AIR RESOURCES BOARD

HEAVY-DUTY VEHICLE SELECTIVE CATALYTIC REDUCTION TECHNOLOGY FIELD EVALUATION

May 2011

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

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 oxides of nitrogen (NOx) standard for heavy duty diesel (HDD) 2010 model year (MY) engines. The majority of engine manufacturers chose selective catalytic reduction (SCR) technology to attain this standard. For SCR systems to operate properly, unlike most emission control systems, the operator needs to periodically replenish the reductant used to catalyze the NOx conversion. The 2010 MY engines equipped with SCR all used a liquid urea solution as the reductant, known commonly as diesel exhaust fluid (DEF). 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. Concerns were raised during the original rulemaking efforts that because SCR relies on the availability of DEF and truck operators periodically refilling their DEF tanks, SCR could be construed as not being an effective emission reduction strategy. In addition, since the use of DEF would likely be seen as an increase in operational cost, the threat of tampering existed.

To minimize the likelihood of improper maintenance and tampering, the U.S. EPA provided manufacturers certification guidance for SCR-equipped engines in the 2007 calendar year, in February 2009, and again in December of 2009 (U.S. EPA reference numbers CISD-07-07 dated March 27, 2007 and CISD-09-04 dated February 18, 2009 and CISD-09-04 REVISED dated December 30, 2009). 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 and consulted the February 2009 Guidance during its 2010 certification reviews for California. Most manufacturers were already certified for the 2010 MY when the December 2009 U.S. EPA Guidance was released.

The February 2009 U.S. EPA Guidance document provided advisory information to manufacturers of SCR-equipped engines that addressed driver warning systems, driver inducement strategies, identification of incorrect reducing agents (also known as DEF), tamper resistant design, and freeze protection.

ARB consulted the February 2009 document during its 2010 MY certification review and expected at a minimum that engines seeking ARB certification would have attributes consistent with the February 2009 U.S. EPA Guidance. 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 February 2009 U.S. EPA Guidance, these inducements first alert the driver that the DEF supply is low, followed by a reduction in truck performance or other inducement to encourage the DEF supply to be refilled. Ultimately, if DEF is not refilled, or if an inappropriate fluid is added, or if hardware is tampered, the vehicle is immobilized. The ARB certified 2010 MY engines that had strategies consistent with the February 2009 U.S. EPA Guidance.

One manufacturer that did not use SCR, Navistar, claimed in a July 2010 public workshop, based on their own test program that the warning and driver 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. In response to the concerns of DEF availability, SCR tampering, and effectiveness of SCR inducement strategies, ARB initiated field investigations to evaluate the first year implementation of SCR - the 2010 MY. 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.

A summary of the findings follows.

1. **Availability of DEF** – Two surveys of DEF availability were performed, one in March 2010 and the second in August 2010. Both surveys indicated that DEF was readily available 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. ARB anticipates that as the demand for DEF increases, it's availability at retailers will increase.

2. Is DEF being used? Are SCR systems being tampered with? – During the first two weeks of September 2010, the staff pulled over as many identifiable SCR-equipped trucks as possible at seven California Highway Patrol commercial vehicle weigh stations and performed roadside inspections on each vehicle to determine if DEF was being used and if other indications of tampering (warning lights or messages) were present. The results indicated that all 69 vehicles inspected were using the proper DEF solution, no tampering was present, and no DEF-related warning lights or audible alerts had been initiated.

A survey of the operators indicated that 60 of the 69 drivers had no problem locating DEF while nine drivers indicated they had experienced problems. Of these nine drivers, four had problems locating DEF out-of-state and the other five had problems locating DEF in California (i.e., the owner could not purchase DEF at a particular diesel refueling station or the station had run out of supply). However, 68 drivers stated that they never ran out of DEF while operating their vehicles and only 1 driver indicated that he drove for only 10 miles with an empty DEF tank as indicated by the driver's gauge.

3. <u>Evaluation of SCR inducements</u>: - ARB procured three 2010 trucks that use SCR-equipped engines for more thorough evaluation. Before testing the vehicles, ARB staff examined the vehicle owner's manuals and the February 2009 U.S. EPA Guidance to ascertain the expected inducement strategies for each vehicle in the ARB evaluation program. 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 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 de-rates 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 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 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.

The evaluation focused on three vehicles with 2010 MY engines equipped with SCR systems. The vehicles evaluated included a 2011 Freightliner Cascadia equipped with a 2010 MY12.8 liter Detroit Diesel DD13 engine (Test Vehicle 1), a 2011 MY Kenworth T800 equipped with a 2010 MY 14.9 liter Cummins ISX15 engine (Test Vehicle 2), and a 2011 MY Dodge Cab Chassis D5500 equipped with a 2010 MY 6.7 liter Cummins ISB engine (Test Vehicle 3). 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 February 2009 U.S. EPA Guidance.

- **DEF Depletion Cycle** –The vehicle would be operated until the DEF tank was depleted and the vehicle experienced a no-start condition, or 5 mile per hour (mph) maximum speed limit, or idle-only operation. According to the February 2009 U.S. EPA Guidance the following scenarios should occur. As DEF depletes, visual and/or audio alerts should warn the driver that the tank needed refilling. As DEF continues to deplete to empty, the driver may experience an engine power de-rate condition ranging between 25% to 40% depending on the vehicle type and DEF tank capacity. Typically, the first level inducement should begin at a 2.5% DEF level known as the DEF Trigger and should be in the form of either a 25% engine power de-rate 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 any time after the 2.5% 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 reserve tank volume, e.g., 2.5% 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 mile per hour (mph) maximum speed limit, or idle-only operation. According to the February 2009 U.S. EPA 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 de-rate should occur at 500 miles or 10 hours after initial detection, and 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 mile per hour (mph) maximum speed limit, or idle-only operation. According to the February 2009 U.S. EPA 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% engine torque power de-rate should occur at 500 miles or 10 hours after the initial detection, and 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.

DDC 12.8L (Test Vehicle 1): Based on the vehicle owner's and engine service manuals, the vehicle was expected to have escalating visual warnings, vehicle speed limited to 55 mph combined with a 25% reduction in engine torque, and a severe inducement limiting vehicle speed to 5 mph once a safe harbor event (in this case a diesel refueling event, or 350 gallons of diesel fuel consumed and engine stop) was encountered.

During the DEF Depletion Cycle, the vehicle performed as expected per the vehicle owner's and engine service manuals. The cycle began with the DEF gauge illuminating one green square gauge light (DEF gauge only shows increments of approximately 25% through the use of four squares) indicating sufficient DEF was present to not trigger any warnings or alerts. Visual warnings (a solid amber circle lit up and one solid green square changed to amber) began 185 miles after starting the cycle, presumably, when the DEF level should have dropped below 10% DEF (based on the vehicle manuals). The SCR system escalated the driver warning sequence 77 miles after the initial warnings with a flashing amber circle, a flashing red square, and illumination of the amber text check engine light, consistent with the vehicle manuals 5% DEF level indicators. The visual warnings were accompanied by the driver noticing the vehicle speed was limited to about 55 mph, which would be consistent or ahead of the U.S. EPA Guidance 2.5% DEF Trigger for first level inducement. The driver experienced an engine power de-rate when negotiating a steep grade 33 miles later and the engine manufacturer diagnostic (EMD) malfunction indicator light (MIL) began flashing periodically. Staff drove for another 233 miles at which point the EMD MIL came on and stayed on. After another 40 miles, staff stopped the vehicle to refuel with 57.8 gallons of diesel fuel. Upon restart the red text stop engine light illuminated and the vehicle would not operate above 5 mph; all accumulated visual warnings continued to illuminate. The inducement strategies used on this truck to detect DEF depletion appear to be consistent with both the vehicle manuals and the February 2009 U.S. EPA Guidance.

To initiate the DEF Contamination Cycle, staff added about three gallons of water, which cleared the depletion inducements. Within an hour (41 miles of driving) of adding water to the DEF tank, the visual warnings (flashing amber DEF circle, amber text check engine light, amber EMD MIL) occurred indicating the detection of poor quality DEF. After driving an additional 345 miles with the continuance of visual warnings, the truck experienced an engine power de-rate coupled with a 55 mph maximum speed limit (consistent with the February 2009 U.S. EPA Guidance of 500 miles to trigger de-rate post detection). The vehicle was driven for another 504 miles until a diesel refueling was needed. After turning off the engine, and filling the diesel tank with 101 gallons of diesel, the vehicle was restarted and staff encountered the 5 mph severe inducement condition (consistent with the February 2009 U.S. EPA Guidance of 1,000 miles to trigger final immobilization post detection). The inducement strategies used on this truck appeared to be consistent with both the vehicle manuals and the February 2009 U.S. EPA Guidance. Staff siphoned out the water and added twelve and a half gallons of DEF to clear the inducements but this was not successful; therefore, the vehicle was taken to a repair center where they reset the engine control unit (ECU) removing all inducement conditions. ARB was charged $240 for this service.

On the DEF System Tampering Cycle, staff disconnected the DEF injection pump and upon starting the vehicle visual warnings (amber text check engine light and EMD MIL) were immediately illuminated. After driving 56 miles the engine power de-rate condition occurred (consistent with both the vehicle manuals and February 2009 U.S. EPA Guidance). Due to time constraints, ARB had to terminate testing of this vehicle and did not complete the final stages of inducements for this test cycle.

Regarding the effectiveness of the inducement strategies, ARB staff reported that visual warnings were effective in drawing the driver's attention to the need for SCR-related service. Also, driving this vehicle once the initial inducement occurred (engine power de-rate and 55 mile per hour speed limit) was neither acceptable nor tolerable when trying to accelerate or driving uphill, and would likely cause a driver to refill with DEF or correct the SCR problem. In addition, once the vehicle entered into a 5 mph limited speed condition under a DEF contamination event, the only way to resume normal operation was to have the vehicle serviced, drain water out of the system and refill the vehicle with DEF, followed by a reset of the system by an authorized service technician; therefore, the driver would be stranded until proper servicing. The ARB staff concludes the inducements were effective for this vehicle because the constant inducement strategies and risk of costly repairs were not worth the lost time and financial business losses when DEF could simply be added to ensure proper vehicle operation.

Cummins 14.9L (Test Vehicle 2): Based on the vehicle owner's manual, the vehicle was expected to have visual warnings, a 25% reduction in engine torque for the initial de-rate, and a severe inducement limiting vehicle speed to 5 mph once a safe harbor (key-off/restart, or 20 hour idle) event was encountered.

During the DEF Depletion Cycle, the first visual warnings (solid DEF gauge light, low DEF message) occurred when the DEF gauge level fell below 1/8th tank level. After driving 44 additional miles, the red DEF light began to flash. The check engine light also illuminated 24 miles later when the DEF gauge read empty and was followed in another 130 miles by an engine torque reduction as experienced by the driver. Even after driving an additional 559 miles after encountering an engine torque de-rate, repeated key-on/key-off events did not trigger the 5 mph inducement. It should be noted since taking delivery of this vehicle from the dealer, the on-board diagnostic (OBD) MIL and the stop engine light intermittently illuminated that was later determined to be related to a throttle position sensor problem. While the vehicle's early warning and first level inducements were consistent with the February 2009 U.S. EPA Guidance, the severe inducement never occurred. Staff investigation found that approximately one quart of DEF remained in the DEF tank; therefore, the vehicle never triggered the zero DEF inducement. When the remaining DEF was siphoned out, the 5 mph inducement was triggered immediately. Further discussion of the intermittent throttle position sensor problem and residual DEF issue is provided below.

To initiate the DEF Contamination Cycle, staff added water to the DEF tank. After driving 57 miles with water in the DEF tank, the vehicle returned to normal operation and all visual warnings cleared. Poor quality DEF was detected after driving an additional 582 miles with illumination of an OBD MIL. An engine power de-rate was felt by the driver 225 miles later. Staff drove the vehicle for another 686 miles with intermittent engine power de-rate fluctuations and visual warnings. However, the vehicle never triggered the 5 mph severe inducement after driving 911 miles (and more than 30 hours) since the first warning occurred and with multiple key off events. The inducement strategies demonstrated for this cycle were inconsistent with the February 2009 U.S. EPA Guidance and the vehicle owner's manual. After the DEF gauge read near empty, staff added DEF several times over the next 143 miles until the DEF gauge read almost full, yet staff was unable to clear the OBD MIL or engine power de-rate conditions. The vehicle was taken to a Cummins dealer, who in their investigation of the problem confirmed the DEF tank was contaminated with water and declined any warranty coverage for the repair, which was verbally estimated to be $800. ARB declined the service, but requested that the dealer reset the computer and clear any trouble codes which cost $125.

While at the dealer, it was also discovered that the vehicle had a defective throttle position sensor and that it caused numerous OBD MIL illuminations along with the red engine stop light, causing an associated engine power de-rate. The engine de-rate condition as a result of the throttle position sensor problem was different than the SCR inducement engine de-rate because the OBD MIL and de-rate event could be quickly cleared by snapping the accelerator throttle. The throttle position sensor was replaced under warranty at a second dealer visit and the Contamination Cycle halted.

For the DEF Tampering Cycle, the DEF system was flushed, appropriate DEF was added, and staff disconnected the DEF doser valve. Immediately upon engine start, the check engine light was illuminated and after driving 97 miles (consistent with the February 2009 U.S. EPA Guidance detection time and 500 mile triggers) additional visual warnings occurred (flashing DEF light, stop engine light, and low DEF fluid) along with a perceived engine power de-rate. However, as with the DEF Contamination Cycle, despite 2,552 additional miles driven and multiple key-off/restarts, the 5 mph speed limit could not be initiated, which is inconsistent with the final immobilization as outlined in the February 2009 U.S. EPA Guidance and the vehicle owner's manual.

Regarding the effectiveness of the inducements for this vehicle, ARB staff reported that visual warnings were effective in drawing the driver's attention to the need for DEF service. However, since the throttle position sensor was suspected of causing engine power fluctuations during the DEF Depletion and Contamination Cycles, staff could not objectively rate the effectiveness of the engine power de-rate under those cycles because it was not clear if de-rate occurred because of a detected SCR problem or was the result of the defective throttle position sensor. However, even after the throttle position sensor was repaired, the engine power de-rate caused the vehicle to lose power and reduce vehicle speed when negotiating uphill or accelerating, but was seldom noticed when driving on level ground. The drivers reported that the Cummins engine power de-rate was not as noticeable as the DDC vehicle engine power de-rate at similar power and engine speeds.

ARB staff contacted Cummins regarding the failure of the vehicle to initiate the 5 mph speed limit severe inducement under the depletion, contamination and tampering scenarios. Cummins had already implemented a change to correct the failure to initiate the severe inducement on their engine production line in the second quarter of 2010 and had launched a voluntary recall (Cummins Campaign C1036) in August of 2010. Staff confirmed that the ARB test vehicle had not yet been recalled and fixed per C1036. Since completing this test program, Test Vehicle 2 has been outfitted with the Cummins' recall fix and ARB is currently re-evaluating these cycles.

Cummins 6.7L (Test Vehicle 3): Based on the vehicle owner's manual, the vehicle was expected to have escalating visual warnings and audible chimes, followed by a 500 mile countdown counter if no action is taken. Once the counter reaches zero miles and no action has been taken, the vehicle should not start upon its next key-off/key-on event. For the DEF Depletion Cycle, the 500 mile countdown should start 500 miles before DEF is depleted, while for the DEF Contamination and DEF Tampering Cycles the 500 mile countdown sequence should begin if no remedy is sought after operating 250 miles after detection. For all cycles a no-start event should occur once the counter reaches zero and the vehicle is turned off. For this vehicle, the manufacturer chose not to implement a first level inducement as outlined in the February 2009 U.S. EPA Guidance with the aim of meeting the severe inducement or final immobilization point using a countdown counter.

During the DEF Depletion Cycle, a visual text message “Low DEF Refill Soon” came on for the first time at approximately 16% DEF gauge level and displayed periodically with an audible chime as the DEF level declined. After driving 195 miles since the first low DEF message appeared, the EMD MIL illuminated (due to a DEF heater malfunction, see below). A new test message "Refill DEF Engine Will Not Restart in 500 Miles” displayed 739 miles after the EMD MIL was first observed and triggered the 500 mile countdown. At this time, with the EMD MIL illuminated again (EMD MIL went on and off throughout this cycle) the DEF gauge read 0%. During the 500 mile countdown sequence a message continuously displayed "Refill DEF Engine Will Not Restart in XXX Miles" and the audible chimes became more frequent as the countdown progressed. The vehicle was shut down overnight 97 miles into the countdown. Upon restarting the vehicle the next day, the DEF gauge showed 1%, compared to 0% the night before, and the countdown had been cleared. Mileage accumulation began again and after driving 35 miles the DEF gauge again reached 0% triggering the 500 mile countdown sequence once more. Upon locating a safe harbor location 497 miles after the countdown sequence began the second time, the vehicle underwent a key-off/key-on event and a no-start condition resulted. The truck’s inducements appeared to be generally consistent with the vehicle owner's manual; however, the mileage accumulation seemed excessive for the amount of DEF consumed. Upon investigation, it was discovered that a DEF heater malfunction was causing suspension of DEF dosing under certain conditions, thus extending the miles driven before DEF depletion occurred. While the vehicle was, in general, consistent with the intentions of the February 2009 U.S. EPA Guidance, the mileage accumulation was too high for the appropriate DEF consumption rate expected; however, this was related to the DEF heater glitch (DEF engine coolant control valve). Staff is unclear as to why the vehicle reset the 500 mile counter when the DEF gauge changed from 0% to 1% after an overnight park and is following up with Cummins’ personnel on this issue.

To initiate the DEF Contamination Cycle, the DEF tank was filled with water, which cleared the no-start condition. Detection of water in the DEF tank occurred after accumulating 12 miles of driving, which caused a visual warning “Service DEF System - See Dealer” and the EMD MIL illuminated on the instrument panel. Two hundred forty nine (249) miles later, the 500 mile countdown initiated alerting the driver that the vehicle will not start after 500 miles, accompanied by periodic chimes as the countdown progressed. After driving another 497 miles, the countdown indicated zero remaining miles. At the first safe opportunity, the vehicle was keyed-off and attempts to restart the vehicle failed. The vehicle had been driven a total of 746 miles after initial detection of poor quality DEF. Since the manufacturer chose to use a countdown to no-start inducement strategy versus a power de-rate or speed limiter as the first level inducement we cannot compare directly with the first inducement level in the February 2009 U.S. EPA Guidance. However, the vehicle reached the no-start event well before the February 2009 U.S. EPA Guidance 1,000 mile after detection severe inducement trigger point.

In order to initiate the DEF System Tampering cycle, staff drained the water from the DEF tank, filled the tank with appropriate DEF, cleared the diagnostic trouble codes and the no-start condition using a scan tool, and disconnected the DEF doser injector to represent tampering. The tampering was detected immediately upon starting the engine and the driver was alerted of the problem through the illumination of the EMD MIL, an audible chime, and the displayed message “Service DEF System - See Dealer.” After 250 miles of driving, the message changed to "Service DEF System Engine Will Not Start in 500 miles – See Dealer". Another 496 miles were driven before the countdown expired. At the first safe opportunity, the vehicle was keyed-off and attempts to restart the truck failed. In total, the vehicle was driven 746 miles after the initial detection of DEF tampering. The inducement strategies used on this vehicle to detect DEF system tampering were consistent with the February 2009 U.S. EPA Guidance and well within its 2,000 mile after detection severe inducement trigger point.

