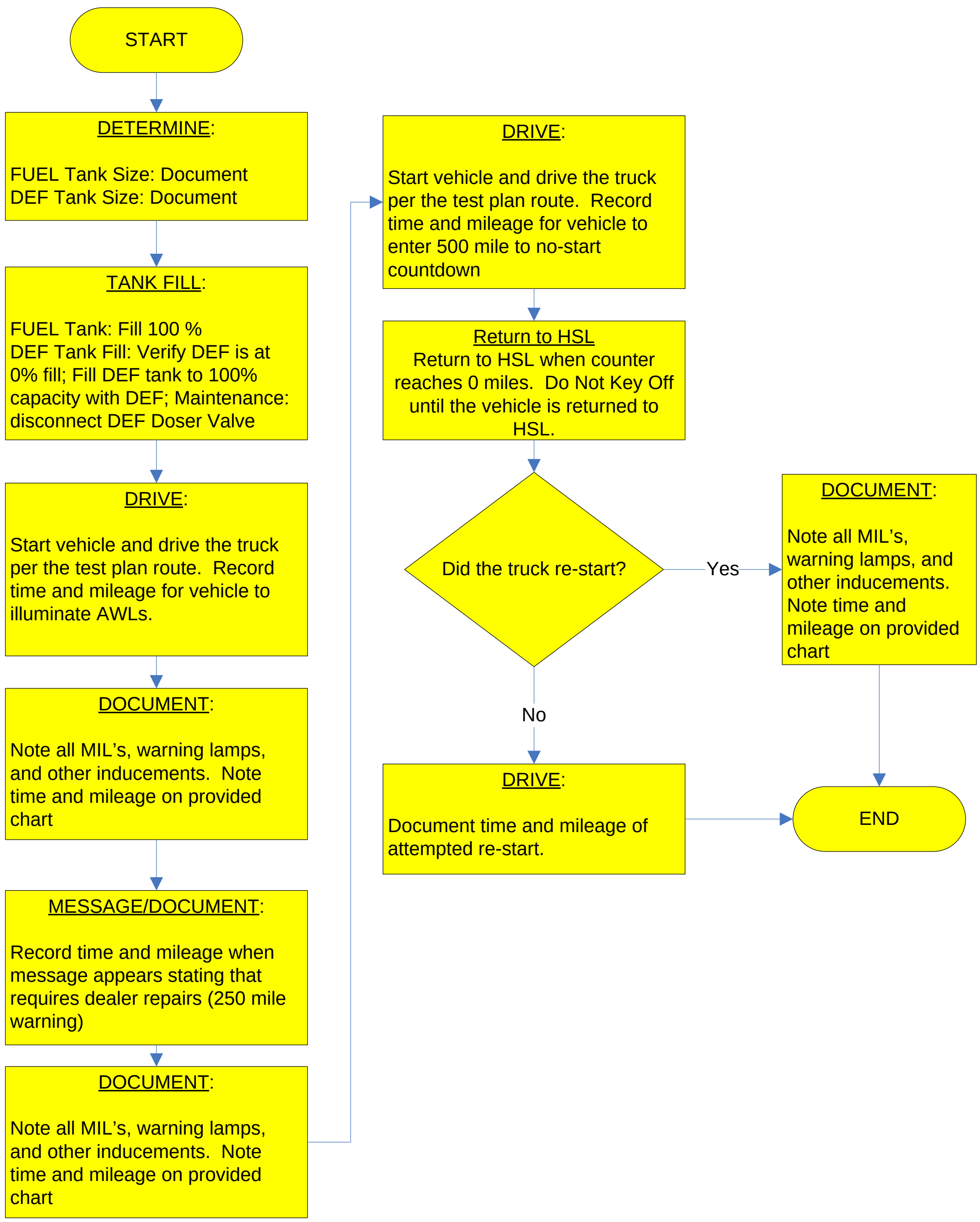


CHART 6
CUMMINS 6.7L DEF TEST PROGRAM OPERATION
(DEF Tamper Test Cycle)

