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Evaluation of Inspection and Maintenance OBD II Data to Identify Vehicles That May Be Sensitive to E10+ Blends

Final Report for CRC Project No. E-90-2a and NREL Task Order KZCI-8-77444-03

prepared for:

Coordinating Research Council

and

National Renewable Energy Laboratory

January 31, 2011

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FINAL REPORT

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List of Acronyms

ALLIANCE	Alliance of Automobile Manufacturers
CHP	California Highway Patrol
CRC	Coordinating Research Council
CY	Calendar Year
DOE	Department of Energy
DTC	Diagnostic Trouble Code
E0	Gasoline without ethanol
E10	Gasoline with 10% ethanol by volume
E10+	Gasoline with greater than 10% ethanol by volume
EISA	the Energy Independence and Security Act of 2007
EPA	Environmental Protection Agency
EPACT	Energy Policy Act of 2005
FFV	Flex-Fuel Vehicle
I/M	Inspection/Maintenance
MIL	Malfunction Indicator Light
MY	Model Year
NREL	National Renewable Energy Laboratory
OBDII	On Board Diagnostic – second generation
P0171	DTC – System too lean (Bank 1)
P0172	DTC – System too rich (Bank 1)
P0174	DTC – System too lean (Bank 2)
P0175	DTC – System too rich (Bank 2)
RFG	Reformulated Gasoline
RFS	Renewable Fuel Standard
RFS2	Renewable Fuel Standard 2
SAE	Society of Automotive Engineers
US	United States
VIN	Vehicle Identification Number

1. EXECUTIVE SUMMARY

Increasing the ethanol content of gasoline above 10% by volume is likely to be necessary to meet the Renewable Fuel Standards established under the Energy Policy Act (EPACT) of 2005 and the Energy Independence and Security Act (EISA) of 2007. To evaluate the sensitivity of vehicles to higher ethanol levels, data collected under different vehicle inspection and maintenance (I/M) programs have been analyzed. The analysis reveals that the on-board diagnostic (OBD) systems in certain model light-duty vehicles are detecting significantly more fuel metering-related "faults" when operating on gasoline blended with 10% ethanol by volume than when operating on gasoline with lower ethanol content. This raises a concern about the possible effect of blends with greater than 10% ethanol (E10+). Based on the analysis performed, approximately 4% of all OBD-equipped light-duty vehicles could be susceptible to fuel metering-related fault codes when using E10+.

To assist in interpreting the results of the analysis, the reader is reminded that a vehicle meeting all regulatory and design specifications may trigger an OBD "fault" if operated outside of its design limits. Reference to an "OBD fault" is not intended to necessarily imply a "failure" or "malfunction" that affects the reliability or driveability of the vehicle. However, the regulations and SAE standards that define OBD systems include a number of terms that imply failure or improper performance. For example, the check engine light is referred to as a "*Malfunction* Indicator Light" (MIL) and the codes stored by an OBD system are referred to as "Diagnostic *Trouble* Codes" (DTCs) or "*fault*" codes. For clarity, this report uses standard OBD nomenclature to refer to OBD results.

Based on the analysis conducted, only 0.39% of 1996 and later model cars and light trucks subject to the I/M program in Georgia, where 10% ethanol is being used, are unable to maintain long-term fuel trim within the preprogrammed OBD limits. However, when results were categorized into make-model-displacement-model year subgroups using the Vehicle Identification Number (VIN), it was possible to identify vehicle categories for which increased ethanol content (to 10% by volume from a lower level) caused a significantly higher percentage of fuel metering-related OBD faults. For example, when subgroups that included more than 100 initial tests were sorted by the increase in failure rate following an increase in fuel ethanol content, it was found that about 4% of vehicles were in make-model-displacement-model year combinations that had at least a 1.0 percentage point increase in OBD fault codes related to fuel trim with higher ethanol content (e.g., a 1.0% fault code rate increasing to at least 2.0%). These are considered the "sensitive" combinations.

It should be noted that while 4% of the vehicles were in the "sensitive" make-model-displacement-model year combinations, only 3.4% of the vehicles in those combinations actually had fuel trim-related fault codes when tested during a state I/M program. However, "pre-inspection maintenance" often results in fault codes being erased immediately before an I/M test. Based on data collected in California, there are 6.85 times more fault codes found in randomly selected vehicles tested at the road side than are recorded during official I/M tests. (The similarity between the rate of fault codes reported by inspection stations in Georgia and California indicates that a similar amount of pre-inspection maintenance is occurring in Georgia.) Applying that ratio, we estimate that about 23% of the vehicles in the "sensitive" combinations (3.4% × 6.85) are likely having fuel trim-related fault codes when tested on E10. That translates to about 1% of the OBD-equipped light-duty vehicle fleet (23% × 4%).

Although the analysis conducted to date indicates that fuel mixture OBD fault codes associated with 10% ethanol content are limited to certain models produced by a few manufacturers, the correlation between ethanol content and fuel trim-related fault codes indicates that more significant problems are likely to be encountered with the use of gasoline blends with ethanol contents in excess of 10%. Recognizing that if a vehicle fuel feedback system is approaching the preprogrammed long-term fuel trim limit as the oxygenate content is increased to E10, it is likely that even more vehicles will exceed the control limit at higher oxygenate levels. The effect of excessively lean operation can include degraded drivability and increased exhaust emissions, particularly of oxides of nitrogen (NOx).

If all vehicles in the sensitive combinations are affected by E10+, they would represent approximately 4% of the fleet. Using the vehicle populations in EPA's MOVES2010a model, there are about 170,000,000 MY1996 and newer (OBDII vehicles) in the 2010 US in-use vehicle population. Four percent of that number is 6,800,000 vehicles. The extent to which other possibly marginal combinations would exhibit problems on E10+ is uncertain.

Additional testing will be necessary to determine whether the approval of gasoline with higher than 10% ethanol content is an appropriate way of ensuring compliance with the Renewable Fuel Standards. A test program to evaluate the most significant emission and performance changes with fuel ethanol levels above 10% should concentrate on the vehicle groups shown to be sensitive in this analysis. Note that the results of this analysis can also be used to identify "control" vehicles not affected by ethanol levels at or below 10%.

I/M program results from Atlanta, Georgia, Southern California, Denver, Colorado and Vancouver, British Columbia were included in this study. Periods before and after the transition to E10 were selected from each area and subjected to analysis. The sample sizes and dates included in the study are summarized in Table 1-1.

Table 1-1
Samples Included in Study

I/M Program Areas Studied	Periods Studied		Initial Tests Included	
	Before Transition	After Transition	Before Transition	After Transition
Atlanta, Georgia	2007	2009	1,436,323	1,671,759
Southern California	2009	2010	1,336,317	1,483,308
Denver, Colorado	Summer 2006	Summer 2008	179,171	174,601
Vancouver, BC Canada	Early 2009	Early 2010	98,256	83,547

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2. TECHNICAL APPROACH

Triggered by the Energy Policy Act of 2005 (EPACT) and the Energy Independence and Security Act of 2007 (EISA), Renewable Fuel Standards (RFS and RFS2) require that 15.2 billion gallons of renewable fuel be used in the transportation sector by 2012 and 36 billion gallons of renewable fuel by 2022. Ethanol is expected to be the blend stock used to meet the bulk of these requirements. Fuels containing up to 10% ethanol (E10) have been used in selected markets across the nation for about 30 years. While initially troublesome, changes have been made to most current passenger car and light-duty truck designs to generally permit trouble-free operation with fuels containing up to 10% ethanol. Most commercial gasoline fuels have or will soon reach the 10% ethanol content level in response to RFS2 requirements. However, even if all commercial gasoline is blended with 10% ethanol, consumption of ethanol will not be sufficient to meet RFS2 mandates in the 2013-2015 timeframe (an effect referred to as the "blend wall").[*] Changes in regulations to permit the ethanol content of standard commercial gasoline to rise from 10% to levels ranging from 12% to 20% (E10+) are being considered. There remain questions regarding the ability of a non-trivial fraction of the in-use fleet to successfully maintain design performance and emission characteristics while operating with the higher ethanol blends.

Since 1996, light-duty vehicles have been required to include self-diagnostic on-board monitoring systems to detect conditions that would cause the vehicle to fail laboratory-based emission certification tests. The current generation of these systems, referred to as On-Board Diagnostic II (OBDII), is used by inspection and maintenance (I/M) programs operated throughout the United States and Canada to evaluate vehicle performance. I/M programs are intended to protect local regions from increases in ambient emission levels resulting from emissions-related defects as vehicles age. The OBDII system performs many system checks as the vehicle is operated, and signals the driver when operation outside of predetermined limits is detected with a dashboard Malfunction Indicator Light (MIL). A repair technician, or an I/M program, can interrogate the vehicle's OBDII system to obtain a list of Diagnostic Trouble Codes (DTCs) stored by the system when an OBD fault is detected.

Modern automobiles continuously monitor and adjust the fuel:air mixture as they operate. One of the parameters that OBDII systems are required to monitor is the ability of the vehicle's fuel system to measure and control this mixture within defined limits, which are usually close to the chemically correct, "stoichiometric" fuel:air ratio. The OBDII

[*] "Renewable Fuel Standard (RFS2) Regulatory Impact Analysis", EPA-420-R-10-006, Feb 2010 p.241 *http://www.epa.gov/otaq/renewablefuels/420r10006.pdf*

system signals the operator when the vehicle feedback control system is unable to maintain a stoichiometric mixture within the predefined limits.

Government regulators, the automotive industry, and the petroleum industry have an interest in the proposed changes to fuels. The use of OBDII data from existing I/M programs provides an opportunity to monitor the impact of changes in fuel ethanol content on very large samples from the in-use population. A preliminary analysis of OBDII data from the California I/M program indicated significant differences between groups of vehicles, warranting this more extensive investigation.

The primary purpose of this analysis (designated E-90-2a by the Coordinating Research Council [CRC]) is to determine whether it is possible to identify specific vehicle models and engines that have higher than average OBD fault rates when operated with currently available E10 blends, as such vehicles are expected to exhibit an even higher OBD fault rate if operated with fuel ethanol contents above 10%. Vehicles identified in the analysis are intended to provide guidance in the selection of vehicles for extensive laboratory testing program(s) using fuels with up to 20% ethanol content.

The tasks that Sierra performed to accomplish the scope of work are discussed in detail below.

2.1 Identification of I/M Program Data to Analyze

Data collected under motor vehicle I/M programs operated by state and local agencies include specific OBD codes reported by monitoring systems installed on 1996 and later model year vehicles. Analyses of these data provide insight regarding the extent to which existing lean air-fuel limit OBD fault codes are occurring in customer service. Combined with regional data on fuel oxygen content, the correlation between such OBD fault codes and changes in fuel oxygen content can be evaluated.

There are two basic approaches for analyzing I/M program data to address this issue:

1. Comparing contemporaneous data from similar I/M programs operating in areas supplied with gasoline that contains different levels of oxygen; and
2. Examining I/M results from a given area collected at different times when the fuel supplied to the area contained differing amounts of oxygen.

Differences in the objectives and controlling regulations governing individual I/M programs can cause significant differences in the observed frequency of DTCs and other failures in vehicles as they are inspected. One source of such differences, for example, is the extent to which pre-inspection maintenance and repair occur. Informed owners are unlikely to present their vehicle for inspection at a test-only, centralized inspection station if aware of a problem that will cause the vehicle to fail. Signage at some centralized inspection stations reinforce this, instructing owners to have their vehicle repaired prior to test if the MIL is illuminated, promising the vehicle will fail and require a retest after repair. Other sources of differences may include deliberate tampering by the owner or technician and/or falsification of results during inspection.

The California decentralized program requires that a vehicle found to be a gross emitter during an initial "official" inspection be directed to a different test-only station for final inspection following repairs. The repair station operator is therefore motivated not to begin the official inspection process on a vehicle with an illuminated MIL before corrections are made, avoiding the possible requirement of sending the vehicle elsewhere during the inspection process. In contrast, the Georgia I/M regulations specifically require an I/M inspector to perform a full "official" test on every vehicle presented to the station for inspection, even if there are indications such as MIL illumination that the vehicle will fail.

These differences suggest the first approach—comparison of results from different I/M program areas—would be unlikely to be as useful as the second approach, comparison of results from given I/M programs during periods of changing fuel specifications.

The primary purpose of a state I/M program is to reduce vehicle emissions, not to assess vehicle performance before inspection. Because of the uncertainties involved with finding perfectly matched I/M programs in different locations, the selected analytical approach was to examine I/M data from given programs during different time periods, noting when the fuel supplied to the area contained differing levels of ethanol and other oxygenates. The preferred approach was to identify one or more I/M programs where the vehicles were subject to significant changes in ethanol content over time <u>and</u> which were expected to have a minimum amount of pre-inspection maintenance.

It should be recognized that average ambient temperatures could also impact OBD performance, as could altitude or other factors. I/M results from given areas were compared over similar time periods, matching available data following change to E10 from preceding periods at lower oxygenate levels. High altitude results were not compared to low altitude results. Results from a centralized program were not compared to decentralized program results. The analysis was limited to measurement of change in OBD inspection results before and after a change in fuel oxygenates level.

2.2 ALLIANCE Commercial Fuel Properties Survey

The Alliance of Automobile Manufacturers (The Alliance) sponsors biannual surveys of commercial fuel properties from many North American cities. The survey results were used to document specific time periods before and after a scheduled change in fuel ethanol levels.[*] Although there are a total of 51 I/M programs currently operating in 35 different states/provinces (U.S., Canada, and the District of Columbia), fuel oxygen content results were not available in the Alliance survey for many of the program areas.

