Evaluation of the Effectiveness of On-Board Diagnostic (OBD) Systems in Identifying Fuel Vapor Losses from Light-Duty Vehicles

Final Report

EPA United States Environmental Protection Agency

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Final Report

Assessment and Standards Division
Office of Transportation and Air Quality
U.S. Environmental Protection Agency

Prepared for EPA by
Eastern Research Group, Inc.
EPA Contract No. EP-C-06-0-80
Work Assignment No. 5-10

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Version 11

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Prepared by:
Eastern Research Group, Inc.

Prepared for:
U.S. Environmental Protection Agency

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1.0 Introduction

This document is Eastern Research Group's (ERG's) final report on evaluating the effectiveness of Second Generation On-Board Diagnostic (OBD) systems through a comparative analysis of evaporative emissions field data collected in the Denver area during the past four years. These field studies were performed through Cooperative Research and Development Agreements (CRADAs 471-08 and 471-A-11) between the Assessment and Standards Division (ASD) within the Office of Transportation and Air Quality (OTAQ) of the United States Environmental Protection Agency (EPA) and the Colorado Department of Public Health and Environment (CDPHE), with support provided by ERG under Work Assignments 1-2, 2-2, 2-4, 3-4 and 4-4 of Contract EP-C-06-080 with the EPA. A wealth of data has been collected at the Denver Lipan[1] and Ken Caryl[2] Inspection and Maintenance (I/M) lanes using a Portable Sealed Housing for Evaporative Determination (PSHED) and remote sensing devices. Because the studies took place at I/M lanes in Colorado, OBD information is also available for each vehicle.

CDPHE independently performed additional work during the summer of 2010 in a repair effectiveness study conducted at CDPHE's Aurora and West Tech test centers. During this "Denver 2010" study, vehicles were recruited and brought to one of the two CDPHE facilities where laboratory-grade Sealed Housing for Evaporative Determination (SHED) testing was performed, in addition to other evaporative control system diagnostic tests. Repairs were performed on vehicles with elevated evaporative emission levels. Repeat tests were conducted to assess the effectiveness of the evaporative emissions repairs performed by CDPHE.

The focus of this report is on the analysis of evaporative emissions and related data collected on model year 1996 and newer light-duty vehicles equipped with OBD systems. Results for the Lipan, Ken Caryl and Denver 2010 studies are analyzed in this report, and Table 1-1 lists the number of 1996 and later OBD equipped vehicles which participated in each of the three studies.

1 DeFries, T; Lindner, J; Kishan, S; Palacios, C (2011) "Investigation of Techniques for High Evaporative Emissions Vehicle Detection: Denver Summer 2008 Pilot Study at Lipan Street Station"
2 DeFries, T; Palacios, C; Kishan, S (2012) "Estimated Summer Hot Soak Distributions for the Denver's Ken Caryl IM Station Fleet "

Table 1-1. Overview of Datasets used in Analysis

Dataset Source	Number of 1996+ Vehicles	Data Available in Dataset
Lipan Participant (LP)	24	OBD, MCM*, PSHED**
Ken Caryl Participant (CP)	89	OBD, MCM, PSHED
Denver 2010 Participant (DP)	68	OBD, MCM, PSHED or LSHED
Total participants (vehicles) in 3 studies	181	OBD, MCM, PSHED or LSHED

*MCM- Modified California Method
**PSHED – Portable Sealed Housing for Evaporative Determination

The purpose of this analysis is to evaluate OBD's ability to identify vehicles with elevated evaporative emissions (due to a leak in the fuel/vapor control system). OBD systems are not designed for and are generally not capable of determining and setting a code for a leak in the fuel system which would result in a liquid leak.[3] Three types of data are used in the analysis in this report:

OBD – OBD codes which indicate system or component malfunctions that could result in elevated exhaust or evaporative emission levels. During routine I/M inspections, vehicle OBD system data (including diagnostic trouble codes (DTCs)) is collected for 1996 and newer vehicles.

MCM – Vehicles in all three studies received a Modified California Method (MCM) inspection, which is an under-hood and under-body inspection for evaporative emissions using olfactory, visual, and electronic hydrocarbon (HC) detector checks. MCM variables are generally discrete. MCM inspections provide several kinds of information including smell/no-smell noted by the inspector, visual condition of various fuel system and evaporative emissions control system components, and detect/no-detect by the electronic HC detector (shown in Figure 1-1).

Figure 1-1. Electronic HC detector used for MCM Inspections

3 40 CFR 86.099-17

PSHED and LSHED – Hot-soak evaporative emission estimates were gathered for each vehicle in the three studies by placing the vehicle in a Laboratory Sealed Housing for Evaporative Determination (LSHED) or a Portable Sealed Housing for Evaporative Determination (PSHED). LSHED values are reported as continuous variables with units of grams HC/15minutes. In the Lipan and Ken Caryl studies, a PSHED was used, while in the Denver 2010 study a PSHED was used for the vehicles tested at the CDPHE's West Tech Center, and a laboratory (conventional) SHED was used for vehicles tested at CDPHE's Aurora laboratory testing facility. Performance of the PSHED has been evaluated in comparison to a laboratory SHED in a separate report[4] which shows that for fifteen minutes the PSHED had an average Recovery of 97.6% and an average Retention of 95.7%, which are within the requirements of the laboratory SHED for this time period. Figure 1-2 shows the PSHED used in the Denver studies.

Figure 1-2. Portable Sealed Housing for Evaporative Determination (PSHED) used in Denver High Evaporative Emission Field Studies

The analysis in this report is broken out by vehicle model year, OBD evaporative system readiness monitor status, and the presence of enhanced evaporative emission controls for 1996-1998 vehicles. Vehicles with "Not Ready" systems (as described in Section 2.0, Background)

4 Lindner, J; DeFries, T (2012) "Evaluation of Portable SHED Characteristics"

associated with the relevant OBD code categories are delineated in the analysis. The break-outs were made to the finest level of detail possible; however, this was dependent on the sample size for each category. OTAQ assisted ERG in identifying those 1996-1998 vehicles that were equipped with enhanced-evaporative emissions systems, as well as whether a vehicle was certified to meet the federal or California emission standards.[5]

5 Note that US EPA enhanced evaporative emission controls for passenger cars and light trucks phased in over the 1996-1999 model years.

2.0 Background

2.1 OBD Overview

Second-Generation Onboard Diagnostics (OBDII, typically referred to simply as OBD) is a system used to monitor the status and performance of a vehicle's powertrain and emissions control system components in order to detect malfunctions which could result in an emissions increase above a specified threshold. For tailpipe emissions, this threshold is 1.5 times the federal certification emission standard.[6] For evaporative emissions control systems, the OBD system monitors for proper operation of components, adequate purge flow of the evaporative control system and vapor leaks equivalent to certain orifice diameters (such as 0.020" or 0.040", depending on which of the applicable OBD standards were followed for certification). All model year 1996 and newer light-duty non-diesel on-road vehicles sold in the United States are federally required to be equipped with OBD.[7]

The OBD system consists of the powertrain control module (PCM), various engine and transmission input sensors and components, emission control components, a malfunction indicator light (MIL) and a diagnostic link connector (DLC). These systems work together to monitor a vehicle's powertrain and emission control components during vehicle operation and to store diagnostic information and alert the driver if a malfunction is identified. Although the emission standards to which OBD must comply are federally defined, development of the systems and algorithms used to identify malfunctions is the responsibility of each vehicle manufacturer. Therefore, monitoring criteria and the amount of time required for a monitor to achieve readiness (as defined in the next section) can vary among vehicle manufacturers and even vehicle models and model years. In addition, some manufacturers choose to comply with more strict standards than federal standards in order to ensure all their vehicles are 50-state legal. For example, many manufacturers choose to have their OBD systems certified to detection of a 0.020" diameter vapor leak required by the California Air Resources Board rather than the less strict federal 0.040" requirement in order to maintain model consistency and avoid the 49-state certification issue.

Diagnostic information is stored in the system using a five digit code which provides information about the source of the malfunction, and the driver is alerted when the MIL (commonly referred to as a check engine light) is illuminated. By connecting an OBD scan tool (or an inspection and maintenance analyzer) to the vehicle's DLC, certain information including

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6 Center for Automotive Science & Technology at Weber State University. (2000). On-Board Diagnostics Conference 2000 On-Board Diagnostics Manual. (pp. 2-5). Ogden, Utah: Weber State University.
7 40 CFR 86.094-17

the vehicle's MIL command status (whether the MIL is commanded on or off) and any stored diagnostic trouble codes (DTCs) can be downloaded from the vehicle's PCM. These DTCs are five-digit alpha numeric codes of the format P####. The codes of primary interest in this report are the generic (set in federal regulations) P0 series codes (i.e., P0###) defined in SAE J1979, since these are common among all vehicle manufacturers and are the codes primarily used in vehicle inspection and maintenance programs.

2.2 OBD Monitors and Readiness

Before a vehicle's OBD system can make a determination about whether or not malfunctions are occurring, a series of tests are required to evaluate the operational status of the various OBD subsystems. These operational tests are categorized into meaningful sets of subsystems referred to as monitors. Each monitor has a readiness code that identifies whether or not the related subsystem has been evaluated. If a monitor is "ready", that simply means that testing on that particular subsystem has been completed, and results are available (a DTC will be stored if a malfunction was identified). On the other hand, if a monitor is "not ready", testing of that particular subsystem has not been completed, so no information is yet available on whether or not malfunctions exist in that subsystem. Therefore, a lack of DTCs for a "not ready" monitor does not indicate that no malfunctions (i.e., DTCs) are present; it simply means the system evaluation is not complete.

Monitors may be classified as those that are always "ready" (continuous monitors), and those that become ready at different times (non-continuous monitors). The three continuous monitors include the Comprehensive Component, Misfire and Fuel System monitors, while the typical non-continuous monitors are the Oxygen Sensor, Catalyst, Exhaust Gas Recirculation (EGR), Evaporative Emissions Control System (evaporative system), Air Injection System (AIR), Thermostat and Positive Crankcase Ventilation System (PCV) monitors.[8] As the name implies, the continuous monitors are always running (these are "critical" monitors which primarily protect the catalytic converter). The non-continuous monitors are only evaluated under certain powertrain operating conditions (the vehicle's PCM uses complex algorithms to determine when these non-continuous monitors may be run). For this reason, at any point in time, a vehicle will have a number of "ready" monitors, and also may have a number of "not ready" monitors. Normally, non-continuous monitors which are "not ready" are set to assess readiness after each key-on operating event.