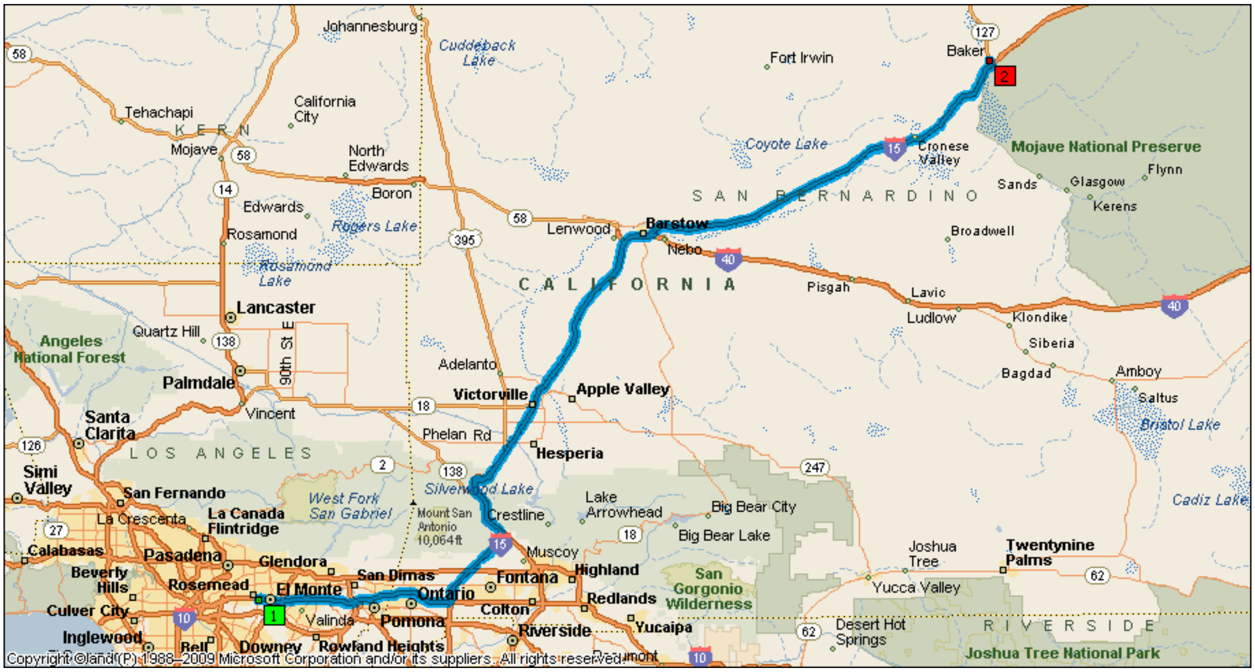


Enclosure 3

Test Routes

Map 1 & Map 2

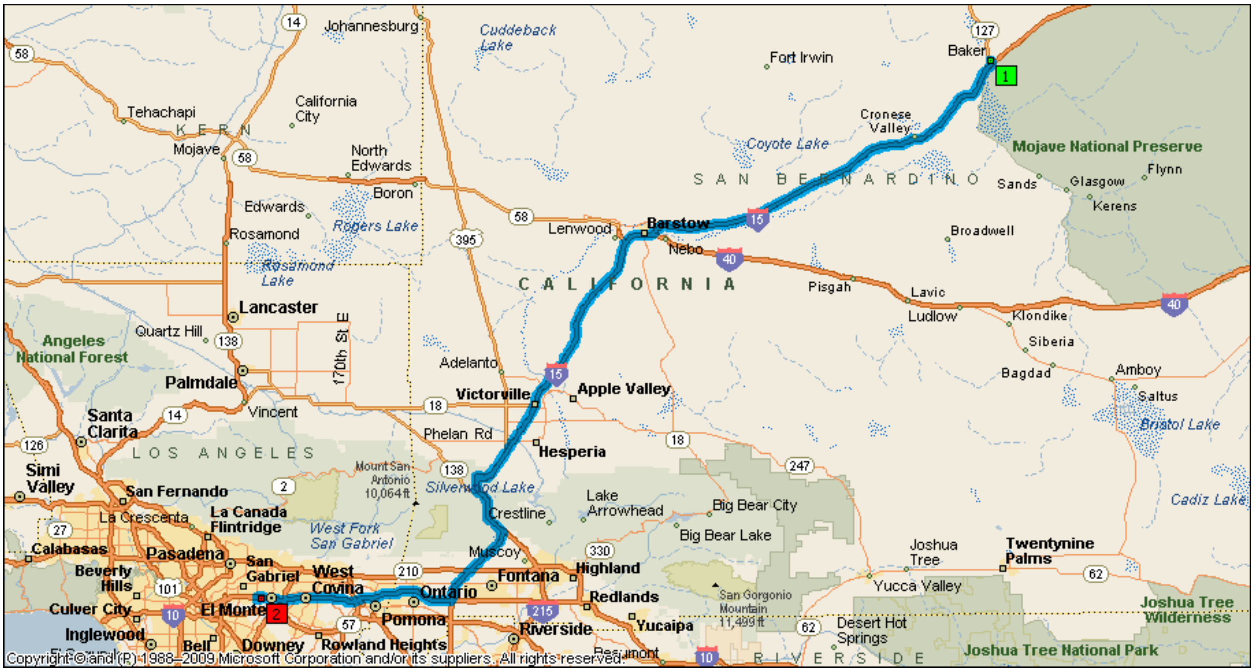
Map 1, El Monte to Baker



Summary: 166.9 miles (2 hours, 22 minutes)

Time	Mile	Instruction	For	Toward
9:00 AM	**0.0**	**Depart 9528 Telstar Ave, El Monte, CA 91731 on Telstar Ave (East)**	**0.4 mi**	
9:00 AM	0.4	Turn RIGHT (East) onto Flair Dr	0.2 mi	
9:01 AM	0.6	Take Ramp (RIGHT) onto I-10 [San Bernardino Fwy]	29.8 mi	I-10
9:26 AM	30.4	Take Ramp (RIGHT) onto I-15 [Ontario Fwy]	14.1 mi	I-15 / Barstow / Las Vegas
9:38 AM	44.5	At exit 123, take Ramp (LEFT) onto I-15 [Barstow Fwy]	121.2 mi	I-15 / Barstow
11:20 AM	165.7	Turn RIGHT onto Ramp	0.2 mi	CA-127 / Kelbaker Rd / Death Valley
11:21 AM	166.0	Turn LEFT (North-West) onto SR-127 [Kelbaker Rd]	0.9 mi	
11:22 AM	**166.9**	**Arrive Baker**		

Map 2, Baker to El Monte



Summary: 168.3 miles (2 hours, 24 minutes)

Time	Mile	Instruction	For	Toward
9:00 AM	**0.0**	**Depart Baker on SR-127 (South)**	**0.7 mi**	
9:01 AM	0.7	Take Ramp (RIGHT) onto I-15	120.8 mi	I-15
10:43 AM	121.4	Take Ramp (RIGHT) onto I-15 [Ontario Fwy]	14.3 mi	I-15 / Los Angeles / San Diego
10:55 AM	135.8	Take Ramp (RIGHT) onto I-10 [San Bernardino Fwy]	31.3 mi	I-10 / Los Angeles
11:21 AM	167.0	At exit 26B, turn RIGHT onto Ramp	0.1 mi	CA-19 / Rosemead Blvd
11:21 AM	167.2	Keep STRAIGHT to stay on Ramp	0.1 mi	CA-19 N / Rosemead Blvd / Pasadena
11:22 AM	167.3	Keep LEFT to stay on Ramp	32 yds	Rosemead Blvd
11:22 AM	167.3	Bear LEFT (West) onto Glendon Way	43 yds	
11:22 AM	167.3	Turn LEFT (South) onto SR-19 [Rosemead Blvd]	0.5 mi	
11:22 AM	167.8	Turn LEFT (North-East) onto Telstar Ave	0.5 mi	
11:24 AM	**168.3**	**Arrive 9528 Telstar Ave, El Monte, CA 91731**		

Enclosure 4
Vehicle Test Cycle Operation Form

Project #: ___________________ Date: _______________ Vehicle #: _________ Chart # _________

Driver: ____________________ Observer: ___________________ Vehicle License #: _______________

Fuel Tank Capacity: _______ gal DEF Tank Capacity: ________ gal Test Cycle: ________________

Date	Time	Odometer	DEF Tank Type Fluid Added	Amt Fluid Added	DEF Gauge Level	Diesel Fuel Added	Diesel Gauge Level	Engine Performance. Note any changes of power de-rate	Engine Start	Engine Stop	Vehicle Speed	How Many AWLs	Red Light Indicator	Comments

Appendix D – Test Plan 1Q1102

Matthew Rodriquez
Secretary for Environmental Protection

Air Resources Board

Mary D. Nichols, Chairman
9480 Telstar Avenue, Suite 4
El Monte, California 91731 • www.arb.ca.gov

Edmund G. Brown Jr.
Governor

TO: Annette Hebert, Chief
Mobile Source Operations Division

THROUGH: Thong Sten
Vehicle Data Services Section

FROM: John M. Urkov, Chief
In-Use Vehicle Programs Branch

DATE: December 5, 2011

SUBJECT: EVALUATION OF ON-ROAD HEAVY-DUTY DIESEL NOx CONTROL STRATEGIES ON IN-USE 2011 MODEL YEAR DIESEL ENGINES (Revision - 3)

The In-Use Compliance Section (IUCS) will conduct an evaluation of on-road heavy-duty diesel (HDD) oxides of nitrogen (NOx) control strategies on in-use 2011 model year (MY) diesel engines. Staff will compare baseline emissions over prescribed driving routes when the NOx control strategies are functioning under proper operating circumstances to various tampered condition operation, along with the effectiveness of any driver inducements that are deployed. The two NOx control strategies that will be evaluated under this test plan are Exhaust Gas Recirculation (EGR), an in-cylinder control strategy, and Selective Catalytic Reduction (SCR), an after-treatment control strategy.