Regarding the effectiveness of the inducement strategies, ARB staff reported that visual and audible warnings/alerts were effective in drawing the driver’s attention for the need of SCR-related service. Although this sequence was different than the other two trucks evaluated in this report, the 500 mile countdown to a no-restart condition was an effective strategy in motivating the driver to pay attention to SCR required service. However, the DEF heater malfunction caused more miles than expected to be consumed before final immobilization was encountered during the DEF Depletion event. Therefore, while the inducement strategies were consistent with the February 2009 U.S. EPA Guidance for the majority of the testing, further evaluation is warranted on this vehicle once the DEF heater malfunction is corrected.

Cummins was already aware of the DEF heater issue and has addressed this problem through a service campaign (Technical Service Bulletin No. 25-002-10). Another issue identified by staff was that this system could be reset with a generic scan tool, which allowed the vehicle to continue operation. ARB has discussed the scan tool issue with all manufacturers, pointing out that this capability is not acceptable and has indicated to manufacturers that it must be corrected as soon as possible, but in no case later than the 2013 model year.

4. <u>NOx emissions evaluation</u> – To determine the impact on NOx emissions, Test Vehicle 3 was outfitted with a Sensors, Inc., Semtech-DS Portable Emissions Measurement System allowing for real-time emissions readings as the vehicle was operated through the different DEF test cycles noted above. Measurements from Test Vehicle 3 showed that NOx emissions were within control limits when operating with DEF and tampering was not present. When staff used water in place of DEF and tampered with the SCR system, the NOx emissions were about four times higher than under normal operation.

Conclusion

The widespread availability of DEF was uncertain prior to the first year of sale in the U.S. of SCR-equipped engines (2010). The EPA guidance accommodated this uncertainty by allowing the engine to be designed to allow for some operation of the truck after the warning system indicated DEF was soon to be depleted. The purpose of this provision was to allow the truck operator several opportunities to procure DEF before the more disabling inducements were initiated. As the ARB survey showed, a small percentage of operators found DEF unavailable during 2010. The survey also showed, however, that DEF was widely available, and only 1 of 69 truck operators operated their truck without DEF because of DEF unavailability.

For the three vehicles evaluated in this study, ARB staff found that the warnings and inducement strategies incorporated by the engine manufacturers were consistent with the February 2009 U.S. EPA Guidance. However, the large Cummins engine had a programming error that caused the intended severe inducement (5 mph maximum operating speed) to not occur. Cummins has recalled the affected engines and has also made the change in production. The test vehicle also had a defective throttle position sensor which made assessing the effectiveness of the power de-rate strategy difficult to assess. The smaller Cummins engine had a defective DEF heater which caused the truck to operate longer than anticipated before DEF depletion was detected. This has been addressed by Cummins with a service campaign.

Changes for 2011 Models

With DEF widely available in California, ARB has worked with the U.S. EPA and engine manufacturers to improve the effectiveness of the SCR monitoring system of 2011 models. In July 2010, ARB held a joint public workshop with the U.S. EPA discussing the changes to the SCR inducement strategies we expected for the 2011 and future MYs, as outlined below:

a. When a low level of DEF remains, for example, sufficient to drive about 100 miles under typical driving conditions, warning signals begin and become increasingly urgent thereafter.
b. After the DEF tank level triggered in paragraph (a) and before an empty DEF tank, a noticeable de-rate begins and is sustained until paragraph c.
c. When the DEF tank is empty, a more significant de-rate occurs. Operation at this second de-rate occurs no longer than necessary to safely reach a location where the engine can be safely shut down, for example, no more than one hour. At the end of this period, the vehicle speed is limited to 5 mph maximum.
d. Upon a disconnected SCR monitor, sensor, or component, warning signals begin and become increasingly urgent thereafter and the engine power will be noticeably de-rated.

e. After an hour of operation pursuant to paragraph d., a second significant de-rate will occur. The engine will operate at this de-rated level for no longer than necessary to confirm disconnection, for example, no more than four hours. At the end of this period the vehicle speed is limited to 5 mph maximum. Normal operation cannot be resumed until the disconnection is cleared.

f. If repeated disconnects and reattachments of a SCR monitor, sensor, or component are detected, the attributes in paragraph c. apply. Normal operation cannot be resumed until the disconnections are cleared.

g. Proper DEF dosing should occur within 40 minutes of a freezing event.

In addition to the above, ARB is also expecting improvements in DEF contamination detection and in making systems unable to clear triggered inducements with generic scan tools.

HEAVY-DUTY VEHICLE SCR TECHNOLOGY FIELD EVALUATION

I. Introduction

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 oxides of nitrogen (NOx) standard for heavy duty diesel (HDD) 2010 model year (MY) engines. The majority of engine manufacturers chose selective catalytic reduction (SCR) technology to attain this standard. For SCR systems to operate properly, unlike most emission control systems, the operator needs to periodically replenish the reductant used to catalyze the NOx conversion. The 2010 MY engines equipped with SCR all used a liquid urea solution as the reductant, known commonly as diesel exhaust fluid (DEF). 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. Concerns were raised during the original rulemaking efforts that because SCR relies on the availability of DEF and truck operators periodically refilling their DEF tanks, SCR could be construed as not being an effective emission reduction strategy. In addition, since the use of DEF would likely be seen as an increase in operational cost, the threat of tampering existed.

To minimize the likelihood of improper maintenance and tampering, the U.S. EPA provided manufacturers certification guidance for SCR-equipped engines in the 2007 calendar year, in February 2009, and again in December of 2009 (U.S. EPA reference numbers CISD-07-07 dated March 27, 2007 and CISD-09-04 dated February 18, 2009 and CISD-09-04 REVISED dated December 30, 2009). 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 and consulted the February 2009 Guidance during its 2010 certification reviews for California. Most manufacturers were already certified for the 2010 MY when the December 2009 U.S. EPA Guidance was released.

The February 2009 U.S. EPA Guidance document provided advisory information to manufacturers of SCR-equipped engines that addressed driver warning systems, driver inducement strategies, identification of incorrect reducing agents (also known as DEF), tamper resistant design, and freeze protection.

ARB consulted the February 2009 document during its 2010 MY certification review and expected at a minimum that engines seeking ARB certification would have attributes consistent with the February 2009 U.S. EPA Guidance. 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 February 2009 U.S. EPA Guidance, these inducements first alert the driver that the DEF supply is low, followed by a reduction in truck performance or other inducement to encourage the DEF supply to be refilled. Ultimately, if DEF is not refilled, or if an inappropriate fluid is added, or if hardware is tampered, the vehicle is immobilized. The ARB certified 2010 MY engines that had strategies consistent with the February 2009 U.S. EPA Guidance.

One manufacturer that did not use SCR, Navistar, claimed in a July 2010 public workshop, based on their own test program that the warning and driver 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. In response to the concerns of DEF availability, SCR tampering, and effectiveness of SCR inducement strategies, ARB initiated field investigations to evaluate the first year implementation of SCR - the 2010 MY. The investigation included: (1) a survey of DEF availability within the State of California; (2) two surveys 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.

II. Investigation Plan

In response to the concerns of DEF availability, SCR tampering, and effectiveness of SCR inducement strategies, ARB initiated field investigations to evaluate the first year implementation of SCR - the 2010 MY. The investigation included: (1) a survey of DEF availability within the State of California; (2) a survey to determine whether truck operators driving SCR-equipped vehicles 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 engines; 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.

A. DEF Availability Survey

Two surveys were conducted to evaluate the availability of DEF throughout California (see Appendix A). The first survey was conducted between March 15-18, 2010 and the second survey was conducted during the period August 2-11, 2010.

1. First Survey, March 2010

Using directories and maps as guides, field staff visited numerous businesses that were selling DEF during the week of March 15-18, 2010. The types of businesses visited included retail HDD truck stops, commercial fleets, vehicle service stations, auto part stores, and automobile dealerships selling diesel vehicles with SCR technology. In general, the sites visited were along Interstate 5, Highway 99, Interstate 10, Interstate 15, and U.S. Route 101. Furthermore, telephone surveys were also conducted to supplement the on-site surveys. Staff also surveyed DEF marketing web sites at www.finddef.com and www.discoverdef.com that identified known DEF distributors. As part of the survey, staff questioned management personnel at all the contacted sites to determine if DEF was available or if their company would be selling DEF in the future. ARB staff also inquired how DEF was sold, what size containers were available and the cost of DEF. The survey results indicated that a typical truck driver could easily find DEF at diesel refueling stations along major interstate routes or at an authorized repair dealer (i.e., 85% of these known distributors had DEF in stock), (see Figure 1).

Figure 1 – DEF Survey – March 2010

DEF Availability Survey Results March 2010						
	Have DEF Available	No DEF Available	DEF To Be Sold Within 6 Months	Total	% Have DEF	% DEF To Be Sold Within 6 Months
Known DEF Dealers*	33	6	4	39	85%	10%
Random Retail Facilities	60	211	34	271	22%	13%
* Includes diesel re-fueling stations and diesel repair facilities.						

In addition, ARB's survey showed that approximately one out of five retail facilities (i.e., auto part stores, light/medium-duty vehicle diesel refueling stations, major shopping retail stores, etc.) had DEF available.

Staff visited two Pilot Travel Center diesel refueling stations located in Madera and Hesperia, California that sold DEF in bulk quantity. These diesel refueling stations had DEF available next to the diesel pumps and dispensed DEF in a similar manner as diesel fuel. The cost for DEF at these locations averaged $2.89 per gallon and was the best overall cost per gallon identified by this survey. Most other diesel refueling stations had DEF available but it was located less conveniently inside the store or facility. Within the stores or facilities, DEF was available in 1.0, 2.0, 2.5 or 5 gallon containers. In some cases, DEF supply companies sold mainly 55 gallon or 275 gallon containers to HDD vehicle warehouses and truck distribution plants. The average prices of DEF distributed in containers are shown in Figure 2 below. Typically, the price of DEF was more expensive when sold in smaller volume containers and less expensive when sold in bulk containers.

Figure 2 – DEF Retail Pricing

Quantity (Gallon)	Cost Per Quantity	Cost Per Gallon
1.0	$8.92	$8.92
2.0	$14.36	$7.18
2.5	$14.24	$5.70
5.0	$25.59	$5.12
55.0	$213.82	$3.89
275.0	$842.19	$3.06

2. Second Survey, August 2010

A second DEF availability survey was conducted August 2–11, 2010. ARB staff revisited potential suppliers of DEF that were part of the first survey. However, for this survey, greater focus was placed on truck stops and heavy-duty truck diesel refueling stations. As with the previous survey, DEF retailers listed on www.finddef.com and www.discoverdef.com were visited to see whether they had stocked DEF as advertised. In addition, staff returned to facilities surveyed previously that did not carry DEF but expressed intent to do so with increased demand. Less focus was placed on dealerships and automobile part stores. As you can see from the survey results in Figure 3 below, the availability of DEF increased slightly from the March survey period.

Figure 3 – DEF Survey – August 2010

DEF Availability Survey Results August 2010						
	Have DEF Available	No DEF Available	DEF To Be Sold Within 6 Months	Total	% Have DEF	% DEF To Be Sold Within 6 Months
Known DEF Dealers*	23	2	0	25	92%	0%
Random Retail Facilities	127	300	36	427	30%	8%
* Includes diesel re-fueling stations and diesel repair facilities.						

3. Conclusion

Both surveys showed that DEF is readily available at major truck stop diesel refueling stations along major interstate highways (more than 90% availability as determined in the second survey). ARB staff understands that auto part stores, light/medium-duty vehicle diesel refueling stations, and major shopping retail stores do not typically carry DEF as part of their normal retail supplies. Nevertheless, over 30% of those businesses identified in the second survey sold DEF.

Nearly all the 2010 MY HDD engines are equipped with the new SCR technology for controlling NOx emissions. These surveys were conducted within the first year of SCR implementation, and the penetration of these vehicles has not reached a significant portion of the full on-road HDD vehicle fleet. As older diesel vehicles are retired, the population of HDD trucks and passenger vehicles with SCR technology would increase and therefore, increase the demand and availability for DEF. ARB's surveys show that DEF is currently being offered in an adequate supply to accommodate the limited number of vehicles operating on DEF.

B. DEF Quality Tampering Survey

ARB staff conducted a different type of survey in September 2010. This survey's focus was to ascertain whether or not truck operators were using DEF and examine if there were any indications of SCR inducements occurring in use. The surveys were performed at seven California Highway Patrol commercial vehicle weigh stations in southern and northern California where ARB staff pulled over as many identifiable SCR-equipped trucks as possible during the first two weeks of September. As part of the survey staff extracted a sample of DEF from each truck to measure urea concentration to determine DEF quality. Staff also inspected the vehicles for DEF warning indicators, engine diagnostic lights, visually inspected emission control for tampering, and conducted a short driver’s questionnaire. Shown in Figure 4 below is an illustration of the number of manufacturers’ vehicles that were inspected for the DEF Quality Tampering Survey.

Figure 4 – DEF Quality Tampering Survey – September 2010

Location	Truck	Cummins	DDC	Mack	Volvo	Grand Total
Antelope	Freightliner	1				1
	Kenworth	3				3
	Peterbilt	2				2
Banning	Freightliner		2			2
	Kenworth	2				2
	Volvo				1	1
Castaic	Freightliner		12			12
	Kenworth	2				2
	Peterbilt	4				4
	Volvo				10	10
Conejo	Freightliner	1	3			4
	Kenworth	1				1
	Peterbilt	3				3
	Volvo				3	3
San Onofre N. B.	Freightliner		2			2
	Kenworth	3				3
	Volvo				1	1
San Onofre S. B.	Freightliner	2	1			3
	Peterbilt	1				1
	Volvo				3	3
Sidewinder W. B.	Freightliner		1			1
	Kenworth	1				1
	Mack			1		1
	Peterbilt	2				2
	Volvo				1	1
Grand Total		28	21	1	19	69

N.B. – North Bound S.B. – South Bound W.B. – West Bound

1. DEF Quality Analysis

The DEF quality analysis involved taking a sample of DEF from each vehicle and testing it with a refractometer. 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 an inspected vehicle was compared to a high quality DEF (32.5% urea and 67.5% deionized water) baseline sample. The results of this analysis indicated that all 69 vehicles inspected had proper DEF in their tanks.

2. Driver Warning Indicators

As part of the visual inspection, ARB staff looked for driver warning and engine diagnostic lights. The visual inspection involved examining each vehicle's instrument panel. No illuminated driver warning lights or engine diagnostic lights were found, indicating that the diagnostic systems detected no problems with the SCR or DEF dosing system.

3. Driver's Questionnaire

Each vehicle operator was asked the following questions with a summary of their responses subsequently shown.

- Question 1: Have you operated your truck without DEF?

  Response: One driver drove his truck for 10 miles without DEF. The remaining 68 drivers indicated they had never run their truck without DEF.

- Question 2: Have you operated your truck on fluids other than DEF in the DEF tank?

  Response: All 69 drivers stated they did not use any fluids other than DEF.

- Question 3: Have you had any problems with your truck's emissions control system?

  Response: All 69 drivers indicated that they have not experienced problems with their emissions control systems.

- Question 4: Have you had any problems locating DEF?

  Response: 60 drivers had no problem locating DEF, while nine drivers indicated they had experienced problems. Of these nine drivers, four had problems locating DEF out-of-state and the other five had problems locating DEF in California (i.e., the owner could not purchase DEF at a particular diesel refueling station or the station had sold out of DEF). However, 68 drivers stated that they never ran out of DEF and only one driver indicated that he drove for only 10 miles with an empty DEF tank.

4. Conclusion

The results of the survey indicated that drivers are using the proper DEF concentration (high quality) in their SCR-equipped vehicles. With the availability of DEF expected to increase in California and across the country, truck drivers are unlikely to be forced to operate without DEF due to unavailability. This type of inspection will be incorporated into ARB's Heavy-Duty Vehicle Inspection Programs (HDVIP) in the future.

C. Evaluation of SCR Driver Inducements

ARB procured three 2010 trucks that use SCR-equipped engines for more thorough evaluation. Before testing the vehicles, ARB staff examined the vehicle owner's manuals and the February 2009 U.S. EPA Guidance to ascertain the expected inducement strategies for each vehicle in the ARB evaluation program. 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 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 de-rates 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 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.

The evaluation focused on three vehicles with 2010 MY engines equipped with SCR systems. The vehicles evaluated included a 2011 Freightliner Cascadia equipped with a 2010 MY12.8 liter Detroit Diesel DD13 engine (Test Vehicle 1), a 2011 MY Kenworth

T800 equipped with a 2010 MY 14.9 liter Cummins ISX15 engine (Test Vehicle 2), and a 2011 MY Dodge Cab Chassis D5500 equipped with a 2010 MY 6.7 liter Cummins ISB engine (Test Vehicle 3). 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 February 2009 U.S. EPA Guidance.

- **DEF Depletion Cycle** –The vehicle would be operated until the DEF tank was depleted and the vehicle experienced a no-start condition, or 5 mile per hour (mph) maximum speed limit, or idle-only operation. According to the February 2009 U.S. EPA 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 de-rate condition ranging between 25% to 40% depending on the vehicle type and DEF tank capacity. Typically, the first level inducement should begin at a 2.5% DEF level known as the DEF Trigger and should be in the form of either a 25% engine power de-rate 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 any time after the 2.5% 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 reserve tank volume, e.g., 2.5% 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 mile per hour (mph) maximum speed limit, or idle-only operation. According to the February 2009 U.S. EPA 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 de-rate 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 mile per hour (mph) maximum speed limit, or idle-only operation. According to the February 2009 U.S. EPA 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% engine torque power de-rate 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.

See Figure 5 for a summary of the February 2009 U.S. EPA Guidance consulted by ARB staff for the 2010 MY certifications and this test program. A copy of the test plan is attached in Appendix B.

Figure 5 - <u>FEBRUARY 2009 U.S. EPA GUIDANCE SUMMARY</u>

DEF DEPLETION
<u>INITIAL WARNING</u> • 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
<u>INDUCEMENTS</u> • 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.