8 Birnbaum, R, & Truglia, J (2000). *Getting to Know OBDII*. asttraining.com, ISBN 0-9706711-0-5, pg, 32.

The amount of time necessary for monitors to achieve readiness varies on a number of factors. OBD systems on older model-year vehicles (i.e., model year 1996-2000 vehicles) typically take longer to achieve "readiness" than newer vehicles (as monitoring algorithms have been refined and improved over the years). In addition, different types of systems require different conditions (referred to as enabling criteria) before they can be tested. For example, the operating conditions required to test an oxygen sensor are more frequently encountered than the operating conditions necessary to evaluate the evaporative system monitor (the enabling criteria are met more frequently for an oxygen sensor monitor than for an evaporative system monitor). Therefore, after a PCM reset, the oxygen sensor monitor status is usually "ready" before the evaporative system monitor status is "ready", and consequently, more vehicles on the road likely have "ready" oxygen sensor monitors than vehicles with "ready" evaporative system monitors. Once a monitor's system evaluation has been completed, the status changes from "not ready" to "ready", and at that time, if any malfunctions are detected, a DTC is stored. However, until the monitor is "ready", no information can be known about whether or not malfunctions are present. This assessment cannot be made until the monitor is "ready".

2.3 OBD DTCs

As previously described, once a fault is detected, a 5-digit DTC is stored. This is a standardized code which provides information about the type of system or fault, which conforms to the following format:[9]

- Position 1: Device Code: B=Body; C=Chassis; P=Powertrain; U=Network or data link
- Position 2: Type: 0 = generic (legislated and common among all vehicle manufacturers); 1 = manufacturer specific
- Position 3: Specific vehicle system:
  - — 1, 2 = Fuel and Air Metering
  - — 3 = Ignition System or Misfire
  - — 4 = Auxiliary Emission Controls
  - — 5 = Vehicle Speed Control and Idle Control System
  - — 6 = Computer Output Circuit
  - — 7, 8 = Transmission
- Positions 4 and 5: These last two digits indicate which component or system has a fault

As an example, P0455 is a powertrain (P) generic (0) code which involves an auxiliary emission control system or component (4), and the last two digits indicate this is an "Evaporative Emission Control System Leak Detected (gross leak)"[10] (this code is typical for a missing, faulty

9 SAE International, J1979 Surface Vehicle Standard, Issued 1991-12, Revised 2004-04, page 33.
10 Society of Automotive Engineers. (1999, March). On-Board Diagnostics for Light and Medium Duty Vehicles Standards Manual, pg. 123.

or incorrectly installed gas cap, among other things). Aftermarket scan tools and I/M analyzers can access and download all generic powertrain (P0) codes, and other codes (such as manufacturer-specific P1 codes) may be accessible by some scanners and systems, including specialized and manufacturer-specific diagnostic equipment.

Logic for setting a code varies depending on what system or component is being monitored. Some codes are immediately set and the MIL is commanded “on” after only one occurrence of a fault. However, PCM algorithms may require repeat failures on two successive trips before the code is set and the MIL is commanded on. For these algorithms, if a fault is identified on the first of two tests, a “pending” DTC is stored. If the fault is again detected on a subsequent trip (generally the next consecutive trip), then the “pending” DTC becomes a “confirmed” DTC, and the MIL is commanded on. On the other hand, if a fault is not identified on the next trip, the “pending” DTC is erased (except for fuel and misfire monitoring codes, which aren’t immediately deleted). Since “pending” DTCs indicate that there may be a problem but this is not yet confirmed, the MIL is not commanded on for a “pending” DTC. The MIL is only commanded on for a confirmed DTC, whether it be a single trip DTC or a two-trip DTC. Once a confirmed DTC is stored, a snapshot of engine operating conditions at the time the code was set is stored in the PCM’s memory. This snapshot of conditions is called freeze frame data and offers clues that can help a repair technician identify and effectively repair the failure.

As previously described, the PCM can be “reset” (codes, freeze frame data and MIL command “on” cleared) by disconnecting the vehicle’s battery or by using the reset feature of a scan tool. This also resets all monitors to “not ready”. However, the PCM will also automatically erase codes and freeze frame data and turn the MIL off if the fault which triggered the DTC is not encountered during three consecutive tests[11] (again, excluding fuel and misfire monitors, which are tested in a different manner whose description is beyond the scope of this general description).

As a side note, a flashing MIL (as opposed to constant MIL illumination) indicates the fault which has been detected poses an immediate threat to the catalytic converter.[12] However, an immediate threat to the catalytic converter isn’t always represented by a flashing MIL.

2.4 Evaporative Emissions Control System Overview

The focus of this report is on OBD monitoring of the evaporative emissions control system. The general purpose of the evaporative emissions control system is to prevent release of

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11 Birnbaum, R, & Truglia, J (2000). *Getting to Know OBDII*. asttraining.com, ISBN 0-9706711-0-5, pg, 26.
12 Birnbaum, R, & Truglia, J (2000). *Getting to Know OBDII*. asttraining.com, ISBN 0-9706711-0-5, pg, 24.

fuel vapor (raw hydrocarbons) into the atmosphere during vehicle operation, hot soaks and diurnal soaks. This is accomplished by a system design which reduces permeation and vapor leaks from various materials and connections. Most of the vapor is routed to a carbon canister where it is stored and then released into the engine to be burned at certain times during operation of the engine.

Two overall types of evaporative system OBD monitoring exist, non-enhanced and enhanced systems. In general, non-enhanced systems only monitor canister purge flow, while enhanced systems monitor both purge flow and test for leaks in the vapor recovery system.[13] Consequently, enhanced systems require leak detection sensors and valves which aren't required in non-enhanced systems. In general, hardware for evaporative emissions control systems may include vapor transport lines, control solenoids and valves, pumps, pressure sensors, and the evaporative carbon canister.

2.5 Recent Evaporative Emissions Real World Test Programs

The Coordinating Research Council (CRC) Real World Group has been conducting permeation evaporative emissions testing in the E-77 and E-77-2 programs.[14] The permeation test procedure was refined in the pilot E-77 program before using it in the larger E-77-2 program. Most of the vehicles were specifically recruited as aging-enhanced evaporative emission vehicles, model years 1996-2000. Three pre-enhanced evaporative emission vehicles and one newer near-zero emissions vehicle which met California PZEV evaporative requirements were also tested. The focus was on non-ethanol fuel with both 7 and 9 RVP. The program also evaluated 24-hour diurnals at the traditional temperature range of 65-105 °F and a higher temperature diurnal of 85-120°F. A subset of the vehicles was tested for 72-hour diurnals. A leak was implanted in the gas cap of one of the aging enhanced vehicles, and the series of tests were run both before and after implanting the leak. The size of the leak was the minimum size necessary for detection by OBD, 0.020" effective diameter as previously described, (although federal OBD monitoring requirements specify detection of a 0.040" leak, most manufacturers certify to California's 0.020" in order to avoid the 49-state certification issue). The E-77 study demonstrated that hydrocarbon emissions can be up to several orders of magnitude larger with an

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13 Birnbaum, R, & Truglia, J (2000). *Getting to Know OBDII*. asttraining.com, ISBN 0-9706711-0-5, pg, 44.
14 CRC E-77 reports: Haskew, H; Liberty, T (2008) "Vehicle Evaporative Emission Mechanisms: A Pilot Study, CRC Project E-77", Haskew, H; Liberty, T (2010) "Enhanced Evaporative Emission Vehicles (CRC E-77-2)", Haskew, H; Liberty, T (2010) "Evaporative Emissions from In-Use Vehicles: Test Fleet Expansion (CRC E-77-2b)", Haskew, H; Liberty, T (2010) "Study to Determine Evaporative Emission Breakdown, Including Permeation Effects and Diurnal Emissions Using E20 Fuels on Aging Enhanced Evaporative Emissions Certified Vehicles, CRC E-77-2c"

implanted leak. This established the need to define the rate of occurrence of "leakers" in the fleet in order to determine the overall impact on the inventory.

During additional laboratory testing in the E-77-2 and E-77-2c programs, similarly-sized leaks were implanted not only in the gas cap, but in other common locations identified during a special study conducted in 2008 by CDPHE at the Lipan I/M station (described later in this section). The results indicated evaporative emissions leak rates are dependent on location of the leak, in particular for vehicles not equipped with On-Board Refueling Vapor Recovery (ORVR). Regardless of ORVR, higher leak rates were measured for leaks implanted at the top of the fuel tank and at the inlet connection to evaporative control canister as compared to the gas cap.

The E-77 testing programs confirmed that both liquid and vapor leaks can be a significant part of any hydrocarbon inventory. The missing piece of information is the prevalence of these leaks in the fleet. A comprehensive program for quantifying these vehicles in the existing fleet has not been attempted since the American Petroleum Institute's "Raw Fuel Leak Survey in I/M Lanes" study in 1998[15] or the California Bureau of Automotive Repair's "Evaporative Emissions Impact of Smog Check" study in 2000.[16] The current fleet consists of aging enhanced evaporative emissions vehicles which were not part of or were quite new in these earlier studies.

During the summer of 2008, CDPHE provided access to the Lipan I/M station as well as staff and remote sensing equipment for a study to determine the prevalence of vehicles with evaporative leaks in the fleet. Certain model year 1981 and newer vehicles were selected (as described in Reference 1) and offered participation in evaporative emissions testing, which consisted of a 15-minute hot-soak test in a portable SHED (PSHED), a visual, olfactory, and electronic HC detector examination of vehicle fuel metering and evaporative emissions control system components. Measurements for a comparison of PSHED results with laboratory SHED were also made on selected participating vehicles.

During the following summer of 2009, CDPHE and the Regional Air Quality Council (RAQC) performed a follow-on study with EPA reverting to an advisory role. This study was performed at the Ken Caryl I/M station in Denver and was developed based on the Lipan experience. Vehicles were selected (as described in Reference 2) and offered participation in intensive evaporative emissions testing, which consisted of the PSHED hot-soak test, visual, olfactory, and electronic HC detector examination of the vehicle.

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15 McClement, D. (1998) "Raw Fuel Leak Survey in I/M Lanes,"
16 Amlin, D.; Carlisle, R.; Kishan, S.; Klausmeier, R.F.; Haskew, H. (2000) "Evaporative Emissions Impact of Smog Check,"

Further work was continued in the summer of 2010 by the CDPHE and the RAQC in a repair effectiveness study in which vehicles were brought to and tested at CDPHE's Aurora and West Tech laboratories. In these efforts, SHED tests were performed followed by extensive diagnostics and repairs. Repeat SHED tests were then performed on vehicles which had received repairs.

Results from these studies suggest vapor leaks can have an impact on the inventory. Traditional evaporative emissions testing, as well as the recent E-77 testing, have shown a range of evaporative emissions from test vehicles, particularly with aging vehicles. The higher emissions levels (but lower than the "gross liquid leakers") have been associated with slow growing vapor leaks which occur as the evaporative emissions control systems age. Vehicles with current (Tier 2 and Enhanced) evaporative emissions control technology are now starting to age, and information on the prevalence of these higher emissions vehicles in the fleet is still being collected.

3.0 Analysis

This analysis involves the comparison of information on OBD evaporative system DTCs with SHED results for the same vehicles. It is not intended to find prevalence rates with OBD evaporative codes. The dataset was drawn from three sets of data: the participants in the High Evaporative Emission studies from 1) the summer of 2008 at the Lipan I/M testing station in Denver, Colorado, 2) the summer of 2009 at the Ken Caryl I/M testing station in Denver, Colorado, and 3) the summer and fall of 2010 at the CDPHE Aurora and West Tech laboratories in Denver, Colorado. Each of these three datasets include vehicles that were tested for evaporative emissions using a PSHED for 15 minutes (at the Aurora station the vehicles were tested using an LSHED for 1 hour, but only the first 15 minutes of continuous measurement were used in this analysis to compare with the PSHEDs).