SCR-equipped engines require the driver to periodically replenish the SCR system with Diesel Exhaust Fluid (DEF) to achieve NOx control. In order to discourage drivers from tampering with their SCR systems through either not refilling with DEF, using water or other inappropriate solution in place of DEF, or otherwise tampering with SCR system hardware, driver inducements in the form of visual and/or audible warnings and power de-rates usually precede final immobilization of the vehicle.

EGR-equipped engine NOx control is achieved by recirculating a portion of the engine's exhaust back into the engine's air intake system. In the case of EGR equipped engines, drivers may desire to achieve more power by turning off or otherwise tampering with the EGR system. In addition, ARB has approved the use of auxiliary emission control devices (AECD), allowing under particular circumstances for EGR to be turned off accompanied by engine power de-rates to discourage the driver from continuing to operate under the undesirable circumstances.

The IUCS staff will procure three heavy-duty vehicles each with a 2011 model year heavy-duty diesel engine (two SCR-equipped and one EGR-equipped). As each procured test vehicle is delivered to ARB's Haagen-Smit Laboratory, the IUCS staff will first operate the accepted test vehicle over the project test route to establish NOx baseline emission levels utilizing a Portable Emissions Measurement System (PEMS) device.

After baseline testing is completed for the SCR-equipped test vehicles, IUCS staff will examine the vehicle owner's manuals, and if necessary consult with confidential business information submitted under the certification process, to determine the expected inducement strategies for each vehicle in this evaluation. Typically, these include a sequence of visual and/or audible warnings on the instrument panel (e.g. warning lights, chimes, and/or text message displays) indicating that DEF supply is low or a problem exists with the SCR system. As additional mileage is accumulated without remedying the problem or refilling the DEF supply, further driver inducements should occur, such as power de-rates or limited vehicle speed. Ultimately, if the problem is not corrected a severe inducement or final immobilization in the form of a no-start condition, or 5 mile per hour (mph) maximum speed limit, or idle-only operation should be triggered once the vehicle reaches a safe harbor (e.g. when refueling the vehicle, turning off the vehicle or idling the vehicle for an extended period of time). IUCS staff will observe and document the various driver warnings and inducements triggered by the SCR system while operating the vehicle under the conditions of depleted DEF, poor DEF quality, and a tampered SCR system. In addition, staff will continuously measure NOx emissions for each of these test cycles as the vehicle is being operated over the project test route.

In regards to the EGR-equipped test vehicle, with the baseline test cycle established, IUCS staff will create a tampered condition of the EGR system and observe and document all (if any) driver warnings and vehicle performance issues caused by this tampering event. Staff may also attempt to trigger an AECD condition and evaluate the effectiveness of any driver inducements triggered. Staff will continuously measure NOx emissions under this test cycle as the vehicle is being operated over the project test route.

This project is expected to commence as soon vehicle procurement has been established, and will be completed in approximately twelve weeks.

Attachment

Test Plan

EVALUATION OF ON-ROAD HEAVY-DUTY DIESEL NOx CONTROL STRATEGIES ON IN-USE 2011 MODEL YEAR DIESEL ENGINES

Project Number:
1Q1102

July 22, 2011

Revised

July 25, 2011
August 11, 2011
December 5, 2011

Project Engineers:
John O'Cain
Bob Torres

In-Use Compliance Section
In-Use Vehicle Programs Branch
Mobile Source Operations Division
Air Resources Board
Haagen-Smit Laboratory
9528 Telstar Avenue
El Monte, CA 9l73l

TEST PLAN

EVALUATION OF ON-ROAD HEAVY-DUTY DIESEL NOx CONTROL STRATEGIES ON IN-USE 2011 MODEL YEAR DIESEL ENGINES

I. SCOPE

The In-Use Compliance Section (IUCS) will conduct an evaluation of on-road heavy-duty diesel (HDD) oxides of nitrogen (NOx) control strategies on in-use 2011 model year (MY) diesel engines. Staff will compare baseline emissions over prescribed driving routes when the NOx control strategies are functioning under proper operating circumstances to various tampered condition operation, along with the effectiveness of any driver inducements that are deployed. The two NOx control strategies that will be evaluated under this test plan are Exhaust Gas Recirculation (EGR), an in-cylinder control strategy, and Selective Catalytic Reduction (SCR), an after-treatment control strategy.

SCR-equipped engines require the driver to periodically replenish the SCR system with Diesel Exhaust Fluid (DEF) to achieve NOx control. In order to discourage drivers from tampering with their SCR systems through either not refilling with DEF, using water or other inappropriate solution in place of DEF, or otherwise tampering with SCR system hardware, driver inducements in the form of visual and/or audible warnings and power de-rates usually precede final immobilization of the vehicle.

EGR-equipped engine NOx control is achieved by recirculating a portion of the engine's exhaust back into the engine's air intake system. In the case of EGR equipped engines, drivers may desire to achieve more power by turning off or otherwise tampering with the EGR system. In addition, ARB has approved the use of auxiliary emission control devices (AECD), allowing under particular circumstances for EGR to be turned off accompanied by engine power de-rates to discourage the driver from continuing to operate under the undesirable circumstances.

The IUCS staff will procure three heavy-duty vehicles each with a 2011 model year heavy-duty diesel engine (two SCR-equipped and one EGR-equipped). As each procured test vehicle is delivered to ARB's Haagen-Smit Laboratory, the IUCS staff will first operate the accepted test vehicle over the project test route to establish NOx baseline emission levels utilizing a Portable Emissions Measurement System (PEMS) device.

After baseline testing is completed for the SCR-equipped test vehicles, IUCS staff will examine the vehicle owner's manuals, and if necessary consult with confidential business information submitted under the certification process, to determine the expected inducement strategies for each vehicle in this evaluation. Typically, these include a sequence of visual and/or audible warnings on the instrument panel (e.g. warning lights, chimes, and/or text message displays) indicating that DEF supply is low or a problem exists with the SCR system. As additional mileage is accumulated without remedying the problem or refilling the DEF supply, further driver inducements should occur, such as power de-rates or limited vehicle speed. Ultimately, if the problem is not corrected a severe inducement or final immobilization in the form of a no-start condition, or 5 mile per hour (mph) maximum speed limit, or idle-only operation should be triggered once the vehicle reaches a safe harbor (e.g. when refueling the vehicle, turning off the vehicle or idling the vehicle for an extended period of time). IUCS staff will observe and document the various driver warnings and inducements triggered by the SCR system while operating the vehicle under the conditions of depleted DEF, poor DEF quality, and a tampered SCR system. In addition, staff will continuously measure NOx emissions for each of these test cycles as the vehicle is being operated over the project test route.