<u>SEVERE INDUCEMENT</u>
• At "DEF Trigger" (2.5% DEF) or at DEF Empty for 1:1 DEF/Fuel Tank Size
  o 25% torque de-rate for DEF Trigger or 40% for 1:1 DEF/Fuel Tank Size
  o 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 5 - FEBRUARY 2009 U.S. EPA GUIDANCE SUMMARY - continued

DEF CONTAMINATION

INITIAL WARNING

- Once Detected: Warning message or light

INDUCEMENTS

- At detection + 500 miles or 10 hrs
    - 25% torque de-rate
    - 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 de-rate 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

DEF SYSTEM TAMPERING CYCLE

INITIAL WARNING

- Once Detected: Warning message or light

INDUCEMENTS

- At detection + 500 miles or 10 hrs
    - 25% torque de-rate
    - 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 de-rate
- 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

Driving routes were selected to represent a broad range of engine loading. Each test vehicle's engine load was expected to vary from nearly full power conditions, when hauling heavy loads uphill, to a near zero engine load when traveling downhill. ARB staff also compared the driver inducements to what was provided in the February 2009 U.S. EPA Guidance for each of the test conditions listed above, as well as, the vehicle owner's manuals and engine service manuals. It was expected that each condition described above would result in staged driver warnings in the form of a DEF level indicator, messages in the instrument cluster, a low DEF light indicator, stop engine light, and/or audible warnings. If warnings were ignored and remedies were not applied as mileage accumulated, further driver inducements would be initiated in the form of engine power de-rating, or speed limiting. Ultimately, a severe inducement would require the vehicle to be immobilized by limiting speed to 5 mph, or restricting engine operation to an idle-only or a no-start condition.

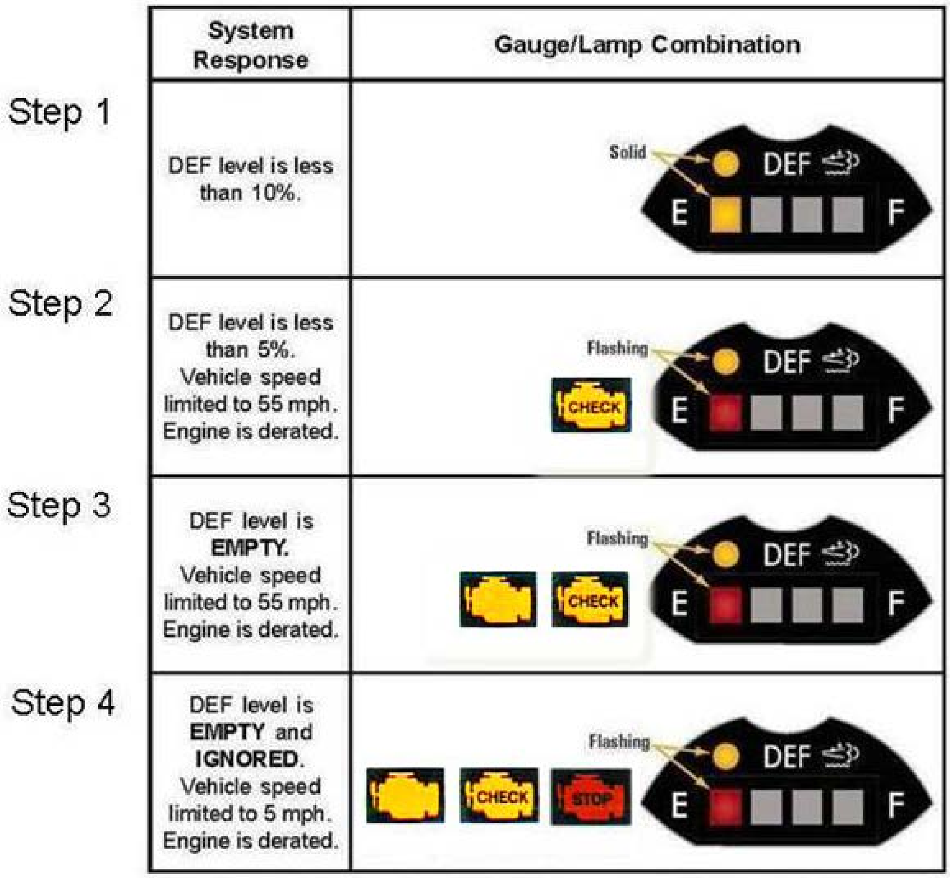
1. Test Vehicle 1

Chassis:	2011 MY Freightliner Cascadia
Axles:	3
Engine:	Detroit Diesel Corporation
Engine Family:	ADDXH12.8FED
Displacement:	12.8 Liter
Horsepower:	470
Trailer:	48-foot flatbed

Test Vehicle 1 was a 2011 MY Freightliner Cascadia equipped with a 2010 MY Detroit Diesel Corporation (DDC) DD13 engine rented from a local Penske Truck Rental. When ARB took possession of the vehicle from Penske, the odometer showed 361 miles. The vehicle towed a 48-foot flatbed trailer and was loaded with five 20-foot "K-rail" concrete barriers that weighed about 40,000 pounds.

Figure 6, shown on the next page, (reproduced with DDC's permission and referenced in part from their engine service manual) describes the expected driver warnings and inducements, the corresponding system response, and the associated dashboard gauge/light combinations. The first driver warning was expected to occur during the DEF Depletion Cycle when the vehicle's DEF level fell below 10% of its capacity (see Step 1, Figure 6). As the DEF level depleted below 5%, the driver should be subjected to specific combinations of illuminated gauge/light combinations (Steps 2 through 4, Figure 6), including an engine power de-rate, and limiting vehicle speed to 55 miles per hour (mph). If the DEF was not refilled and the vehicle reached a safe harbor event (i.e., the vehicle was re-fueled, or the engine was turned off and restarted, or after 350 gallons of diesel fuel had been consumed since the DEF tank empty warning alert), a severe inducement limiting vehicle speed to 5 mph should be initiated. The SCR system was expected to trigger similar driver warnings and inducements during the DEF Contamination Cycle and the DEF System Tampering Cycle, but at different mileage/hour triggers after detection of poor quality DEF or tampering consistent with the February 2009 U.S. EPA Guidance Summary in Figure 5.

Figure 6 - DDC's DEF Fluid Level Warning Lights



a) DEF Depletion Cycle

In preparation for the DEF Depletion Cycle staff adjusted the truck's DEF level to illuminate one green square on the DEF level gauge (odometer = 841 miles). After driving 14 miles to a diesel refueling station, the truck's diesel fuel level was then filled to 75% of capacity indicated by the diesel fuel level gauge (odometer = 855 miles). Driving 185 more miles after diesel refueling (odometer = 1,040 miles), the first driver warning occurred by illuminating the DEF gauge's solid amber circle and one solid amber square (see Step 1, Figure 6).

The SCR system escalated the driver warning sequence 77 miles after the initial warnings (odometer = 1,117 miles) with a flashing amber circle and a flashing red square on the DEF gauge, as well as illuminating the amber text check engine light. In conjunction with these visual warnings, the first vehicle inducement occurred when the driver noticed the vehicle speed was limited to about 55 mph, as described in the engine service manual. The driver experienced an engine power de-rate when negotiating a steep grade 33 miles (odometer = 1,150 miles) after the 55 mph limiter was triggered (see Step 2, Figure 6).

The engine manufacturer diagnostic (EMD) malfunction indicator light (MIL) flashed periodically and after accumulating 233 miles (odometer = 1,383 miles) the MIL stayed on continuously. At this time, the DEF gauge's amber circle and red square continued flashing, and the amber text check engine light remained illuminated (see Step 3, Figure 6). The vehicle continued to experience an engine power de-rate and a maximum vehicle speed limited to about 55 mph.

After driving another 40 miles since the EMD MIL illumination (odometer = 1,423 miles) (see Step 3, Figure 6), staff stopped to refuel the vehicle and turned off the engine. Upon adding 57.8 gallons of diesel fuel to the vehicle and restarting the engine, the final driver warnings occurred. This warning series included the DEF gauge's flashing amber circle and a flashing red square on the DEF level gauge, the illumination of the amber text check engine light, the illumination of the amber EMD MIL, and the illumination of the red text stop engine light. As staff attempted to exit the diesel refueling station, staff immediately experienced the 5 mph severe inducement condition (see Step 4, Figure 6).

With the SCR system limiting the vehicle speed to 5 mph, the final step of the DEF Depletion Cycle had occurred (odometer = 1,423 miles). Staff drove the vehicle out of the way of other station traffic and shut down the vehicle.

b) DEF Contamination Cycle

To begin the DEF Contamination Cycle, about three gallons of water were added to the DEF tank prior to engine startup. After starting the engine, staff observed that all the various illuminated dashboard warning lights that were previously active, were now off as the SCR system had reset, and one solid green square was illuminated on the DEF gauge. As staff began to drive the vehicle, they also noticed the vehicle was no longer experiencing any engine power de-rate and seemed to drive normal. The odometer was at 1,424 miles as the test route was resumed.

The SCR system triggered the first driver warning and inducement for contaminated DEF after driving 41 miles (odometer = 1,465 miles) with the illumination of the DEF gauge's flashing amber circle, the amber text check engine light, and the amber EMD MIL (similar to Step 3, Figure 6). Note: the red square was not flashing (one green bar was illuminated). Over the next 345 miles (odometer = 1,810 miles) the first set of driver warnings as listed above remained illuminated, and at this point the vehicle initiated the inducements of an engine power de-rate and the 55 mph speed limiter as noticed by the driver.

The operator continued driving the vehicle for several days accumulating an additional 504 miles (odometer = 2,314 miles) before having to refuel the vehicle. While accumulating these miles, the SCR system maintained the driver warnings illuminating the DEF gauge's flashing amber circle, the amber text check engine light, the amber EMD MIL and continued the engine power de-rate and 55 mph speed limiter. Upon adding 101 gallons of diesel fuel to the vehicle and restarting the vehicle, the SCR system continued all previous visual warnings and illuminated a new red text stop engine light (similar to Step 4, Figure 6). The vehicle immediately experienced the 5 mph limited speed event. With the SCR system limiting the vehicle speed to 5 mph, the final step of the DEF Contamination Cycle had occurred (odometer = 2,314 miles).

In preparation for the next test cycle, ARB staff completely siphoned the water out of the DEF tank and refilled it with approximately twelve and a half gallons of DEF. The vehicle continued to experience the 5 mph speed limiter severe inducement along with the illuminated visual warnings leaving the driver stranded. With the inducement occurring next to a repair center, staff proceeded to drive to this location with the 5 mph limited speed condition. Although the technician attempted to clear the codes with a standard scan tool, he was unsuccessful. The technician stated that he could make the repair with another scan tool but ARB would be charged for this service. ARB staff called the Penske Truck Rental office for assistance, and Penske authorized the repair. Within 30 minutes, and after utilizing an advanced scan tool, the technician reset the engine control unit (ECU) removing all inducement conditions. ARB staff was charged $240 by Penske for this service call. Staff drove the vehicle for 20 miles to ensure the vehicle returned to its normal operation (odometer = 2,334 miles).

c) DEF System Tampering Cycle

Test Vehicle 1 was prepared for testing by unplugging the DEF Injection Pump electrical connector (odometer = 2,334 miles). After startup, the SCR system immediately triggered the driver warnings illuminating the amber text check engine light and the amber EMD MIL (similar to Step 3, Figure 6), and after driving 56 miles, an apparent engine power de-rate occurred (odometer = 2,390 miles). Staff continued to drive for another 160 miles (odometer = 2,550 miles) but did not experience any additional inducement conditions. Unfortunately, due to contractual obligations, ARB staff had to terminate testing and was unable to complete the final stages of inducements for this test cycle.

d) Vehicle 1's Inducement Test Summary

ARB staff operated Test Vehicle 1 under various test cycles comparing the vehicle's SCR-related driver warnings and inducements to those supplied in the vehicle owner's and engine service manuals and their consistency with the February 2009 U.S. EPA's Guidance. ARB staff checked the driver warnings and inducements under the following conditions: DEF Depletion Cycle, DEF Contamination Cycle, and DEF System Tampering Cycle. Under the DEF Depletion Cycle, this vehicle performed as expected inducing visual warnings that were preceded by escalating lower DEF level inducements: an engine power reduction, a maximum vehicle speed limited to 55 mph and ultimately a 5 mph limited vehicle speed inducement. All prescribed inducement strategies appeared consistent with the February 2009 U.S. EPA Guidance of a 2.5% DEF Trigger to search for severe inducement with an engine power de-rate.

The DEF Contamination Cycle performed similar to the DEF Depletion Cycle prompting escalating low DEF level warnings and inducements including an engine power reduction and a 55 mph speed limiter, well within the U.S. EPA's 500 mile guidance and finally induced a severe 5 mph limited vehicle speed event that was within the U.S. EPA's 1,000 mile search for severe inducement guidance.

Under the DEF System Tampering Cycle the vehicle was consistent with the U.S. EPA's 500 mile preliminary inducement guidance (i.e., the vehicle invoked visual warnings and an engine power de-rate) but due to time constraints, ARB staff had to end this program early and did not complete the final stages of inducements for this test cycle.

Regarding the effectiveness of the inducement strategies, ARB staff reported that visual warnings were effective in drawing the driver's attention to the need for SCR-related service. Also, driving this vehicle once the initial inducement occurred (engine power de-rate and 55 mile per hour speed limit) was neither acceptable nor tolerable when trying to accelerate or driving uphill, and would likely cause a driver to refill with DEF or correct the SCR problem. In addition, once the vehicle entered into a 5 mph limited speed condition under a DEF contamination event, the only way to resume normal operation was to have the vehicle serviced, drain water out of the system and refill the vehicle with DEF, followed by a reset of the system by an authorized service technician; therefore, the driver would be stranded until proper servicing. The ARB staff concludes the inducements were effective for this vehicle because the constant inducement strategies and risk of costly repairs were not worth the lost time and financial business losses when DEF could simply be added to ensure proper vehicle operation.

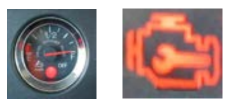
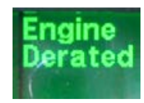
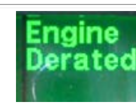
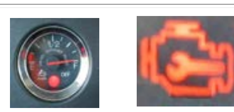
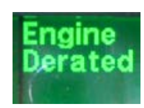
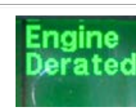
2. Test Vehicle 2

Chassis: 2011 MY Kenworth T800
Axles: 3
Engine: Cummins ISX15
Engine Family: ACEXH0912XAP
Displacement: 14.9 Liter
Horsepower: 450
Trailer: 45-foot Curtain Trailer

Test Vehicle 2 was a 2011 MY Kenworth T800 equipped with a 2010 MY Cummins ISX15 450 engine that was procured in July 2010 by ARB. When ARB took possession of the vehicle from the dealer/owner, the odometer showed 457 miles. The vehicle towed a 45-foot curtain trailer and carried five 20-foot "K-rail" concrete barriers that weighed about 40,000 pounds.

Figure 7, shown on the next page, describes the expected driver warnings and inducements by showing the specific dashboard lights and warnings, as well as the expected vehicle inducements, triggered by the SCR system (see Stages 1 through 4, Figure 7). This chart was created by ARB staff as an interpretation of the inducements specified in the vehicle owner's manual. The first driver warning was expected to be triggered when the truck's DEF level drops below 1/8 of tank capacity during the DEF Depletion Cycle (see Stage 1, Figure 7). 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 de-rate (see Stage 3, Figure 7). 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 accompanied by a stop engine light (see Stage 4, Figure 7). The SCR system should trigger similar driver warnings and inducements during the DEF Contamination Cycle and the DEF System Tampering Cycle but at different mileage/hour trigger points as shown in Figure 7, Stage 1a through 3a.

Figure 7 - Cummins Driver Warnings and Inducements

	NOTIFICATION	
DEF DEPLETION	LAMP	INDUCEMENT
DEF TANK LEVEL **STAGE 1** ~10% DEF or 1/8[TH] of TANK	 SOLID	
STAGE 2 Below 1/8[th] 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	
DEF QUALITY OR TAMPERING		
STAGE 1a Problem Detected	 SOLID	
STAGE 2a 10 hrs or 500 mi after detection	 FLASHING	
STAGE 3a 20 hrs/1,000 mi after detection (Quality) 40 hrs/2,000 mi after detection (Tampering)	 FLASHING	- 5 mph speed after key-off/restart or, - Engine Idles for 20 hrs
KEY:	 LOW DEF MESSAGE  DEF GAUGE ALERT  CHECK ENGINE LIGHT  STOP ENGINE LAMP  OBD MIL	 ENGINE DERATE MESSAGE

a) DEF Depletion Cycle

Staff adjusted the vehicle's DEF level to roughly 20% of full capacity as indicated by the DEF level gauge on the vehicle's dash panel (see Figure 8, ≈ 20% DEF Tank Level). The cycle began with 457 miles on the odometer. After driving 113 miles (odometer = 570 miles) staff stopped to fill the diesel fuel tank to approximately 75% of full capacity as indicated by the vehicle's fuel level gauge.

Figure 8 - Cummins Driver Panel DEF Level Gauge

≈ 20% DEF Tank Level

The first low DEF driver warning occurred when the DEF gauge level fell below 1/8th of a tank accompanied by a solid red DEF gauge light (see Stage 1, Figure 7) 115 miles after the diesel fueling (odometer = 685 miles). Additionally, the Driver Information Center (DIC) displayed the message "Low Diesel Exhaust Fluid" (see Figure 9). –

Figure 9 - Driver Information Center Low DEF Message

After driving an additional 44 miles (odometer = 729 miles), the red DEF gauge light began to flash (see Stage 2, Figure 7). When the DEF gauge reached empty 24 miles later (odometer = 753 miles), the check engine light illuminated, and was followed in another 130 miles by an engine torque reduction as experienced by the driver (odometer = 883 miles). The driver commented that the vehicle labored through gears and perceived an engine power de-rate when driving on uphill grades. The driver also noted there seemed to be de-rate fluctuations as he continued to operate the vehicle under various driving conditions.

Even after driving an additional 559 miles (odometer = 1,442 miles) after encountering an engine torque de-rate, repeated key-on/key-off events did not trigger the 5 mph inducement. This officially terminated this test cycle.

While the vehicle's early warning and first level inducements were consistent with the February 2009 U.S. EPA Guidance, the severe inducement never occurred. Over the next 124 miles staff investigated the reasons why the vehicle would not enter its severe inducement and found that approximately one quart of DEF remained the DEF tank; therefore the vehicle never triggered the zero DEF inducement. Staff removed the residual DEF from the tank and started the vehicle which was immediately limited to 5 mph. ARB staff believed the truck would not have entered the 5 mph speed limited condition if the final quart of DEF was not pumped out of the tank. It should be noted since taking delivery of this vehicle from the dealer, the on-board diagnostic (OBD) MIL and the stop engine light intermittently illuminated that was later determined to be related to a throttle position sensor problem. The engine de-rate condition as a result of the throttle position sensor problem was different than the SCR inducement engine de-rate because the OBD MIL and de-rate event could be quickly cleared by snapping the accelerator throttle.

b) DEF Contamination Cycle

Staff prepared for this test cycle by completely filling the DEF tank with water and the diesel fuel tank with diesel fuel. With the odometer reading 1,567 miles, testing commenced and staff began operating the vehicle over the designated test route. After 57 miles of operation (odometer = 1,624 miles) the SCR system had restored engine power to normal, as well as, turned off the dashboard warning lights that were attained during the DEF Depletion Cycle. The first driver warning occurred 582 miles since the SCR system restored itself back to normal operation (odometer = 2,206 miles) and illuminated the OBD MIL. After driving another 225 miles (odometer = 2,431), the OBD MIL continued to illuminate and the driver experienced an engine power de-rate condition. Although the engine power was de-rated, the vehicle continued to operate satisfactorily on flat surfaces (less acceptable on steeper grades). The engine appeared to intermittently de-rate as felt by the driver, and the red stop engine light illuminated at times, as staff continued to drive another 686 miles (odometer = 3,117). Staff decided to terminate the cycle after a total of 1,550 miles had been accumulated for this cycle (i.e., 911 miles had been driven and more than 30 hours had elapsed) since the first driver warning occurred. This was accompanied by several key-off/restart events due to the intermittent nature of the warning and inducements. The results of the DEF Contamination Cycle inducement strategies were inconsistent with the vehicle owner's manual and the February 2009 U.S. EPA Guidance.