The I/M dataset included 1996 and newer vehicles. Records for vehicles whose I/M inspections were aborted or incomplete due to OBD communication problems were removed from the dataset. The excluded vehicles are described in more detail in Sections 3.1 (Data Preparation) and 3.2 (Data Analysis Results). Each vehicle's SHED results were then matched with the OBD test that was performed immediately before the SHED test.

In the case of the Lipan and Ken Caryl high evaporative field studies, the vehicles received an OBD test as part of their regular I/M inspection prior to solicitation for participation in the study. Therefore, the OBD test usually happened several hours or even a day before the SHED test occurred. Therefore, because the vehicle was solicited during the I/M inspection (immediately before or just after the I/M test was performed, before the motorist left the facility) and was then retained by the staff performing the high evaporative emissions study, it was still in the same repair state for both the SHED test and the OBD test.

In the case of the summer 2010 high evaporative emissions study performed at CDPHE's West Tech and Aurora laboratories, vehicles were solicited by letter and then brought to the vehicle test station by the owner. The vehicle was kept for several days by the CDPHE staff and SHED tested several times, before and after repair. Each time a SHED test was performed, a series of six IM240 tests were performed just prior to the SHED test in order to condition the vehicle for the SHED testing. The last IM240 with OBD test that was performed of the six prior to the SHED test was used to match with the SHED testing for this analysis. Only the before repair test for each of the vehicles in this dataset was used for each vehicle to limit the analysis to "as received" condition.

The specific number of OBD/SHED data pairs available is described for each of the three datasets below. The overall results for the three datasets combined are described in the Data Analysis Results section after that.

3.1 Data Preparation

Twenty-four PSHED tests were conducted on 24 vehicles during the Lipan High Evaporative Emissions Field Study conducted in the summer of 2008. ERG successfully matched 17 of these 24 PSHED results with each vehicle's I/M OBD results (the I/M test was either aborted or did not contain OBD data for the other 7 tests - OBD is advisory only in the Colorado I/M program, meaning no pass or fail is assigned based on OBDII results). Similarly, 89 PSHED tests were conducted on 89 vehicles during the Ken Caryl High Evaporative Emissions Field Study, and ERG successfully matched 76 of these 89 records with corresponding OBD results (as before, the I/M test was either aborted or did not contain OBD data for the other 13 tests).

Eighty-seven PSHED/SHED tests were conducted on 68 vehicles during the Denver 2010 study (some of the 68 vehicles in the Denver 2010 study received two tests, a "before repair" and an "after repair" test). ERG was able to successfully match all 87 of the Denver 2010 study PSHED/SHED results with valid OBD results. Table 3-1 provides a summary of the final datasets used in this analysis. As shown in this table, in total, ERG successfully matched results from 180 PHED/SHED tests with OBD data. Results for comparison of OBD evaporative codes with PSHED/SHED results are provided in the following section.

Table 3-1. Summary of Matched SHED and I/M Records used in Analysis

Study	Total # of Vehicles	Total # of PSHED/SHED Tests	"Dropped" PSHED/SHED Tests (those with no corresponding OBD record)	Remaining PSHED/SHED Tests matched with OBD records
Lipan	24	24	7	17
Ken Caryl	89	89	13	76
Denver 2010	68	87	0	87
Total	**181**	**200**	**20**	**180**

3.2 Data Analysis Results

As shown in the last column of Table 3-1, when the participant vehicle tests from each of the three studies were combined, there were a total of 180 PSHED/SHED tests with valid OBD matches (for the remainder of this report, both PSHED and SHED results will be generically referred to as "SHED" results for clarity). However, some of these SHED tests were performed after the vehicle was repaired. These after-repair SHED results have been removed from the analysis. Also, some of the SHED and OBD test pairs had an evaporative OBD monitor status of "Not Ready" at the time of the OBD test, so these test pairs have also been removed from this analysis. Table 3-2 summarizes the remaining vehicle SHED and OBD pairs after application of each of these filters.

In this analysis, only test results with "confirmed" evaporative-related DTCs (DTCs in the range P0440 to P0469 with a MIL command status of "on") were considered. No "Pending" evaporative DTCs (DTCs in the range P0440 to P0469 but which were "pending" as described in Section 2.3, OBD DTCs) were identified in the data used for this analysis.

Table 3-2. Pair Counts for MY96 Lipan, Ken Caryl, and Denver High Evap Study Participants Combined

	SHED/OBD Test Pairs
Total matched SHED/OBD test pairs	180
Before repair SHED/OBD test pairs	157
Before repair test pairs with evaporative system monitor status of "Ready"	**149**
Before repair test pairs with evaporative monitor status of "Ready" and with no confirmed DTCs	145
Before repair test pairs with evaporative monitor status of "Ready" and with confirmed DTCs and MIL commanded "on"	4

3.3 Comparison of SHED Values to Presence of OBD Evaporative System DTCs

To compare the OBD and SHED results for each matched pair of records, each SHED result was defined as either high or low using two SHED cut point values; either 0.3 grams of total HC emissions per 15 minutes (0.3 g/Qhr), or 1 gram of total HC emissions per 15 minutes (1 g/Qhr). Separate analyses were performed by defining "high" SHED test results above each of these cut points or below each of these cut points. The SHED cut point of 1 g/Qhr was used because it was found to be the approximate average emission level for the first fifteen minutes of a laboratory Hot Soak of implanted leaks with 0.02" diameter (the minimum detectable diameter of the evaporative OBD systems) in the Coordinating Research Council (CRC) E-77 test programs.[17] The 0.3 g/Qhr cut point is an estimate of a 15-minute hot-soak portion of the 2 g/hr Diurnal + Hot Soak enhanced evaporative emission standard. This value was derived from the 2 g/hr Diurnal + Hot Soak enhanced evaporative emission standard by assuming 20% of the 2 g/hr emissions are due to Hot Soak, and then assuming 75% of that would be in the first 15 minutes.

17 It was found that when leaks were implanted at the gas cap on an ORVR equipped vehicle the emission levels were contained. This effect will be system dependent, and it is therefore likely that some designs of ORVR vehicles would show uncontrolled levels of emissions for a leak. The average discussed here is approximate for the implanted leak locations at the canister connection and at the top of the tank.

The SHED values were compared for pairs with and without confirmed evaporative system DTCs. It can be seen from Table 3-2 that only 4 of the 145 records had confirmed evaporative DTCs stored. Tables Table 3-3 and Table 3-4 compare the number of paired records with confirmed evaporative DTCs and high/low SHED classification for 1 g/Qhr and 0.3 g/Qhr, respectively. As stated earlier, these tables are provide a comparison of OBD-equipped vehicles that were measured with a SHED test, but due to the recruitment methods (see references (1) and (2)), the percentages in these tables are not intended to be representative of the fleet. The tables also list the percentages of pairs within the four quadrants for each row and column. All 4 paired records with confirmed evaporative DTCs had high corresponding SHED values (when defining "high" as 0.3 g/Qhr) and 75% had confirmed evaporative DTCs when defining "high" as 1.0 g/Qhr. In contrast, 12% of the 145 pairs with no confirmed evaporative DTCs had high SHED values (with a 1.0 g/Qhr cut point) and 16% were "high" at the 0.3 g/Qhr cut point. In both Table 3-3 and Table 3-4, 85% of the vehicles with high SHED values did not have a confirmed evaporative DTC. This could be due to a number of reasons, such as the fact that not all high evaporative emissions are due to vapor leaks which the OBD system is designed to identify, but the high percentages does indicate additional investigation is warranted.

Table 3-3. Number of Pairs with Evap DTCs Set Versus High and Low SHEDs (1.0 g/Qhr cutpoint)

	OBD Evap DTCs not set	**OBD Evap DTCs set**	**Total**
HIGH SHED (> 1.0 g/15 minutes)	17 Vehicles *(85% of 20)* **(12% of 145)**	3 Vehicles *(15% of 20)* **(75% of 4)**	20 Vehicles
LOW SHED (<= 1.0 g/15minutes)	128 Vehicles *(99% of 129)* **(88% of 145)**	1 Vehicles *(1% of 129)* **(25% of 4)**	129 Vehicles
Total	145 Vehicles	4 Vehicles	149 Vehicles

Table 3-4. Number of Pairs with Evap DTCs Set Versus High and Low SHEDs (0.3 g/Qhr cutpoint)

	OBD Evap DTCs not set	**OBD Evap DTCs set**	**Total**
HIGH SHED (> 0.3 g/15/minutes)	23 Vehicles *(85% of 27)* **(16% of 145)**	4 Vehicles *(15% of 27)* **(100% of 4)**	27 Vehicles
LOW SHED (<= 0.3 g/15 minutes)	122 Vehicles *(100% of 122)* **(84% of 145)**	0 Vehicles *(0% of 122)* **(0% of 4)**	122 Vehicles
Total	145 Vehicles	4 Vehicles	149 Vehicles

Table 3-5 provides additional vehicle and test information for vehicles with SHED results above the 1 g/Qhr designated threshold, including the packet ID, vehicle make, model year, model and the evaporative certification family for the vehicle. The "evap_mon_ready" column describes the readiness status of the vehicle's evaporative system monitor. Table 3-5 also lists DTCs that were downloaded at the time of the OBD test and indicates whether or not the DTCs were categorized as evaporative DTCs (confirmed DTCs in the range of P0440 to P0469). A footnote in the table provides definitions of the evaporative DTCs. Additional information on these vehicles and all vehicles with PSHEDs > .3 g/Qhr, including non-ready OBD evaporative monitor vehicles, is provided in the appendix of this report.

Table 3-5 also lists comments provided by the vehicle inspectors as they tried to identify the source of the vapor leaks using a hand held HC vapor detector. In many instances, the vehicle vapor lines were inaccessible. Some were behind sheet metal shrouds and no intrusive process was undertaken to get behind these coverings. Based on the inspector comments, the make and model year of the vehicle, and any other visual evidence, ERG and OTAQ made a determination regarding whether or not a malfunction should be detectable by the vehicle's OBD system. This determination is listed in the column labeled "Should Problem be Detectable by OBD?" If the vehicle inspector was not able to identify the source of the leak, then a determination was not made regarding whether or not the OBD system should have been able to detect the malfunction, and a "?" is listed in the table. The areas of the fuel system inaccessible to the HC detector, as mentioned above, were behind shrouds, above the fuel tank, or within bundles of hoses packed too tightly to be reached by the HC detector probe. Due to their locations and lack of evidence of a liquid leak, leaks located in these inaccessible areas were likely to be a vapor leaks, rather than liquid leaks. Liquid leaks would likely occur at connection points in the fuel line or the fuel rail and would likely be detectable by the handheld detector. It is unlikely these liquid leaks would be detectable by the OBD systems for most vehicles, since OBD systems are not designed to detect liquid leaks.