In regards to the EGR-equipped test vehicle, with the baseline test cycle established, IUCS staff will create a tampered condition of the EGR system and observe and document all (if any) driver warnings and vehicle performance issues caused by this tampering event. Staff may also attempt to trigger an AECD condition and evaluate the effectiveness of any driver inducements triggered. Staff will continuously measure NOx emissions under this test cycle as the vehicle is being operated over the project test route.

NOTE: Only one vehicle will be evaluated at a time during this project.

II. PROGRAM MANAGEMENT

The IUCS staff will administer this test program with the assistance of the Mobile Source Control Division's (MSCD) In-Use Retrofit Section who will outfit the vehicle with a PEMS unit to monitor/measure the exhaust emissions as the vehicle is driven through the designated test route. In addition, the IUCS staff may utilize the Heavy Duty Diesel I/M Development Section to conduct PEMS testing for this project. The IUCS will provide a project engineer for each individual vehicle: the project engineer will be the contact for all issues related to the completion of this program.

III. VEHICLE PROCUREMENT

California Environmental Engineering (CEE), ARB's current procurement contractor, will deliver the test vehicles for this program based on the specifications provided to the Laboratory Logistics and Test Support (LLTS) Section by the project engineers. Each test vehicle will be operated out of the ARB's HSL by an ARB driver possessing a valid California Class A driver's license.

IUCS staff has already rented K-Rail and a trailer that will be towed behind each of the test vehicles. This trailer will allow a test vehicle's engine load to vary from nearly full power conditions, when traveling uphill, to a near zero engine load when traveling downhill.

The IUCS staff will also secure an experimental operating permit from the Aftermarket Parts Section for each test vehicle. This permit is necessary when operating a vehicle outside of its certified condition on California roadways.

IV. VEHICLE DELIVERY AND CHECK-IN

Vehicles will be checked-in and all pre-existing damage will be documented and photographed upon check-in.

V. TEST FUEL REQUIREMENTS

Commercially available low sulfur diesel fuel will be used for this program. Diesel fuel and DEF will be purchased at any local supplier that accepts the California Voyager Card.

VI. VEHICLE MAINTENANCE

Any necessary maintenance of the test vehicle will be performed by the LLTS staff; maintenance that cannot be done using LLTS staff will be performed by a local maintenance vendor. Any required maintenance must be authorized by the project engineer prior to the work being performed.

VII. TESTING

The test vehicle will be evaluated while driving over the project test route (see Project Test Route and Lean Cruise Test Route) following the testing patterns as prescribed in the enclosed test cycle charts (see Charts 1-8). Each vehicle will be outfitted with a PEMS unit so that on-road emissions can be continuously monitored measured throughout each test cycle by MSCD’s In-Use Retrofit Section (testing may also be conducted by the Heavy Duty Diesel I/M Development Section). Each test vehicle will have two staff on-board while operating the vehicle during its test cycles (i.e., one driver and one staff to operate the PEMS unit). The test vehicles will be operated for as many miles as possible during a normal work shift. Because each test vehicle will be loaded to near full load capacity, all safety precautions must be taken when operating these vehicles. Staff will adhere to all State and federal traffic laws. In the case of an accident, the California Highway Patrol or local police authority and the project engineer must be notified immediately.

- SCR-Equipped Truck Evaluation

A baseline evaluation will be performed on the SCR-equipped vehicle (see Chart 1) to establish normal vehicle operation parameters and emission values. Once the baseline evaluation is completed, the vehicles will be driven and evaluated as per the established test patterns shown in Charts 2-5. Under each test cycle staff will observe and document on the Vehicle Test Cycle Operation Form (enclosed) any visual warnings, audible alerts and vehicle performance problems propagated by the prescribed SCR test cycles. On-road emissions will be continuously measured throughout each test cycle with the on-board PEMS unit.

- EGR-Equipped Truck Evaluation

A baseline evaluation will be performed on the EGR-equipped vehicle (see Chart 6) to establish normal vehicle operation parameters and emission values. Once the baseline evaluation is completed, the vehicle will be driven and evaluated as per the established test patterns shown in Chart 7. Under this test cycle staff will observe and document on the Vehicle Test Cycle Operation Form (enclosed) any visual warnings, audible alerts and vehicle performance problems promulgated by the tampered EGR system. On-road emissions will be continuously measured throughout each test cycle with the on-board PEMS unit. The EGR equipped truck will undergo additional testing utilizing a test route where the truck can maintain a constant speed of 55 mph (see Lean Cruise Test Route - attached). The lean cruise test cycle (see Chart 8) is being utilized to determine if any lean cruise calibrations exist that may have an impact on NOx emissions.

VIII. DATA HANDLING AND PROCESSING

All data will be reviewed by the project engineers for completeness and accuracy. The In-Use Retrofit Section will review, quality audit and forward the PEMS emissions data to the applicable project engineer upon its acceptance. All emission data sampled during this project will be analyzed using a PEMS unit; the data generated will not be entered into the VEDS database, also this project does not require a test engineer.

IX. DOCUMENTATION

It is of the utmost importance that all forms, documents, test data sheets, etc., are accurate and complete.

X. LABORATORY VISITORS

The project engineers must be notified if a non-ARB staff member is to be involved in the project. Persons other than ARB staff members may not occupy the vehicles while they are operated on the roadways, unless advance approval is granted by the project engineer.

XI. VEHICLE RELEASE

A test vehicle will be released from the program when the project engineer releases the test vehicle to the procurement contract manager.

Enclosures

CHART 1

SCR-EQUIPPED HDD TRUCK OPERATION
(Baseline Evaluation)