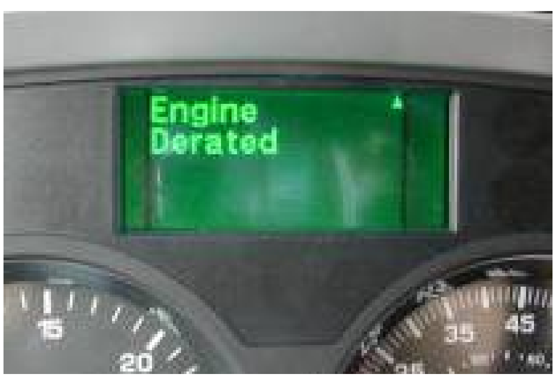
After the DEF gauge read near empty, staff added DEF several times over the next 143 miles (odometer = 3,260 miles) until the DEF gauge read almost full, yet staff was unable to clear the OBD MIL or engine power de-rate conditions. The vehicle was taken to a Cummins dealer, who in their investigation of the problem confirmed the DEF tank was contaminated with water using a refractometer and declined any warranty coverage for the repair, which was verbally estimated to be $800. The repair would involve removing and flushing the system with DEF fluid and reinstalling the components. ARB declined the service, but requested that the dealer reset the computer and clear any trouble codes which cost $125. Cummins' proprietary equipment was used to communicate with the vehicle's electronic control module (ECM) to reset the system clearing the DTCs. ARB staff returned the vehicle to ARB's Stockton facility and flushed the DEF system (i.e., the DEF tank and associated hoses) with DEF.

Following the DEF system flush, staff drove the vehicle to a Kenworth dealer to have the ongoing throttle position sensor problem repaired. The dealer provided warranty replacement of the defective throttle position sensor. Although the throttle position sensor was problematic, the vehicle should have entered into the 5 mph severe inducement condition, yet failed to do so. However, staff later learned that Cummins instituted a voluntary recall plan (Cummins Campaign C1036) to recalibrate the ECM which corrected the failure to initiate the 5 mph severe inducement.

c) DEF System Tampering Cycle

After repairs were performed and the vehicle appeared to operate normally, staff began the DEF System Tampering Cycle by disabling Test Vehicle 2's DEF doser valve (odometer = 3,487 miles). The first driver warning occurred at initial engine start up with an OBD MIL illumination. After accumulating 97 miles (odometer = 3,584 miles), the vehicle's DEF warning light was flashing, the OBD MIL and check engine lights were illuminated, the engine went into an engine power de-rate (see Stage 2a, Figure 7) and the driver display indicated "Low Diesel Exhaust Fluid" (see Figure 9).

Figure 10 - Driver Information Center Engine De-rated Message



The driver subsequently discovered at 3,991 miles shown on the odometer that the DIC would display the message "Engine De-rated" (see Figure 10). Unfortunately, this message doesn't display automatically as the vehicle de-rates; the driver must initiate the message by manually changing the DIC display. Staff continued to drive the vehicle for more than 2,500 miles and more than 48 hours with multiple key-off/restarts events after the engine de-rated for this test cycle (odometer = 6,136 miles). However, as with the DEF Contamination Cycle the 5 mph speed limit did not occur. The DEF System Tampering Cycle inducement strategies were inconsistent with the vehicle owner's manual and the February 2009 U.S. EPA Guidance.

d) Vehicle 2's Inducement Test Summary

ARB staff operated Test Vehicle 2 comparing the vehicle's SCR-related driver warnings and inducements to those strategies stated in the February 2009 U.S. EPA Guidance and the expected SCR inducement conditions as laid out in the vehicle owner's manual. ARB staff checked the driver warnings and inducements triggered by the SCR system during the following cycles: DEF Depletion Cycle, DEF Contamination Cycle, and DEF System Tampering Cycle. Under the DEF Depletion Cycle, this vehicle initiated the visual warnings, induced the engine power de-rate sequence, but failed to enter into the 5 mph severe vehicle speed inducement condition after traveling 757 miles from the first driver warning detection point. Staff did force the 5 mph limited speed inducement condition by removing the last quart of DEF from the tank.

The DEF Contamination Cycle raised concerns as it took over 639 total miles to detect the addition of water in place of DEF. In addition, while the engine power reduction seemed to occur well within the U.S. EPA's 500 mile after detection guidance, the de-rate inducement and warnings were intermittent. After multiple key-off/restart events and intermittent first level inducements, staff determined the vehicle was inconsistent with the February 2009 U.S. EPA Guidance and terminated the cycle.

Under the DEF System Tampering Cycle, the vehicle prompted escalating warnings including an engine power reduction well within the U.S. EPA 500 mile guidance. However, after traveling more than 48 hours and 2,649 miles, the vehicle failed to enter into a severe 5 mph speed limited inducement despite several key-off/restart events which is outside of the U.S. EPA 40 hour or 2,000 mile guidance.

Midway through staff's vehicle testing, staff discovered that Cummins was already aware of the failure to reach severe inducement and had made production line programming changes in the second quarter of 2010. They also followed up with a voluntary recall (Cummins Campaign C1036) in August of 2010 to correct in-use engines. A voluntary recall is an inspection, repair, adjustment, or modification program voluntarily initiated and conducted by a manufacturer or its agent or representative to remedy any vehicle issue in which direct notification of the vehicle or engine owners is necessary. The campaign included the recalibration of the ECM to correct SCR inducement strategies concerning DEF depletion and DEF quality for their 2010 MY engines. However, staff elected not to apply the recall to their test vehicle until the completion of its testing period to avoid an interruption of its testing process. Since completing the original test program, the Cummins 14.9L engine has been reflashed with the Cummins' recall fix and ARB staff is currently re-evaluating these cycles.

Regarding the effectiveness of the inducements for this vehicle, ARB staff reported that visual warnings were effective in drawing the driver's attention to the need for DEF service. However, since the throttle position sensor was suspected of causing engine power fluctuations during the DEF Depletion and Contamination Cycles, staff could not objectively rate the effectiveness of the engine power de-rate under those cycles because it was not clear if de-rate occurred because of a detected SCR problem or was the result of the defective throttle position sensor. However, even after the throttle position sensor was repaired, the engine power de-rate caused the vehicle to lose power and reduce vehicle speed when negotiating uphill or accelerating, but was seldom noticed when driving on level ground. The drivers reported that the Cummins engine power de-rate was not as noticeable as the DDC vehicle engine power de-rate at similar power and engine speeds.

3. Test Vehicle 3

Chassis:	2011 MY Dodge Cab Chassis D5500
Axles:	2
Engine:	Cummins ISB
Engine Family:	ACEXH0408BAL
Displacement	6.7 Liter
Horsepower:	305

Test Vehicle 3 was a 2011 MY Dodge Cab Chassis D5500 incomplete vehicle equipped with the 2010 MY Cummins ISB 305 engine rented from a local Southern California Dodge dealer. When ARB took possession of the vehicle, the Dodge dealer outfitted the vehicle with a flatbed platform with 15 miles showing on the odometer. To add weight to the vehicle, the vehicle was loaded with a single 10-foot “K-rail” concrete barrier that weighed about 4,000 pounds. 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 as the vehicle was operated through the DEF Depletion Cycle, DEF Contamination Cycle, and DEF System Tampering Cycle.

The driver warnings and inducements included various displays on the Electronic Vehicle Information Center (EVIC) prominently located in the center of the instrument panel (see Figure 11). This was the only vehicle tested by ARB that had both audible alerts and visual warnings. Figure 12 shown below, was created by ARB staff as an interpretation of the SCR inducement sequences for this vehicle based on the information provided in the vehicle owner’s manual. As indicated in the vehicle owner’s manual, the first DEF Depletion inducement in the form of warning messages (as shown in Figure 12) 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. Similarly, during the DEF Contamination and DEF

Tampering Cycles the 500 mile countdown sequence should begin if no remedy is sought after operating 250 miles with warnings and chimes, versus 500 miles for DEF Depletion. NOTE: For monitoring Test Vehicle 3 inducement mileage information, the inducement segments were tracked using the vehicle's trip odometer.

a) DEF Depletion Cycle

Testing began with an 18% tank capacity of DEF and a full tank of diesel fuel with zero miles indicated on the trip odometer (Note: the EVIC can display the DEF level capacity in percentage as shown in Figure 11). The vehicle was operated over the test route and the baseline emissions of the vehicle were established (i.e., the measured emissions of the vehicle while operating on appropriate DEF and no tampering).

Figure 11 – Electronic Vehicle Information Center

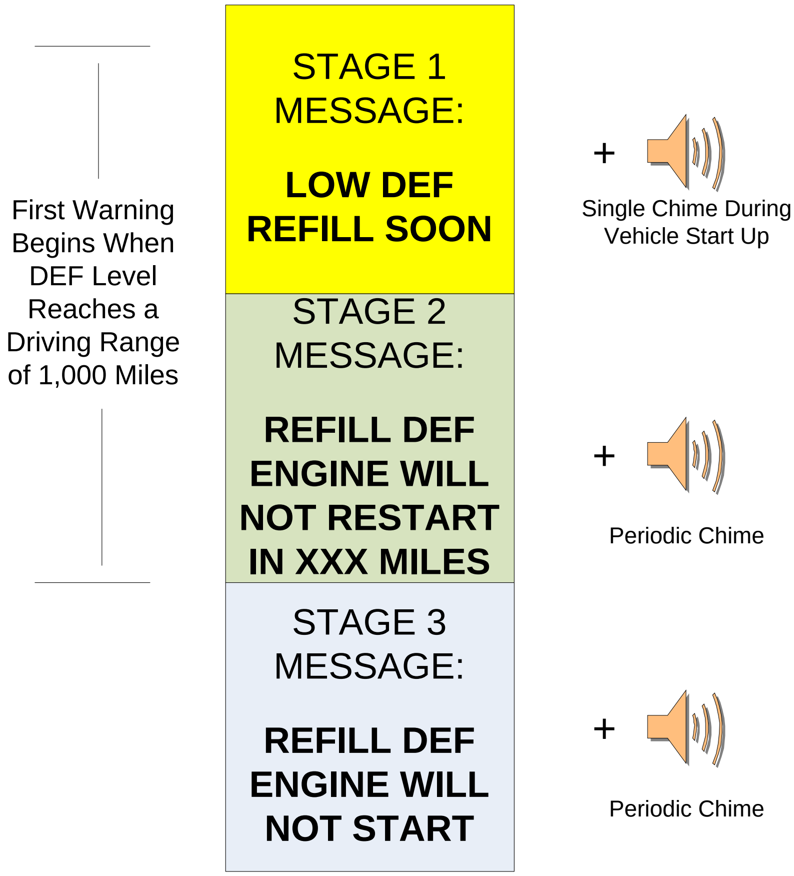
After 53.8 miles of operation, as the DEF was being consumed, the first driver warning took place when the DEF level gauge reached 16% of full capacity. The EVIC displayed the message "Low DEF Refill Soon" and then extinguished (see Stage 1, Figure 12 below). This message reappeared during vehicle start up and about every 50 miles accompanied by an audible chime for about the first 100 miles and decreased to approximately 50 mile intervals as the DEF became increasingly empty. After 195 miles of operation since beginning this cycle (trip odometer = 195 miles), staff noticed that the EMD MIL illuminated and subsequently extinguished (Note: the EMD MIL illuminated

due to the DEF heater circuit problem discussed below) before any other messages or inducements occurred. When the trip odometer reached 934 miles, the DEF gauge level read 0%, the EMD MIL was illuminated again and remained on this time, and the EVIC displayed the message “Refill DEF Engine Will Not Restart in 500 Miles” (see Stage 2, Figure 12) initiating the 500 mile countdown. For the duration of the 500 mile countdown, the EVIC message was continuously displayed to the driver and was accompanied with a chime alert approximately every 50 miles decreasing to about every 25 miles and then to about every 10 miles. Staff continued to drive the vehicle route and accumulated 97 miles (trip odometer = 1,031 miles) since the 500 mile countdown initiated and stopped for the night. The following morning at the next key start, the DEF level gauge read 1%, cancelling the 500 mile counter and displayed the message, “Low DEF Refill Soon.” Staff was unclear as to why the counter reset and will discuss this issue with Cummins to obtain more information regarding this concern. After the morning restart, staff accumulated another 35 miles on the vehicle (trip odometer = 1,066 miles) and the no-start counter reinitiated the 500 mile countdown. After driving 497 miles since the countdown had initiated the second time, the EVIC message displayed “Refill DEF Engine Will Not Start” (see Stage 3, Figure 11). Staff drove for seven more miles with the audible chime sounding about every two minutes, and the EMD MIL illuminating continuously, and then executed a key-off/restart event. The vehicle did not start (trip odometer = 1,570 miles).

Staff later determined that the vehicle had a DTC 205B-DEF heater malfunction. A DEF heater is used to prevent DEF from freezing during very cold weather operation; under normal weather conditions, the DEF heater is not used. If the DEF temperature becomes too hot, the DEF can degrade and become less effective at reducing NOx levels in the SCR catalyst. The DEF is heated during cold temperature situations by the flow of engine coolant passing through coolant tubes in the DEF tank. Based on the PEMS emission results, rate of DEF consumption and subsequent discussions with Cummins on their DEF heater issue, staff has deduced that the DEF heater was malfunctioning during this cycle. It is suspected on return trips to El Monte from Baker under elevated afternoon ambient temperatures, a DEF engine coolant control valve was not able to completely shut the flow of engine coolant passing through the coolant tubes in the DEF tank. This allowed the DEF temperature to rise above its normal operating range and caused the vehicle to stop dosing DEF. Staff did find out during their discussions with the manufacturer, that Cummins was addressing this problem and launched a service campaign (Technical Service Bulletin No. 25-002-10) through Chrysler's Dodge dealer network. The Technical Service Bulletin stated that some Dodge trucks may have been built with a DEF engine coolant control valve that may be internally misassembled causing the overheated DEF problem. Due to this issue, the vehicle was driven nearly twice as far (i.e., 880 miles vs 500 miles) to reach the next phase of inducements because the SCR system was dosing DEF about half of the time.

While the vehicle was, in general, consistent with the intentions of the February 2009 U.S. EPA Guidance, the mileage accumulation was too high for the appropriate DEF consumption rate expected; however, this was related to the DEF heater glitch (i.e., DEF engine coolant control valve) as described above.

Figure 12 – Cummins' 6.7L SCR System 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; if incorrect reducing agent/tampering is also detected, the "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); if incorrect reducing agent/tampering is also detected, 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. If incorrect reducing agent/tampering is also detected, 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

b) DEF Contamination Cycle

To initiate the DEF Contamination Cycle, the DEF tank was filled with water, which cleared the no start condition. This cycle began with 1,574 miles on the trip odometer. The vehicle was operated for 12 miles (trip odometer = 1,586 miles) over the designated test route when the SCR system detected contaminated DEF and displayed the EVIC message “Service DEF System – See Dealer” and the EMD MIL illuminated on the vehicle instrument panel (see Stage 1, Figure 12). The vehicle was operated for 249 additional miles passed the first warning message (trip odometer = 1,835 miles) until the EVIC message changed to “Service DEF System Engine Will Not Start In 500 Miles - See Dealer” and was accompanied by an audible chime (see Stage 2, Figure 12). The EMD MIL remained illuminated and the audible chime sounded in an increased frequency during the 500 mile countdown. Staff continued to drive the vehicle for 497 miles (trip odometer = 2,332 miles) trip and the countdown expired at zero miles. When the counter reached zero, the EVIC message displayed “Service DEF System Engine Will Not Start – See Dealer” (see Stage 3, Figure 12), still accompanied by an illuminated EMD MIL. As staff continued to drive for six more miles (trip odometer = 2,338 miles), the message was also accompanied by an audible chime about every 2 minutes. Staff stopped the vehicle and turned off the engine. Attempts to restart the vehicle failed. The vehicle inducement strategies were consistent with the February 2009 U.S. EPA Guidance and vehicle owner’s manual.

Following this no-start condition, staff used a Mastertech OBD scan tool to review the stored DTC information and then cleared the trouble codes. The following is a list of stored DTCs: P205B-Reductant Tank Temp Sensor Circuit, P20EE-SCR NOx Cat Efficiency Below Threshold, and P207F-Reductant Quality Poor. With the stored trouble codes removed, and the EVIC warning message and illuminated EMD MIL turned off, staff noted the vehicle started and returned to normal operation. This completed the DEF Contamination Cycle.

c) DEF System Tampering Cycle

In order to initiate the DEF System Tampering cycle, staff drained the water from the DEF tank, filled the tank with appropriate DEF, cleared the diagnostic trouble codes and the no-start condition using a scan tool, and disconnected the DEF doser injector to represent tampering. At start up with trip odometer at 2,376 miles, the vehicle immediately set an EMD MIL and audible chime and the EVIC displayed the message "Service DEF System - See Dealer". The vehicle was operated for 250 miles (trip odometer = 2,626 miles) after disconnecting the DEF doser injector at which time the EVIC display changed to "Service DEF System Engine Will Not Start In 500 Miles – See Dealer" (see Stage 2, Figure 12), accompanied by an illuminated EMD MIL. As staff continued to drive the vehicle, an audible chime sounded in an increased frequency during the 500 mile countdown and the EMD MIL continued to illuminate. The countdown expired after accumulating 496 miles (trip odometer = 3,122 miles) triggering a new EVIC message, "Service DEF System Engine Will Not Start – See Dealer" (see Stage 3, Figure 12). Staff drove for one additional mile passed the countdown expiration and executed a key-off/restart event; the vehicle did not start (trip odometer = 3,123 miles). The vehicle inducements were consistent with the February 2009 U.S. EPA Guidance and the vehicle owner's manual.

Using an inexpensive generic OBD II scan tool, ARB staff was able to clear the stored DTCs. The following is a list of the stored DTCs: P205B-Reductant Tank Temp Circuit; P20E8-Reductant Injector Circuit Low (Bank 1 Unit 1) and P2048-Reductant Injector Valve Circuit Low. Leaving the DEF doser injector disconnected, ARB staff cleared the DTCs with the scan tool, which extinguished all visual and audible messages/alerts, and removed the no-start condition.