Table 3-5. Details for Vehicles with SHED Results > 1 g/Qhr (excluding liquid and unmonitored vapor leaks)

Table 3-5A

PacketID	Evap Family	Dataset	Model Year	Make	Model	SHED_g/15min	PSHED_over_1g HC	evap_DTC
LIP-22	2FJXR01251BB	LIPAN	2002	SUBARU	IMPREZA	1.30	Yes	No
CRL-540	.	CARYL	1998	HONDA	ACCORD	2.10	Yes	No
LIP-256	XGMXR0124912	LIPAN	1999	OLDS	ALERO	2.18	Yes	No
CRL-475	YGMXE0111911	CARYL	2000	CHEV	ASTRO VAN	2.45	Yes	No
HE-6725	WTYXE0095AE1	DENVER	1998	TOYOTA	CAMRY	6.30	Yes	No
LIP-193	WFMXE0045AAA	LIPAN	1998	FORD	MUSTANG	11.22	Yes	No
HE-6763	VFM1057BYMA	DENVER	1997	MERCURY	VILLAGER	20.81	Yes	No
HE-6011	2FJXR01251CC	DENVER	2002	SUBA	LEGACY	5.21	Yes	Yes
HE-6799	TFM2045AYPBA	DENVER	1996	FORD	RANGER	12.21	Yes	Yes
HE-6018	WFMXE0115BAE	DENVER	1998	FORD	TAURUS	19.93	Yes	Yes

Table 3-5B

PacketID	Evap Family	Dataset	evap_mon_ready	DTC codes	Should Malfunction be Detectable by OBD?	Vapor/ Liquid/ No Leak Identified
LIP-22	2FJXR01251BB	LIPAN	Yes	-	Not ascertainable*, **	No Leak Identified
CRL-540	.	CARYL	Yes	-	Not ascertainable*, **	Vapor
LIP-256	XGMXR0124912	LIPAN	No	-	Not ascertainable*, **	No Leak Identified
CRL-475	YGMXE0111911	CARYL	No	-	Yes**	Vapor
HE-6725	WTYXE0095AE1	DENVER	Yes	-	Yes***	Vapor
LIP-193	WFMXE0045AAA	LIPAN	Yes	-	Not ascertainable*, ***	No Leak Identified
HE-6763	VFM1057BYMA	DENVER	Yes	-	yes - purge solenoid	Vapor
HE-6011	2FJXR01251CC	DENVER	Yes	451|457	Yes***	Vapor
HE-6799	TFM2045AYPBA	DENVER	Yes	443	Yes-purge solenoid	Vapor
HE-6018	WFMXE0115BAE	DENVER	Yes	443	Yes-purge solenoid	Vapor

*The source of the high SHED emissions could not be determined from the technician comments in the field studies.

**Manufacturer and EPA certification representatives have stated that these manufacturers are certified to California enhanced OBD requirement of a 0.020" diameter orifice detection capability.

***The magnitude of the emissions indicates that this would have been equivalent to at least a 0.040" diameter orifice and therefore should have been detected by Federal OBD.

Table 3-5C			
PacketID	**Evap Family**	**Dataset**	**Inspector Comments**
LIP-22	2FJXR01251BB	LIPAN	Nothing Found
CRL-540	.	CARYL	Sniffer leak detected at vapor canister. No non-OEM installations. Did not find fuel filter. Canister leak = vapor not liquid.
LIP-256	XGMXR0124912	LIPAN	Nothing Found
CRL-475	YGMXE0111911	CARYL	Suspect that fuel pump replacement damaged gasket. Areas on top of tank and near tank to fill pipe connect set sniffer off. Also evap canister set sniffer off. No access to engine and that part of fuel system.
HE-6725	WTYXE0095AE1	DENVER	Gas cap was cause of leak.
LIP-193	WFMXE0045AAA	LIPAN	Nothing Found
HE-6763	VFM1057BYMA	DENVER	Vapor/purge hose cracked.
HE-6011	2FJXR01251CC	DENVER	Vapor lines at the top of filler neck not connected.
HE-6799	TFM2045AYPBA	DENVER	Found wires corroded/broken that activated the purge valve. Supplying power and ground showed the purge valve did not operate. Removed canister and evacuated over night.
HE-6018	WFMXE0115BAE	DENVER	Extreme HC odor at right rear. Exhaust collector is right behind this area.

Table 3-5 Legend

- P0440 Evaporative Emission Control System Malfunction
- P0441 Evaporative Emission Control System Incorrect Purge Flow
- P0442 Evaporative Emission Control System Leak Detected (small leak)
- P0443 Evaporative Emission Control System Purge Control Valve Circuit
- P0444 Evaporative Emission Control System Purge Control Valve Circuit Open
- P0445 Evaporative Emission Control System Purge Control Valve Circuit Shorted
- P0446 Evaporative Emission Control System Vent Control Circuit Malfunction
- P0447 Evaporative Emission Control System Vent Control Circuit Open
- P0448 Evaporative Emission Control System Vent Control Circuit Shorted
- P0449 Evaporative Emission Control System Vent Valve/Solenoid Circuit Malfunction
- P0450 Evaporative Emission Control System Pressure Sensor Malfunction
- P0451 Evaporative Emission Control System Pressure Sensor Range/Performance
- P0452 Evaporative Emission Control System Pressure Sensor Low Input
- P0453 Evaporative Emission Control System Pressure Sensor High Input
- P0454 Evaporative Emission Control System Pressure Sensor Intermittent
- P0455 Evaporative Emission Control System Leak Detected (gross leak)
- P0456 Evaporative Emissions System Small Leak Detected
- P0457 Evaporative Emission Control System Leak Detected
- P0458 Evaporative Emission System Purge Control Valve Circuit Low
- P0459 Evaporative Emission System Purge Control Valve Circuit High
- P0465 Purge Flow Sensor Circuit Malfunction
- P0466 Purge Flow Sensor Circuit Range/Performance
- P0467 Purge Flow Sensor Circuit Low Input
- P0468 Purge Flow Sensor Circuit High Input
- P0469 Purge Flow Sensor Circuit Intermittent

As shown in Table 3-3, twenty vehicles with an evaporative system monitor status of "ready" had SHED measurements greater than 1 g/Qhr. Details of these 20 vehicles are listed in Appendix A. However, it can be seen that only 10 vehicles with SHED measurements greater than 1 g/Qhr are listed in Table 3-5, and of these only 8 have evaporative monitors with a "ready" status (as opposed to all 20 vehicles in Table 3-3). The following reasons explain differences between the "ready" vehicles emitting greater than 1 g/Qhr in Table 3-5 and the vehicles listed in Table 3-3:

- Table 3-5 includes two vehicles (vehicles associated with packet IDs LIP-256 and CRL-475) whose evaporative system monitor status was "not ready" (these are not included in the counts provided in Table 3-3). Appendix A provides details of vehicles with both "ready" and "not ready" evaporative system monitors.

- OBD evaporative system monitoring is not designed to identify liquid leaks; since Table 3-5 was developed to assess OBD's ability to identify monitored vapor leaks, these vehicles with (unmonitored) liquid leaks which are included in Table 3-3 are not listed in Table 3-5.

- Since many 1996 and 1997 vehicles which conform to Federal (non-California) standards were only designed to monitor purge solenoid checks but not vapor leaks[18], those model year 1996 and 1997 vehicles included in Table 3-3 for which the inspection indicated the malfunction was anything other than a purge solenoid were excluded from Table 3-5, as these would be malfunctions not monitored by OBD. Again, details on each of these vehicles are provided in Appendix A.

- As OBD requirements developed and phased in, it became common practice for auto companies, such as those listed in Table 3-5, to certify to the California OBD leak detection standard of 0.020" all of their vehicles sold federally. Laboratory data has shown a 0.020" diameter orifice to be roughly equivalent to an emission rate of 1 g/Qhr. Using the formula for the area of a circle (πr^2), it can be seen that the magnitude of emissions quadruples with the doubling of the diameter size to 0.040", and this has been found to be the case with laboratory testing comparing 0.020" and 0.040" leaks. Consequently, based on the magnitude of emissions, for the vehicles in Table 3-5 with SHED emissions of 6.30 g/Qhr and greater, it is reasonable to assume that they have leaks of diameter 0.040".

Based on these two datasets, this preliminary analysis suggests that OBD systems did not identify 50-70% of the potential high evaporative emitters in these studies. The lower range, 50% (3 out of 6), is based on the occurrences of when the OBD system should probably have detected the leak from a known source based on the technician comments, disregarding the "?" vehicles in the "Should Malfunction be Detectable by OBD?" column. The higher range, 70% (7

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out of 10), includes the unknown leak sources ("?") for which no leak was identified or the vapor leak was likely located in the area of the evaporative control system inaccessible to the HC detector. Liquid leaks (which would generally not be monitored by OBD) were not included in this estimate.

It should be noted that this preliminary analysis was based on a qualitative review of the technician comments, rather than a quantitative assessment of OBD monitoring criteria (such as a pressure drop associated with a 0.020" or 0.040" diameter orifice leak). In addition, since 2 of these 10 vehicles had a "not ready" evaporative system monitor, it is possible that the vehicle's OBD system would have detected the leak and stored a DTC once the evaporative system monitor achieved readiness. However, as most I/M programs in the United States typically allow 1 to 2 "not ready" monitors, these vehicles could potentially pass an I/M OBD inspection with these types of evaporative system failures before the monitor achieved readiness.

Some of the vehicles in these studies were model year 1996 through 1998 vehicles and therefore may not have been equipped with OBD enhanced evaporative system monitoring. For these older vehicles, some of the evaporative system failures could be undetectable by the OBD systems installed on those vehicles. ERG compared the model year distributions with high/low SHED categories to determine if a correlation existed between SHED values and vehicle model year. The high SHED pairs included vehicles with model years from 1996-2003, and the low SHED pairs included vehicles with model years from 1996-2010. This suggests that high SHED results tended to be associated with older model year vehicles. Table 3-6 lists model year counts for high and low SHED pairs vehicles of model year 1996-2010 in the dataset.