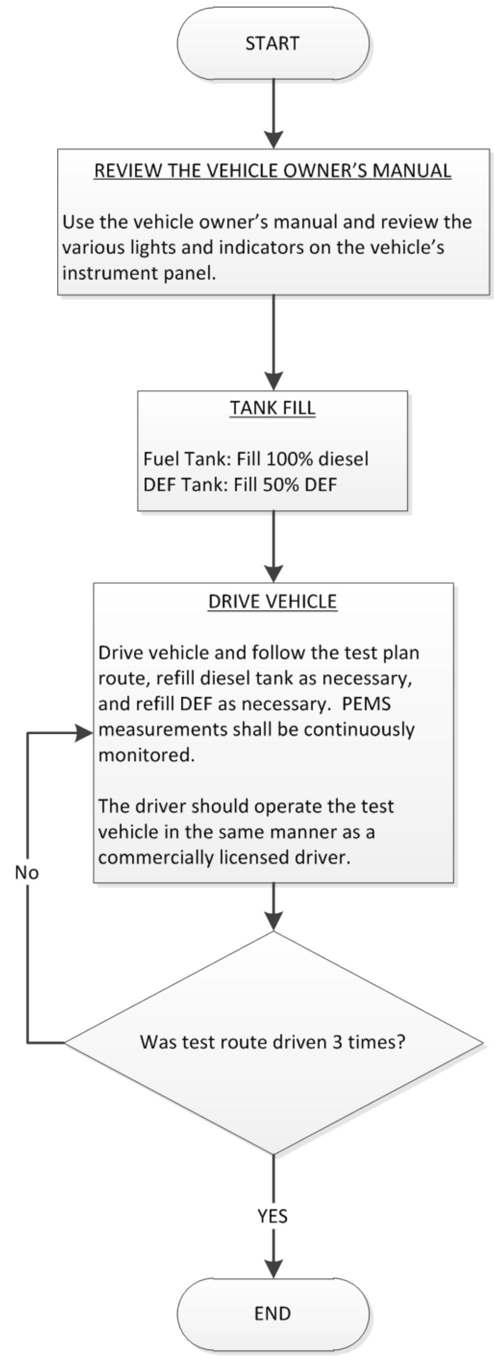


CHART 2

SCR-EQUIPPED HDD TRUCK OPERATION (DEF DEPLETION)

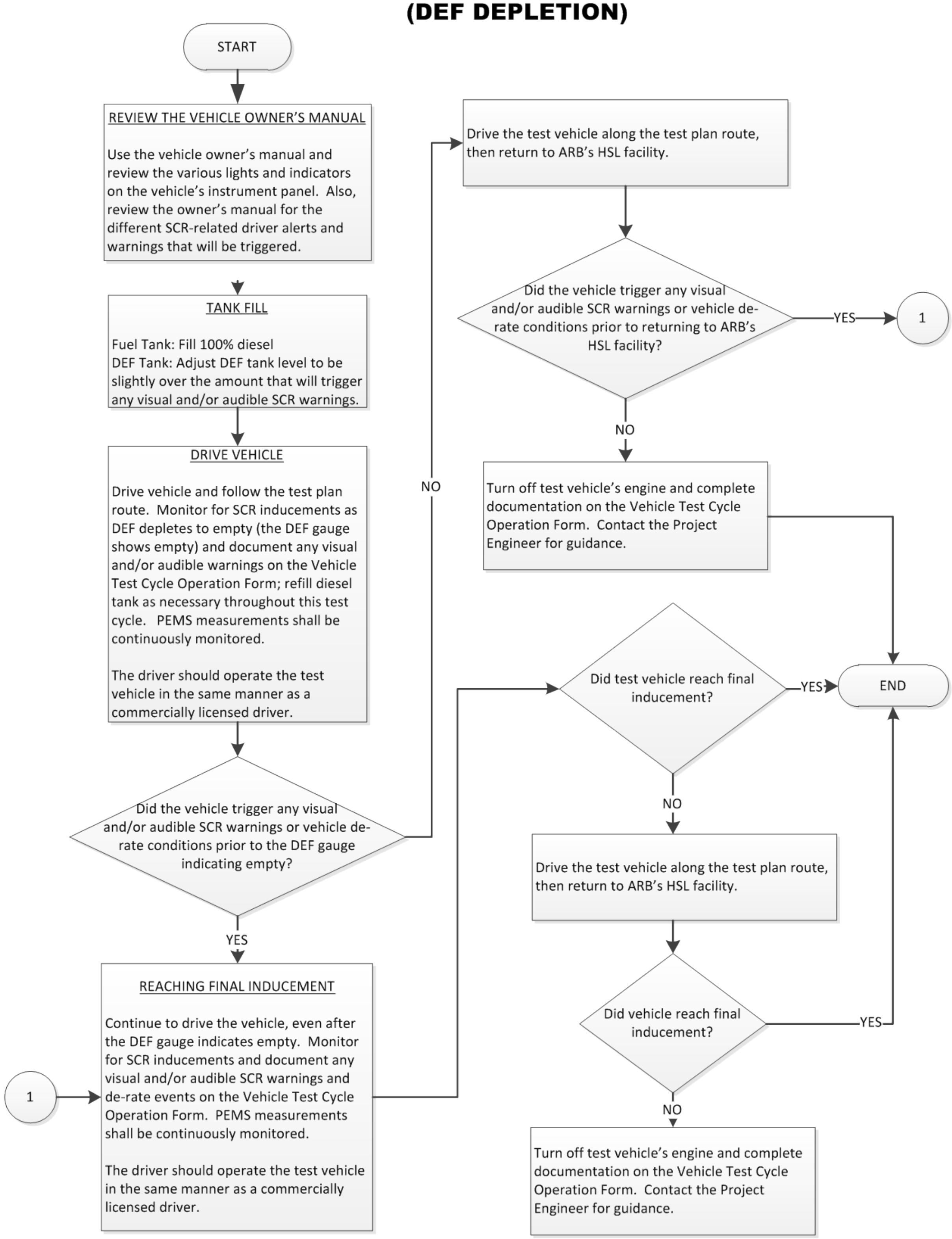


CHART 3

SCR-EQUIPPED HDD TRUCK OPERATION (DEF QUALITY)