[*] Technical details of the survey available at *http://www.pcxhost.com/sdata/assets/3/313/page_31397.pdf.*

Areas that implement I/M programs also typically require the use of reformulated fuels (RFG) that include an oxygenate such as ethanol, minimizing their value for this analysis. Factors considered in selection of programs included the following:

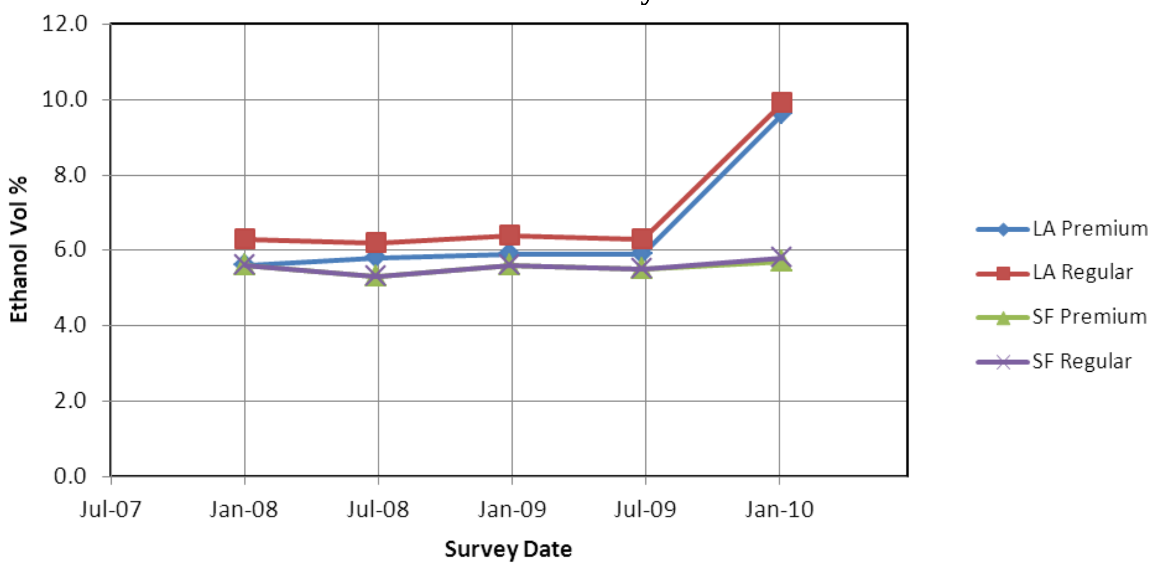
1. Documented change in commercial fuel ethanol level;
2. Ongoing, well managed I/M program to insure data quality;
3. Availability of results from the program on a timely basis; and
4. Availability of results at reasonable cost.

Four I/M programs were selected for detailed analysis:

1. California;
2. Georgia;
3. Vancouver, British Columbia; and
4. Wisconsin.

Commercial fuel in the Los Angeles, California area recently underwent a transition from 2% gasoline oxygen content to 3.5% gasoline oxygen content by weight (E6 to E10 by volume). Alliance survey results for Los Angeles and San Francisco are displayed in Figure 2-1.

Figure 2-1
California Alliance Fuel Survey Results: 2007-2010



Source: Alliance of Automobile Manufacturers North American Fuel Survey

I/M Results from January of 2010 were not included in the analysis to increase the likelihood of one or more vehicle refueling events with the higher ethanol fuel level before the test. Comparison of I/M results from February through June 2009 from the

Los Angeles area to the same period and geographical area in 2010 is expected to reveal effects of the fuel ethanol content change. Four counties surrounding Los Angeles were included: Ventura, Los Angeles, Orange, and San Diego. Only results from stations in enhanced testing areas were considered, in recognition that some of the outlying county areas were not in the Serious, Severe, or Extreme non-attainment areas that require enhanced I/M testing.

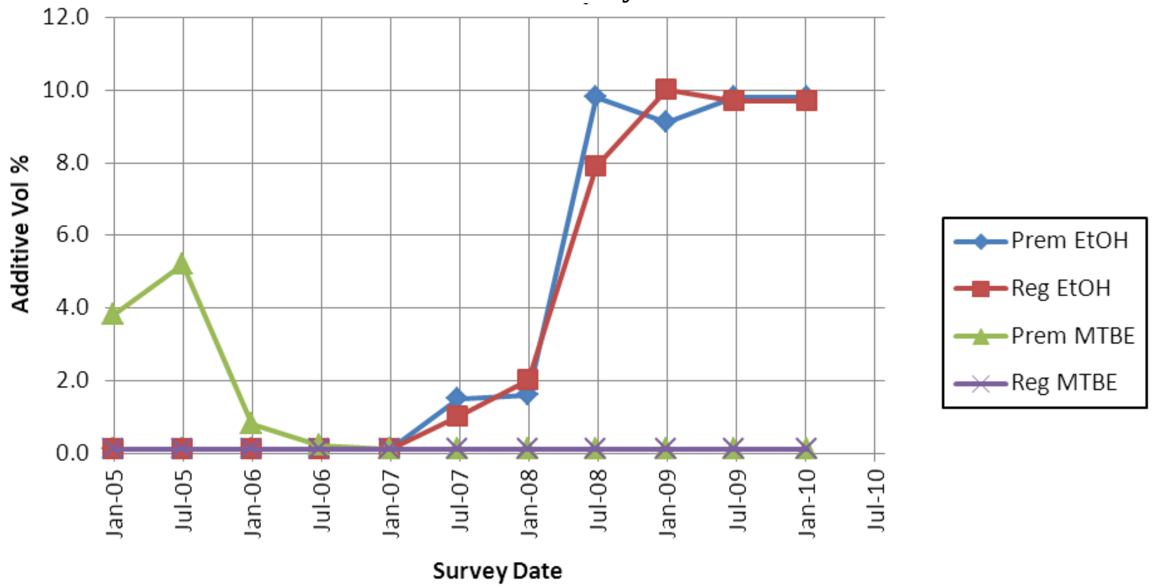
California is also the only I/M program that includes an ongoing independent random sampling of the in-use vehicle population using the same equipment and procedures as are used in the standard I/M program. California Smog Check personnel, with the assistance of the California Highway Patrol (CHP) regularly perform random roadside inspections of in-use vehicles. In the roadside program, vehicles are directed to the side of the road by CHP officers who request the owners to voluntarily participate in a roadside inspection. The portable inspection apparatus is frequently moved to different locations to provide broad coverage of different areas in the state. Results of both the standard and roadside testing programs are collected in well-documented centralized databases that were available for use in this program.

I/M program data frequently do not reflect on-road performance of the in-use fleet. One cause is pre-inspection repairs performed prior to the scheduled I/M inspection. (An additional issue, not addressed in the CRC Statement of Work, is that data collected from decentralized I/M programs include falsified test results from vehicles reported as passing that actually failed. Tampering by the vehicle owner and/or technician before and after the vehicle I/M inspection may also impact on-road performance.) To address the combined effects of falsified test results and pre-inspection maintenance, Sierra compared results obtained from the California Roadside testing program to the results collected in the same period in the standard I/M program. This analysis provides an estimate of the true frequency of lean malfunction DTCs in the fleet. The roadside program is performed to meet many program needs. The data used for this analysis included only a documented stratified random sample intended to mirror the initial test results at statewide Smog Check inspection stations.

Georgia is unusual because it recently underwent a period of zero oxygenate usage following the phase-out of MTBE and the statewide adoption of E10 fuels. While the state did not undergo an overnight transition from non-oxygenated fuel to 100% usage of E10, it is a very large program with a well-documented fuel ethanol implementation schedule. Based on the Alliance survey results, displayed in Figure 2-2, calendar years 2007 and 2009 were selected for comparison in this project.

Like the California I/M program, the Georgia program structure is decentralized and conducted by licensed private garages. However, the program regulations require that technicians at inspection and repair stations perform a complete baseline initial test on any vehicle presented for inspection before any maintenance is performed, even if, specifically, the MIL is illuminated. Inspection results are communicated to a centralized data contractor.

Figure 2-2
Atlanta Alliance Fuel Survey Results: 2005-2010



Source: Alliance of Automobile Manufacturers North American Fuel Survey

The Vancouver program was selected because it has recently undergone a transition from E0 to E10 fuel ethanol content. Regulations that became effective in January 2010 require the use of renewable fuels. The requirements of the regulation are being met by the introduction of E10 fuels in the Vancouver metropolitan area. The Alliance survey reflects that a transition began during January 2010, with a range of ethanol content between 0.0 and 10%, and an average of about 5% at the time the samples were collected. Communication with Canadian government officials indicates petroleum marketers in the province intend to meet annual province-wide mandates for British Columbia by marketing E10 in the Vancouver area throughout the calendar year. It is probable that many of the vehicles tested early in January were not operated on E10, but that most vehicles in February and later did reflect E10 operation. This prompted use of the limited results from Vancouver in this analysis.

Because Vancouver is a centralized program, the concern exists that pre-inspection maintenance might affect the observed rate of DTCs indicating lean operation. However, the scarcity of I/M data related to ethanol change and the well documented test results prompted inclusion of the program in the analysis.

2.3 Identification of Specific DTCs to Analyze

In addition to the P0171 (System too lean, bank 1) and P0174 (System too lean, bank 2) DTCs identified by CRC in the original Statement of Work, inquiries were made of the vehicle manufacturer representatives on the CRC task force committee and other manufacturer contacts to determine whether any manufacturer-specific DTCs that are related to lean air-fuel ratio limit faults should be included in the analysis. No such codes, however, were identified. DTCs P0172 and P0175 are used to identify when rich operation is encountered. Data on rich failures were tabulated in conjunction with the lean failure data. The frequency of rich failures would be expected to decrease at higher fuel oxygenate levels.

Following a review of initial results with the program sponsors, it was agreed to combine the results of both lean codes and both rich codes into single metrics. The P0171 and P0174 codes are associated with cylinder "banks" on the engine. "V" configuration engines (e.g., V-6 and V-8) have two banks of cylinders, and independently report lean and rich operation by bank. It is not possible to simply add the results of the two banks, as frequently both banks will report a failure at the same time, and simple addition will result in double counting of individual vehicles. A lean code was therefore tallied if either or both P0171 and P0174 codes were reported on given vehicle (LOGICAL OR). Rich codes were similarly treated, with detection of either or both a P0172 and P0175 code being combined into a single rich code before further analysis.

The significance of the procedure used for combining the bank codes can be illustrated from an analysis of all initial OBDII results in the statewide California Smog Check program for CY2009. A total of 6,664,885 tests were included in the sample. In this set of data, 37,931 vehicles (0.57%) were noted with P0171 codes stored. A total of 23,329 vehicles (0.35%) with P0174 codes were found; 19,004 of these vehicles, however, had both P0171 and P0174 codes stored. Simply adding 37,931 and 23,329 would yield 61,260 (0.92%). The correct total number of vehicles with either one OR both lean codes is 42,256 (0.63%), exactly as obtained by calculating 37,931 + 23,329 – 19,004, because the 19,004 value is already included in <u>both</u> of the first two values but should only be counted once.

The relative counts are consistent with expected values. The total number of P0171 codes noted is 37,931 without regard for whether the engine had only one bank, or whether the code was for bank one of two. Engines with a failure in the second bank (DTC P0174) total 23,329. The higher P0171 count reflects the expected fraction of single bank (primarily 4-cylinder) engines in the total population of engines. Furthermore, considering engines with two banks having a bank 2 code, most (19,004 out of 23,329) also had a DTC stored for bank 1.

2.4 Data Analysis and Identification of Sensitive Vehicles

The approach used to identify groups of sensitive vehicles was broken into several subtasks. The methods used are described below.

<u>Initial Tests</u> − A critical first step in the data analysis involved selection of the initial test for a vehicle during a given time period. This was necessary to avoid over-sampling failing vehicles, which are often tested more than once as a result of multiple attempts by the owner or mechanic to pass the I/M test. The approach used to select initial tests involved adding the results for a ninety day period before the window of time being

analyzed, then sorting all tests on each VIN into chronological order. If the first test of a series of tests on a VIN occurred within the designated time window, it was selected as the initial test on the vehicle. Any series of tests on a specific VIN that began prior to the window of interest was discarded. Any additional tests performed on a given vehicle after the initial tests were similarly discarded.

A fairly common occurrence was a second series of tests starting several months after an initial series. These tests are believed to have been performed following a change in ownership, triggering the requirement for a test to obtain a new title and registration. It was also possible in the annual Georgia program for a vehicle to receive an initial test early in a calendar year, and to start the process again late in the same calendar year for the following registration year. The later tests were discarded to avoid double-counting a single vehicle.

<u>Program Time Periods</u> − Different time windows were available for the different programs examined. Full calendar year (CY) data were obtained from the Georgia program for 2005 through 2009. The CY2005 results were limited to April through December, using the first three months only to select initial tests performed later in the year. Results from the last three months of the previous year were used for each year between 2006 and 2009 to confirm that all results reported for the year were initial tests. Incomplete and aborted tests were discarded. Only a valid and complete initial test on a vehicle in a given calendar year was retained. The Georgia five-year data were used to assess deterioration of a given model year over time.

The period of interest for the California and Vancouver programs was the first months of 2010. Vancouver underwent a transition from no oxygenates in 2009 to E10 in January 2010. California underwent a transition from E6 in 2009 to E10 in 2010. Data for January through April 2010 were available for Vancouver, while results from January through June were available for California. Data from the last three months of 2008 were available for both programs. The same periods in 2009 were selected for comparison to the available data in 2010 in both programs to avoid any possible seasonal bias.

Only CY2009 data were obtained from Wisconsin. Initial results were limited to April through December. This program was included only to determine typical DTC rates for a fleet of vehicles that had long-term exposure to E10 levels.

<u>VINStem_MY and Description</u> − The analysis required a method of combining similar vehicles into groups. Federal regulations and SAE standards require that certain parts of the VIN be used to uniquely identify make, model, model year, and other vehicle characteristics. The first 8 characters and the 10^{th} character are designated for this purpose.

The next step in the data analysis involved combining the sample into subsets of make, model, model year, and engine displacement description groups. This is an extension of prior work accomplished by using the first 8 characters of the VIN, and the 10^{th} character representing Model Year, which was referred to as the VINStem_MY. Examination of the results in the initial effort revealed that the basic VINStem_MY categories were too narrow for all but the highest sales volume groups, resulting in very small sample sizes. As expected, the basic approach did successfully identify several high-volume vehicle groups that had substantially higher DTC failure rates than the bulk of the fleet. However, a refined method for combining vehicles was required to better characterize subsets of the vehicle population less tolerant of high ethanol content. For example, examination of results from large programs (with 1,000,000+ OBDII tests per year) revealed that many specific make/model/model year/engine displacement groups included more than one unique VINStem_MY category. Table 2-1 displays an excerpt from I/M program results showing the actual number of tests performed on a group of nominally identical vehicles with slight variations in VINStem_MY structures.