Table 3-6. Model year Counts for High and Low SHED Pairs in the Data

Model Year	SHED Cut Point of 1.0 g/Qhr		SHED Cut Point of 0.3 g/Qhr	
	# of Pairs with SHED Value High	# of Pairs with SHED Value Low	# of Pairs with SHED Value High	# of Pairs with SHED Value Low
1996	5	9	7	7
1997	7	13	9	11
1998	4	10	4	10
1999	-	10	1	9
2000	2	12	2	12
2001	-	15	1	14
2002	2	17	2	17
2003	-	12	1	11
2004	-	9	-	9
2005	-	13	-	13
2006	-	-	-	-
2007	-	1	-	1

Table 3-6. Model year Counts for High and Low SHED Pairs in the Data

Model Year	SHED Cut Point of 1.0 g/Qhr		SHED Cut Point of 0.3 g/Qhr	
	# of Pairs with SHED Value High	**# of Pairs with SHED Value Low**	**# of Pairs with SHED Value High**	**# of Pairs with SHED Value Low**
2008	-	2	-	2
2009	-	4	-	4
2010	-	2	-	2
Total Vehicles	**20**	**129**	**27**	**122**

4.0 Conclusions

Three different datasets were used in this study to determine if high evaporative emitters, as defined by LSHED or PSHED tests, were appropriately identified by each vehicle's OBD system. Although the total number of observations was limited, this analysis indicates that many vehicles with high SHED values (hot-soak emissions equal to or greater than 1 g/Qhr as measured by a SHED test) do not have stored evaporative DTCs or MILs. For vehicles with high SHED HC measurement results, an attempt was made to determine the source of the vapor leak. Results are shown in Table 4-1, which summarizes pertinent information for all vehicles listed in Table 3-5. Due to the configuration of the vehicle chassis the source or sources of each leak could not always be isolated. Table 4-1 shows that OBD systems did not identify 50-70% of the high evaporative emitters in these studies (for various reasons including "not ready" evaporative system monitors). The lower range, 50% (3 out of 6), is based on evaporative system failures that should probably have been detected by the OBD system. The higher range, 70% (7 out of 10), includes vehicles for which no leak source was identified or the vapor leak was likely located in an area of the evaporative control system inaccessible to the HC detector ("Not ascertained" in Table 4-1). Liquid leaks (which generally are not monitored by OBD) were not included in this estimate.

From an overall perspective, this study identified 29 vehicles (27 listed in Table 3-4 plus 2 with "not ready" evaporative monitors) with PSHED values greater than 0.3 g/Qhr (roughly equivalent to the hot-soak component of the 2 g/hr Diurnal + Hot Soak standard), and only 4 of those 29 vehicles had stored evaporative DTCs. Two vehicles had "not ready" evaporative monitors. The source of elevated evaporative emissions from the remaining 23 "ready" vehicles which had no evaporative DTCs was either undetectable by current OBD design (for example, a hidden liquid leak not observed by field technicians), was from a part of the system not monitored by OBD, or was a vapor leak which should have been identified but was not (i.e., the evaporative emissions monitoring system was malfunctioning in some way).

No "OBD false positive" vehicles were identified in this study (those with stored evaporative system DTCs with SHED emissions under 0.3 g/Qhr). The preferential recruiting of vehicles with high evaporative emissions would tend to reduce the likelihood of this category of vehicles from participation in these studies, so no conclusions can be drawn from the lack of these vehicles in these results. However, the key finding of this report is the high number of vehicles with high evaporative emissions which were not identified by the OBD evaporative system.

Since the sample size used for this analysis was limited to ten vehicles which were expected to set DTCs, EPA sought to enhance our understanding with larger OBD datasets. Analysis was performed using inspection and maintenance data from Texas and California. Preliminary conclusions from detailed analysis of data from these states complement the conclusions of this report and can be found in Appendix B.

Table 4-1. Comparison of SHED and OBD Results for Vehicles with SHED Emissions > 1 g/Qhr (Summary of Information for Vehicles Listed in Table 3-5)

Data Set	Model Year	SHED g/15 min	Evap DTC	Evap Monitor Ready	Evaporative DTC code	Should Malfunction be detectable by OBD?
Lipan	2002	1.30	No	Yes	-	Not ascertainable*, **
Ken Caryl	1998	2.10	No	Yes	-	Not ascertainable*, **
Lipan	1999	2.18	No	No	-	Not ascertainable*, **
Ken Caryl	2000	2.45	No	No	-	Yes**
Denver	1998	6.30	No	Yes	-	Yes***
Lipan	1998	11.22	No	Yes	-	Not ascertainable*, ***
Denver	1997	20.81	No	Yes	-	Yes – purge solenoid
Denver	2002	5.21	Yes	Yes	451/457	Yes***
Denver	1996	12.21	Yes	Yes	443	Yes – purge solenoid
Denver	1998	19.93	Yes	Yes	443	Yes – purge solenoid

*The source of the high SHED emissions could not be determined from the technician comments in the field studies.

**Manufacuter and EPA certification representatives have stated that these manufacturers certified to California enhanced OBD requirement of a 0.020" diameter orifice detection capability.

*** the magnitude of the emissions indicates that this would have been equivalent to at least a 0.040" diameter orifice and therefore should have been detected by OBD on a federally certified vehicle

Appendix A

Appendix A: Details for All Study Vehicles with SHED Results > 0.3 g/Qhr

PacketID	Evap Family	Dataset	Model Year	Make	Model	SHED g/15min	PSHED > 1	PSHED > .3	evap DTC	evap monitor ready	DTC codes
LIP-254	TCR1073AYPBP	LIPAN	1996	JEEP	CHEROKEE	0.33	No	Yes	No	Y	.|.|.|.
CRL-568	VGM1035AYPAA	CARYL	1997	STRN	SL	0.39	No	Yes	No	Y	733|734|.|.|.
CRL-393	.	CARYL	2001	TOYOTA	SOLARA	0.46	No	Yes	No	Y	1135|1155|.|.|.
CRL-546	TNT1047DYMAO	CARYL	1996	*GEO*	PRIZM	0.62	No	Yes	No	Y	.|.|.|.
HE-6454	XFMXE0120BAE	DENVER	1999	MERCURY	MOUNTAINEER	0.67	No	Yes	No	Y	.|.|.|.
CRL-395	VGM1095AYMEA	CARYL	1997	CHEV	S10	0.72	No	Yes	No	Y	172|175|.|.|.
CRL-271	VGM1098AYMBA	CARYL	1997	GMC	SIERRA	1.28	Yes	Yes	No	Y	.|.|.|.
LIP-22	2FJXR01251BB	LIPAN	2002	SUBA	IMPREZA	1.30	Yes	Yes	No	Y	.|.|.|.
HE-6418	VFM1065BYMAA	DENVER	1997	FORD	ASPIRE	1.47	Yes	Yes	No	Y	.|.|.|.
CRL-540	.	CARYL	1998	HOND	ACCORD	2.10	Yes	Yes	No	Y	.|.|.|.
LIP-256	XGMXR0124912	LIPAN	1999	OLDS	ALERO	2.18	Yes	Yes	No	N	.|.|.|.
CRL-357	VNS1110AYMEA	CARYL	1997	NISS	PATHFINDER	2.32	Yes	Yes	No	Y	325|1447|.|.|.
CRL-475	YGMXE0111911	CARYL	2000	CHEV	ASTRO VAN	2.45	Yes	Yes	No	N	.|.|.|.
HE-6331	TFM1045AYPAB	DENVER	1996	FORD	CONTOUR	2.79	Yes	Yes	No	Y	133|304|.|.|.
HE-6609	YGMXE0095905	DENVER	2000	OLDS	BRAVADA	5.77	Yes	Yes	No	Y	.|.|.|.
CRL-85	TCR1073AYPOB	CARYL	1996	DODG	RAM 1500	6.08	Yes	Yes	No	Y	.|.|.|.
HE-6725	WTYXE0095AE1	DENVER	1998	TOYOTA	CAMRY	6.30	Yes	Yes	No	Y	420|.|.|.|.
HE-6647	YSZXT0095ME0	DENVER	2000	ISUZU	RODEO	8.65	Yes	Yes	No	Y	401|463|171|172|174
HE-6759	VGM1070AYMAA	DENVER	1997	OLDS	DELTA 88	9.10	Yes	Yes	No	Y	.|.|.|.
LIP-193	WFMXE0045AAA	LIPAN	1998	FORD	MUSTANG	11.22	Yes	Yes	No	Y	.|.|.|.
CRL-321	VGM1095AYMEA	CARYL	1997	CHEV	S10	12.33	Yes	Yes	No	Y	.|.|.|.
HE-6620	TNS1057BYMBB	DENVER	1996	NISS	QUEST	12.79	Yes	Yes	No	Y	400|325|.|.|.
HE-6519	YTY1047DYMA0	DENVER	1997	TOYT	COROLLA	16.41	Yes	Yes	No	Y	.|.|.|.
HE-6702	TGM1089AYMEA	DENVER	1996	CHEV	CAVALIER	19.53	Yes	Yes	No	Y	.|.|.|.
HE-6763	VFM1057BYMA	DENVER	1997	MERCURY	VILLAGER	20.81	Yes	Yes	No	Y	325|300|.|.|.
CRL-316	3HYXR0105PEA	CARYL	2003	HYUN	ACCENT	0.69	No	Yes	Yes	Y	442|650|463|.|.
HE-6011	2FJXR01251CC	DENVER	2002	SUBA	LEGACY	5.21	Yes	Yes	Yes	Y	451|457|420|.|.
HE-6799	TFM2045AYPBA	DENVER	1996	FORD	RANGER	12.21	Yes	Yes	Yes	Y	443|.|.|.|.
HE-6018	WFMXE0115BAE	DENVER	1998	FORD	TAURUS	19.93	Yes	Yes	Yes	Y	1518|443|.|.|.

Appendix A: Details for All Study Vehicles with SHED Results > 0.3 g/Qhr

PacketID	Evap Family	Dataset	Model Year	Make	Model	Should Malfunction be detectable by OBD?	Vapor/ Liquid/ No Leak Found	Comments
LIP-254	TCR1073AYPBP	LIPAN	1996	JEEP	CHEROKEE	no evap codes yet*	Vapor	Gas cap IM failure. MCM Comments: Nothing found.
CRL-568	VGM1035AYPAA	CARYL	1997	STRN	SL	no evap codes yet*	Vapor	Gas cap IM failure. MCM Comments: Sniffer goes off inconsistently in area of fuel tank especially around top. Odor of gasoline under vehicle in fuel tank area.
CRL-393	.	CARYL	2001	TOYOTA	SOLARA	?	Vapor	Underbody-fuel lines not visible but accessible to sniffer. Fuel injectors pretty much hidden below intake manifold.
CRL-546	TNT1047DYMAO	CARYL	1996	*GEO*	PRIZM	no evap codes yet*	Vapor	While lying below fuel tank area I thought I got a faint whiff of gasoline. Bruce said same as we were closing PSHED door.
HE-6454	XFMXE0120BAE	DENVER	1999	MERCURY	MOUNTAINEER	?	No Leak Found	No comments
CRL-395	VGM1095AYMEA	CARYL	1997	CHEV	S10	no evap codes yet*	Vapor	Tank is severely dented. Cannot see liquid fuel but top of fuel tank activates sniffer. Can hear fuel pump whining while driving.
CRL-271	VGM1098AYMBA	CARYL	1997	GMC	SIERRA	no evap codes yet*	Vapor	Cannot see filler to tank connection. Fuel tank skid plate has some damage. Around top of tank on fill pipe side (right) the sniffer went off particularly near the front of tank.
LIP-22	2FJXR01251BB	LIPAN	2002	SUBA	IMPREZA	?	No Leak Found	Nothing Found