The ability to reset the no-start condition and clear DTCs with a generic OBD scan tool warranted further investigation. With the doser disconnected, staff drove the vehicle and just as before, the EMD MIL immediately illuminated. The vehicle was driven over the designated route to determine whether the SCR system inducements could be reset at any time. After approximately 200 miles of driving, the vehicle was refueled and the generic scan tool was used to reset the EMD MIL once again. The vehicle was operated for an additional 250 miles before entering the 500 mile no-start countdown. After reaching zero miles on the countdown, staff executed a key-off/restart event and the vehicle did not start. The DTCs were again cleared with the generic scan tool and the vehicle started without incident. This confirmed that a generic scan tool could be used to reset the warning system, thus allowing at least another 750 miles of operation before a reoccurrence of a no-start condition. Therefore, the warning system seemed to be vulnerable to indefinite resetting of the SCR system allowing indefinite vehicle operation. ARB has discussed the scan tool issue with all manufacturers, pointing out that this capability is not acceptable and has indicated to manufacturers that it must be corrected as soon as possible, but in no case later than the 2013 model year.

d) Vehicle 3's Inducement Test Summary

The primary inducement for this vehicle was a 500 mile countdown to no-start preceded by various warning messages and chimes based on the cycle. With the exception of the malfunctioning DEF heater system that caused the DEF system to overheat and stop dosing, the DEF Depletion Cycle was consistent with the February 2009 U.S. EPA Guidance and the vehicle owner's manual. Cummins has developed a correction for the malfunctioning DEF heater system and has issued Technical Service Bulletin No. 25-002-10 to remedy the DEF overheating problem. In addition, while this vehicle was undergoing the 500 mile countdown event, the DEF level changed from 0% to 1% after an overnight park thus eliminating the 500 mile countdown. Although the 500 counter was reinitiated 35 miles later, this is a concern that staff will investigate with Cummins.

For the DEF Contamination and DEF Tampering Cycles, audible chimes, visual messages and an illuminated EMD MIL alerted the driver of an existing DEF system issue needing the driver's attention approximately 250 miles after detection of the issue. Since no repairs were performed after the first 250 miles for either cycle, the vehicle entered a 500 mile countdown to no-restart while alerting the driver with audible and visual messages that the engine would not restart when the countdown reached zero. In this case, the vehicle performed consistent with the 1,000 mile/20 hour severe inducement point for DEF Contamination, and the 2,000 mile/40 hour severe inducement point for DEF Tampering as per the February 2009 U.S. EPA Guidance.

The scan tool clearing capability is believed to be more widespread than this manufacturer and has been discussed with all manufacturers, pointing out that this capability is not acceptable and must be corrected as soon as possible, but in no case later than the 2013 model year.

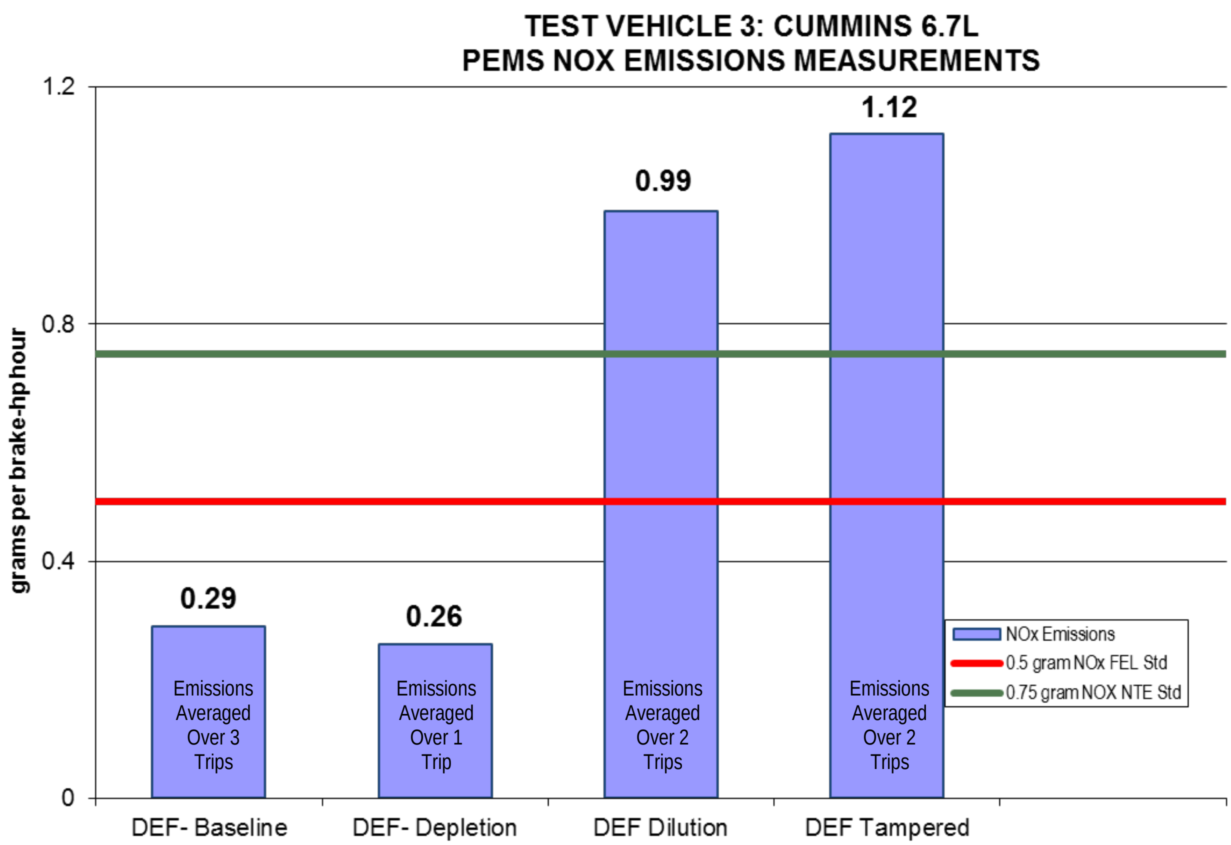
Regarding the effectiveness of the inducement strategies, ARB staff reported that visual and audible warnings/alerts were effective in drawing the driver's attention for the need of SCR-related service. Although this sequence was different than the other two trucks evaluated in this report, the 500 mile countdown to a no-restart condition was an effective strategy in motivating the driver to pay attention to SCR required service. However, the DEF heater malfunction caused more miles than expected to be consumed before final immobilization was encountered during the DEF Depletion event. Therefore, while the inducement strategies were consistent with the February 2009 U.S. EPA Guidance for the majority of the testing, further evaluation is warranted on this vehicle once the DEF heater malfunction is corrected.

e) Vehicle 3's Emissions Measurements

Test Vehicle 3 was outfitted with a PEMS unit which measured NOx emissions continuously as the vehicle was operated over the designated route. Emissions were measured under the following conditions: with appropriate DEF in the tank, with the DEF tank empty, with it filled with water, and while the DEF/SCR system was tampered.

Figure 13 (see below) is a summary of the NOx emissions measured for each of these test cycles. When operating in normal DEF conditions and throughout the entire DEF Depletion Cycle, NOx was within control limits. This was attainable because the design of the SCR system allowed the vehicle to go into the no-start condition with a nominal amount of DEF remaining in the tank (i.e., with NOx measuring within control limits it was assumed a portion of DEF remained in the tank). However, when the vehicle was operated in the DEF Contamination Cycle and DEF System Tampering Cycle, the NOx emissions increased and were about four times higher as compared to normal operation with DEF (i.e., as the vehicle normally operates with a supply of DEF).

Figure 13 – NOx Emissions Cummins 6.7L



Note: The PEMS values in Figure 13 were measured values taken during this test program while the vehicle was operated under on-road conditions (Note: One Trip = Emissions test run from El Monte, CA to Baker, CA only). 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 only provided for general reference only. The PEMS unit used for this operation meets the U.S. EPA requirements as per 40 CFR 1065.

III. Overall Conclusions

The widespread availability of DEF was uncertain prior to the first year of sale in the U.S. of SCR-equipped engines (2010). The U.S. EPA guidance accommodated this uncertainty by allowing the engine to be designed to allow for some operation of the truck after the warning system indicated DEF was soon to be depleted. The purpose of this provision was to allow the truck operator several opportunities to procure DEF before the more disabling inducements were initiated. As the ARB survey showed, a small percentage of operators found DEF unavailable during 2010. The survey also showed, however, that DEF was widely available, and only 1 of 69 truck operators operated their truck without DEF because of DEF unavailability.

For the three vehicles evaluated in this study, ARB staff found that the warnings and inducement strategies incorporated by the engine manufacturers were consistent with the February 2009 U.S. EPA Guidance (see Figure 14). However, the large Cummins engine had a programming error that caused the intended severe inducement (5 mph maximum operating speed) to not occur. Cummins has recalled the affected engines and has also made the change in production. The test vehicle also had a defective throttle position sensor which made assessing the effectiveness of the power de-rate strategy difficult to assess. The smaller Cummins engine had a defective DEF heater which caused the truck to operate longer than anticipated before DEF depletion was detected. This has been addressed by Cummins through Chrysler with a service campaign.

Figure 14 – Test Vehicles Results per the February 2009 U.S. EPA Guidance

	TEST CYCLE			
TEST VEHICLE	DEF Depletion Cycle	DEF Contamination Cycle	DEF System Tampering Cycle	Comments
#1 (DDC 12.8L)	YES	YES	INCOMPLETE	
#2 (CUMMINS 14.9L)	NO*	NO*	NO*	* Vehicle did not enter 5 mph severe speed limited inducement for any of the test cycles. **Corrective action: Cummins voluntary recall campaign (C1036).**
#3 (CUMMINS 6.7L)	YES**	YES	YES	** DEF heater circuit problem allowed additional miles before triggering no-start inducement countdown. **Corrective action: Chrysler Technical Service Bulletin (No. 25-002-10).**

Changes for 2011 Models

With DEF widely available in California, ARB has worked with the U.S. EPA and engine manufacturers to improve the effectiveness of the SCR monitoring system of 2011 models. In July 2010, ARB held a joint public workshop with the U.S. EPA discussing the changes to the SCR inducement strategies we expected for the 2011 and future MYs, as outlined below:

a. When a low level of DEF remains, for example, sufficient to drive about 100 miles under typical driving conditions, warning signals begin and become increasingly urgent thereafter.

b. After the DEF tank level triggered in paragraph (a) and before an empty DEF tank, a noticeable de-rate begins and is sustained until paragraph (c).

c. When the DEF tank is empty, a more significant de-rate occurs. Operation at this second de-rate occurs no longer than necessary to safely reach a location where the engine can be safely shut down, for example, no more than one hour. At the end of this period, the vehicle speed is limited to 5 mph maximum.

d. Upon a disconnected SCR monitor, sensor, or component, warning signals begin and become increasingly urgent thereafter and the engine power will be noticeably de-rated.

e. After an hour of operation pursuant to paragraph d., a second significant de-rate will occur. The engine will operate at this de-rated level for no longer than necessary to confirm disconnection, for example, no more than four hours. At the end of this period the vehicle speed is limited to 5 mph maximum. Normal operation cannot be resumed until the disconnection is cleared.

f. If repeated disconnects and reattachments of a SCR monitor, sensor, or component are detected, the attributes in paragraph c. apply. Normal operation cannot be resumed until the disconnections are cleared.

g. Proper DEF dosing should occur within 40 minutes of a freezing event.

In addition to the above, ARB is also expecting improvements in DEF contamination detection. ARB staff is also working with the manufacturers to use only proprietary scan tools to reset the system for 2011 and future engines and produce more robust repeat tampering detection inducements. In addition, as glitches and/or programming errors surface, ARB staff is working with the manufacturers on service campaigns/recalls to fix such problems.

IV. Appendix A – Field Survey Forms

DEF Availability Survey

Attach Business Card Here
or Enter Contact Information Below

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

Check as Many as Applicable: New [ ] Revisit - Had DEF [ ] Revisit - Didn't have DEF [ ]

Revisit - Didn't have DEF but said would have later [ ]

DiscoverDef.com Station [ ]

ARB STAFF ______________________________ SURVEY DATE _______________

FACILITY TYPE: Truck Stop ____ Auto Parts Retailer ____ Fleet Operator ____

Truck Sales & Service ____ Service Only ____ Other: ________________________________

FACILITY NAME ____

CONTACT PERSON __________________________ PH. NO. (___) ______________________

ADDRESS ____

CITY _______________________ COUNTY ______________________ ZIP __________________

1a) Do you sell Diesel Exhaust Fluid (DEF/Urea)?

Yes [ ] ↙ No [ ] →

1b) Do you intend to begin selling DEF in the next 6 months? Yes [ ] No [ ] –END SURVEY!

2) How long have you been selling DEF?

no. mos: or - since (mo/yr):

3) How is it sold/dispensed? (check all and enter price)

Containers:

1gal [ ] __gal [ ] __gal [ ] __gal [ ] Tote _____gal[ ]

Price: $ ______ $ ______ $ ______ $ ______ $ __________

Amt. normally stocked

Bulk/metered pump:

Installed? Yes[ ] No [ ]

$ _________ per gal

Max capacity:

Amt. normally sold/mo

Amt. normally sold/mo

4) How often do you receive shipments?

5) Have you ever run out of stock and turned away a customer?

Yes[ ] No[ ]

Comment on above (no of times, no of days, reason, etc.):

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!

Diesel Exhaust Fluid Survey

<u>Diesel Exhaust Fluid Survey</u>

Date: ____________ Time: ____________ Location: _________________________

ARB Representative(s): _______________________, ________________________

Truck Make: _____________________ VIN: ________________________________

Odometer: _____________________ DEF Tank Size: Gallon _________

Engine Make: ___________________ Engine Family: ________________________

Engine Serial No.: _______________________________ Engine HP: ____________

Diagnostic Trouble Codes: ___________, ___________, ___________, ___________

DEF Quality Check: Take one drop of DEF from truck DEF tank and place on refractometer and record results in % of scale from Ethylene Glycol _____________

An example of a refractometer view through the viewer is in the image 1 below. Refractometer lenses should be covered as indicated in image 2 below.

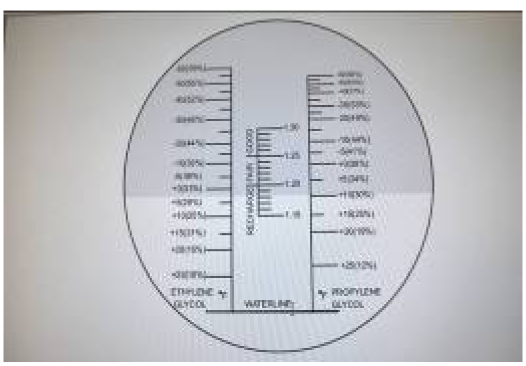


Image 1

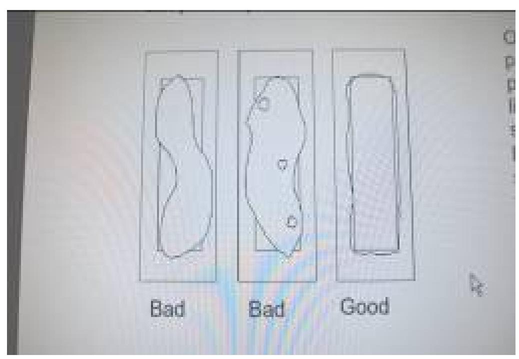


Image 2

Check for engine diagnostic lamps that are illuminated on drivers display and record.

Lamps illuminated: ____

<u>DRIVERS QUESTIONAIRE</u>:

1. Have you operated your truck without DEF? Yes: ____ No: ____

   If yes, how many miles? ___________________

   Reason: ____

2. Have you operated your truck on fluids other than DEF in the DEF tank?

   Yes: ____ No: ____

   If yes, what fluid did you operate the truck with: ____________

   How many miles? ____________

   Reason: ____

3. Have you had any problems with your trucks emissions control system?

   Yes: ____ No: ____

   If yes, what problems have you experienced? ____________________________

   ____

4. Have you had any problems locating DEF? Yes: ____ No: ____

   If yes, what problems? ____

____

Comments: ____

____
____
____
____

____

V. Appendix B – SCR Test Plan (2R1004)

Test Plan

Investigation of Selective Catalysis Reduction NOx Strategy

Project Number: 2R1004
Investigation of SCR Operation

2010 Heavy Duty Diesel
Engine Family ACEXH0912XAP
Engine Family ACEXH0408BAL
Engine Family ADDXH12.8FED

July 29, 2010

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

Selective Catalyst Reduction NOx Strategy Test Program

I. SCOPE

The primary objective of this program is to investigate the effectiveness of driver inducements used by Selective Reduction Catalysts (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. 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; 1) if engine manufacturers are producing engines as certified and 2) the effectiveness of driver inducements for driver actions or inactions relating to the use of DEF. The project will determine how long a vehicle will operate once the DEF supply is depleted and evaluate the vehicles' engine operation and operator alert systems as the DEF is being depleted. Staff will determine if the vehicle can be normally operated with water as a substitute for DEF. Additionally, staff will evaluate the case of a hardware tamper by disconnecting the DEF injector. For baseline operation (normal DEF dosing) and all specified routes (no DEF, water as a substitute for DEF, and hardware tampering--see Flowcharts), staff will measure NOx emissions utilizing a Portable Emissions Measurement System (PEMS).

To investigate the implementation of driver inducements, the IUCS staff will procure three HDD vehicles equipped with 2010 diesel engines using SCR technology.

The three test vehicles to be procured for this program will consist of one vehicle equipped with a 14.9L Cummins engine, one with a 6.7L Cummins engine and one with a 12.8L Detroit Diesel engine.

II. PROGRAM MANAGEMENT

The In-Use Compliance Section (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.

III. VEHICLE PROCUREMENT

The ARB Procurement Contractor, California Environmental Engineering (CEE), will provide three test vehicles for this program. These vehicles will be from Cummins engine families ACEXH0912XAP and ACEXH0408BAL, and Detroit Diesel engine family ADDXH12.8FED. The vehicle locations will be provided to the ARB Stockton laboratory on or about August 3, 2010.

IV. VEHICLE DELIVERY AND CHECK-IN

Two vehicles will be delivered to the Heavy-Duty Diesel I/M Development Section (HDDV I/M DS) at ARB's Stockton laboratory. The Southern California vehicle will be delivered to the Mobile Source Control Division's In-Use Retrofit Section in El Monte. Vehicles will be checked-in and all pre-existing damage will be documented and photographed upon check-in. PEMS units will be installed on each vehicles, checked for proper operation and calibrated after check-in is completed.

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. All California Voyager Card purchases must have a receipt and all receipts must accompany the California Voyager Card when returned to the Vehicle Diagnostic and

Repair Section when testing is complete and the vehicles are returned to the rental agencies. Please make every effort to keep all receipts.

VI. VEHICLE MAINTENANCE

Any necessary vehicle maintenance will be performed by the HDDV I/M DS staff. Maintenance that cannot be performed by staff will be performed by a local maintenance vendor. The project engineer will be notified of any maintenance prior to maintenance being performed.