The differences may reflect trim levels, or two and four-door models, for example. While an engine identifier code is also embedded in these VIN based groupings, no attempt was made to differentiate between differing performance levels of engines with the same displacement. While the different specific examples might be tested with small differences in weight and loading, they essentially have the same engine and would be expected to respond similarly to ethanol on the road, and were therefore combined into a single group for this analysis. For example, the first four subgroups of 1997 vehicles were combined into a single group of 338 vehicles.

Another problem noted during the review was the variety of vehicle descriptions assigned by individual inspectors and/or inspection program to vehicles in the same VIN stem group. Some differences were systematic—for example, using only four-letter abbreviations for a given manufacturer vs. five-letter abbreviations for the same manufacturer. Others were obvious errors, such as where an alphabetized listing by VIN reflects a long series of one manufacturer with a single embedded instance of a completely different manufacturer. The first three characters of the VIN are required by regulation to identify the country of origin and manufacturer of a vehicle, so this error was easy to identify. Other discrepancies were less obvious, with a mixture of engine displacements within a given group of vehicles with the same VIN stem, for example. To permit analysis and comparison of results from multiple large datasets, it was important to consistently assign different VINstem_MY groups to consistent manufacturer, make, and model name groups. The earlier VINstem_MY assignments were used as a starting point, but a significant part of the effort for this analysis was the development of an extensive VIN stem library to enable assignment of consistent Manufacturer/Make/ Model/Engine Displacements to the majority of VINs encountered in each of the I/M programs analyzed.

The approach used for each set of data was to first confirm the integrity of the VIN reported. The 9th character of the VIN is a "check digit" assigned by defined mathematical computations performed on the remaining 16 digits of a VIN. Most transcription or other errors will be detected by a mismatch between the embedded check digit and the computed check digit.[*] A second test was performed by comparing the

[*] 49 CFR § 565.6(c) Part 565-VEHICLE IDENTIFICATION NUMBER REQUIREMENTS defines the requirements for VIN content, including the check digit calculation algorithm.

model year embedded in the VIN to that reported by the I/M program vehicle description. Test results failing these two checks were discarded.

Table 2-1
VIN Stem and Description Groups

Count	vinstem_my	Description MAKE/MODEL/ENGINE/MY	# of Tests in VIN group	# of Tests in Description Group
1	19UYA114V	MAKE1 MODEL1 DISP1 1997	32	338
2	19UYA115V	MAKE1 MODEL1 DISP1 1997	60	
3	19UYA124V	MAKE1 MODEL1 DISP1 1997	67	
4	19UYA125V	MAKE1 MODEL1 DISP1 1997	179	
1	19UYA314W	MAKE1 MODEL1 DISP2 1998	25	202
2	19UYA315W	MAKE1 MODEL1 DISP2 1998	34	
3	19UYA324W	MAKE1 MODEL1 DISP2 1998	42	
4	19UYA325W	MAKE1 MODEL1 DISP2 1998	101	
1	19UYA315X	MAKE1 MODEL1 DISP2 1999	26	127
2	19UYA325X	MAKE1 MODEL1 DISP2 1999	101	
1	19UYA224V	MAKE1 MODEL1 DISP3 1997	61	281
2	19UYA225V	MAKE1 MODEL1 DISP3 1997	220	
1	19UYA224W	MAKE1 MODEL1 DISP3 1998	43	249
2	19UYA225W	MAKE1 MODEL1 DISP3 1998	206	
1	19UYA225X	MAKE1 MODEL1 DISP3 1999	201	201
1	19UYA4241	MAKE1 MODEL1 DISP4 2001	140	441
2	19UYA4251	MAKE1 MODEL1 DISP4 2001	32	
3	19UYA4261	MAKE1 MODEL1 DISP4 2001	162	
4	19UYA4271	MAKE1 MODEL1 DISP4 2001	107	
1	19UYA4242	MAKE1 MODEL1 DISP4 2002	41	104
2	19UYA4252	MAKE1 MODEL1 DISP4 2002	5	
3	19UYA4262	MAKE1 MODEL1 DISP4 2002	42	
4	19UYA4272	MAKE1 MODEL1 DISP4 2002	16	
1	19UYA4163	MAKE1 MODEL1 DISP4 2003	8	91
2	19UYA4173	MAKE1 MODEL1 DISP4 2003	5	
3	19UYA4243	MAKE1 MODEL1 DISP4 2003	28	
4	19UYA4253	MAKE1 MODEL1 DISP4 2003	2	
5	19UYA4263	MAKE1 MODEL1 DISP4 2003	34	
6	19UYA4273	MAKE1 MODEL1 DISP4 2003	14	

Next, individual results were checked for completeness, and for the presence of codes indicating the test had been aborted or was otherwise not representative of a standard I/M test. Each program provides codes to identify non-standard and aborted tests.

The OBD regulations specify different conditions under which DTCs are stored. OBDII systems define the fuel system as a continuous monitor. The first time a "lean" condition is encountered, a "pending" code and the operating conditions under which the problem occurred are stored. The pending code is converted to a confirmed code if the same condition is detected during the next trip that includes the operating conditions of the pending code. The vehicle MIL is commanded on when a confirmed code is stored. The code will be demoted to pending, and the MIL will be commanded off if three consecutive driving cycles occur without detection of the condition that resulted in the confirmed code. This is expected to occur following a repair to correct the condition causing the code. A lean mixture code is retained as pending until 80 additional cycles elapse without a repeat, to ensure correction of the problem.*

Different I/M programs treat pending and confirmed codes differently. The Georgia program records only confirmed codes, when both DTCs are present and the MIL is commanded on. Other programs store both pending and confirmed codes, and separately record if the MIL is commanded on. I/M programs use the combined storage of a DTC and presence of the MIL command signal as the condition required to consider a vehicle to have failed the I/M test. For this analysis, both the MIL command status and any stored DTCs were retained for subsequent analysis.

Next, the DTCs from the individual I/M results were coded in a consistent manner. Most programs report DTCs in up to 20 individual fields, with one code stored as DTC1, the next as DTC2, and so on. The order of codes is not specified—a P0171 code of interest could be in the first field or the 20th field. Other programs pack the results into a single string which also includes additional information, such as failure of the bulb used to illuminate the MIL. The approach used for this analysis was, to the extent possible, to put all programs on a common basis by collecting all reported DTCs together and identifying tests with one or more P0171 or P0174 codes. A test with either or both a P0171 or P0174 code was assigned a lean value of 1. Similarly, tests containing a P0172 or P0175 value were assigned a rich value of 1. The DTC commanded on was identified by assigning a 1 to the MIL status. The variables were otherwise assigned a value of 0.

Following these steps resulted in large sets of data with a verified VIN, consistently named Manufacturer/Make/Model/Model Year/displacements, consistently identified rich and lean DTCs, and MIL status. Other values collected by the various programs were removed. The resulting data sets were visually scanned to determine if significant groups of VINs had not been matched from the VIN stem table. If necessary, the VIN stem table was updated, and the process was repeated.

Vehicle description groups were then formed by combining vehicles with common Make, Model, Displacement, and engine Displacement values. The resulting records were sorted by the standardized Description groups. The previously assigned values for Lean and Rich, as well as for Lean and MIL-commanded-on, and for Rich and MIL-commanded-on, were then summed for each description group. This process

* Title 13, California Code Regulations, Section 1968.2, "Malfunction and Diagnostic System Requirements for 2004 and Subsequent Model-Year Passenger Cars, Light-Duty Trucks, and Medium-Duty Vehicles and Engines (OBD II)"

disaggregated a data set with 1,000,000 or more individual initial test records into a set of up to 5,500 individual Description groups, each with summary statistics for the number of tests, the number of lean and rich failures, and the number of lean and rich failures that also included the MIL-commanded-on signal. For example, 500 tests might be included in a given Description group; 10 tests might have had a lean DTC stored, and 5 tests might have had both a lean DTC and a MIL-commanded-on signal. This would indicate 10/500, or 2%, of this group had a pending or confirmed lean code, and 5/500 or 1% had both a lean DTC and a MIL command signal.

Results from the different calendar years for a given program were then merged into a single table. Comparisons were then made between the baseline period prior to the change in ethanol content and the period following the change. Changes in the baseline year vs. subsequent years were determined by subtracting the fraction with lean and rich codes for the baseline year from the same fraction in the "after change" year. Note that specific examples of these comparisons are presented in the Results section of this report. Actual names and engine displacements are masked. These examples are included to explain the process used to form the groups and how to use and interpret the results. Complete results (not coded) will be provided to the CRC sponsors for their use in selecting vehicles for inclusion in test programs using different fuel ethanol contents.

Analysis Recap – As stated above, the basic analysis concept was to examine whether an increasing frequency of DTCs related to lean operation would, at least for certain models, be associated with an increasing oxygen content of gasoline. Should such a trend be apparent, it would be indicative of more significant problems with oxygen contents higher than the 3.5% currently allowed in gasoline blends. It should be emphasized, however, that the trouble code frequency calculated from I/M data can significantly understate trouble code frequency in the vehicle fleet. Under state and local I/M programs, vehicles fail the inspection if the presence of one or more diagnostic trouble codes causes the MIL to be commanded on. Motorists are generally aware the MIL illumination is a cause for failure and they therefore have an incentive to address the problem before subjecting the vehicle to the I/M test. However, addressing the problem of MIL illumination in order to pass an I/M test does not mean that the source of the problem has necessarily been eliminated. It is a common practice for mechanics to clear DTCs without actually performing any repairs.

OBD system measurements and computations performed to detect specific out of tolerance conditions are called "monitors." All I/M programs allow vehicles to pass an I/M test before all of the individual monitors have had sufficient time undergo all modes of vehicle operation required to detect a fault (referred to as "complete"). EPA Guidance documents* for local I/M programs recommend passing I/M test results be permitted for later model vehicles with zero or one incomplete monitors. Older vehicles are permitted to have two incomplete monitors at the time of the test. Even though a condition exists that may eventually cause MIL illumination, the vehicle can pass a test with a monitor in "incomplete" status because there has not yet been sufficient time to evaluate system

* "Performing Onboard Diagnostic System Checks as part of a Vehicle Inspection and Maintenance Program", EPA420-R-01-015, June 2001, footnote 14, at *http://www.epa.gov/otaq/regs/im/obd/r01015.pdf*.

performance under the specific conditions required to determine whether a fault exists. While fuel trim monitoring (which triggers the P0171, P072, P0174, and P0175 codes) is performed on a "continuous" basis, it is possible for a vehicle with a recurring fuel trim problem that does not occur under all driving conditions to pass an I/M test shortly after DTCs have been cleared. As long as all but one of the monitors has run to completion, the vehicle can be recorded as passing if the intermittent fuel trim problem does not recur.

The potential for fault code clearing prior to I/M is considered significant in all I/M programs. However, centralized programs, such as the Vancouver, British Columbia and Wisconsin programs, are especially likely to produce a lower frequency of DTCs than exist in the in-use fleet. In centralized programs, testing with an illuminated MIL guarantees that the vehicle will have to return for a retest after an effort is made to correct the problem.

Decentralized I/M programs are less likely to record an unrepresentatively low frequency of DTCs because repairs can generally be performed at the same facility that performs the initial inspection. This is not the case in California. Fault code clearing prior to the I/M test is significant in the decentralized California I/M program for two reasons.

- First, California requires vehicles that are identified as belonging to a high-emitter profile group be tested at either "Test-Only" or "Gold Shield" inspection facilities. (A Gold Shield station must have no history of disciplinary actions and meet stricter testing and repair performance standards.) Since the owner is denied the option of having testing performed at a preferred repair facility, the same incentive exists for pre-inspection maintenance as exists in centralized I/M programs.

- Second, unlike other decentralized I/M programs, California's program has two tiers of tailpipe standards. One set of standards is used to determine whether a vehicle passes or fails, and a second set of standards is used to determine whether a failing vehicle will be classified as a "gross polluter." Because of long-term concerns with the effectiveness and honesty of garages participating in the California program, vehicles classified as gross polluters are required to be repaired at a "Gold Shield" station, which is a station determined to have a higher probability of properly repairing a defective vehicle. Garages that are not designated as "Gold Shield" facilities are aware that they will lose the opportunity to perform repair work on a vehicle determined to be a gross polluter during the initial I/M test. This provides the incentive for testing and repairs to be performed prior to the "official" I/M test. Clearing DTCs as part of the pre-inspection maintenance can mask potential problems with fuel trim.

Garages participating in the decentralized Atlanta program may also recognize that they can better satisfy their customers by insuring that the vehicle will pass. It is therefore possible for "pre-inspection" maintenance to be performed, which might include clearing fault codes and testing the vehicle as soon as the requisite number of "not ready" monitors (currently one, previously two) has been achieved. However, this type of pre-inspection maintenance may not be as significant because the State of Georgia requires I/M stations to test all vehicles presented, regardless of whether the MIL is illuminated. The frequency of DTCs observed in the Georgia I/M data is expected to more closely represent the actual frequency occurring in customer service.

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3. RESULTS

Although the average rates of rich and lean DTC occurrences varied between programs and calendar years, the overall trends were consistent: an increase in fuel-trim-related fault codes was observed during the time periods when increases in ethanol usage occurred, with certain groups consistently being affected more than others regardless of the geographic area. Detailed results are presented below.

3.1 Program Summaries

The transition from lower to higher ethanol occurred incrementally, over an extended period of time in Georgia (2006-2008). The analysis was focused on the change in results between CY2007 and CY2009 because that was the period over which the largest step change in ethanol content occurred. The transitions in California and Vancouver were much more distinct. In both cases, a significant change in ethanol occurred in January 2010. The California data included a transition from E6 to E10, while the Vancouver program reflects changes from E0 to E10. The Georgia and California samples are very robust (more than 1,000,000 samples per year), while the Vancouver sample is more limited. (The Vancouver sample will expand as 2010 progresses.)

As stated above, changes in I/M test results related to changes in the fuel ethanol content were determined by comparing the fraction of vehicles with fuel-trim-related fault codes in a baseline period to the fraction with fuel-trim-related fault codes after the change occurred. More specifically, the change in test results is computed for each vehicle group by subtracting the baseline fraction of vehicles with fuel-trim-related fault codes from the fraction observed after the change in fuel ethanol content is in place.