Appendix A: Details for All Study Vehicles with SHED Results > 0.3 g/Qhr

PacketID	Evap Family	Dataset	Model Year	Make	Model	Should Malfunction be detectable by OBD?	Vapor/ Liquid/ No Leak Found	Comments
HE-6418	VFM1065BYMAA	DENVER	1997	FORD	ASPIRE	no evap codes yet*	Vapor	No visible liquid leaks, but occasional HC from gas analyzer. Filter mount is broken. Fuel filter was replaced, and the mount was repaired. Fuel spilled down the driver's side strut mount during replacement. This was picked up during after repair 1 test.
CRL-540	.	CARYL	1998	HOND	ACCORD	?	Vapor	Sniffer leak detected at vapor canister. No non-OEM installations. Did not find fuel filter. Canister leak = vapor not liquid.
LIP-256	XGMXR0124912	LIPAN	1999	OLDS	ALERO	?	No Leak Found	Nothing Found
CRL-357	VNS1110AYMEA	CARYL	1997	NISS	PATHFINDER	no evap codes yet*	Vapor	There is some sort of contraption that sets sniffer off back between fuel tank and canister (see photo).
CRL-475	YGMXE0111911	CARYL	2000	CHEV	ASTRO VAN	yes	Vapor	Suspect that fuel pump replacement damaged gasket. Areas on top of tank and near tank to fill pipe connect set sniffer off. Also evap canister set sniffer off. No access to engine and that part of fuel system.
HE-6331	TFM1045AYPAB	DENVER	1996	FORD	CONTOUR	no evap codes yet*	Vapor	Significant HC from top of tank.
HE-6609	YGMXE0095905	DENVER	2000	OLDS	BRAVADA	no	Liquid	Visible fuel stainage bottom of tank.
CRL-85	TCR1073AYPOB	CARYL	1996	DODG	RAM 1500	no evap codes yet*	Liquid	Tank looks stained possibly from gasoline. I can smell gasoline when lying under vehicle by filler neck. The vent line clamp is rusted and looks like it has been wet but sniffer is inconsistent about sensing fumes in that area.

Appendix A: Details for All Study Vehicles with SHED Results > 0.3 g/Qhr

PacketID	Evap Family	Dataset	Model Year	Make	Model	Should Malfunction be detectable by OBD?	Vapor/ Liquid/ No Leak Found	Comments
HE-6725	WTYXE0095AE1	DENVER	1998	TOYOTA	CAMRY	yes	Vapor	Gas cap was cause of leak.
HE-6647	YSZXT0095ME0	DENVER	2000	ISUZU	RODEO	no	Vapor	There is a fuel odor under hood. Sniffer in V_engine valley under intake manifold sets it off.
HE-6759	VGM1070AYMAA	DENVER	1997	OLDS	DELTA 88	no evap codes yet*	No Leak Found	No comments
LIP-193	WFMXE0045AAA	LIPAN	1998	FORD	MUSTANG	?	No Leak Found	Nothing Found
CRL-321	VGM1095AYMEA	CARYL	1997	CHEV	S10	no evap codes yet*	Liquid	Major gasoline leak with gas puddling on engine. Not sure where leak is exactly. Some part of supply or injector to TBI system?
HE-6620	TNS1057BYMBB	DENVER	1996	NISS	QUEST	no evap codes yet*	Vapor	Major HC at mid tank area, driver's side.
HE-6519	YTY1047DYMA0	DENVER	1997	TOYT	COROLLA	no evap codes yet*	No Leak Found	No comments on MCM test. Comment on repair note said that the trouble code indicated P0401 EGR flow. Investigate to see why this was not in IM.
HE-6702	TGM1089AYMEA	DENVER	1996	CHEV	CAVALIER	no evap codes yet*	Liquid	#3 fuel injector leaks, gas cap is missing, #1 fuel injector started leaking.
HE-6763	VFM1057BYMA	DENVER	1997	MERCURY	VILLAGER	yes - purge solenoid	Vapor	Vapor/purge hose cracked.
CRL-316	3HYXR0105PEA	CARYL	2003	HYUN	ACCENT	small leak - .02", fuel level sensor	Vapor	Something seems to be damaged or leaking at top of fuel tank. Sniffer active many places around top pipe to tank joint. Looks dry - tank appears to have evaporated fluid of some kind but that did not activate sniffer.

Appendix A: Details for All Study Vehicles with SHED Results > 0.3 g/Qhr

PacketID	Evap Family	Dataset	Model Year	Make	Model	Should Malfunction be detectable by OBD?	Vapor/ Liquid/ No Leak Found	Comments
HE-6011	2FJXR01251CC	DENVER	2002	SUBA	LEGACY		Vapor	Vapor lines at the top of filler neck not connected.
HE-6799	TFM2045AYPBA	DENVER	1996	FORD	RANGER	purge solenoid	Vapor	Found wires corroded/broken that activated the purge valve. Supplying power and ground showed the purge valve did not operate. Removed canister and evacuated over night.
HE-6018	WFMXE0115BAE	DENVER	1998	FORD	TAURUS	purge solenoid	Vapor	Extreme HC odor at right rear. Exhaust collector is right behind this area.

* 1996 and 1997 vehicles and 1998 federal-only OBD vehicles did not have OBD evaporative system leak checks but did have purge solenoid checks.

Appendix B

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
NATIONAL VEHICLE AND FUEL EMISSIONS LABORATORY
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ANN ARBOR, MICHIGAN 48105-2498

OFFICE OF
AIR AND RADIATION

February 22, 2013

MEMORANDUM

SUBJECT: Preliminary Analysis of On-Board Diagnostic (OBD) Evaporative System Information from State Inspection and Maintenance (I/M) Stations – California and Texas

FROM: Carl Fulper, Chemical Engineer, Assessment and Standards Division

TO: Docket EPA-HQ-OAR-2011-0135

Introduction:

EPA is reviewing data gathered from selected state I/M test programs on vehicle evaporative emission system OBD codes and their evaporative monitor "ready" information to help inform our understanding of the incidence rate of evaporative system monitor "not ready" events and the incidence of evaporative system related DTCs. While five states have been selected for analysis, this memo summarizes completed analyses for Texas and California. Since the data was gathered by the states under different protocols and time periods, the contents of the data sets are not identical. To provide some degree of uniformity in our analysis, we examined the data for five model years (MY) covering (2000 – 2004) when all systems (absent specific exemptions called "deficiencies") were required to be OBDII compliant (which includes evaporative system monitoring) and all passenger cars and light trucks would meet the enhanced evaporative emissions standards promulgated in 1993. We looked at only calendar years of data beginning after the initial state I/M new vehicle exemption period. A state's new vehicle exemption period can vary between 2 to 4 calendar years and require a vehicle to be test with annual, biennial or a hybrid of these two frequencies (see Table 1). This memorandum shows the preliminary analysis of evaporative monitor readiness and their associated evaporative diagnostic trouble codes (DTCs).

Table 1. List of I/M OBD Data

State	MY Exemption	Calendar years I/M data Evaluated	Network Type	Program Frequency	OBD MIL+DTC	Evap Testing
TX	2	2004-2010	Decentralized	Annual	Yes	Gas Cap
CA	4	2004-2010	Hybrid	Biennial	Yes	Gas Cap

The OBDII system monitors the performance of various engine and emission control systems, including the vehicle's evaporative emissions control system. The vehicle software monitors these systems and when monitoring enable conditions are met, conducts self – diagnostics tests to see if they are performing properly. Whether or not a vehicle's evaporative control system monitoring has been conducted and completed (self diagnostic program on the vehicle), it will indicate by a "ready" or "not ready" code that is stored in the vehicle's computer. If the monitoring has been completed and a problem has been found, using established protocols a DTC will be set. The presence of an evaporative DTC indicates a system malfunction has been detected which could result in elevated evaporative emissions from that vehicle. These OBD DTCs are stored on the vehicle and can be retrieved when the vehicle goes for its routine I/M inspection. It is these recorded monitor codes and DTCs that were used by EPA to conduct its analysis.

A 'not ready" monitor on the vehicle's evaporative system indicates that the system has not completed monitoring. Normally, if the system is ready, the OBD evaporative system will run and update results at each key on event. There are some circumstances, normally called "global disenables", when the system is not expected to run. Key global disenables are based on factors such as tank fill level, outside air temperature, and elevation. In addition, there are some relatively rare instances when a manufacturer is granted an individual "deficiency" for a given vehicle system. This occurs when the OBD system cannot give a reliable monitoring result in certain operating circumstances even though it would be expected to do so under the regulations. Furthermore, this can occur if the readiness code was cleared as a result of external actions such as a battery disconnect or system maintenance. When the codes are cleared, the vehicle's evaporative emissions system monitor will indicate a "not ready" code until the vehicle completes a self diagnostic test and will change the vehicle's status from "not ready" to "ready' and record any DTCs on the vehicle's evaporative system.

Numerous filters were applied to each state's data to remove any inspection records that should not be used for this analysis. This included for example; heavy-duty vehicles, vehicles with a fuel type other than gasoline, special inspections performed at government-operated stations and inspections performed outside the enhanced I/M areas. All records with invalid vehicle identification numbers (VINs) and passenger cars and light trucks with model year 1995 and older were removed since they are not required to have enhanced evaporative emission controls or OBDII.

Analysis:

Our analysis of two out of the five states (Texas and California) has been completed. The findings are discussed below. We will first describe the I/M OBD data sets, then the evaporative emissions monitor readiness rates, next the rates for evaporative system DTCs and finally evaporative system leak DTC rates. For internal consistency, this analysis looked at MYs 2000-2004 vehicle evaluated at I/M during calendar years 2004-2010. However, additional information is included in the tables.

The State of Texas has an annual I/M vehicle inspection program with in most cases a two year exemption for new vehicles. The dataset that was analyzed for Texas includes seven calendar years of data (2004-2010) containing over 41 million inspection cycles and covers over 11 million individual vehicles. The State of California has a hybrid I/M vehicle inspection program with in most cases a four year exemption for new vehicles.[1] The dataset that was analyzed for California includes seven calendar years of data (2004-2010) containing over 47 million inspection cycles and covers over 17 million individual vehicles.

Tables 2 and 3 shows the percent of the vehicle's evaporative monitors that are "ready" in a given I/M cycle by calendar year and vehicle model year. Data from these tables indicate that about 3-16 percent of the vehicles arrived at the I/M station with their evaporative emission monitors in a "not ready" mode.[2] Furthermore, data from both states shows that as the vehicle population ages, they are more likely to have a "not ready" evaporative monitor in a given calendar year. Evaporative emission monitor readiness at the I/M inspection improved by 1-2 percentage points over time relative to the first year for two model years of the ten model years studied (2000-2004 for CA and TX) but generally decreased by 2-10 percentage points for model year 2000-2004 vehicles evaluated at I/M during calendar years 2004-2010.

For the vehicles in these two states that had their evaporative monitor "ready" for at least one inspection of their I/M cycle in each calendar year, EPA conducted additional analysis to determine if one or more evaporative DTCs were set at any time during the I/M cycle. A list of the evaporative DTCs that were analyzed for is listed in Table 4. Tables 5 and 6 show that for the first inspections for a model year of vehicles evaporative system DTCs were set on 0.2 to 1.1 percent of vehicles. However, as the fleets aged, these percentages increased. For model year 2000-2004 vehicles evaluated at I/M during calendar years 2004-2010, evaporative related DTC rates increased by a factor in the range of 1.7 to 5. The median value was about 3. This is an important finding, since it can at least be hypothesized that a DTC found in I/M in Texas or California is usually fixed. Thus, this indicates not only that similar problems occur in subsequent years within a model year's vehicles but usually at a greater rate. Absent repair, the total number of evaporative DTC occurrences may be more cumulative in nature.