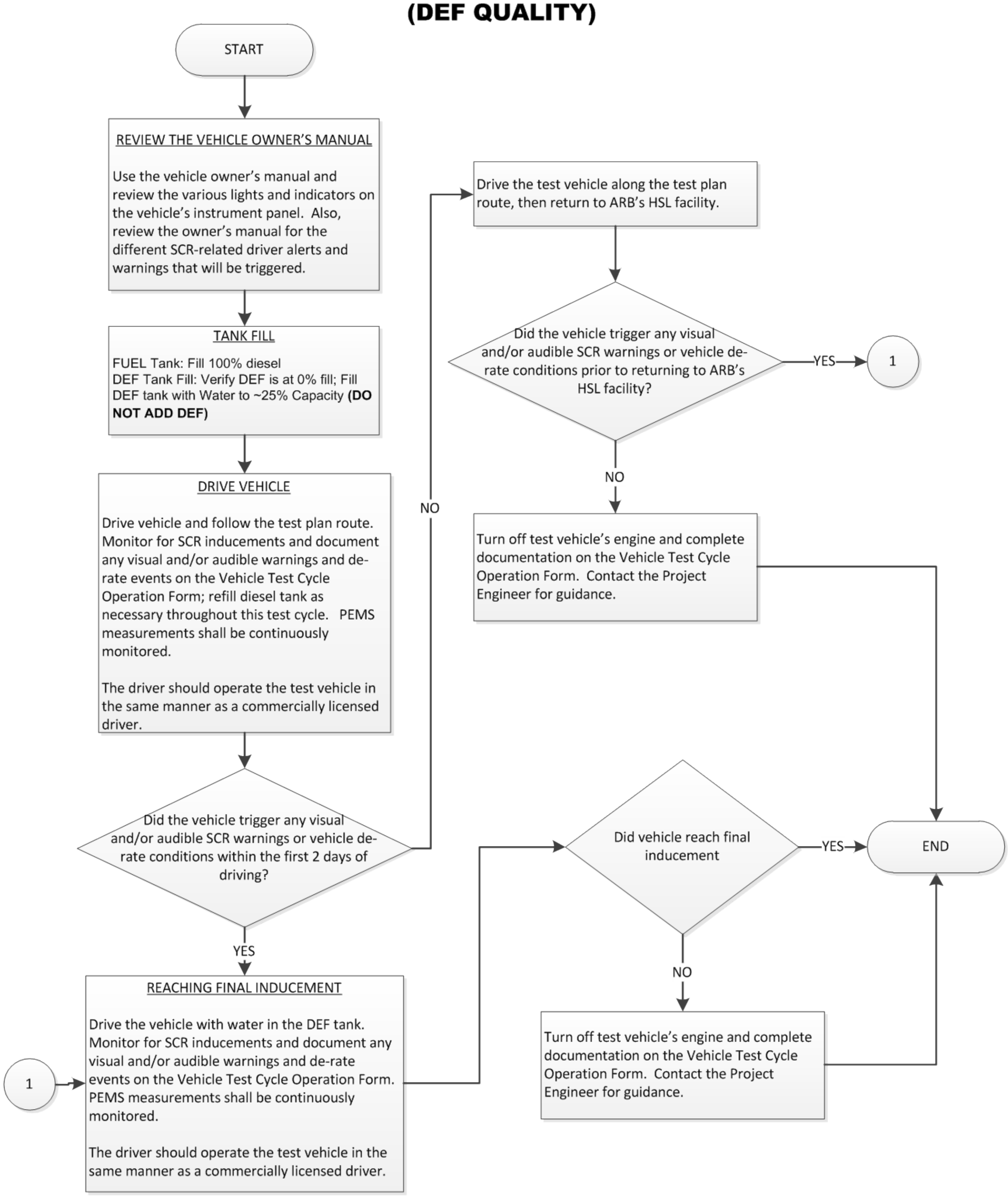


CHART 4

SCR-EQUIPPED HDD TRUCK OPERATION (DEF SYSTEM TAMPER)

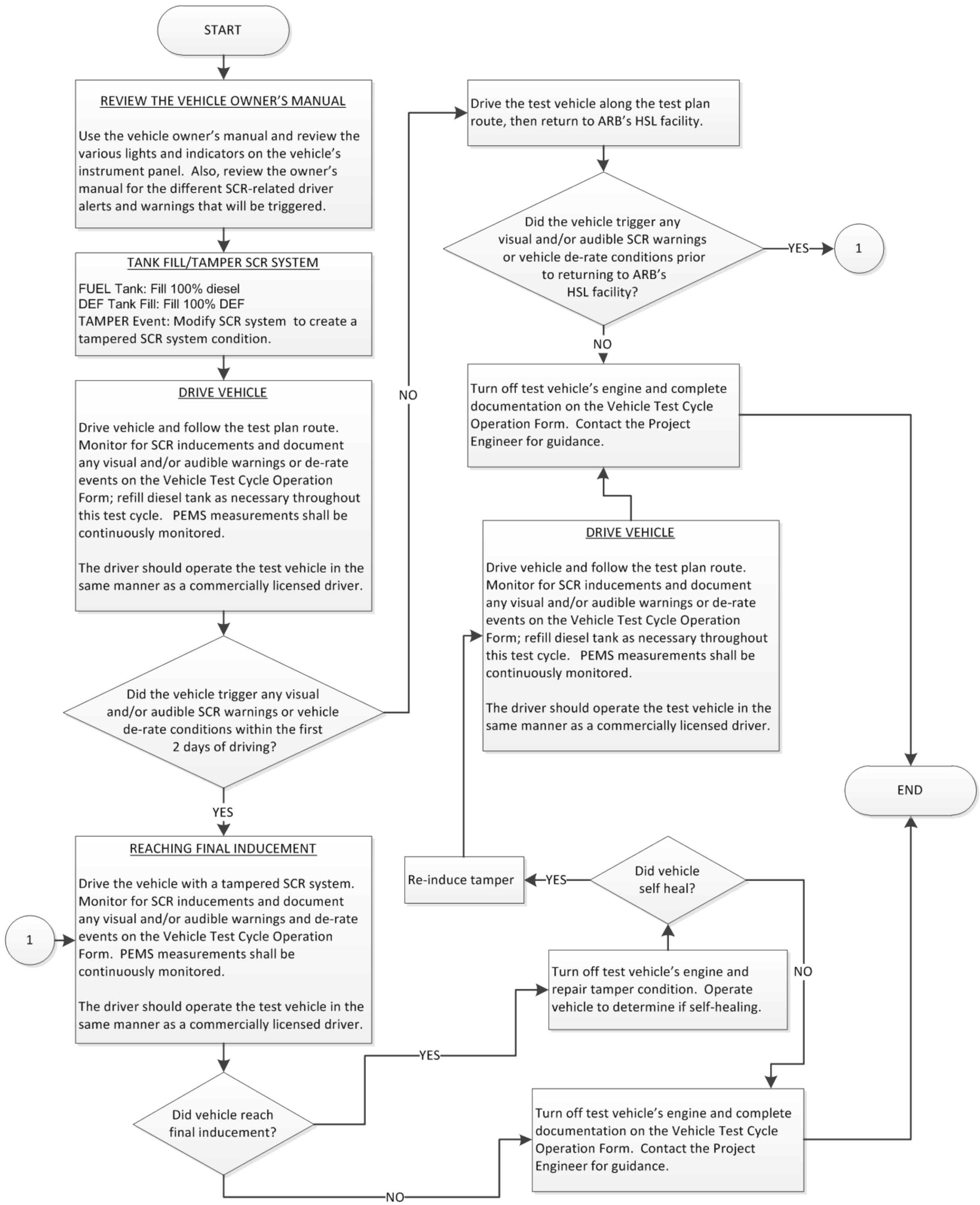


CHART 5

SCR EQUIPPED HDD TRUCK OPERATION (DEF CONCENTRATION)