The California I/M program is decentralized, and requires vehicles to be tested every two years (biennially). Testing is waived for the first six model years for the original vehicle owner or the first four years following a change in ownership. Cars from out of state receiving their initial California registration must be tested regardless of age. Areas in California that do not meet federal ozone standards require “enhanced” inspection equipment and procedures, including ASM dynamometer loaded testing. Basic inspection areas delete the requirement for dynamometer loaded testing, including NOx measurements. Only results from enhanced areas were considered for this project.

California testing stations are designated as test and repair, test-only, or Gold Shield—each with increasingly stringent qualification requirements. Most newer vehicles are allowed to obtain initial tests and repairs at a test and repair station. Vehicles included in a High Emitter Profile are directed to test-only or Gold Shield stations for initial tests. Gold Shield stations are permitted to test, repair if required, and certify "directed" vehicles. In addition, they can issue certificates to "gross polluters" identified earlier in the inspection process, and perform state subsidized repairs.

Vehicles in the decentralized Georgia I/M program are required to be tested every year (annual). Testing is waived for the first three model years. Inspections are limited to vehicles registered in 13 counties surrounding the metropolitan Atlanta area that are designated as not in attainment of federal clean air standards. Approximately 2.5 million vehicles are tested each year. Georgia regulations include a requirement that any vehicle presented for initial inspection receive a "paid" official baseline test, even if it is evident that the vehicle will fail, including those with an illuminated MIL. Vehicles are allowed one free retest following repairs. "No-Pass, No-Pay" policies are forbidden.

The Vancouver program is centralized, and limited to the Vancouver metropolitan area. The program includes IM240 transient mass emission testing for 1992 and newer vehicles, and includes an OBDII scan for 1998 and newer vehicles. Older vehicles receive an ASM test.

The Milwaukee, Wisconsin program is limited to 1996 and newer vehicles registered in the seven-county area surrounding Milwaukee. It is a biennial OBDII only program, with a three-year new vehicle exemption.

3.2 Correcting for Pre-Inspection Maintenance

Previous studies have demonstrated that results obtained from initial tests in an I/M program usually under-represent the number of failures observed in the actual in-use vehicle population, primarily as a result of pre-inspection maintenance. California performs an ongoing roadside inspection of vehicles outside of the normal I/M program test cycle, providing a better estimate of the true proportion of vehicle failures occurring in the in-use fleet. Portable inspection stations using the same equipment and test procedures as are used in the I/M test program are located at a variety of locations throughout the state. With the assistance of the California Highway Patrol, vehicle owners are asked to participate in the test program. Vehicles receive a dynamometer test and OBDII check. Results are added to an ongoing database that is an extension of that used in the base I/M program. In 2009, Sierra Research performed an extensive analysis of California's Smog Check program using roadside testing results.[*] That analysis concluded that improper procedures and/or fraud by Smog Check inspection stations are more responsible for the differences in the results of I/M tests vs. roadside inspections than owner tampering following the roadside inspection.

The majority of samples in the roadside program are performed in accordance with a stratified random sampling approach that attempts to match the sample selected at the

[*] "Evaluation of the California Smog Check Program using Random Roadside Data", March, 2009, T. Austin et al, at *http://www.arb.ca.gov/msprog/smogcheck/march09/roadsidereport.pdf*.

time of test to the in-use vehicle population. Samples selected in accordance with the stratified sample protocol are identified in the roadside database as "STRATIFIED." All samples used in this comparison were so identified.

The period of performance for the sample used in this analysis was February 2003 through November 2009, with the majority of tests performed between 2003 and 2006. Table 3-1 displays the number of vehicle tests from each model year and the number of lean codes observed in that sample. The annual sample size was disproportionately weighted towards the earlier model years due to the program's late model year vehicle exemption policy, described above.

Table 3-1
Roadside Summary - MY 1996+

Model Year	Vehicles Tested	Lean Codes	Fraction Lean
1996	1,725	46	0.0267
1997	1,894	63	0.0333
1998	1,759	54	0.0307
1999	1,736	45	0.0259
2000	46	1	0.0217
2001	39	1	0.0256
2002	34	1	0.0294
2003	11	-	0.0000
2004	5	-	0.0000
2005	2	-	0.0000
Totals:	7,251	211	0.0291

Table 3-2 displays the results for the entire 2005 calendar year standard California I/M testing program. The fraction of vehicles with lean codes in the roadside pullover program is 0.0291, while the fraction in the basic I/M program is 0.0039—a ratio of 7.4 roadside failures per standard I/M program failure. The ratio is biased slightly high due to the stratified sampling scheme used at the roadside. A calculated ratio of 6.85:1 is obtained when the roadside results are weighted in proportion to the I/M program model year distribution for 2005.

A similar comparison of California roadside pullover results to Georgia calendar year 2005 results yields an in-use frequency of 8.48 times higher than observed in the Georgia I/M program. While this may be a result of a higher pre-inspection repair rate in that state, a more likely explanation is that Georgia begins testing after three model years and requires annual tests thereafter, resulting in more frequent vehicle repairs and fewer in-use failures than California.

Table 3-2 California I/M Program CY2005			
Model Year	Vehicles Tested	Lean Codes	Fraction Lean
1996	379,562	2,334	0.0061
1997	744,161	3,377	0.0045
1998	467,133	2,329	0.0050
1999	873,927	3,425	0.0039
2000	261,188	682	0.0026
2001	206,014	288	0.0014
2002	98,738	48	0.0005
2003	64,655	17	0.0003
2004	61,251	6	0.0001
2005	30,498	1	0.0000
2006	738	-	0.0000
Totals:	3,187,865	12,507	0.0039

3.3 Vehicle Deterioration

Attempts to identify the response to changes in fuel over extended periods of time require that normal rates of vehicle deterioration for similar time periods be examined. As noted above, results were obtained from the Georgia program for calendar years 2005 through 2009. They include all results for model year 1996 to present. As expected, test results for older vehicles in any given calendar year yield a higher proportion of fault codes than newer vehicles.

Table 3-3 summarizes the fraction of lean DTCs that each model year vehicle group achieved in each calendar year of testing between 2005 and 2009. The right-most "Slope" column indicates the average rate of increase in lean DTCs observed for the given model year—i.e., 1996 model year vehicles increase at an average rate of 0.0005 per year. The first two years of testing on any model year yield near-zero lean DTC rates, although very few vehicles receive tests because of a three-year new-car waiver. The 1996 through 1999 model year vehicles attained a very similar rate of 0.0006 per calendar year of testing. Higher change per year rates were observed in between these two model year ranges, reaching an average rate of 0.001 in the 2001 model year groups over the 2005-2009 testing interval investigated. Figures 3-1 and 3-2 emphasize these observations. What should be noted is the maximum fleet average change for any model year between two consecutive calendar years is less than or equal to 0.1%.

Table 3-3
Test Fraction with Lean DTCs (P0171/P0174)

CY \MY	2005	2006	2007	2008	2009	Slope
1996	0.0052	0.0058	0.0061	0.0068	0.0071	0.0005
1997	0.0047	0.0058	0.0062	0.0070	0.0079	0.0008
1998	0.0044	0.0052	0.0056	0.0061	0.0072	0.0007
1999	0.0046	0.0055	0.0057	0.0068	0.0067	0.0006
2000	0.0036	0.0042	0.0054	0.0063	0.0064	0.0008
2001	0.0023	0.0032	0.0045	0.0054	0.0061	**0.0010**
2002	0.0007	0.0013	0.0020	0.0027	0.0033	0.0007
2003	0.0002	0.0003	0.0009	0.0018	0.0030	0.0007
2004	-	-	0.0003	0.0008	0.0014	0.0004
2005	-	-	0.0002	0.0005	0.0008	0.0002
2006	-	-	-	0.0005	0.0005	0.0002
2007	-	-	-	-	0.0003	0.0001
2008	-	-	-	-	-	-

Figure 3-1
Fraction Lean 1996-1999 MY

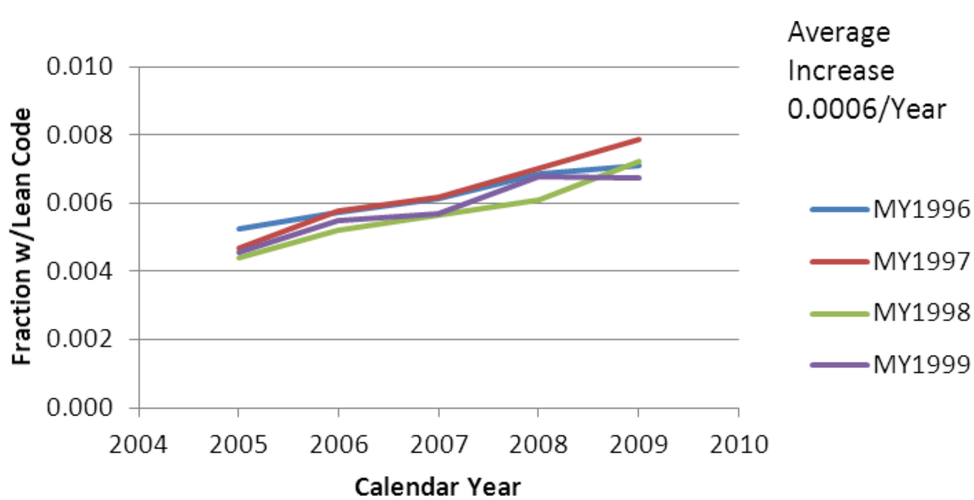
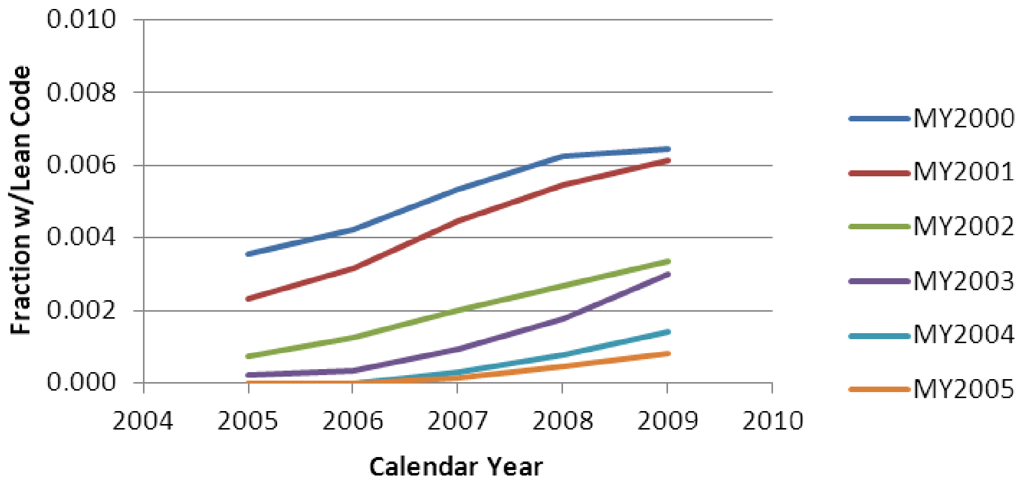


Figure 3-2
Fraction Lean 2000-2005 MY



The overall fleet trend is fairly consistent. A change 10 times higher than the observed fleet average maximum (1.0% change between calendar years) was selected as a good value to merit further investigation of any particular model year/make/engine size vehicle group.

3.4 Results by Program

The California and Vancouver results compare single calendar year periods immediately before and after a change in fuel ethanol composition. The Georgia results encompass a more extended transition period, but focus is placed on the difference between calendar year 2007 and 2009.

As previously described, the millions of individual I/M test results in the programs were assigned to specific vehicle description groups. Results within the groups were tabulated by calendar year for: (1) the number of initial tests within the group; (2) the number of occurrences of rich and lean DTCs observed within the group; and (3) the calculated fraction of initial tests with the rich and lean DTCs for the calendar years examined. The change in these fractions between two calendar years was the metric selected to identify vehicles sensitive to changes in ethanol content.

Final results were provided to the CRC technical group in spreadsheet format, with a separate tabulation for each of the programs examined. The actual make/model/displacements are coded in this report, but were provided in total to the group.

3.4.1 California Program Results

The steps performed with the California data are presented below in detail. The same steps were followed for the Georgia and Vancouver programs.

Table 3-4 summarizes the results across all groups in the California program. More than 1.25 million vehicles were inspected in a four-county/five-month subset of the statewide California results. The fraction of vehicles with lean DTCs is about 0.75%, which drops to less than 0.5% when the MIL-commanded-on is considered. The overall fleet average change between 2009 and 2010 is very close to 0.0%. Recall that these results represent the average change observed during the transition from E6 to E10.

Table 3-4
California Program Summary

Calendar Year	2009	2010	Difference
Initial Tests	1,336,317	1,483,308	-
Lean DTCs	9,936	11,441	-
Fraction Lean	0.0074	0.0077	0.0003
Lean and MIL cmd ON	6,597	7,134	-
Fraction Lean and MIL	0.0049	0.0048	(0.0001)
Rich DTCs	1,630	1,449	-
Fraction Rich	0.0012	0.0010	(0.0002)
Rich and MIL cmd ON	736	650	-
Fraction Rich and MIL	0.0006	0.0004	(0.0001)

Table 3-5 displays the column headings related to lean codes in the California data. The results displayed were obtained after sorting the results as described below.

The first column in Table 3-5 shows the group “Descriptions,” followed by the number of initial tests included in the first six months of calendar year 2009, and the first six months of calendar year 2010 (N09c and N10c). Next are the numbers of lean DTC occurrences with the MIL commanded on recorded in each calendar year (Lean09_MILc and Lean10_MILc), followed by the fraction of the total tests represented by the DTC occurrences (Plean09_MIL and Plean10_MIL). The next column (PLean_MILDiff) is the difference between the PLean10c and PLean09c columns, with positive differences reflecting an increase in the fraction found in 2010.