VII. TESTING

Testing of the vehicles will be performed on California highways using a PEMS system to collect NOx emission samples while testing. A Pre Drive Inspection Form is enclosed and must be completed prior to each drive. Charts A shows the basic flow for this program and Charts 1-9 identify the actual test cycle sequence to be performed on each vehicle for the given test cycle condition. NOx emissions levels will be monitored and recorded during all driving sequences (the baseline condition is defined as when normal DEF dosing is occurring under various driving conditions). All test sequence conditions will be documented in the Vehicle Test Cycle Operation Form (enclosed). The HDDV I/M DS staff will install the PEMS units on the Northern California vehicles and the v In-Use Retrofit Section will install the PEMS system on the Southern California vehicles. All PEMS will be calibrated as necessary. Each vehicle will have two staff on-board during all phases of testing. One will operate the vehicle and the second will document the operation of the vehicles. Vehicles will be operated for as many miles as possible during a normal shift. Vehicles will be ballasted with weight to near full load capacity; therefore all safety precautions must be taken to safely operate these vehicles. All State and federal traffic laws will be adhered to. In the case of an accident, the California Highway Patrol or local police authority and the project managers must be notified immediately.

Vehicle testing will be as follows (NOx emissions monitored and recorded for all below):

- One testing sequence with DEF in the tank, normal dosing conditions
- One testing sequence with no DEF in the tank; all the way to trigger engine immobilization
- One testing sequence with water replacing DEF; all the way to trigger engine immobilization
- One testing sequence with the DEF injector disconnected; all the way to trigger engine immobilization

Photographs will be taken whenever an event occurs on the DEF drivers' information display. These photographs will become part of the final data and forwarded to the project engineer.

Two on-road test routes, one route beginning at the Stockton Laboratory and one route starting at the HSL will be utilized. The northern California route will start at the Stockton laboratory and proceed to Truckee. At Truckee the driver will allow the truck to idle for five minutes prior to the return drive to Stockton. NOx will be recorded throughout the entire drive cycle. See enclosed maps for driving route (Map 1 and Map 2). The In-Use Retrofit Section will use an alternate route in Southern California. This route will start in El Monte and proceed to Baker. At Baker the truck will idle for five minutes prior to the return drive to El Monte. NOx emissions will be recorded throughout the entire drive cycle. See enclosed maps for driving route (Map 3 and Map 4). These routes are expected to operate the engine under various power requirements. During the engine torque de-rate periods, the vehicle driver feels it is unsafe to operate the vehicles over the driving routes described in this test plan, the driver may choose a route where the vehicle can be safely operated.

Each vehicle must have an experimental permit in the vehicle while operated on highways.

VIII. DATA HANDLING AND PROCESSING

All raw data (notes, pictures, PEMS data printouts, etc.) 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 and submitted to the project engineer. State digital cameras serial numbers 20018325 and 20050849 will be supplied to the HDDV I/M DS staff for photographs. Camera batteries should be checked for charge level and recharged as necessary. Cameras and photographs' must be returned to the project engineer up completion of testing.

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 (Bob Torres) of the vehicle's release.
- The HDDV I/M DS staff will de-prep and return the vehicle to the supplier where the vehicle was received.

XII. TEST REPORT

A final project report will be submitted to management for review/approval as soon as possible after the completion of the field portion of the project.

Enclosures

Pre Drive Inspection Form

Project Number: ________________ Date: ______________

Vehicle License Number: ______________ Vehicle Number: __________

Driver: ____________________ Observer: ____________________

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

Chart A
SCR Test Flowchart

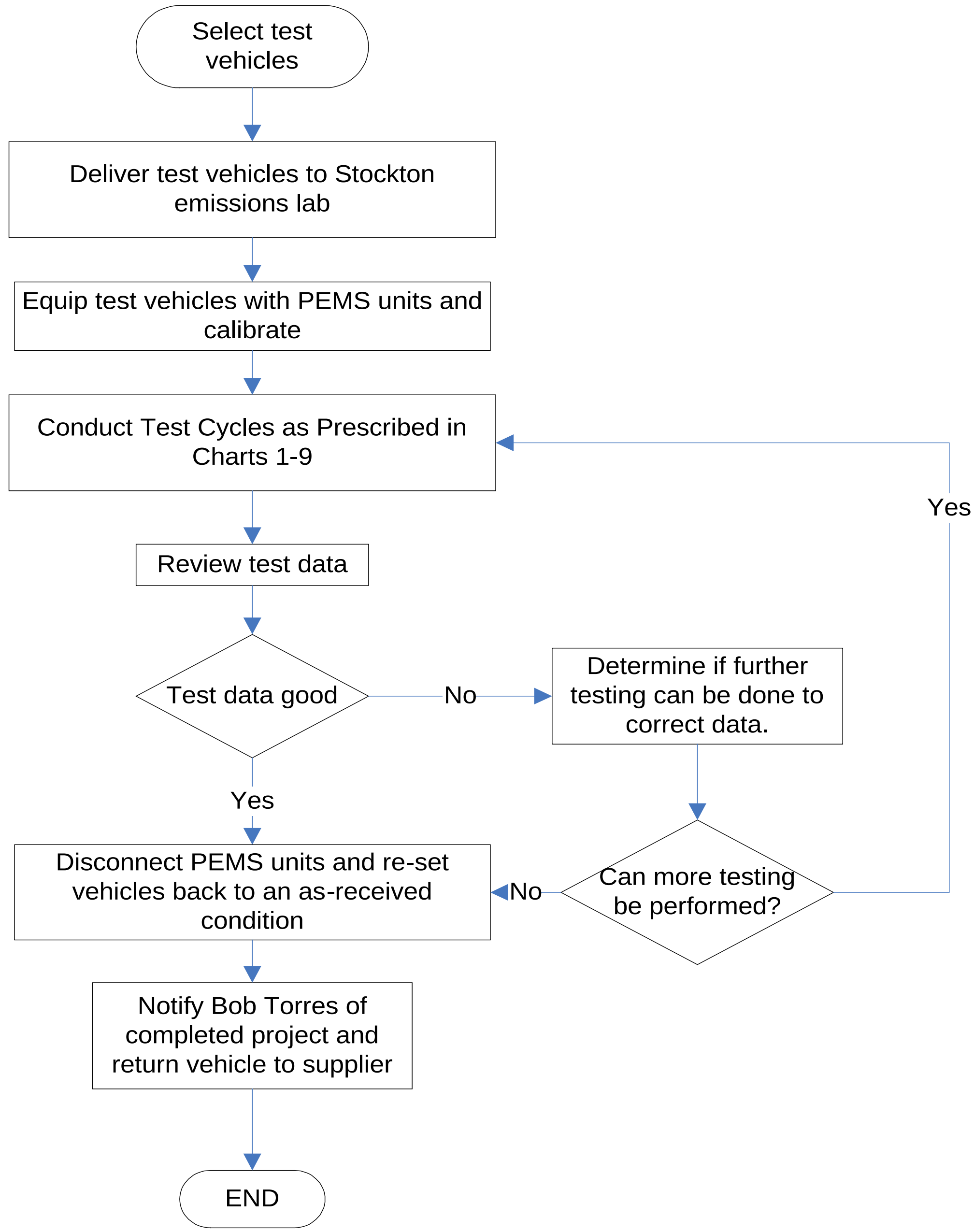


CHART 1
DDC 12.8L DEF TEST PROGRAM OPERATION
(Low DEF Test Cycle)

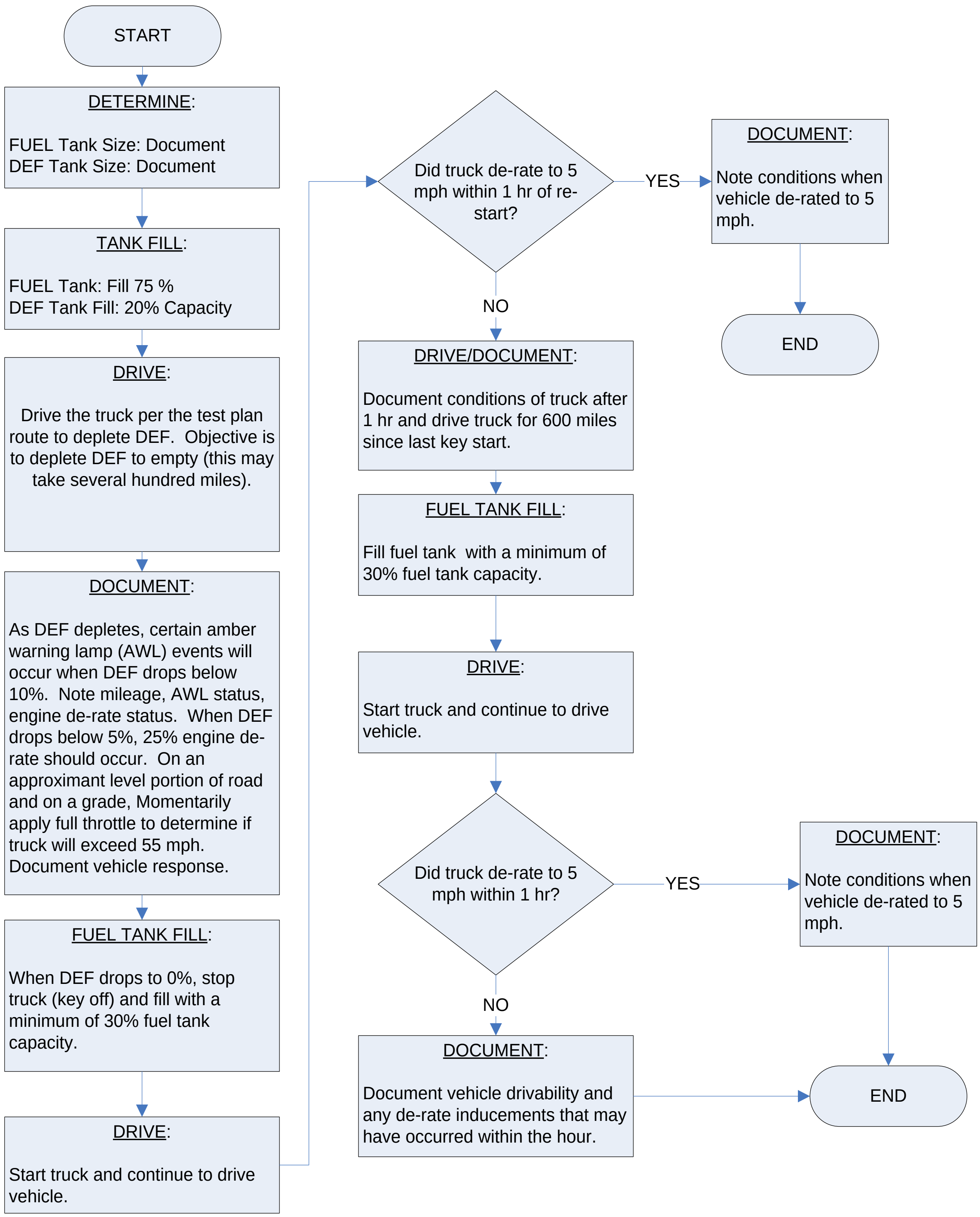


CHART 2
DDC 12.8L DEF TEST PROGRAM OPERATION
(DEF Dilution Test Cycle)

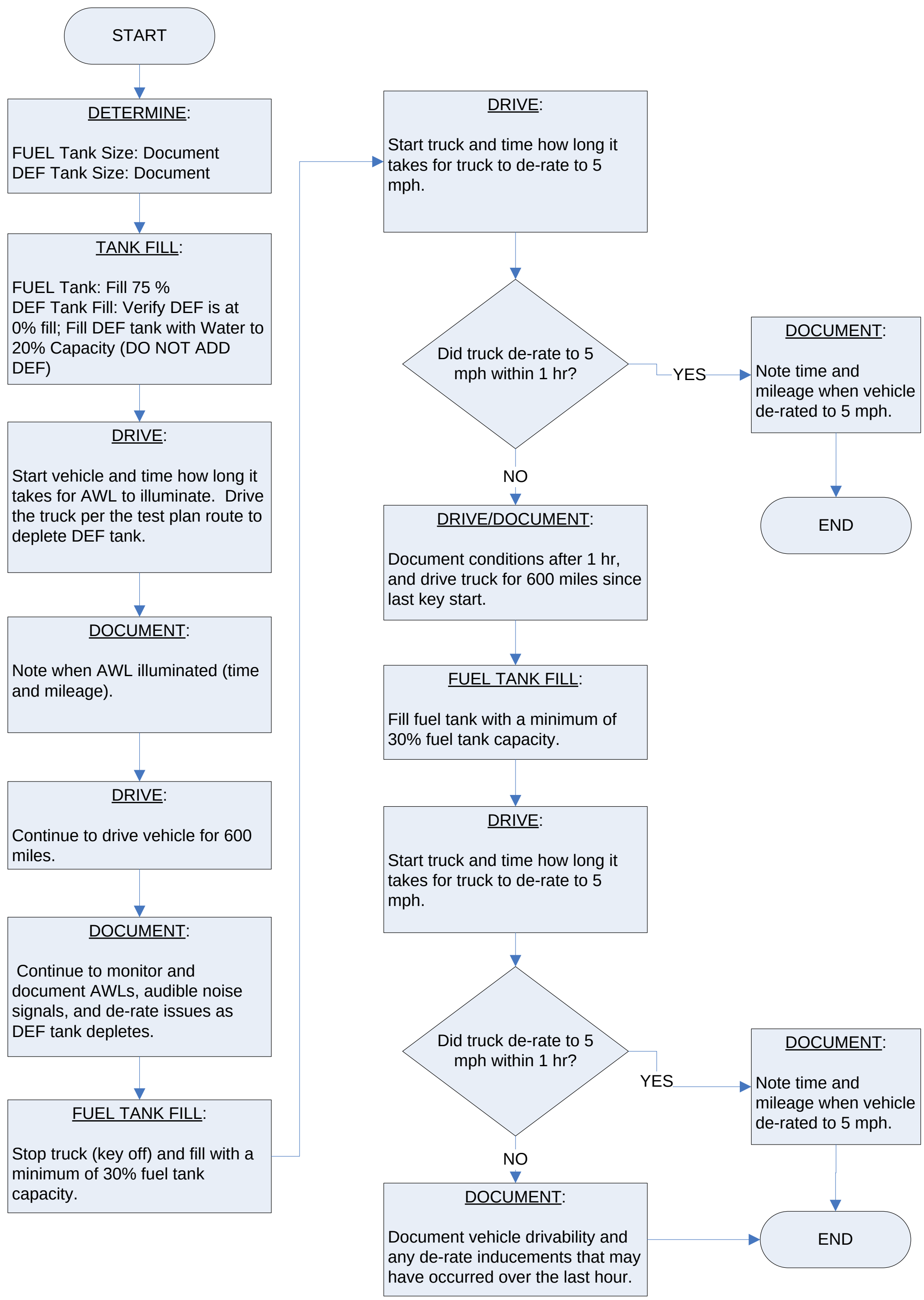


CHART 3
DDC 12.8L DEF TEST PROGRAM OPERATION
(DEF Tamper Test Cycle)

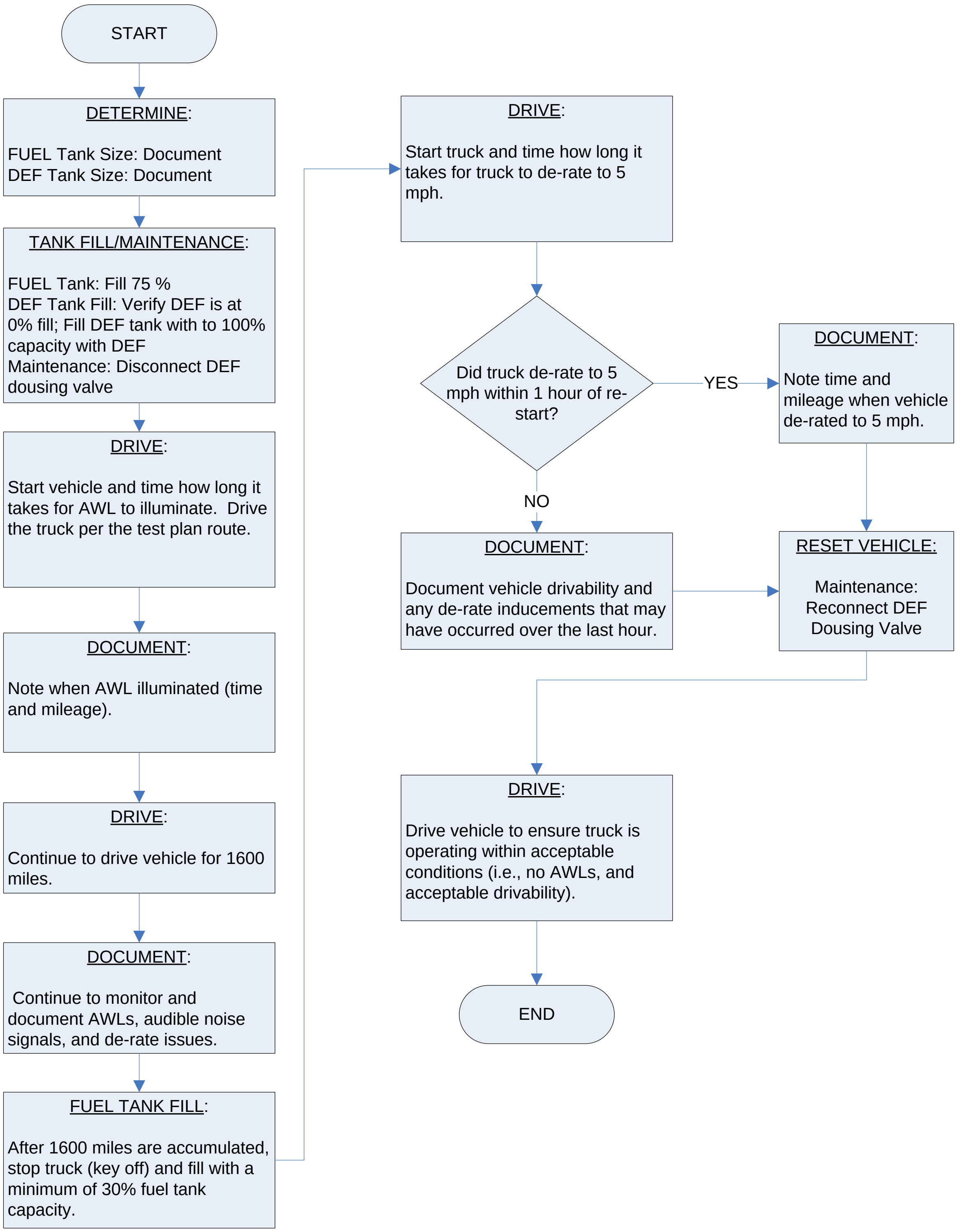


CHART 4
CUMMINS 14.9L DEF TEST PROGRAM OPERATION
(Low DEF Test Cycle)