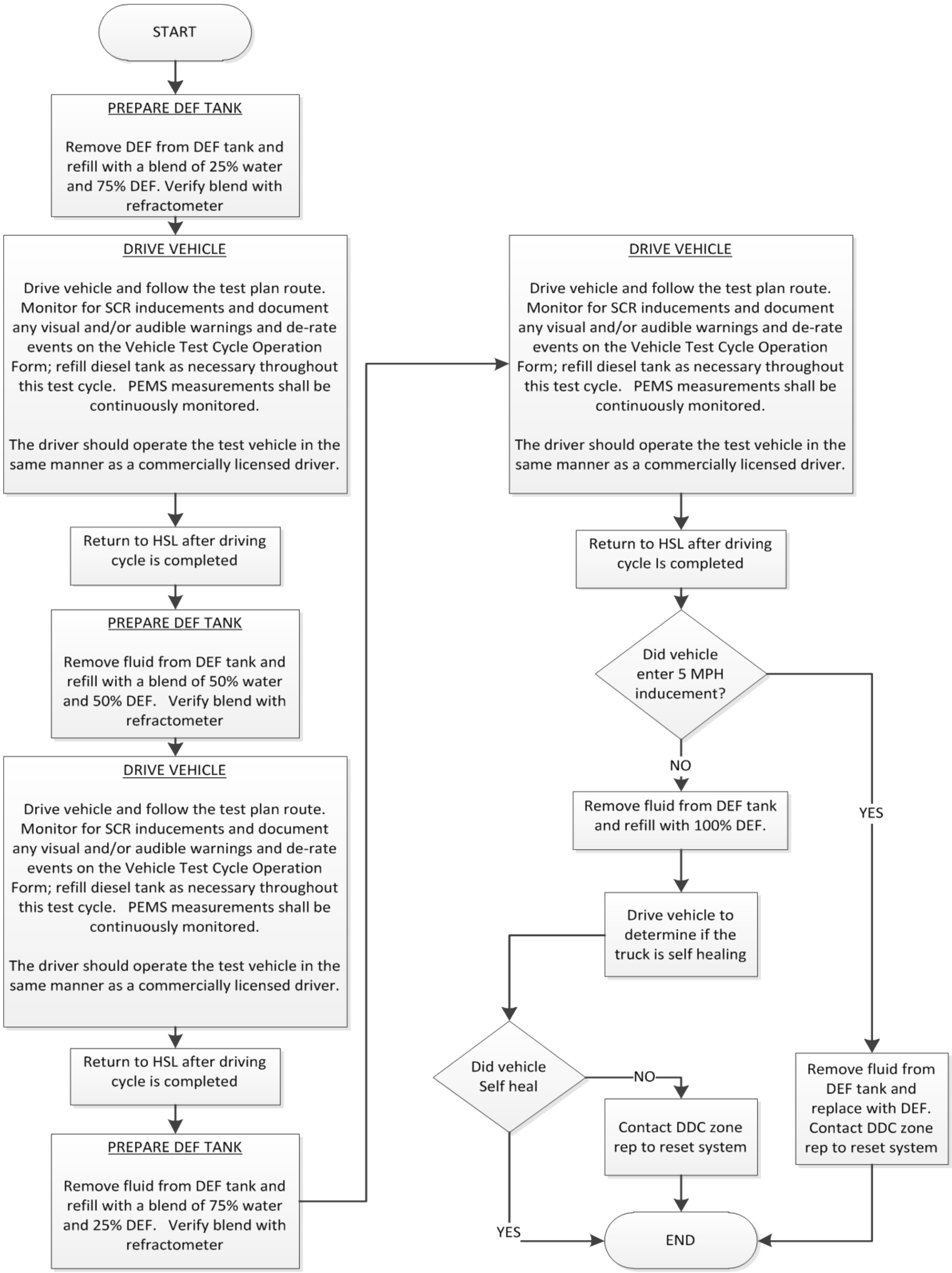


CHART 6

EGR-EQUIPPED HDD TRUCK OPERATION
(Baseline Evaluation)

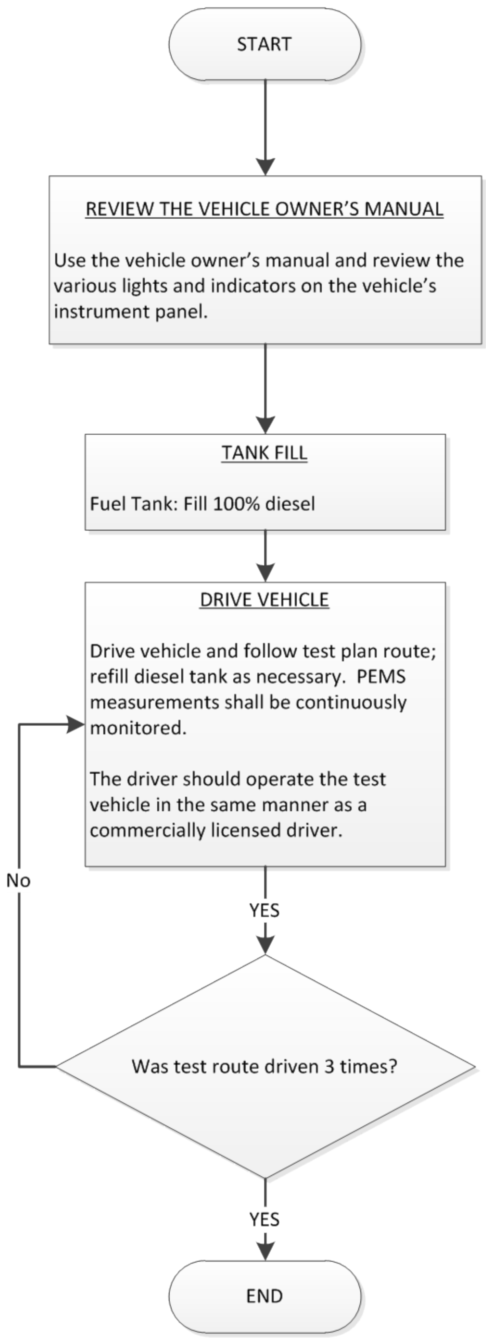


CHART 7

EGR-EQUIPPED HDD TRUCK OPERATION
(EGR System Tamper)