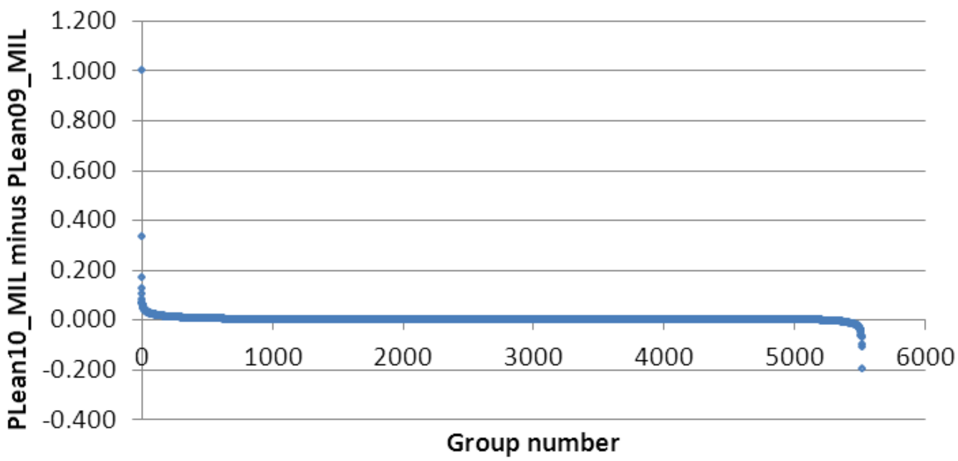
The Georgia program records only confirmed DTCs. The California program records all DTCs returned by the vehicle during the inspection, as well as a separate indication of whether the OBDII MIL light was commanded on by the system. The California results of DTC with MIL commanded on is most directly comparable to the Georgia results.

Table 3-5 Excerpt from California Results							
Description	N09c	N10c	Lean09_MILc	Lean10_MILc	PLean09_MIL	Plean10_MIL	**PLean_MILDiff**
MAKE MOD DISP 2003	388	177	0	2	0.000	0.011	**0.011**
MAKE MOD DISP 2001	2403	1087	41	33	0.017	0.030	**0.013**
MAKE MOD DISP 2003	3074	904	14	13	0.005	0.014	**0.010**
MAKE MOD DISP 2004	341	3106	0	31	0.000	0.010	**0.010**
MAKE MOD DISP 2001	593	237	9	7	0.015	0.030	**0.014**
MAKE MOD DISP 2001	763	338	8	9	0.010	0.027	**0.016**
MAKE MOD DISP MY	450	277	0	3	0.000	0.011	**0.011**
MAKE MOD DISP MY	173	198	0	3	0.000	0.015	**0.015**
MAKE MOD DISP MY	100	177	1	13	0.010	0.073	**0.063**
MAKE MOD DISP MY	443	348	4	11	0.009	0.032	**0.023**
MAKE MOD DISP MY	723	271	2	7	0.003	0.026	**0.023**
MAKE MOD DISP MY	74	171	0	4	0.000	0.023	**0.023**
MAKE MOD DISP MY	2524	998	33	27	0.013	0.027	**0.014**
MAKE MOD DISP MY	1953	565	138	50	0.071	0.088	**0.018**

Initially the results are presented in alphabetical order, beginning with vehicle make. Inspection of the unprocessed results reveals large differences in the number of vehicles in each subgroup, which resulted in very large changes in the fractions of vehicles with lean and rich DTCs from the smallest groups. For example, if a group includes only two vehicles and one of them failed the OBDII inspection, the failure rate for the group would be 50%. A more useful result would be from a group of 500 vehicles—if one additional vehicle failed, it would represent only a 0.2% change.

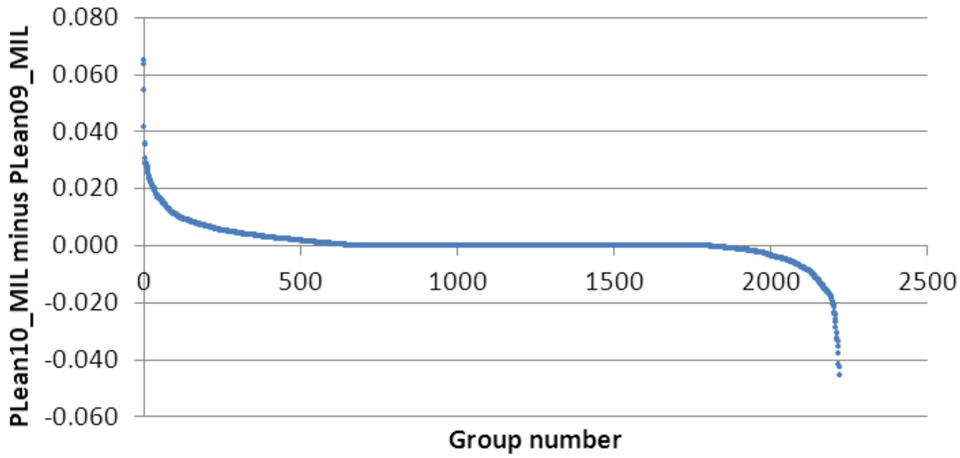
Figure 3-3 displays the range of the fraction of vehicles tested in California with confirmed (MIL on) lean DTCs between CY2009 and CY2010, after the results are sorted from highest to lowest change. The actual range in values is from +100% (for a single vehicle group with a code in 2010 but no codes in 2009) to -20% for a similar change of 1 out 5 vehicles. Any changes of note are obscured by the vast majority of more than 5000 groups with results very close to 0%.

Figure 3-3
Change in Lean DTCs with MIL - ALL GROUPS
(California Data)



Different sample size cuts were also considered. The 100-test minimum used in the original Request for Proposal proved to be a good starting point and is recommended for other users of the data. Figure 3-4 displays the change when only groups with more than 100 samples are sorted and plotted. This change leads to a 60% reduction in the number of groups−from 5,525 to 2,223. There are 114 groups with both a sample size greater than 100 and an increase in rate of Lean DTCs-with-MIL greater than 1.0%. These are the 114 groups that merit further investigation.

Figure 3-4
Change in Lean DTCs with MIL - Groups > 100
(California Data)



While Figure 3-4 shows groups with a negative Lean DTC rate, the distribution of positive and negative rates is not symmetrical, which would be expected if the changes were purely random. Figure 3-5 compares the frequencies obtained with the same information. To highlight the lack of symmetry, the decreasing fractions are plotted adjacent to the increasing fractions (i.e., the number of test groups with a +0.01 increase are plotted alongside of the number of test groups with a -0.01 [decreasing] fraction).

Figure 3-5
Frequency of Increasing and Decreasing Proportions
California I/M Program Results CY2009-CY2010

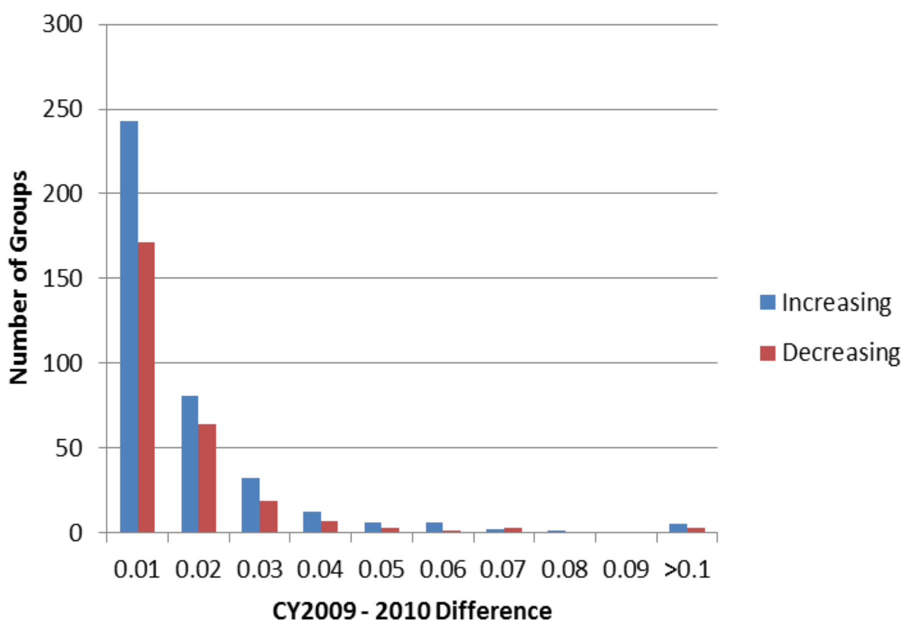
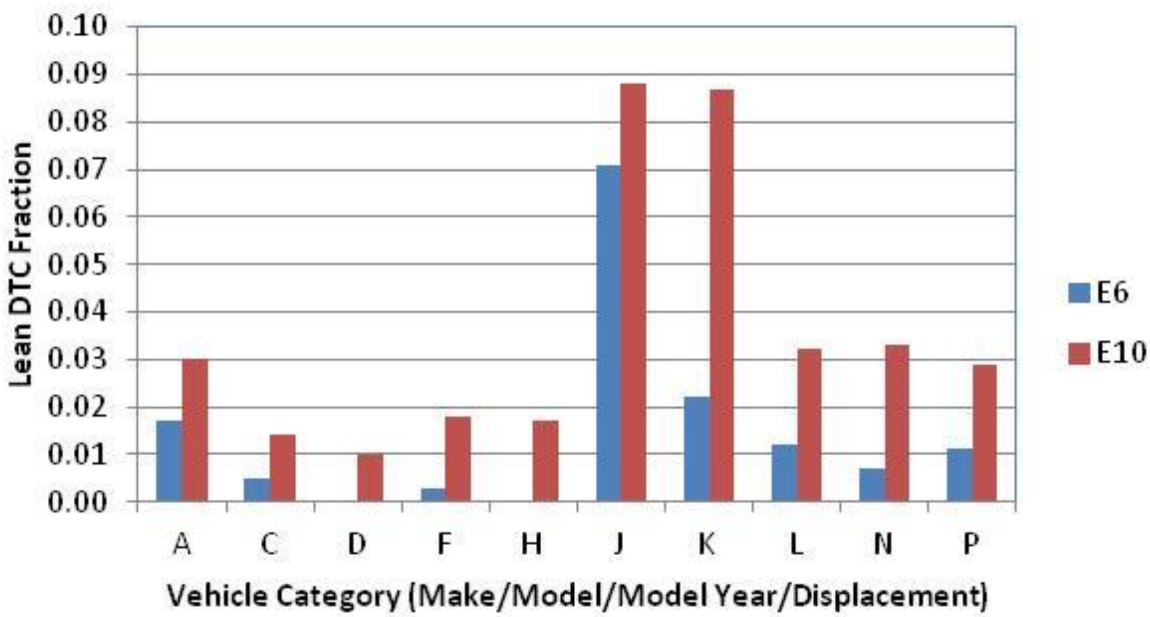


Table 3-5 shows a subset of a data set that includes more than 5,500 groups. The groups in the abbreviated set were limited to those with more than 100 samples and a change in Lean DTC fraction with MIL commanded on greater than or equal to 1%. More than 36,000 initial vehicle tests are included in this subset, with 999 Lean DTCs with MIL-commanded-on. The difference between 2009 and 2010 averaged 0.0144, with a maximum difference of 0.065 observed for one make/engine/MY combination.

Some of the groups identified were of marginal interest. The first row of the sample, reflecting the actual results for all tests of one manufacturer, had only one engine/model year combination that exceeded the 1% criterion. The 1.1% increase was actually the result of two vehicles with codes stored in 2010 versus 0 vehicles with codes stored in 2009. This group is not recommended for additional testing consideration.

Figure 3-6 shows some examples of the change in Lean DTC fraction for selected vehicle categories.

Figure 3-6
Selected California I/M Results – Lean DTC Failures
CY2009 (E6) vs. CY2010 (E10)



Other manufacturers yielded more interesting results, particularly when the same engine displacement categories appeared in consecutive model years. Groups with sample sizes greater than 1,000 tests were less affected by changes in one or two vehicles, giving more confidence to the reported changes. Confirmation of this was determined via examination of related groups falling below the 100 test/1.0% sample cut points. For example, examination of previously excluded results could be used to complete a series of groups with a “missing” model year (for example, 2001, 2003, and 2004). The 2002 results in the example would often be found to fall slightly below the 1.0% or 100 test limits.

3.4.2 Georgia Program Results

Results of the Georgia program are more complex because of the five calendar years examined, but also simplified because only confirmed DTCs with the MIL light commanded on are recorded. Table 3-6 summarizes the overall fleet results from testing in the Atlanta metropolitan area. Recall CY2005 included some MTBE usage, 2006 had no oxygenate usage, and there was increasing ethanol content from 2007 through 2009.

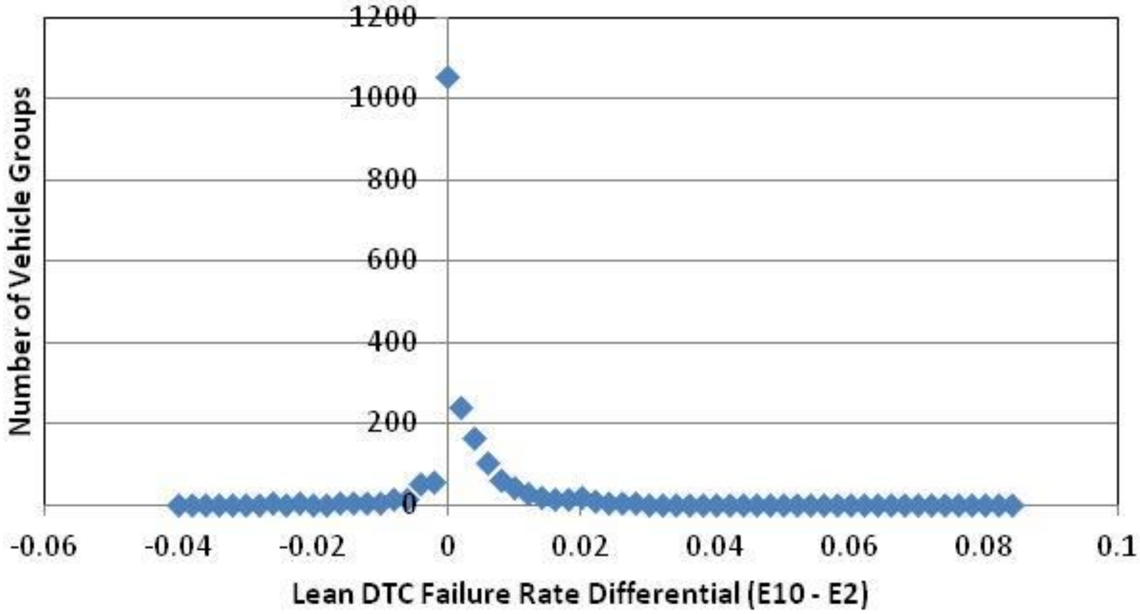
Table 3-6
Georgia Program Summary

Calendar Year	2005	2006	2007	2008	2009	2009-2007
Initial Tests	1,090,205	1,333,756	1,436,323	1,529,121	1,671,759	-
Lean and MIL cmd ON	3,741	4,705	5,320	6,007	6,601	-
Fraction Lean and MIL	0.0034	0.0035	0.0037	0.0039	0.0039	0.0002
Rich and MIL cmd On	731	830	806	730	526	-
Fraction Rich and MIL	0.0007	0.0006	0.0006	0.0005	0.0003	(0.0002)

A very small increase in Lean DTCs with MIL is seen between the 2007 and 2009 calendar year testing periods. The opposite trend exists in Rich DTCs. A slightly higher fraction of lean DTCs with MIL was observed in the overall Georgia fleet in comparison to the California results. This is consistent with the transition from E2 to E10 in Georgia, compared to the transition from E6 to E10 in California. The decrease in Rich DTCs with MIL is also larger in Georgia than California.