EPA also analyzed the two states for vehicles that had their evaporative monitors convert from "not ready" in their previous I/M cycle to "ready" when they came back to the I/M station. The results show a higher percentage of evaporative DTCs set than the whole dataset by 0.1 to 1.5 percent depending on vehicle model year to calendar year. This could suggest that some of

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[1] California began a six year exemption after the 2004 model year.

[2] In some cases these vehicles are required to return at a later date.

that vehicle's previous I/M cycle evaporative monitor "not ready" could be masking a set of evaporative DTCs.

Leaks from fuel and evaporative systems are potentially significant source of VOCs. Since OBD systems are required to monitor for vapor leaks when the system is ready, EPA examined the evaporative DTC code data for the prevalence of vapor leak DTCs (P0455, 0456, 0457, 0442). For both Texas and California, a review of the data shows that leaks represent 60-80 percent of all evaporative system DTCs. As is shown in Tables 7-8 this is generally the same for all model years evaluated (2000-2004) in calendar years (2004-2010). As before for evaporative DTCs, this suggests that, even assuming repair for problems found at I/M, the absolute number of leaks in the fleet increases with time since the overall number of vehicles with evaporative-related DTCs increases with time.

Preliminary Conclusions

A review of the information leads to the following conclusions:

- Depending on age, 0.3-2.5 percent of vehicles with evaporative monitors ready came into the I/M stations with evaporative related DTC
- The percent of vehicles with evaporative emission related MILs set increased by a factor of 2 - 4 over about 5 years
- Evaporative emission monitors were not ready for 3-16 percent of vehicles when arriving at the I/M station.
- The percent of vehicles with monitors ready at the I/M station generally decreased by 3 to 7 percentage points over about 5-6 years; decrease was less for model year vehicles less than five years old.
- While it varies by age, 60-80 percent of evaporative systems DTCs are leak related.

Table 2. State of Texas: Percent of Evap Monitors Ready for All Test Cycles by Calendar Year and Model Year

Calendar Year		Vehicle Model Year															
		1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
2003	Ready	212,417	251,581	272,443	309,056	355,644	379,122	154,252	13,419	.	.	.	.	.	.	.	.
	Total	220,933	269,143	290,293	332,586	376,551	396,569	158,674	14,610	.	.	.	.	.	.	.	.
	% Rdy	96.1%	93.5%	93.9%	92.9%	94.4%	95.6%	97.2%	91.8%	.	.	.	.	.	.	.	.
2004	Ready	313,693	367,795	399,109	449,390	515,902	547,999	572,621	157,985	15,197	.	.	.	.	.	.	.
	Total	326,483	394,701	426,793	485,114	548,579	579,579	591,211	163,647	16,370	.	.	.	.	.	.	.
	% Rdy	96.1%	93.2%	93.5%	92.6%	94.0%	94.6%	96.9%	96.5%	92.8%	.	.	.	.	.	.	.
2005	Ready	291,195	345,213	376,605	423,980	480,111	504,195	548,960	520,428	135,366	14,489	.	.	.	.	.	.
	Total	304,452	372,957	407,451	464,217	516,785	542,086	577,221	541,005	139,968	15,490	.	.	.	.	.	.
	% Rdy	95.6%	92.6%	92.4%	91.3%	92.9%	93.0%	95.1%	96.2%	96.7%	93.5%	.	.	.	.	.	.
2006	Ready	250,340	311,992	347,948	395,327	461,071	482,983	529,371	520,779	497,530	131,305	13,181	.	.	.	.	.
	Total	263,481	341,632	383,548	441,628	504,553	528,661	565,441	552,213	516,906	135,905	14,329	.	.	.	.	.
	% Rdy	95.0%	91.3%	90.7%	89.5%	91.4%	91.4%	93.6%	94.3%	96.3%	96.6%	92.0%	.	.	.	.	.
2007	Ready	216,940	273,782	317,575	368,364	437,128	458,359	505,696	498,690	513,471	508,401	133,867	12,569	.	.	.	.
	Total	228,994	301,642	354,138	416,017	483,946	507,627	545,934	536,160	542,118	526,145	139,238	13,679	.	.	.	.
	% Rdy	94.7%	90.8%	89.7%	88.5%	90.3%	90.3%	92.6%	93.0%	94.7%	96.6%	96.1%	91.9%	.	.	.	.
2008	Ready	190,786	242,440	283,472	341,183	412,567	435,470	484,262	477,145	499,715	533,651	523,024	172,294	12,679	.	.	.
	Total	201,734	268,180	318,843	391,220	463,453	487,595	528,414	520,419	533,560	562,201	545,437	178,659	13,651	.	.	.
	% Rdy	94.6%	90.4%	88.9%	87.2%	89.0%	89.3%	91.6%	91.7%	93.7%	94.9%	95.9%	96.4%	92.9%	.	.	.
2009	Ready	174,496	223,925	260,651	317,243	394,155	426,793	475,295	470,690	498,950	535,342	565,315	610,822	163,513	7,972	.	.
	Total	185,249	250,148	297,498	369,098	451,067	474,273	518,062	515,973	533,256	564,203	595,716	632,552	167,504	8,462	.	.
	% Rdy	94.2%	89.5%	87.6%	86.0%	87.4%	90.0%	91.7%	91.2%	93.6%	94.9%	94.9%	96.6%	97.6%	94.2%	.	.
2010	Ready	153,703	200,074	234,004	285,068	357,546	396,415	448,922	447,643	480,563	516,386	545,403	635,317	575,293	131,103	9,493	.
	Total	164,677	225,624	271,529	337,927	416,928	447,224	495,984	498,683	519,797	548,346	579,195	668,581	592,703	133,948	10,041	.
	% Rdy	93.3%	88.7%	86.2%	84.4%	85.8%	88.6%	90.5%	89.8%	92.5%	94.2%	94.2%	95.0%	97.1%	97.9%	94.5%	.
2011	Ready	135,428	179,677	211,545	260,075	327,158	368,489	423,436	427,437	464,433	501,214	529,345	611,814	611,047	372,079	126,440	11,775
	Total	146,713	204,628	248,507	312,484	388,235	421,481	473,674	482,296	508,086	538,304	567,942	648,549	638,320	382,941	129,255	12,544
	% Rdy	92.3%	87.8%	85.1%	83.2%	84.3%	87.4%	89.4%	88.6%	91.4%	93.1%	93.2%	94.3%	95.7%	97.2%	97.8%	93.9%

Table 3. State of California: Percent of Evap Monitors Ready for All Test Cycles in an I/M Cycle by Calendar Year and Model Year

Calendar Year		Vehicle Model Year															
		1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
2004	Ready	810,561	516,697	971,755	511,922	1,245,836	308,108	256,568	247,453	143,357	7,887	.	.	.	.	.	.
	Total	843,246	569,106	1,065,028	583,806	1,343,798	359,696	284,912	268,590	154,769	8,863	.	.	.	.	.	.
	% Rdy	96.1%	90.8%	91.2%	87.7%	92.7%	85.7%	90.1%	92.1%	92.6%	89.0%	.	.	.	.	.	.
2005	Ready	432,051	842,942	501,595	1,040,290	296,247	243,609	118,992	79,784	77,762	51,387	2,688	.	.	.	.	.
	Total	456,604	917,775	572,812	1,150,154	349,579	290,644	138,695	91,474	85,050	55,153	3,071	.	.	.	.	.
	% Rdy	94.6%	91.8%	87.6%	90.4%	84.7%	83.8%	85.8%	87.2%	91.4%	93.2%	87.5%	.	.	.	.	.
2006	Ready	667,343	499,630	836,110	518,456	1,350,221	259,989	229,412	99,549	68,995	75,619	45,474	3,122	.	.	.	.
	Total	699,816	557,066	937,095	602,608	1,481,334	306,798	268,900	117,918	77,522	80,950	48,352	3,424	.	.	.	.
	% Rdy	95.4%	89.7%	89.2%	86.0%	91.1%	84.7%	85.3%	84.4%	89.0%	93.4%	94.0%	91.2%	.	.	.	.
2007	Ready	387,300	704,889	478,407	893,653	442,636	1,314,166	239,320	215,297	87,833	64,136	68,348	40,544	2,115	.	.	.
	Total	411,795	775,171	557,093	1,012,319	518,372	1,439,185	277,118	254,939	100,926	69,741	71,905	41,804	2,137	.	.	.
	% Rdy	94.1%	90.9%	85.9%	88.3%	85.4%	91.3%	86.4%	84.5%	87.0%	92.0%	95.1%	97.0%	99.0%	.	.	.
2008	Ready	540,399	439,432	695,175	484,571	1,140,170	409,179	1,290,781	208,776	182,380	77,783	58,321	58,816	28,066	1,758	.	.
	Total	571,533	495,384	794,806	576,994	1,280,294	478,032	1,395,503	245,367	212,833	87,004	62,259	60,203	28,240	1,779	.	.
	% Rdy	94.6%	88.7%	87.5%	84.0%	89.1%	85.6%	92.5%	85.1%	85.7%	89.4%	93.7%	97.7%	99.4%	98.8%	.	.
2009	Ready	348,025	600,445	432,646	769,712	452,706	1,147,469	380,440	1,308,578	188,646	167,453	78,192	55,180	56,542	19,145	1,639	.
	Total	374,438	672,594	519,581	896,492	546,853	1,287,831	440,307	1,430,133	216,017	189,553	84,929	57,323	56,966	19,266	1,657	.
	% Rdy	92.9%	89.3%	83.3%	85.9%	82.8%	89.1%	86.4%	91.5%	87.3%	88.3%	92.1%	96.3%	99.3%	99.4%	98.9%	.
2010	Ready	463,884	409,166	611,897	469,722	1,012,825	462,347	1,193,482	388,749	1,355,367	218,014	196,057	95,001	68,529	48,734	23,220	2,013
	Total	497,470	470,704	723,119	573,883	1,168,494	540,824	1,305,366	447,463	1,437,297	236,415	209,837	98,327	69,384	49,147	23,496	2,034
	% Rdy	93.2%	86.9%	84.6%	81.8%	86.7%	85.5%	91.4%	86.9%	94.3%	92.2%	93.4%	96.6%	98.8%	99.2%	98.8%	99.0%