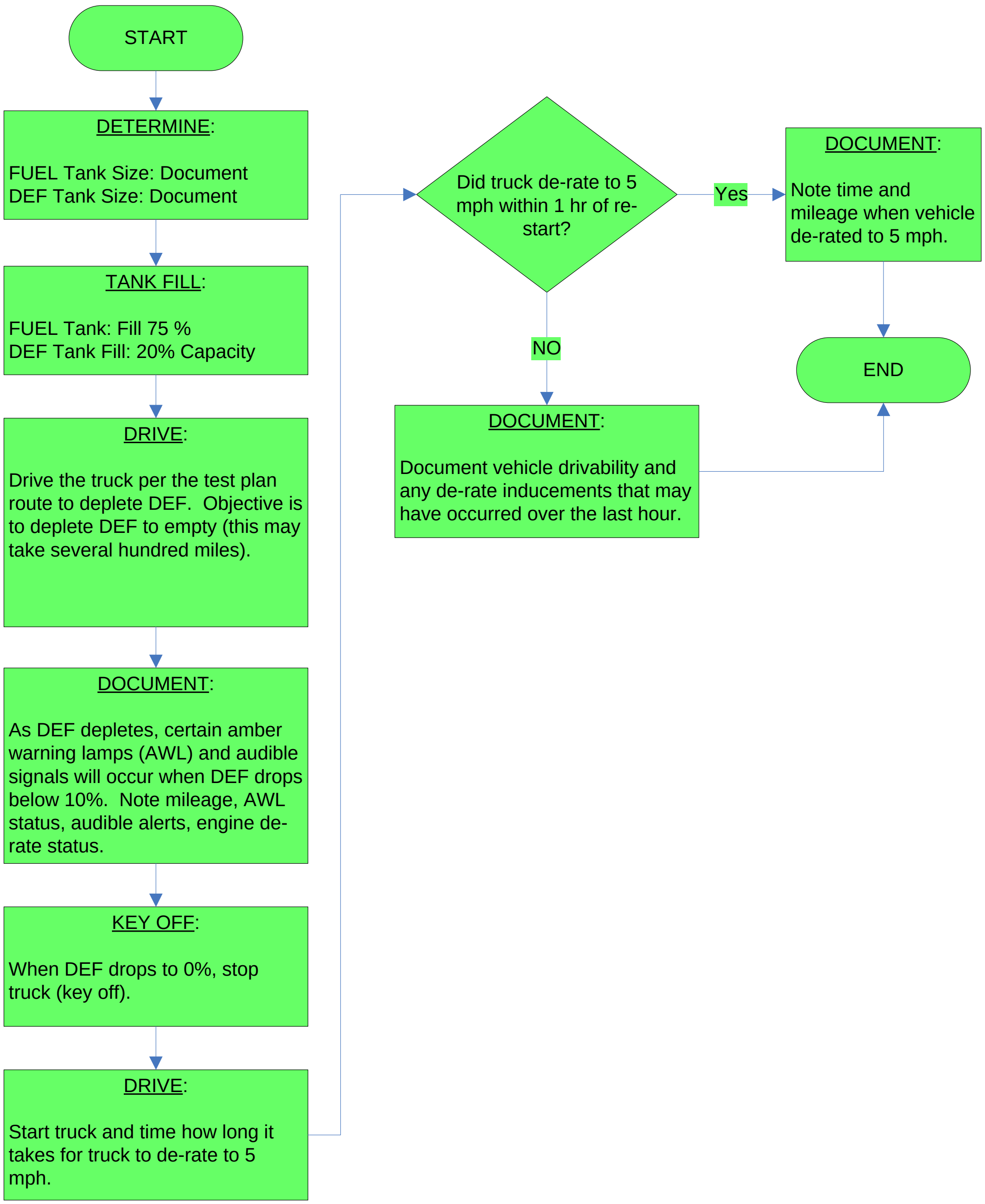


CHART 5
CUMMINS 14.9L DEF TEST PROGRAM OPERATION
(DEF Dilution Test Cycle)

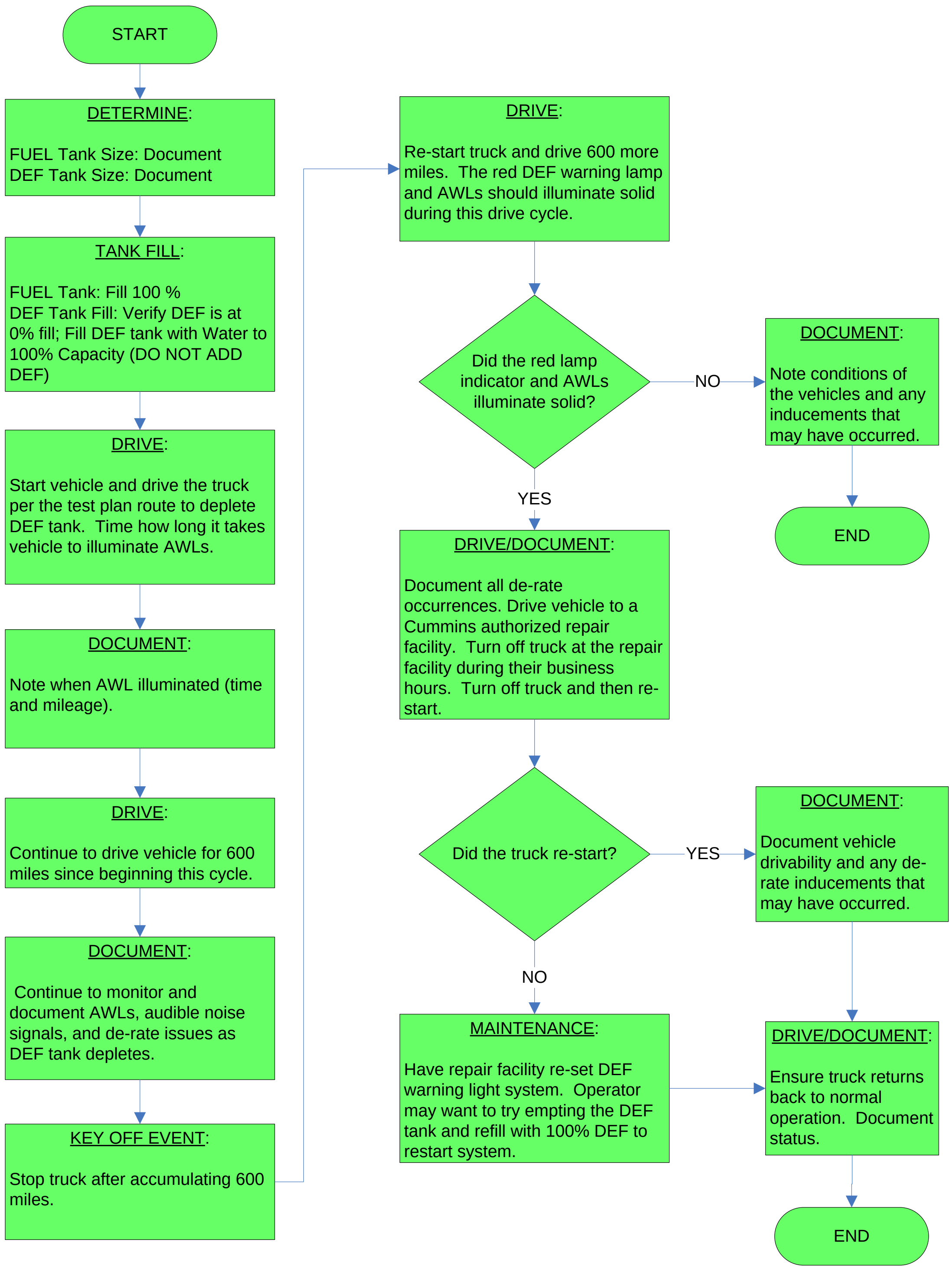


CHART 6
CUMMINS 14.9L DEF TEST PROGRAM OPERATION
(DEF Tamper Test Cycle)

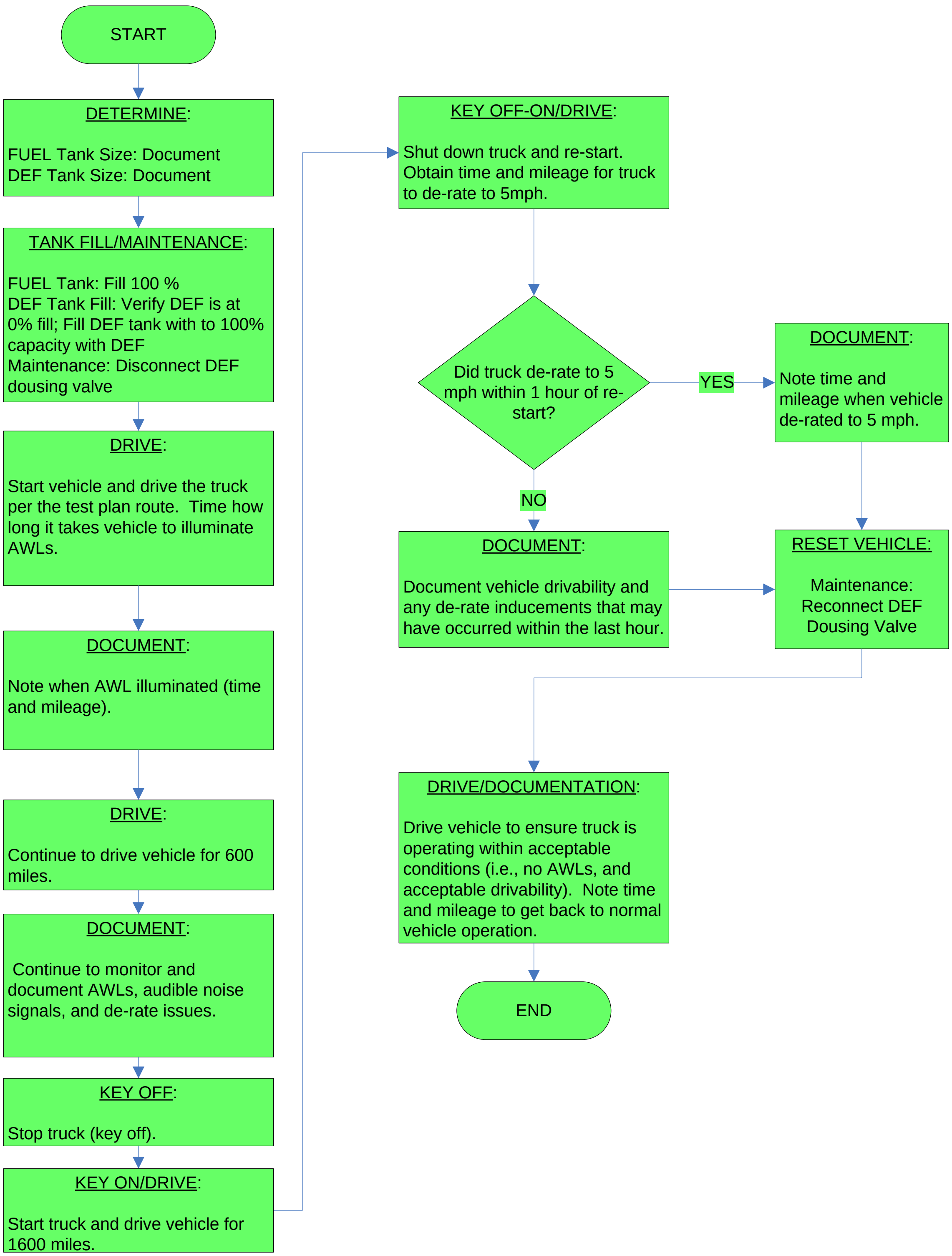


CHART 7
CUMMINS 6.7L DEF TEST PROGRAM OPERATION
(Low DEF Test Cycle)

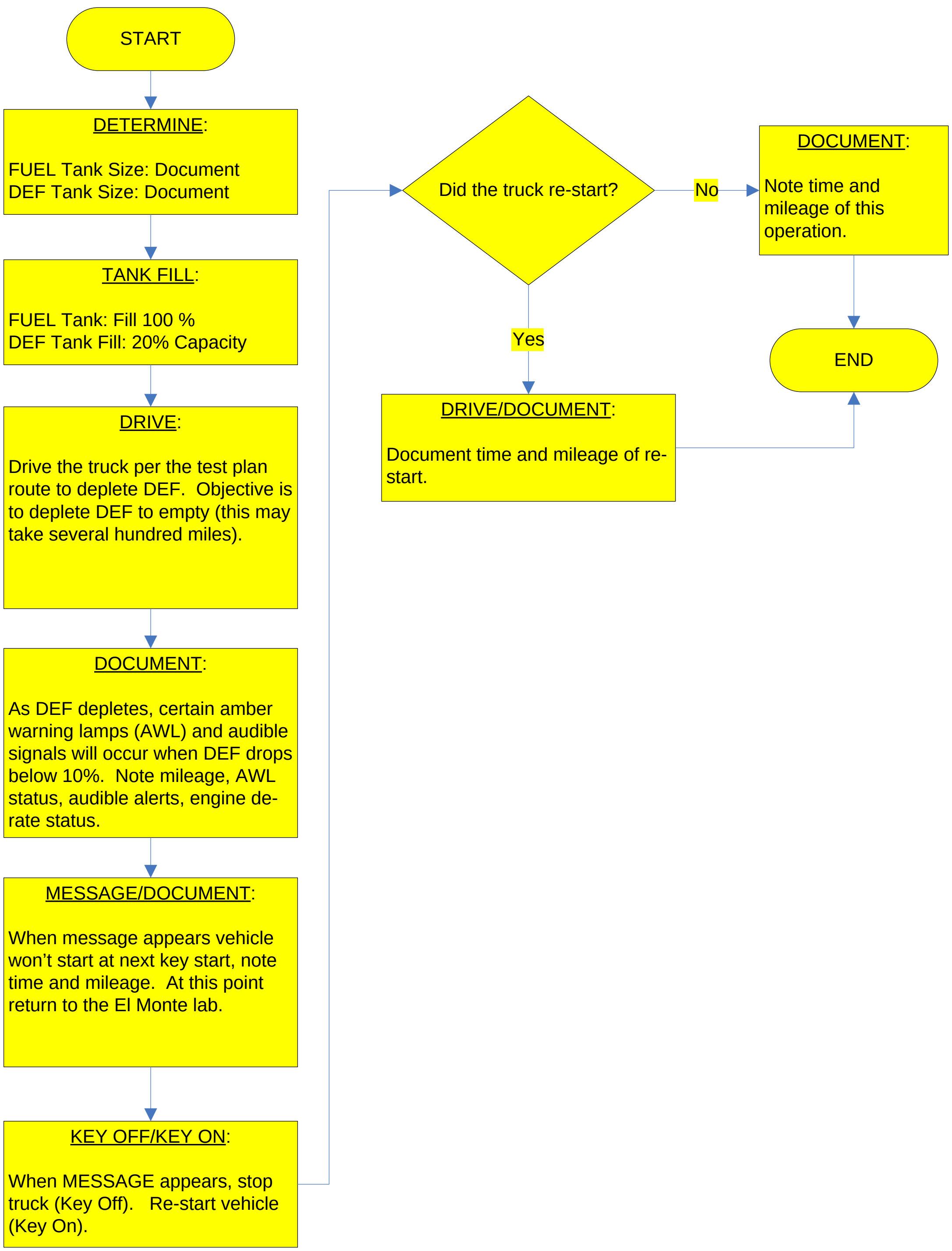


CHART 8
CUMMINS 6.7L DEF TEST PROGRAM OPERATION
(DEF Dilution Test Cycle)