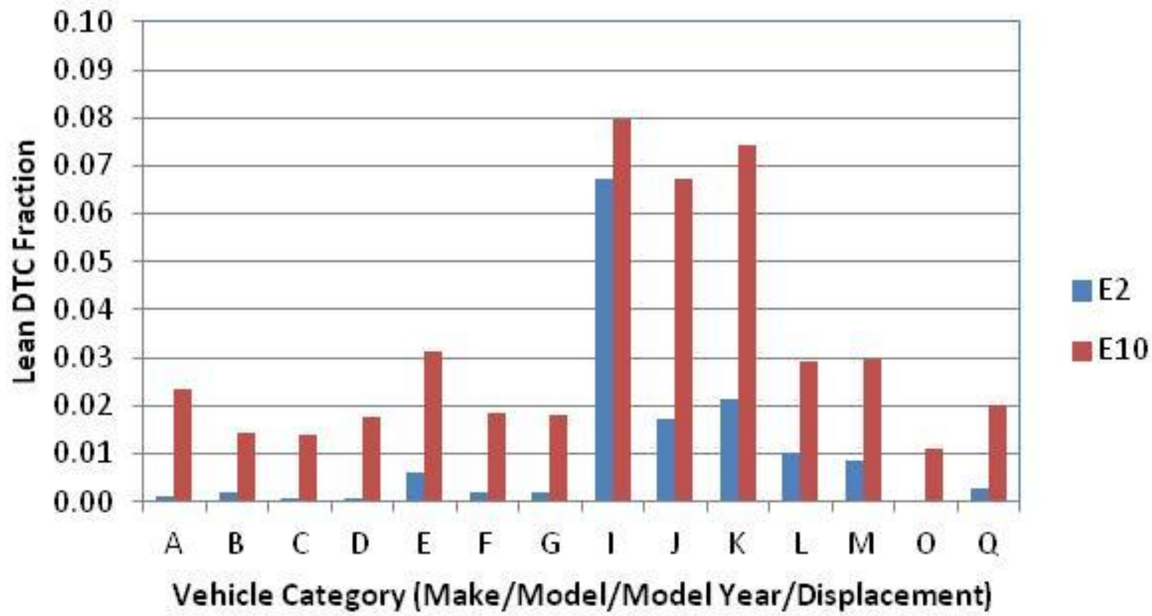
The Georgia data set was sorted using the same procedures that were applied to the California results. Initially, the results were sorted by sample size for the 2009 calendar year, and groups with fewer than 100 tests were eliminated. The results are shown in Figure 3-7.

Figure 3-7
Georgia I/M Program 2009 (E10) vs. 2007 (E2)
Lean DTC Failure Rate Differential
for Vehicle Groups with More than 100 Vehicles



The remaining groups were then sorted by the difference in fractions with Lean DTCs between the 2007 and 2009 test years. Groups with less than a 1.0% increase were again segregated. There were 137 out of the initial 4,849 groups remaining, which included 79,967 initial tests in CY2007 and 73,556 initial tests in CY2010. A total of 1,312 lean DTCs with MIL were found in 2007, and 2,331 in 2009. The average fraction rose from 1.64% to 3.17%, an increase of 1.53%. The remaining group included 4.4% of all initial tests, but accounted for 35.3% of the tests with more than a 1.0% increase in rate. Figure 3-8 shows some examples of the change in Lean DTC fraction for selected vehicle categories.

Figure 3-8
Selected Georgia I/M Results – Lean DTC Failures
CY2007 (E2) vs. CY2009 (E10)



When the groups identified in the Georgia program were compared to those identified in the California program, a number of matches were found. Table 3-7 displays several results, with make, model, and engine displacement coded. The larger change in ethanol in Georgia resulted in more groups being identified, but there was agreement across the make/model/displacement groups in many groups. While many of the groups included low-volume luxury vehicles, a number of vehicles from higher-volume makes were identified.

Table 3-7
Comparison of Selected Georgia and California Results

Model Year	Make	Model	Disp	Georgia Program - E2 to E10					California Program - E6 to E10				
				DTC 2007	DTCs 2009	Fraction 2007	Fraction 2009	Diff	DTC 2009	DTCs 2010	Fraction 2009	Fraction 2010	Diff
2001	A	21	D	1	27	0.0009	0.0236	0.0227	41	33	0.017	0.030	0.013
2002	A	21	D	2	16	0.0019	0.0143	0.0124	-	-	-	-	-
2003	A	21	D	1	17	0.0008	0.0140	0.0132	14	13	0.005	0.014	0.010
2004	A	21	D	1	21	0.0006	0.0177	0.0170	0	31	0.000	0.010	0.010
2001	A	21	E	5	26	0.0060	0.0314	0.0255	-	-	-	-	-
2002	A	21	E	1	10	0.0018	0.0185	0.0167	1	19	0.003	0.018	0.014
2003	A	21	E	1	9	0.0020	0.0181	0.0160	-	-	-	-	-
2004	A	21	E	-	-	-	-	-	0	19	0.000	0.017	0.017
2002	B	1/2 T	F	81	89	0.0671	0.0795	0.0124	-	-	-	-	-
2003	B	1/2 T	F	18	63	0.0171	0.0672	0.0501	138	50	0.071	0.088	0.018
2004	B	1/2 T	F	14	34	0.0213	0.0741	0.0528	2	68	0.022	0.087	0.065
1999	C	41	G	3	6	0.0101	0.0293	0.0192	4	8	0.012	0.032	0.020
2000	C	41	G	5	14	0.0084	0.0297	0.0212	-	-	-	-	-
1997	C	63	H	-	-	-	-	-	1	4	0.007	0.033	0.026
1999	C	64	J	0	2	0.0000	0.0112	0.0112	-	-	-	-	-
2001	C	64	J	-	-	-	-	-	5	6	0.011	0.029	0.018
2002	C	64	J	1	7	0.0026	0.0201	0.0175	-	-	-	-	-

3.4.3 Vancouver Program Results

Although the Vancouver program included a change from E0 to E10 over a short time span, the quantity of initial tests available after January 1, 2010 was insufficient to detect significant groups of vehicles sensitive to the change in ethanol.

Table 3-8
Vancouver Program Summary

Calendar Year	2009	2010	Difference
Initial Tests	98,256	83,547	-
Lean DTCs	560	468	-
Fraction Lean	0.0057	0.0056	0.0000
Lean and MIL cmd ON	459	354	-
Fraction Lean and MIL	0.0047	0.0042	0.0000
Rich DTCs	186	141	-
Fraction Rich	0.0019	0.0017	0.0000
Rich and MIL cmd ON	74	60	-
Fraction Lean and MIL	0.0008	0.0007	0.0000

Following the trend established in the larger programs, the number of Lean DTCs observed in the fleet was larger than the number of Rich DTCs. The combination of DTC presence and MIL-commanded-on status reduced the available groups substantially.

Only eight groups were identified using the procedures applied to the larger groups. Of these eight samples, three matched groups identified in other programs. No new information was gleaned from the Vancouver results.

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4. CONCLUSIONS

The primary objective of this effort, which was to determine whether I/M program results could be used to identify vehicles that are sensitive to changes in fuel ethanol content, was achieved. To accomplish this objective, areas that underwent a change in commercial gasoline ethanol content and that used OBDII in a vehicle I/M program were identified. The vehicle VIN was used to identify groups of vehicles with common characteristics affecting how well a vehicle might tolerate fuels with higher ethanol content, as indicated by certain OBD fault codes related to excessively lean operation.

Since the ability of a vehicle to operate on gasolines with a range of ethanol content is obviously related to the fuel metering and feedback control system being used, information contained in the VIN was used to group vehicles of the same make, model, engine displacement, and model year. With rare exceptions, vehicles sharing these characteristics would be expected to be using the same fuel metering system. The fraction of vehicles in each group with confirmed DTCs related to lean operation was calculated from state I/M program data before and after the point in time when an increase in ethanol content occurred. The lean DTC fraction before the change was subtracted from the fraction after the fuel change for each group. These results were summarized in spreadsheets.

Over 5,000 make-model-displacement-model year combinations were identified. The number of vehicles tested in each group varied from one to several thousand. Groups with relatively few vehicles contributed to large variations in the calculated difference in the fraction of vehicles with lean DTCs before and after a change in ethanol content. For example, if there were only ten vehicles in a group, a single vehicle could change the result to either a 10% increase or a 10% decrease in vehicles with a confirmed lean DTC.

To avoid the effect of small sample sizes, the approach outlined below is recommended for using the spreadsheet results.

- Retain the original complete results, in alphabetical order by vehicle description code. This results in groups by Make – Model – Engine size with consecutive listings for the group by model year.

- Using a copy of the original, sort by the number of vehicles tested in the two calendar years of interest. Segregate the groups with more than a selected number of vehicles from those with less. The recommended initial cut point is 100 vehicles for both the before-change and after-change groups.

- Sort the remaining group by the calculated difference. Retain only the groups with a difference greater than a selected cut point. A minimum fraction of 0.01 (1% increase) is recommended. This will provide sets of about 100 vehicle groups in both the California and Georgia program.

Use of the above-described approach leads to the conclusion that approximately 4% of OBD-equipped vehicles in the fleet are in groups that exhibit a 1% higher rate of lean DTCs when the ethanol content of gasoline is increased to 10% by volume from some lower concentration. While 4% of the vehicles were in the "sensitive" make-model-displacement-model year combinations, only 3.4% of the vehicles in those combinations actually had fuel trim-related fault codes when tested during a state I/M program. However, "pre-inspection maintenance" often results in fault codes being erased immediately before an I/M test. Based on data collected in California, there are 6.85 times more fault codes found in randomly selected vehicles tested at the roadside than are recorded during official I/M tests. (The similarity between the rate of fault codes reported by inspection stations in Georgia and California indicates that a similar amount of pre-inspection maintenance is occurring in Georgia.) Applying that ratio, we estimate that about 23% of the vehicles in the "sensitive" combinations (3.4% × 6.85) are likely to have fuel trim-related fault codes when tested on E10. That translates to about 1% of the OBD-equipped light-duty vehicle fleet (23% × 4%).

If a vehicle fuel feedback system is approaching the preprogrammed long-term fuel trim limit as the oxygenate content is increased to E10, it is likely that even more vehicles will exceed the control limit at higher oxygenate levels. If all vehicles in the sensitive combinations are affected by E10+, they would represent approximately 4% of the fleet. The extent to which other combinations would exhibit problems on E10+ is uncertain.

Although the analytical approach described above identifies the groups with the highest percent increase in lean DTCs and may produce a reasonable estimate of the fraction of OBD-equipped vehicles that are likely to experience lean DTCs on E10+, detailed examination of the results indicates that certain groups identified as being sensitive to increasing ethanol content may <u>not</u> be good candidates for testing on E10+. For example, the results for a specific group tested in one I/M program may be quite different in another I/M program. Groups that show a significant increase in lean DTCs in both I/M programs would probably be better candidates for further testing. Another example is that different model years that are known to have the same engine family might exhibit significantly different results. Although more complicated to analyze, it would be useful to examine the detailed results to determine whether a particular engine family is exhibiting different results in different models that use the same engine.

A specific example illustrating the inconsistencies that can exist in the detailed analytical results is illustrated in Table 4-1. After removing groups with fewer than 100 samples and removing groups with less than a 0.01 difference between calendar years, the single group with the greatest increase in lean DTCs associated with an increase in ethanol content was a particular 2000 model year make-model-displacement combination shown in Table 4-1 as "Group X 2000." In the California I/M program, 6.33% more of the vehicles in Group X 2000 exhibited lean DTCs when the ethanol content was increased from 6% to 10%. The results for several other model years of this same make-model-displacement combination are also shown in the table for both the California and Georgia I/M programs. The California 2000 model year results have the highest increase in lean DTCs at 0.0633. The sample size is right at the cutpoint, with 100 samples. The model years immediately before and after 2000 had differences less than 0.03, neglecting the fact that the after-change sample sizes were less than 100. The corresponding results for the Georgia program do not mirror the California results, with the 2000 model year showing only a 0.003 difference. The 1999 and 2001 model years do show close to a 0.01 difference.

Table 4-1
Examples of Inconsistent Results for the Same Engine Family

		Samples		Lean DTCs		Fraction		
Group	Program	Before	After	Before	After	Before	After	Diff.
Group X 1998	CA	173	157	0	3	0.0000	0.0191	**0.0191**
Group X 1999	CA	134	***87***	1	3	0.0075	0.0345	**0.0270**
Group X 2000	CA	**100**	**150**	**1**	**11**	**0.0100**	**0.0733**	**0.0633**
Group X 2001	CA	151	***58***	1	2	0.0066	0.0345	**0.0279**
Group X 1998	GA	*254*	*151*	*0*	*0*	*0.0000*	*0.0000*	*0.0000*
Group X 1999	GA	134	116	2	3	0.0149	0.0259	0.0109
Group X 2000	GA	***168***	***138***	***2***	***2***	***0.0119***	***0.0145***	***0.0026***
Group X 2001	GA	131	116	0	1	0.0000	0.0086	0.0086

It is unknown why 11 of the 2000 model year vehicles in California were found with the lean DTCs, but the results do not support using this make/model/displacement family in a test program. It might be informative to determine from the manufacturer if there is a difference between the California and Federal certification systems.