Table 4. For List of Evap OBD DTCs

DTC Code	DTC Description
P0440	Evaporative Emission Control System Malfunction
P0441	Evaporative Emission Control System Incorrect Purge Flow
P0442	Evaporative Emission Control System Leak Detected (small leak)
P0443	Evaporative Emission Control System Purge Control Valve Circuit
P0444	Evaporative Emission Control System Purge Control Valve Circuit Open
P0445	Evaporative Emission Control System Purge Control Valve Circuit Shorted
P0446	Evaporative Emission Control System Vent Control Circuit Malfunction
P0447	Evaporative Emission Control System Vent Control Circuit Open
P0448	Evaporative Emission Control System Vent Control Circuit Shorted
P0449	Evaporative Emission Control System Vent Valve/Solenoid Circuit Malfunction
P0450	Evaporative Emission Control System Pressure Sensor Malfunction
P0451	Evaporative Emission Control System Pressure Sensor Range/Performance
P0452	Evaporative Emission Control System Pressure Sensor Low Input
P0453	Evaporative Emission Control System Pressure Sensor High Input
P0454	Evaporative Emission Control System Pressure Sensor Intermittent
P0455	Evaporative Emission Control System Leak Detected (gross leak)
P0456	Evaporative Emissions System Small Leak Detected
P0457	Evaporative Emission Control System Leak Detected
P0458	Evaporative Emission System Purge Control Valve Circuit Low
P0459	Evaporative Emission System Purge Control Valve Circuit High
P0465	Purge Flow Sensor Circuit Malfunction
P0466	Purge Flow Sensor Circuit Range/Performance
P0467	Purge Flow Sensor Circuit Low Input
P0468	Purge Flow Sensor Circuit High Input
P0469	Purge Flow Sensor Circuit Intermittent

Table 5. State of Texas: For All Test Cycles with Evap Monitor Ready: Percent with Evap DTCs Set, by Calendar Year and Model Year

Calendar Year		Vehicle Model Year															
		1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
2003	Yes	1411	2050	2083	2053	1927	2429	528	30	.	.	.	.	.	.	.	.
	Total	212417	251581	272443	309056	355644	379122	154252	13419	.	.	.	.	.	.	.	.
	%w/DTC	0.66%	0.81%	0.76%	0.66%	0.54%	0.64%	0.34%	0.22%	.	.	.	.	.	.	.	.
2004	Yes	2220	3314	3663	3435	3419	4496	2688	533	48	.	.	.	.	.	.	.
	Total	313693	367795	399109	449390	515902	547999	572621	157985	15197	.	.	.	.	.	.	.
	%w/DTC	0.71%	0.90%	0.92%	0.76%	0.66%	0.82%	0.47%	0.34%	0.32%	.	.	.	.	.	.	.
2005	Yes	2240	3265	3536	3533	3959	5052	3634	3029	728	44	.	.	.	.	.	.
	Total	291195	345213	376605	423980	480111	504195	548960	520428	135366	14489	.	.	.	.	.	.
	%w/DTC	0.77%	0.95%	0.94%	0.83%	0.82%	1.00%	0.66%	0.58%	0.54%	0.30%	.	.	.	.	.	.
2006	Yes	2056	3335	3914	3901	4731	6069	5283	4916	3444	675	39	.	.	.	.	.
	Total	250340	311992	347948	395327	461071	482983	529371	520779	497530	131305	13181	.	.	.	.	.
	%w/DTC	0.82%	1.07%	1.12%	0.99%	1.03%	1.26%	1.00%	0.94%	0.69%	0.51%	0.30%	.	.	.	.	.
2007	Yes	1727	2968	3769	3942	5165	6289	5863	6093	4674	3285	565	41	.	.	.	.
	Total	216940	273782	317575	368364	437128	458359	505696	498690	513471	508401	133867	12569	.	.	.	.
	%w/DTC	0.80%	1.08%	1.19%	1.07%	1.18%	1.37%	1.16%	1.22%	0.91%	0.65%	0.42%	0.33%	.	.	.	.
2008	Yes	1571	2757	3756	3771	5184	6297	6074	6693	5340	4020	2898	787	48	.	.	.
	Total	190786	242440	283472	341183	412567	435470	484262	477145	499715	533651	523024	172294	12679	.	.	.
	%w/DTC	0.82%	1.14%	1.32%	1.11%	1.26%	1.45%	1.25%	1.40%	1.07%	0.75%	0.55%	0.46%	0.38%	.	.	.
2009	Yes	1542	2737	3769	3982	5563	6971	7019	7860	6491	5068	4176	3284	666	35	.	.
	Total	174496	223925	260651	317243	394155	426793	475295	470690	498950	535342	565315	610822	163513	7972	.	.
	%w/DTC	0.88%	1.22%	1.45%	1.26%	1.41%	1.63%	1.48%	1.67%	1.30%	0.95%	0.74%	0.54%	0.41%	0.44%	.	.
2010	Yes	1239	2303	3206	3500	4958	6542	6943	7766	6757	5589	4672	4199	2640	381	18	.
	Total	153703	200074	234004	285068	357546	396415	448922	447643	480563	516386	545403	635317	575293	131103	9493	.
	%w/DTC	0.81%	1.15%	1.37%	1.23%	1.39%	1.65%	1.55%	1.73%	1.41%	1.08%	0.86%	0.66%	0.46%	0.29%	0.19%	.
2011	Yes	1060	2028	2753	3027	4246	6158	6259	7213	6698	5927	5193	4549	3322	1303	264	18
	Total	135428	179677	211545	260075	327158	368489	423436	427437	464433	501214	529345	611814	611047	372079	126440	11775
	%w/DTC	0.78%	1.13%	1.30%	1.16%	1.30%	1.67%	1.48%	1.69%	1.44%	1.18%	0.98%	0.74%	0.54%	0.35%	0.21%	0.15%

Table 6. State of California: For All Test Cycles with Evap Monitor Ready: Percent with Evap DTCs Set, by Calendar Year and Model Year

Calendar Year		Vehicle Model Year															
		1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
2004	Yes	10,665	7,627	11,746	6,137	13,539	2,969	2,058	1,398	515	8	.	.	.	.	.	.
	Total	810,561	516,697	971,755	511,922	1,245,836	308,108	256,568	247,453	143,357	7,887	.	.	.	.	.	.
	%w/DTC	1.3%	1.5%	1.2%	1.2%	1.1%	1.0%	0.8%	0.6%	0.4%	0.1%	.	.	.	.	.	.
2005	Yes	7,163	12,622	8,082	12,960	3,330	2,739	1,209	671	408	109	1	.	.	.	.	.
	Total	432,051	842,942	501,595	1,040,290	296,247	243,609	118,992	79,784	77,762	51,387	2,688	.	.	.	.	.
	%w/DTC	1.7%	1.5%	1.6%	1.2%	1.1%	1.1%	1.0%	0.8%	0.5%	0.2%	0.0%	.	.	.	.	.
2006	Yes	9,483	9,439	12,739	7,916	19,307	3,359	2,590	902	482	288	44	5	.	.	.	.
	Total	667,343	499,630	836,110	518,456	1,350,221	259,989	229,412	99,549	68,995	75,619	45,474	3,122	.	.	.	.
	%w/DTC	1.4%	1.9%	1.5%	1.5%	1.4%	1.3%	1.1%	0.9%	0.7%	0.4%	0.1%	0.2%	.	.	.	.
2007	Yes	6,632	12,149	9,407	12,771	7,976	23,772	3,022	1,966	664	308	81	32	0	.	.	.
	Total	387,300	704,889	478,407	893,653	442,636	1,314,166	239,320	215,297	87,833	64,136	68,348	40,544	2,115	.	.	.
	%w/DTC	1.7%	1.7%	2.0%	1.4%	1.8%	1.8%	1.3%	0.9%	0.8%	0.5%	0.1%	0.1%	0.0%	.	.	.
2008	Yes	8,033	9,262	12,569	8,683	19,051	9,354	24,675	2,524	1,566	391	130	64	5	0	.	.
	Total	540,399	439,432	695,175	484,571	1,140,170	409,179	1,290,781	208,776	182,380	77,783	58,321	58,816	28,066	1,758	.	.
	%w/DTC	1.5%	2.1%	1.8%	1.8%	1.7%	2.3%	1.9%	1.2%	0.9%	0.5%	0.2%	0.1%	0.0%	0.0%	.	.
2009	Yes	6,167	11,432	10,015	13,019	9,709	23,801	9,136	23,952	1,957	886	188	81	17	4	0	.
	Total	348,025	600,445	432,646	769,712	452,706	1,147,469	380,440	1,308,578	188,646	167,453	78,192	55,180	56,542	19,145	1,639	.
	%w/DTC	1.8%	1.9%	2.3%	1.7%	2.1%	2.1%	2.4%	1.8%	1.0%	0.5%	0.2%	0.1%	0.0%	0.0%	0.0%	.
2010	Yes	6,938	8,694	12,665	9,486	18,930	11,408	26,055	8,010	20,256	1,269	459	125	27	15	7	0
	Total	463,884	409,166	611,897	469,722	1,012,825	462,347	1,193,482	388,749	1,355,367	218,014	196,057	95,001	68,529	48,734	23,220	2,013
	%w/DTC	1.5%	2.1%	2.1%	2.0%	1.9%	2.5%	2.2%	2.1%	1.5%	0.6%	0.2%	0.1%	0.0%	0.0%	0.0%	0.0%

Table 7. State of Texas: Sum of Evaporative DTC Leaks/All Evap DTCs
By Calendar Year and Model year

Calendar		Model Year									
Year	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
2003	0.58	0.42	0.70	0.77							
2004	0.54	0.41	0.68	0.76	0.72						
2005	0.52	0.41	0.67	0.76	0.73	0.66					
2006	0.54	0.37	0.66	0.75	0.75	0.72	0.74				
2007	0.52	0.37	0.67	0.75	0.74	0.68	0.73	0.86			
2008	0.49	0.37	0.64	0.72	0.72	0.67	0.69	0.87	0.87		
2009	0.52	0.38	0.62	0.72	0.72	0.68	0.71	0.85	0.84	0.87	
2010	0.50	0.37	0.62	0.68	0.71	0.66	0.69	0.83	0.84	0.85	0.89

DTC Ratio = Evaporative DTC Leak (P0442+P0455+P0456 +P0457)//Total Evap DTCs

Table 8. State of California: Sum of Evaporative DTC Leaks/All Evap DTCs By Calendar Year and Model year

Calendar	Model Year											
Year	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
2003												
2004	0.11	0.36	0.72	0.66	0.80	0.83	0.86	0.84	0.87	1.00		
2005	0.10	0.34	0.68	0.66	0.76	0.80	0.83	0.75	0.78	0.83		
2006	0.11	0.33	0.67	0.63	0.76	0.78	0.84	0.76	0.77	0.72	0.77	
2007	0.11	0.32	0.63	0.62	0.72	0.77	0.80	0.78	0.81	0.83	0.80	0.84
2008	0.11	0.32	0.65	0.58	0.73	0.75	0.80	0.77	0.78	0.89	0.80	0.89
2009	0.12	0.31	0.62	0.59	0.69	0.74	0.76	0.78	0.80	0.82	0.85	0.86
2010	0.13	0.33	0.65	0.57	0.71	0.74	0.78	0.74	0.79	0.83	0.82	0.90

DTC Ratio = Evap (P0442+P0455+P0456+P0457)/Total Evap DTCs

Note: Highlight (yellow) are high vehicle recruitment years (biannual)