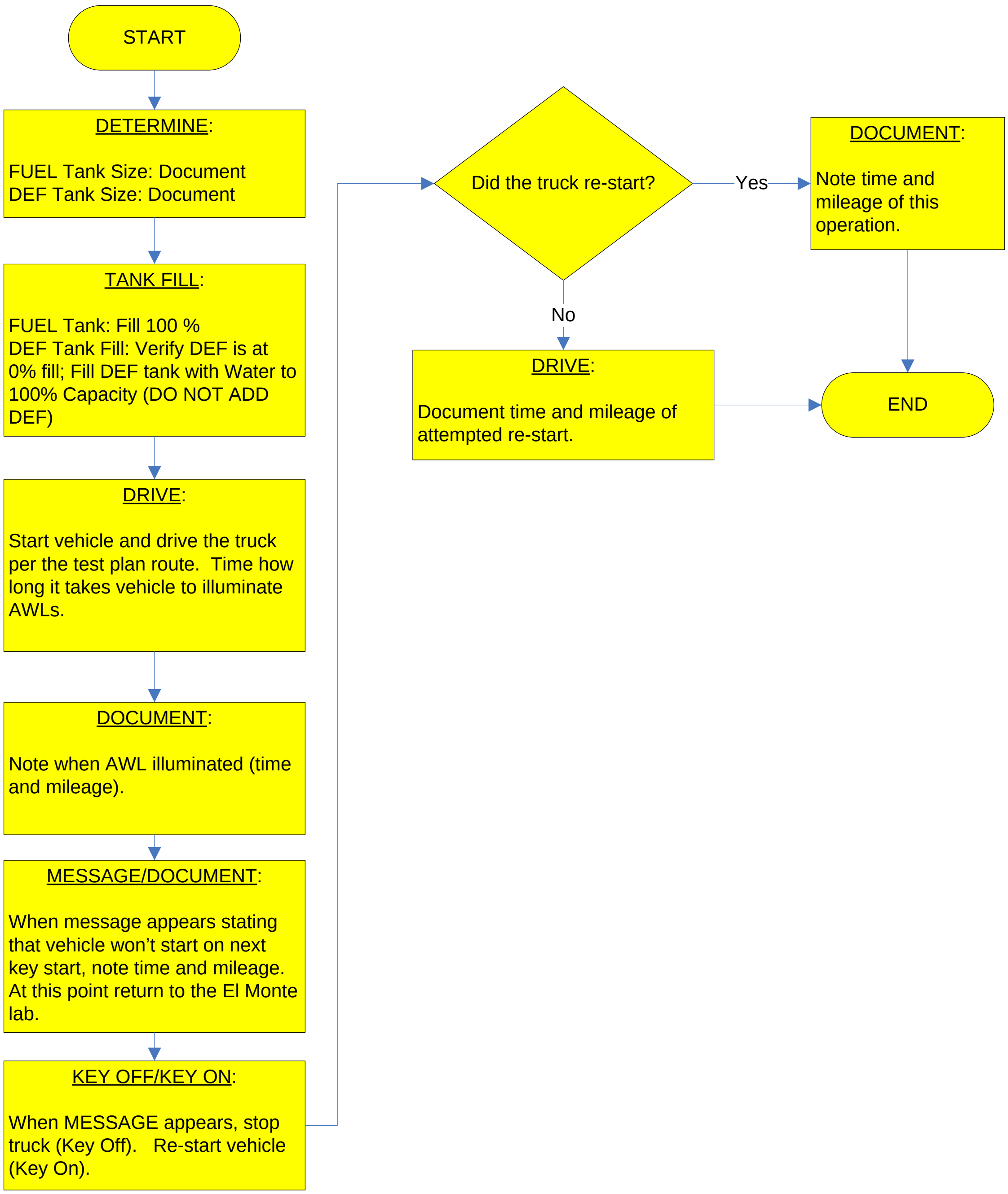
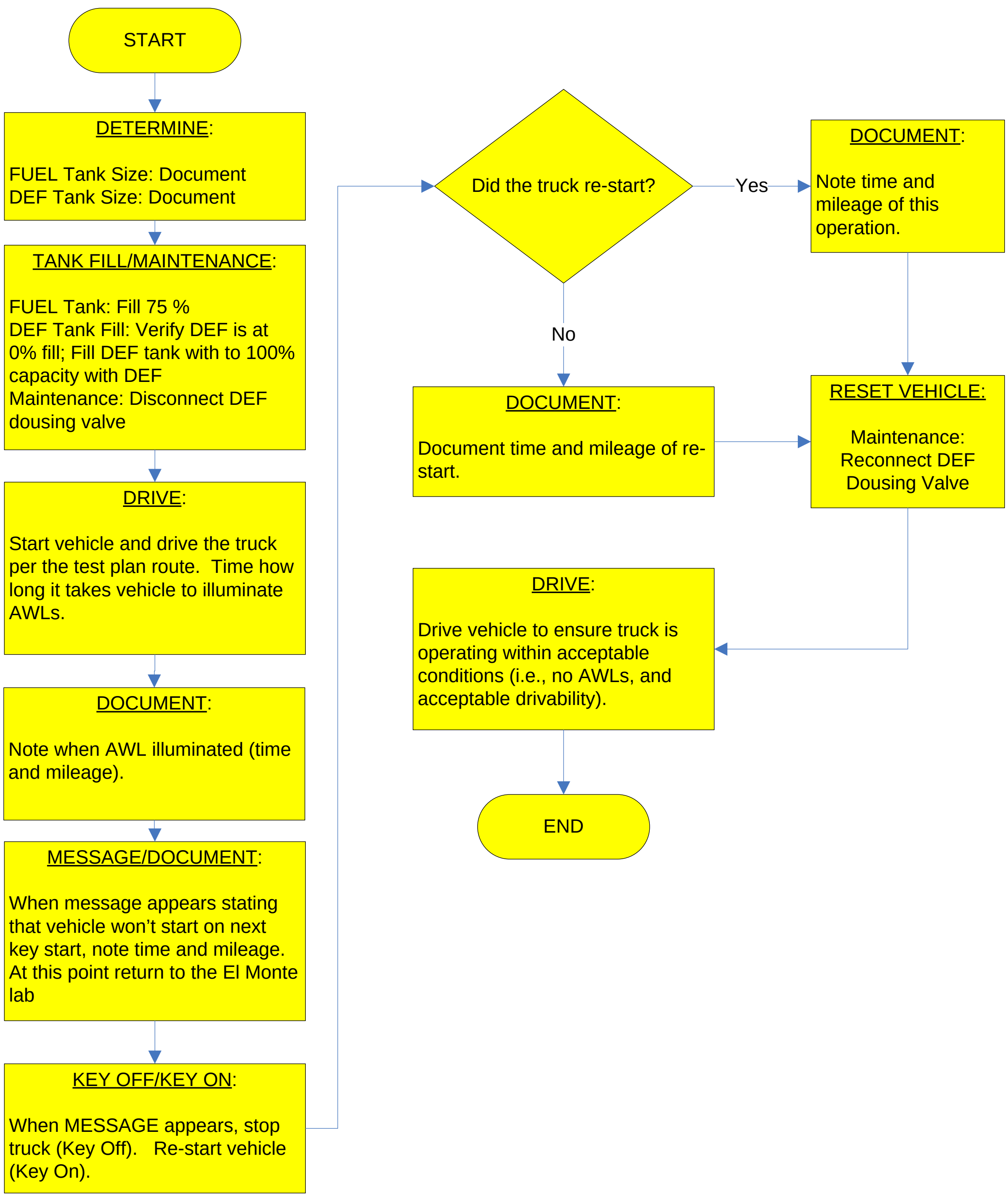
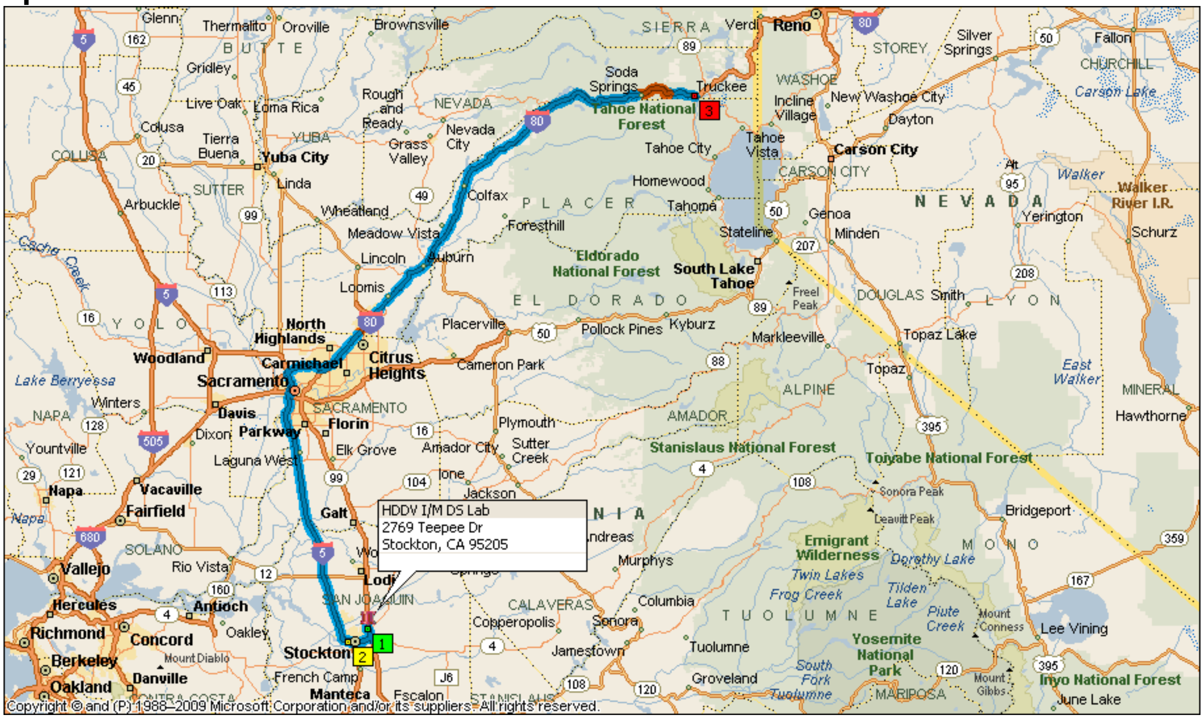


CHART 9
CUMMINS 6.7L DEF TEST PROGRAM OPERATION
(DEF Tamper Test Cycle)



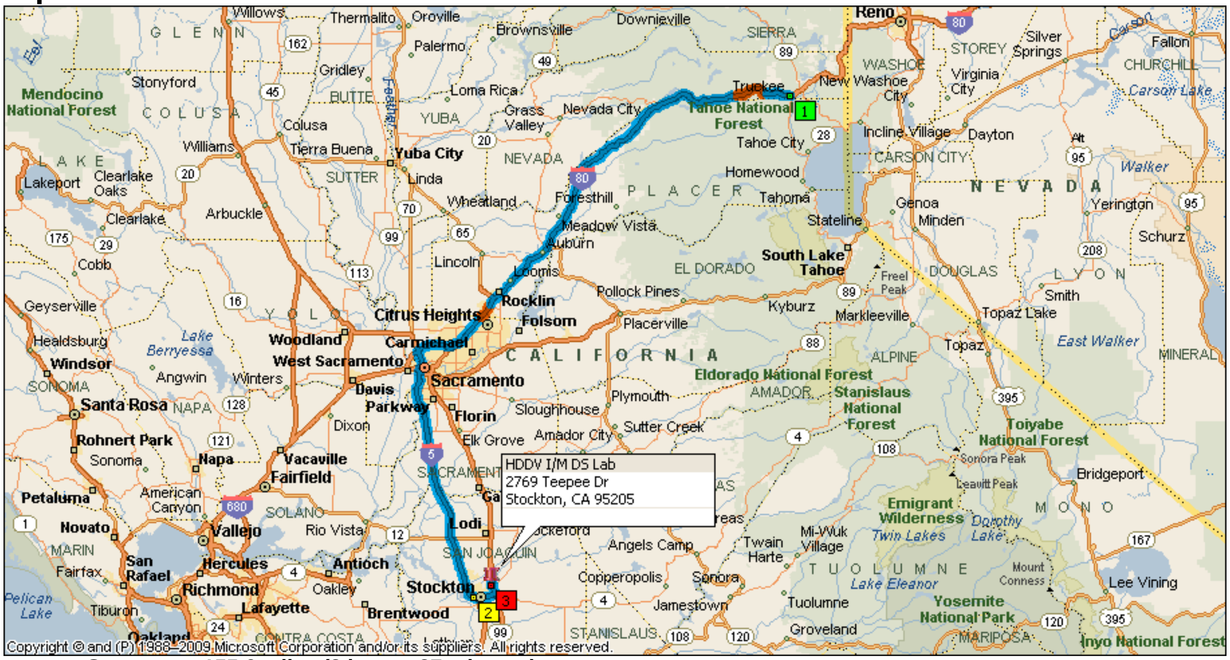
Map 1 - Stockton to Truckee Route



- **Summary: 155.3 miles (2 hours, 39 minutes)**

Time	Mile	Instruction	For	Toward
9:00 AM	**0.0**	**Depart 2769 Teepee Dr, Stockton, CA 95205 on Teepee Dr (West)**	**0.1 mi**	
9:00 AM	0.1	Turn RIGHT (North-East) onto Cherokee Rd	0.2 mi	
9:01 AM	0.3	Take Ramp (RIGHT) onto SR-99	1.5 mi	CA-99 / Los Angeles
9:03 AM	1.9	Road name changes to SR-26 [SR-99]	0.3 mi	
9:03 AM	2.2	At exit 254A, take Ramp (RIGHT) onto SR-4 [Ort Lofthus Fwy]	3.0 mi	CA-4 / I-5 / Downtown Stockton / San Francisco
9:06 AM	5.2	Turn RIGHT onto Ramp	0.3 mi	I-5 / CA-4 / San Francisco / Los Angeles / Sacramento
9:07 AM	5.5	Take Ramp (LEFT) onto I-5	0.8 mi	I-5 / Sacramento
9:08 AM	6.3	At exit 473, turn RIGHT onto Ramp	0.3 mi	Pershing Avenue
9:08 AM	6.5	Road name changes to N Pershing Ave	142 yds	
9:08 AM	6.6	Turn LEFT (West) onto W Flora St, then immediately turn LEFT (South) onto N Pershing Ave	0.2 mi	
9:10 AM	6.9	Turn RIGHT (West) onto W Fremont St	0.1 mi	
9:11 AM	**7.0**	**At near Stockton, return East on W Fremont St**	**0.1 mi**	
9:11 AM	7.1	Turn LEFT (North) onto N Pershing Ave	0.1 mi	
9:12 AM	7.2	Take Ramp (LEFT) onto I-5	49.2 mi	I-5 / Sacramento
10:01 AM	56.5	At exit 522, turn RIGHT onto Ramp	0.2 mi	I-80 / San Francisco / Reno
10:01 AM	56.7	Take Ramp (RIGHT) onto I-80	98.4 mi	I-80 / Reno
		Road widening near Roseville (NB) (October 10, 2008 - March 24, 2011)		
11:39 AM	155.1	At exit 185, turn RIGHT onto Ramp	0.2 mi	CA-89 / Lake Tahoe

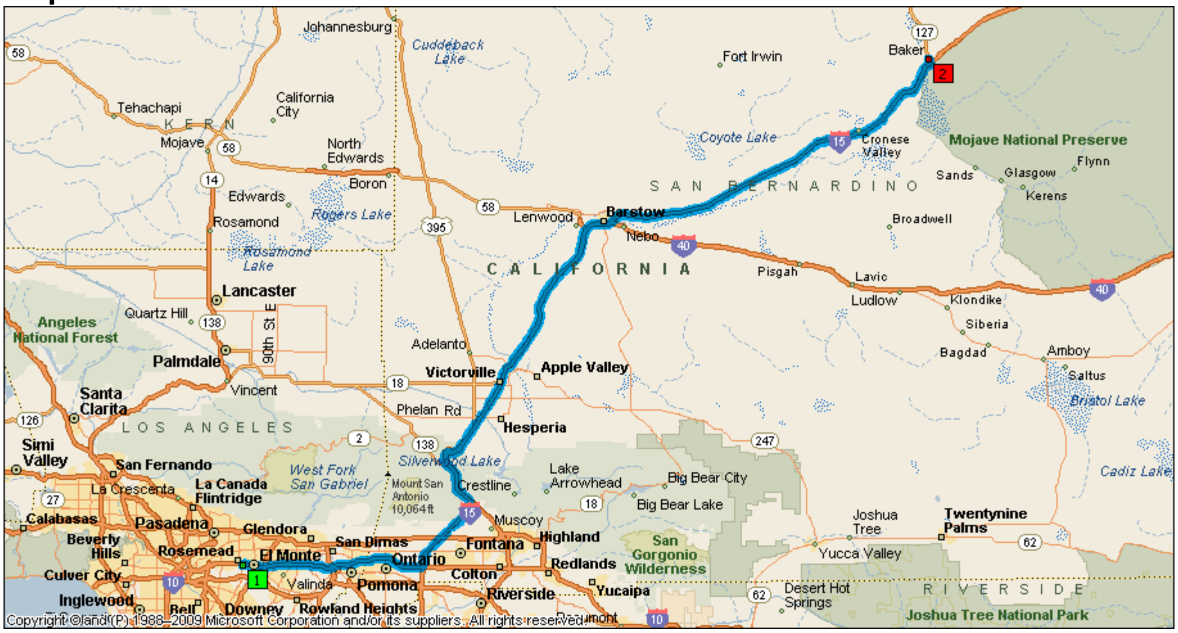
Map 2 - Return Route



Summary: 155.6 miles (2 hours, 37 minutes)

Time	Mile	Instruction	For	Toward
12:00 PM	**0.0**	**Depart near Gateway on SR-89 (North)**	**120 yds**	**CA-89 / US-80 W / Donner Pass Rd / Sacramento**
12:00 PM	0.1	At roundabout, take the SECOND exit onto Ramp	0.2 mi	I-80 / Sacramento
12:00 PM	0.3	Merge onto I-80	97.9 mi	
		Reconstruction near Eder (WB) (March 1, 2009 - February 29, 2012)		
1:37 PM	98.2	Turn RIGHT onto Ramp	0.2 mi	CA-99 / I-5 / Los Angeles / Redding
1:37 PM	98.4	Take Ramp (LEFT) onto I-5 [SR-99]	49.7 mi	I-5 / CA-99 / Sacramento / Los Angeles
2:27 PM	148.1	At exit 473, turn RIGHT onto Ramp	0.2 mi	Fremont St / Oak St
2:28 PM	148.3	Turn LEFT (East) onto W Fremont St	87 yds	
2:28 PM	**148.4**	**At near Stockton, take Ramp (LEFT) onto I-5**	**0.4 mi**	**I-5 / Tracy**
2:29 PM	148.8	Turn RIGHT onto Ramp	0.3 mi	Fresno Avenue / CA-4 E / Downtown Stockton
2:29 PM	149.1	Keep LEFT to stay on Ramp	0.7 mi	CA-4 / CA-99 / Downtown Stockton
2:30 PM	149.7	Take Ramp (LEFT) onto SR-4 [Ort Lofthus Fwy]	2.7 mi	
2:32 PM	152.5	Take Ramp (LEFT) onto SR-26 [SR-99]	0.7 mi	CA-99 / Sacramento
2:33 PM	153.2	At exit 254B, road name changes to SR-99	1.8 mi	
2:35 PM	154.9	At exit 256, turn RIGHT onto Ramp	0.1 mi	Cherokee Rd
2:36 PM	155.1	Keep RIGHT to stay on Ramp	87 yds	Cherokee Rd West
2:36 PM	155.1	Keep STRAIGHT onto Cherokee Rd	0.4 mi	
2:37 PM	155.5	Turn LEFT (East) onto Teepee Dr	0.1 mi	
2:37 PM	**155.6**	**Arrive 2769 Teepee Dr, Stockton, CA 95205**		

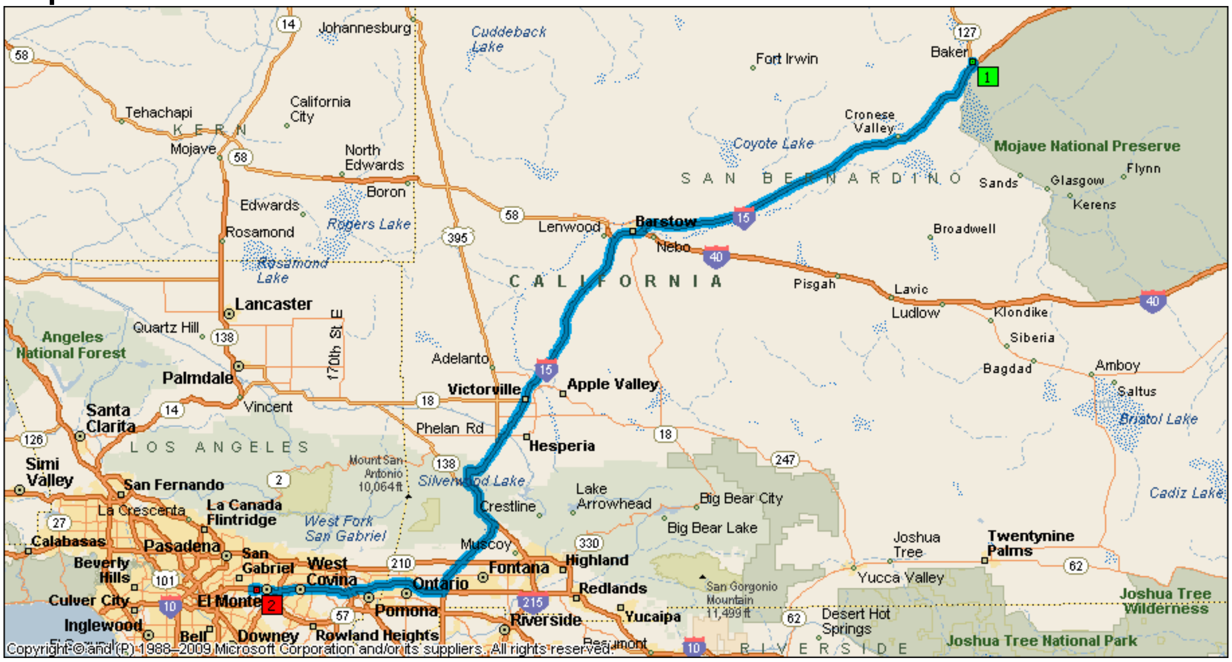
Map 3 - El Monte to Baker



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 4 - 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**		

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 derate	Engine Start	Road Grade %	Vehicle Speed	How Many AWLs	Red Light Indicator	Comments