The spreadsheets can also be used to identify groups that show little response to ethanol changes. These could serve as control vehicles in an extended emission testing program of gasoline ethanol fuel effects. For example, 13 candidate control vehicle groups from the California data were identified by using a minimum sample criterion of 3,000 vehicles and a maximum difference between calendar years of ±0.0010. A similar analysis of the Georgia program identified 25 candidate control vehicle groups, including most of the vehicles identified in the California data. Several of the vehicles in both sets were of the same make/model/displacement groups with successive model years. These high sales volume vehicles would be easy to procure.

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Appendix A

Supplemental Analysis of Colorado I/M Program Data

A study of the impact of changes in fuel ethanol content on results obtained in Onboard Diagnostic II (OBDII) based Inspection/Maintenance (I/M) programs was performed and reported for the Coordinating Research Council and the National Renewable Energy Laboratory (NREL) under the initial phase of CRC Project E-90-2a. The study was intended to provide a means to identify vehicles that are sensitive to the addition of ethanol in gasoline. Additional laboratory testing of such vehicles is planned.

The supplemental study described in this Appendix was performed to extend the methods developed in the initial effort to the Colorado I/M program. The Colorado program was not originally selected because of concern regarding the impact of altitude on vehicle operation and the absence of a distinct change in ethanol level. OBDII results collected in the Colorado program are advisory only, but can be used to examine the relationship between fuel oxygen content and diagnostic trouble codes (DTCs) related to lean operation. As described below, the supplemental study also examined the correlation between OBD status and transient dynamometer exhaust emissions test results. A brief background from the CRC project is repeated here, followed by results specific to the Colorado program.

Introduction

The federal Renewable Fuel Standard 2 (RFS2) requires that 15.2 billion gallons of renewable fuel be used in the transportation sector by 2012. By 2022, the requirement will rise to 36 billion gallons. Using only ethanol to meet the standard would require the average ethanol content of gasoline to be greater than 10%.

Sale of commercial gasoline with up to 10% ethanol has been permitted by the US Environmental Protection Agency (EPA) for some time. Automobile designs and materials have changed over the years to generally permit operation with ethanol fuel blends at this level. In addition, a limited number of vehicles have been designed specifically to operate with up to 85% ethanol fuels. These vehicles were designed to operate with any gasoline mix between straight hydrocarbon fuel and 85% ethanol fuel. The special vehicles are commonly referred to as “Flex Fuel Vehicles” (FFVs) and EPA permits the use of blends containing 85% ethanol for such vehicles.

The US EPA and the Department of Energy (DOE) are considering an increase in the allowable level of ethanol, with levels of up to 20% under review. Preliminary testing has demonstrated that some vehicles are capable of maintaining performance and emission standards with the elevated ethanol levels, while others, particularly older legacy vehicles and gasoline powered equipment without feedback fuel control systems, are not.

CRC E-90-2a was performed to identify in-use vehicles that might be more sensitive to elevated ethanol levels, as reflected in changes in OBDII results obtained from state vehicle I/M programs. The study also identified vehicles that appear to be less sensitive to ethanol content and that can serve as a "control" group for the testing of blends with greater than 10% ethanol.

The Denver area I/M program was not originally selected for inclusion in the E-90-2a analysis because the area did not undergo a sharply defined change in ethanol content and there were concerns regarding the applicability of high altitude testing to the remainder of the nation. However, the National Renewable Energy laboratory (NREL) requested analysis of the Denver data to additionally examine the correlation between the OBD test results and the IM240 exhaust emission test results that are used to make pass/fail determinations in that program.

Commercial fuels in the Denver area, prior to 2008, had regulated levels of ethanol in the winter season to help reduce carbon monoxide emissions. Ethanol content in the summer season was at the discretion of the fuel supplier, and varied between 0 and 10% by volume. The primary objective of this effort was to apply the analytical procedures developed during the CRC E-90-2a program to determine if a difference could be discerned in OBDII results between the periods with different ethanol fuel levels. A second objective was to compare the advisory OBDII results to those results obtained from the IM240 exhaust emission test.

Alliance Commercial Fuel Properties Survey

As described in the original report prepared under Project E-90-2a, The Alliance of Automobile Manufacturers ("the Alliance") sponsors biannual surveys of commercial fuel properties for selected North American cities. Fuel samples are collected in January and July of each year. Denver is one of the cities included in the survey.

Carbon Monoxide (CO) levels in Colorado exceeded Clean Air Act National Ambient Air Quality Standards (NAAQS), triggering a requirement for oxygenated fuels during colder months. Oxygenated gasoline was mandated between November 1 and January 31. Blending practices in the state were unusual in that some suppliers opted to provide E10 throughout the year, while others chose to supply non-oxygenated fuels in the warmer months. This changed in January of 2008 when E10 was mandated for the entire year.

Table A-1 displays the Alliance fuel survey results for average ethanol content by grade in Denver for January 2005 through July 2009. Figure A-1 displays this information graphically. Average ethanol content after January 2008 is consistently between 9.5 and 10.3 volume %. The summer (July) of 2006 was selected as the low ethanol comparison period based on the sales weighted average ethanol level of 6.82 volume %. The same period in 2008 was selected as the high ethanol comparison period.

Table A-1 Average Ethanol Content (Vol %) in Denver Based on Alliance Fuel Survey Results		
Date	**Premium**	**Regular**
Jan 05	9.7	9.4
Jul 05	9.8	7.8
Jan 06	8.5	9.5
Jul 06	8.1	6.0
Jan 07	9.6	9.6
Jul 07	5.8	8.3
Jan 08	10.0	9.8
Jul 08	9.7	9.7
Jan 09	10.3	9.5
Jul 09	9.6	9.6

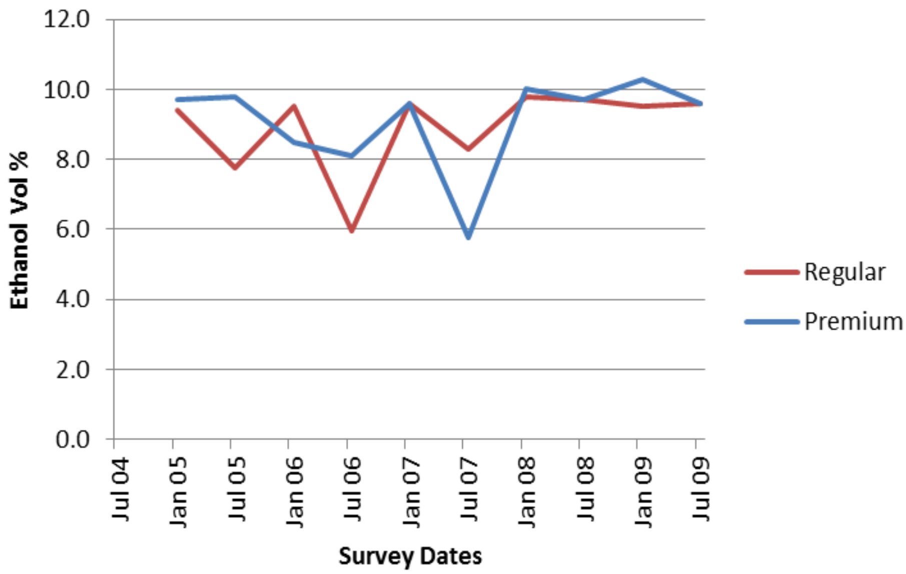
Source: Alliance of Automobile Manufacturers North American Fuel Survey

The 6.8% low ethanol value in Colorado is about 1% higher than the 5.7% low ethanol benchmark used for the California analysis. An important distinction between the two programs exists, however. In California, the 5.7% content was required for all gasolines, while in Colorado, where ethanol usage was discretionary, fuels ranged from 0.0% to 10.0+%, with an average of 6.8%. This difference means that it is not possible to assign the results of the analysis for Colorado to the average fuel ethanol content, only to infer that reductions or increases in fleet average OBDII status resulted from the subset of vehicles in the fleet operating on fuel with lower levels of ethanol.

Figure A-1 displays the average ethanol contents, highlighting July of 2006 and July of 2007 as the target periods for comparison with the other results. Fuels are regularly monitored by the State of Colorado, including ethanol content. A review of their records for the 2006 through 2008 period confirmed the overall range and averages reported by the Alliance survey.[*]

[*] Personal communication with Mr. Kim Livo, Colorado Department of Health, September 2010.

Figure A-1
Colorado Alliance Fuel Survey Results: 2005-2009



Identification of Specific DTCs to Analyze

The OBDII regulations require manufacturers to monitor the fuel control system of the vehicle,* reporting "when the adaptive feedback control has used up all of the adjustment allowed by the manufacturer." The amount of "trim" required from the fuel metering system is obviously affected by the addition of ethanol to gasoline because the oxygen content of the fuel mixture increases the amount of fuel that must be injected to achieve the target air-fuel ratio. DTCs P0171 and P0174 are used to signal when the control limit is exceeded. DTC P0171 reflects results of the "primary" engine bank, and P0174 reflects the "secondary" engine bank. All vehicles have a "primary" bank, while "V" engines (primarily 6 or 8 cylinder) designate one bank as primary and the remaining bank as secondary. Using the protocol developed for the E-90-2a project, the P0171 and P0174 were combined for this analysis. When either or both a P0171 and P0174 code was found (logical OR), the I/M test was identified as having a "Lean Code" set.

Data Analysis and Identification of Sensitive Vehicles

The raw results from the Denver I/M program were reviewed before inclusion in the final analysis. This review included segregation of initial tests by time period, identification of valid emission and OBDII results, identification of tests with a lean code stored,

* Title 13, California Code of Regulations, Section §1968.2." Malfunction and Diagnostic System Requirements--2004 and Subsequent Model-Year Passenger Cars, Light-Duty Trucks, and Medium-Duty Vehicles and Engines, paragraph e(6) FUEL SYSTEM MONITORING"

identification of tests with both a lean code and a MIL-commanded-on signal, and assignment of tests to vehicle description groups by VIN.

Initial Tests

Because a failing vehicle is normally repaired and returned for one or more retests, it is important to identify the first test on a vehicle in a given inspection cycle to avoid oversampling of failing vehicles as they pass repeatedly through the I/M process. All tests in the 90 days preceding a given test period were reviewed for each vehicle in a given test group. Any vehicle that followed a test in the preceding 90 day period was eliminated from the sample. Similarly, because vehicles are retested following change of ownership, only the first test on a vehicle in a given calendar year was retained in the sample.

As previously discussed, the summer period of 2006 was selected for comparison to the same period in 2008. The Alliance Fuel Survey is performed in July. I/M tests performed between April 15, 2006 and September 15, 2006 were used to establish the low ethanol baseline OBDII levels for Denver. These dates were selected to minimize fuel differences caused by the Cold CO fuel oxygenate mandate. The 90 days prior to April 15 were used to confirm initial OBD tests performed after the 15^{th} had not actually received a test shortly before the initial date. Any series of tests on a vehicle that were started in this 90 day period were not included in the OBDII analysis.

Tests performed between April 15, 2008 and September 15, 2008 were used as the high ethanol OBDII comparison period. Again the 90 day period prior to April 15 was used to verify only initial tests were included in the sample.

The entire 2009 calendar year was used to perform the IM240 exhaust emission to OBDII results comparison. Initial tests were also used in this analysis - results from the last ninety days in 2008 were used to identify non-initial tests.

OBDII Communication Rates

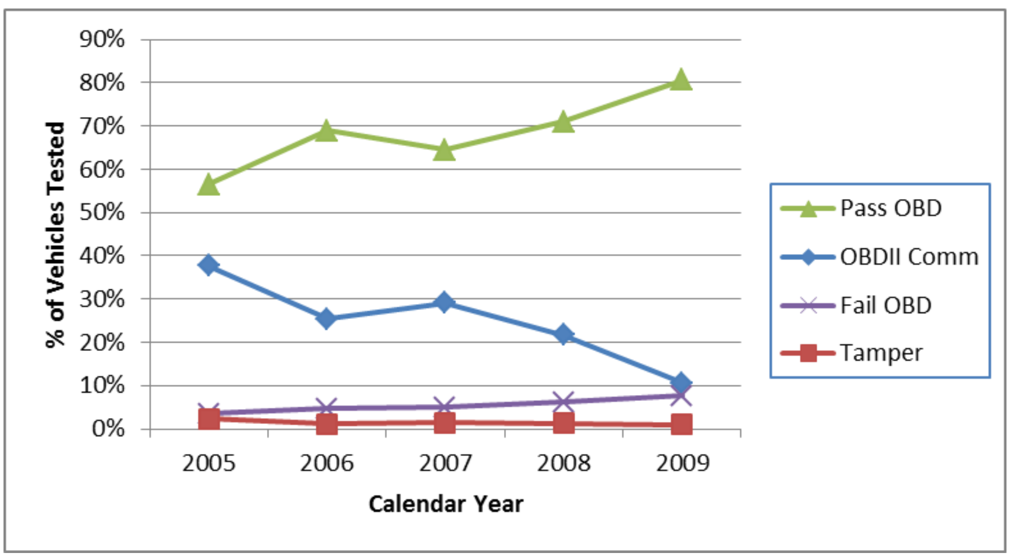
The initial review of the Colorado results revealed that a relatively high fraction of the vehicles tested did not have OBDII results associated with passing/failing emission test results. Additional follow up revealed that Colorado Department of Health staff were fully aware of this problem, and had worked with their I/M contractor to improve OBDII performance. The primary focus of the Colorado program, however, is on IM240 exhaust emission testing and related functional and visual tests. The OBDII program is advisory, and is not currently used to determine pass/fail status for a particular vehicle.