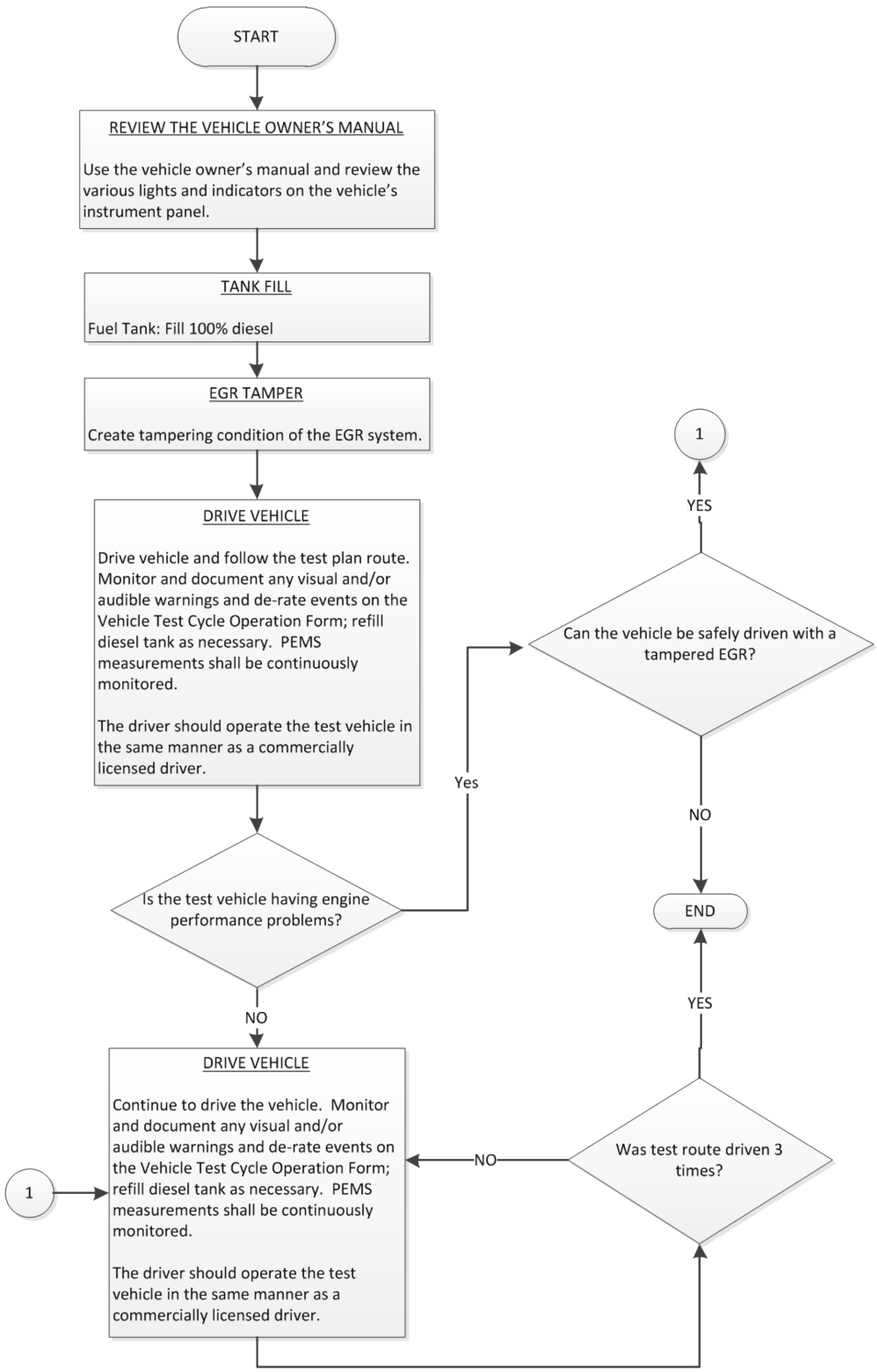
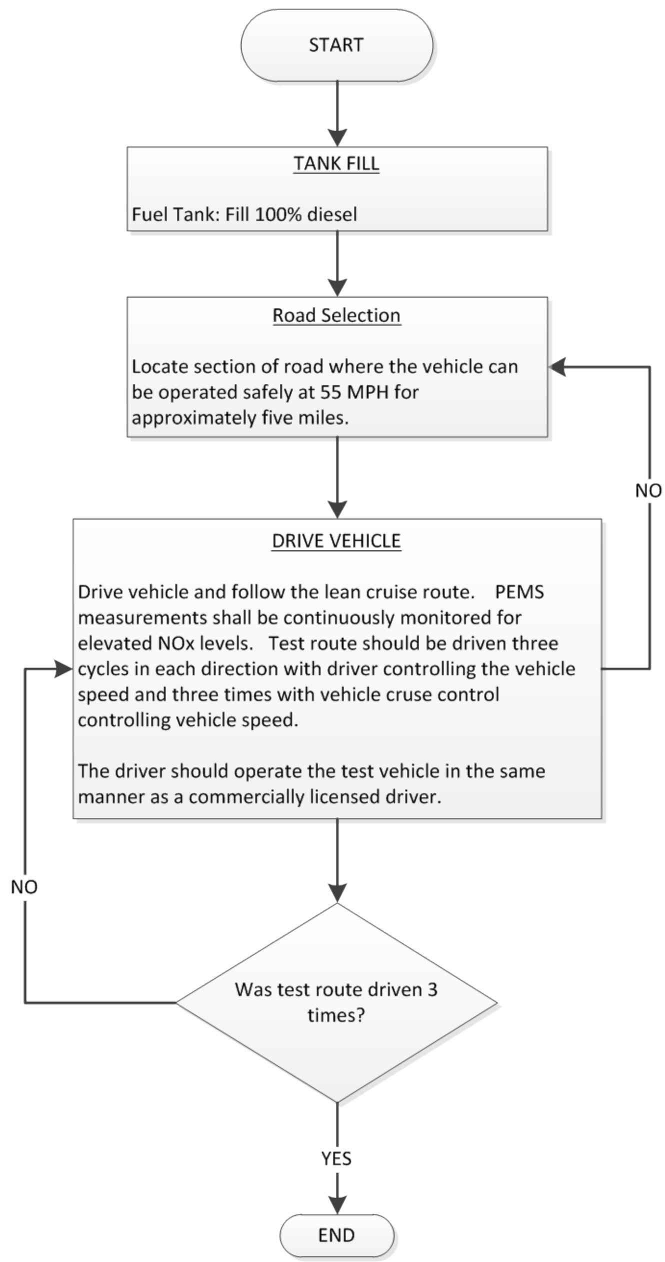


CHART 8

EGR-EQUIPPED HDD TRUCK OPERATION
(Lean Cruise)



PROJECT TEST ROUTE

ARB [9528 Telstar Ave, El Monte, CA 91731]
- I-10 east
- CA-605 north
- CA-210 east
- I-15 north
- US-395 north

Joshua St, Hesperia, CA 92344
- I-15 south
- CA-210 west

North Campus Ave, Upland, CA 91784
- CA-210 east
- I-15 north
- US-395 north

Joshua St, Hesperia, CA 92344
- I-15 south
- CA-210 west
- I-15 south
- CA-210 west
- CA-605 south
- I-10 west

ARB [9528 Telstar Ave, El Monte, CA 91731]

SUMMARY - Approximated driving distance: 197 miles

LEAN CRUISE TEST ROUTE

Start 4 Street on ramp into I-15 south

Exit I-15 to Limonite

Limonite on-ramp to I-15 North

Exit I-15 to 4th street

Summary: Approximated driving distance 14.8 miles

Vehicle Test Cycle Operation Form

Project #: ____________________ Date: _______________ Vehicle #: _________ Chart # _________

Driver: _____________________ Observer: ____________________ Vehicle License #: _______________

Fuel Tank Capacity: ________ gal DEF Tank Capacity: _________ gal Test Cycle: ________________

Date	Time	Odometer	DEF Tank Type Fluid Added	Amount Fluid Added	DEF Gauge Level	Diesel Fuel Added	Diesel Gauge Level	Engine Performance. Note any changes of power de-rate	Engine Start	Road Grade (Uphill/Flat /Downhill)	Vehicle Speed	How Many AWLs	Red Light Indicator	Comments

AWL – Amber Warning Light