Detailed records of OBDII communication success are recorded for the 2005 – 2009 period examined. “No communication” or “partial communication” was observed on many vehicles. Some vehicle classes are bypassed (with manager approval). Additional vehicles had missing OBD data. These categories were considered together as untested. The remaining vehicles received either a pass, fail, or tampered OBDII result. Table A-2 and Figure A-2 display the relative frequencies of these results during the calendar years examined. The reported frequencies are for initial tests on vehicles with a Pass or Fail overall result. It is apparent that improvements are being made to the program over time as the percent of vehicles not receiving an OBDII test because of communications problems dropped from 37.7% to 10.7%.

Table A-2
OBDII Communication by Model Year

	2005	2006	2007	2008	2009
Missing Results	0.4%	0.3%	0.3%	0.3%	0.2%
No Communication	15.3%	3.9%	4.5%	4.0%	1.0%
Partial Communication	16.5%	17.5%	21.5%	15.1%	7.0%
Not Tested	5.5%	3.7%	2.8%	2.2%	2.5%
Untested Subtotal	37.7%	25.3%	29.0%	21.6%	10.7%
Tamper/block	2.4%	1.2%	1.5%	1.3%	1.0%
Pass	56.5%	68.9%	64.5%	71.0%	80.8%
Fail	3.5%	4.6%	5.0%	6.1%	7.7%
Number of Tests	379,901	515,115	527,207	476,100	499,896

Figure A-2
OBDII Results by Calendar Year



Emission Result to OBDII Result Comparison

The 2009 calendar year results were selected for the OBDII/Exhaust emission comparison. Because of the advisory nature of the Colorado OBDII testing, several intermediate steps were required to produce results comparable to those reported for other programs.

Both exhaust emission and OBDII results were required for the comparison. A subset of the CY2009 data was extracted in two steps. First, all results with valid exhaust emission tests were segregated by:

1. Merging all vehicle test record and vehicle OBD records.
2. Retaining only tests that yielded a "pass" or "fail" overall outcome (based on exhaust emission and other visual and functional tests).
3. Retaining vehicles that were tested using the IM240 procedure, excluding idle only tests.
4. Deleting all records with a reported VIN that did not yield a check digit matching the ninth VIN character.
5. Deleting records with a reported model year that did not match the model year specified in the 10^{th} VIN digit.
6. Retaining only the initial test on a vehicle in CY2009, considering tests performed in the last 90 days of CY2008.

Next, tests with valid OBDII results were identified. Records in which the overall OBD results were reported as "missing" were removed.

Table A-3 displays the initial comparison of OBDII and IM240 Emission results. (The "advisory" nature of the Colorado OBDII results makes it difficult to directly compare these results to mandatory I/M programs.)

In mandatory OBDII based I/M programs, communication rates average better than 99%. Those vehicles that were bypassed ("Not Tested"), and those that had no communication or partial communication were removed for this comparison. This reduced the sample size to 424,629, as displayed in Table A-4.

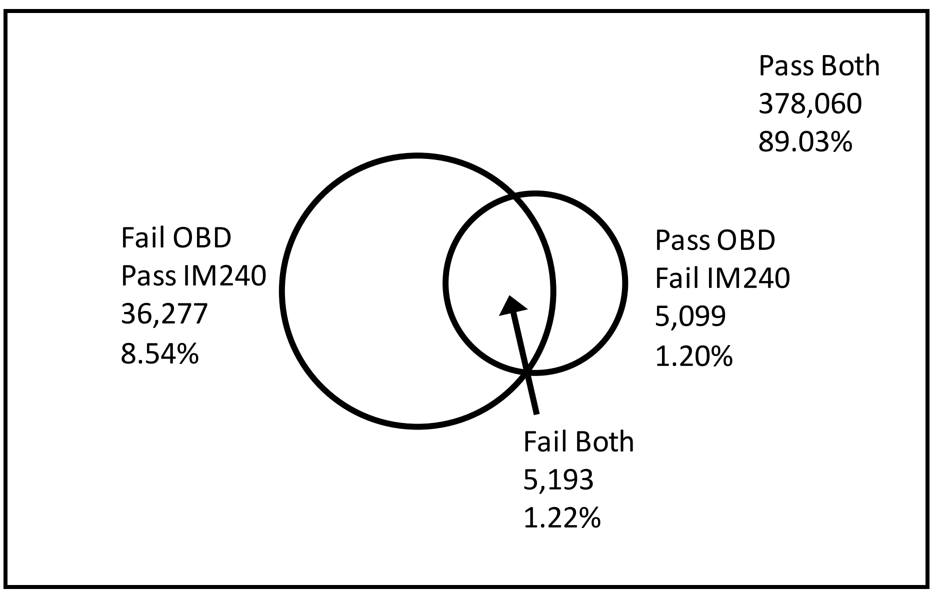
Table A-3 OBDII – IM240 Exhaust Emission Result Comparison – All vehicles (Number of Tests and per cent of Total Tests)							
	OBDII Result						
Exhaust Result	**Not Tested**	**No Comm**	**Partial Comm**	**Fail**	**Missing/ Blocked**	**Pass**	**Total**
Fail	409 0.09	125 0.03	1,309 0.28	4,971 1.06	222 0.05	5,099 1.09	12,135 2.59
Pass	8,574 1.83	4,552 0.97	28,547 6.10	32,233 6.89	4,044 0.86	378,060 80.76	456,010 97.41
Total	8,983 1.92	4,677 1.00	29,856 6.38	37,204 7.95	4,266 0.91	383,159 81.85	468,145 100.00

Table A-4 OBDII - IM240 Exhaust Emission Result Comparison Less Vehicles Not Tested or Incomplete Communication (Number of Tests and per cent of Total Tests)				
	OBD Result			
Exhaust Result	**Fail**	**Missing/ Blocked**	**Pass**	**Total**
Fail	4,971 1.17	222 0.05	5,099 1.20	10,292 2.42
Pass	32,233 7.59	4,044 0.95	378,060 89.03	414,337 97.58
Total	37,204 8.76	4,266 1.00	383,159 90.23	424,629 100.00

Finally, if a vehicle's OBDII port is damaged, missing, or blocked in a mandatory program, the vehicle fails the test. Vehicles with missing, damaged, or blocked OBDII ports were added to those identified as Fail. The final results are summarized in Table A-5 and illustrated in Figure A-3.

Table A-5 OBDII - IM240 Exhaust Emission Result Comparison Less Vehicles with Blocked/Missing OBD Port (Number of Tests and per cent of Total Tests)			
Exhaust Result	**OBD Result**		
	Fail	**Pass**	**Total**
Fail	5,193 1.22	5,099 1.20	10,292 2.42
Pass	36,277 8.54	378,060 89.03	414,337 97.58
Total	41,470 9.77	383,159 90.23	424,629 100.00

Figure A-3
Colorado Calendar Year 2009
IM240/OBDII Comparison



About 1.2% of the vehicles fail both the OBDII and IM240 test, and 89.0% pass both tests. About 8.5% of the sample fail the OBDII test but pass the IM240 test, while 1.2% pass the OBD test while failing the IM240 test.

Many more vehicles fail the OBDII test than the IM240 test. OBD systems are designed to detect a wide range of exhaust and evaporative emissions-related discrepancies before they necessarily affect exhaust emissions. In addition, the standards used for the IM240 test are set at levels associated with more significant emissions problems.

Figure A-3 illustrates that some vehicles that failed the IM240 test do not also fail the OBD test. This has the potential to cause a loss of emission reductions in I/M programs, as described in the 2001 National Research Council report titled "Evaluating Vehicle Emissions Inspection and Maintenance Programs".[*] The significance of the potential loss in benefits could not be determined by the current analysis.

One of the components of an OBDII test is the "bulb check," in which the dashboard lamp is checked without starting the vehicle engine. Normally if the vehicle failed the bulb check, the vehicle would fail the OBD check. Table A-6 and Figure A-4 summarize the results of the bulb check.

In this sample 71.4% of the vehicles failing the OBD test also failed the bulb check (29,602 of 41,470 failing OBD), which does not seem plausible. We question whether the bulb check is being performed properly. Of vehicles passing the OBD test, only 1.5% failed the bulb test. If the bulb check results are correct, 9.8% of the vehicles fail the OBD test, but only 2.8% of the fleet is being operated with an illuminated MIL light.

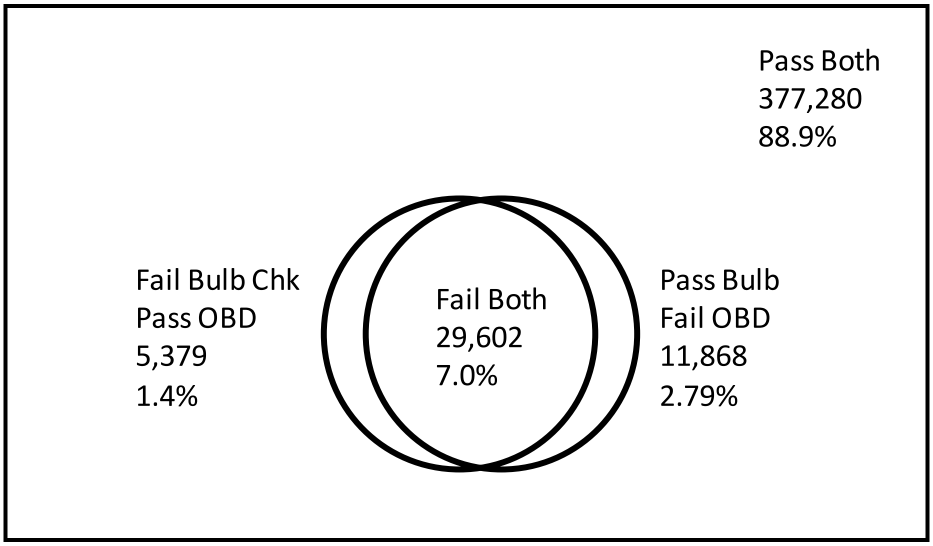
The fact that approximately half of the IM240 failures pass the OBD check may be explained by two factors. First, some vehicles may be failing the IM240 test because they have not been adequately preconditioned. Preconditioning effects are minimized, however, by immediate retests of failing IM240 vehicles. Second, it is a common practice for mechanics (and owners having the special equipment) to clear OBD fault codes to extinguish the MIL light prior to I/M testing. If monitors have not had sufficient time to run to completion, an emissions related defect may have not yet been detected at the time of the IM240 test.

Table A-6
Bulb Check – OBD Result Comparison
(Number of Tests and per cent of Total Tests)

Bulb Check	**OBD Result**		
	Fail	**Pass**	**Total**
Fail	29,602 6.97%	5,879 1.38%	35,481 8.36%
Pass	11,868 2.79%	377,280 88.85%	389,148 91.64%
Total	41,470 9.77%	383,159 90.23%	424,629 100.00%

[*] See *http://www.nap.edu/catalog.php?record_id=10133*.

Figure A-4
Bulb Check – OBD Result Comparison



The OBD and IM240 failure rates by model year are displayed in Table A-7. The OBD failure rates in the Colorado program are typical of OBD failure rates observed in other states, with high failure rates in the 1996-1998 model years, dropping to very low levels with current production vehicles. This is attributed to both deterioration in the earlier years and system design improvements in the later years. CY2009 is the first mandatory test cycle for MY2005 vehicles. The biennial nature of the Colorado program is clearly reflected in the lower number of vehicles tested in even years. Most MY2004 vehicles were tested in CY2008, and won't be required to receive another test until CY2010, with vehicles tested during change of ownership or transfer into the state smoothing the difference between calendar years over time.

The IM240 inspection results are similar to OBD trends in that they show passing results for most new vehicles and failing results for many of the oldest ones. Increases in the failure rate occur earlier with the OBD test, with noticeable increases occurring in 5 to 9 year old vehicles. The IM240 test shows a similar trend, but it occurs later - with vehicles 9 to 11 years old. Overall, the OBD test fails about 4 times more vehicles than the IM240, using current cut point and testing procedures. As reported in several earlier studies[*,†] the two inspection methods frequently do not identify the same failing vehicles: some vehicles fail

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[*] "Findings and Recommendations" and "Technical Appendix", November 2002, On-Board Diagnostics (OBD) Policy Workgroup, Mobile Source Technical Review Subcommittee, Clean Air Act Advisory Committee at *http://www.epa.gov/otaq/regs/im/obd/3-15-03_workgroup_findings.pdf* and *http://www.epa.gov/otaq/regs/im/obd/3-15-03_tech_appendix.pdf* summarizes many studies.

[†] "On-Board Diagnostics II (OBDII) and Light-Duty Vehicle Emission Related Inspection and Maintenance (I/M) Programs" D. Cope Enterprises, April 2004, prepared for Environment Canada, at *http://www.ccme.ca/assets/pdf/jia_trnsprt_obd_e.pdf*.

one procedure but pass the other, and others fail the second but pass the first. No attempt to further investigate the cause of the difference was made in this analysis.

Table A-7
CY2009 Colorado Inspection Results by Model Year

		OBD Results			IM240 (Exhaust) Results		
MY	Tested	Fail	Pass	Fail Rate	Fail	Pass	Fail Rate
1996	25,547	5,800	19,747	22.7	1,770	23,777	6.9
1997	35,719	6,636	29,083	18.6	1,957	33,762	5.5
1998	34,432	5,568	28,864	16.2	1,718	32,714	5.0
1999	43,541	5,193	38,348	11.9	1,752	41,789	4.0
2000	38,869	4,444	34,425	11.4	1,191	37,678	3.1
2001	47,682	4,921	42,761	10.3	730	46,952	1.5
2002	35,800	3,425	32,375	9.6	449	35,351	1.3
2003	49,472	2,466	47,006	5.0	274	49,198	0.6
2004	27,752	1,120	26,632	4.0	138	27,614	0.5
2005	57,848	1,392	56,456	2.4	144	57,704	0.2
2006	14,444	319	14,125	2.2	108	14,336	0.7
2007	6,821	119	6,702	1.7	30	6,791	0.4
2008	5,465	51	5,414	0.9	21	5,444	0.4
2009	1,201	16	1,185	1.3	10	1,191	0.8
2010	36	-	36	-	-	36	-
Totals	424,629	41,470	383,159	9.8	10,292	414,337	2.42

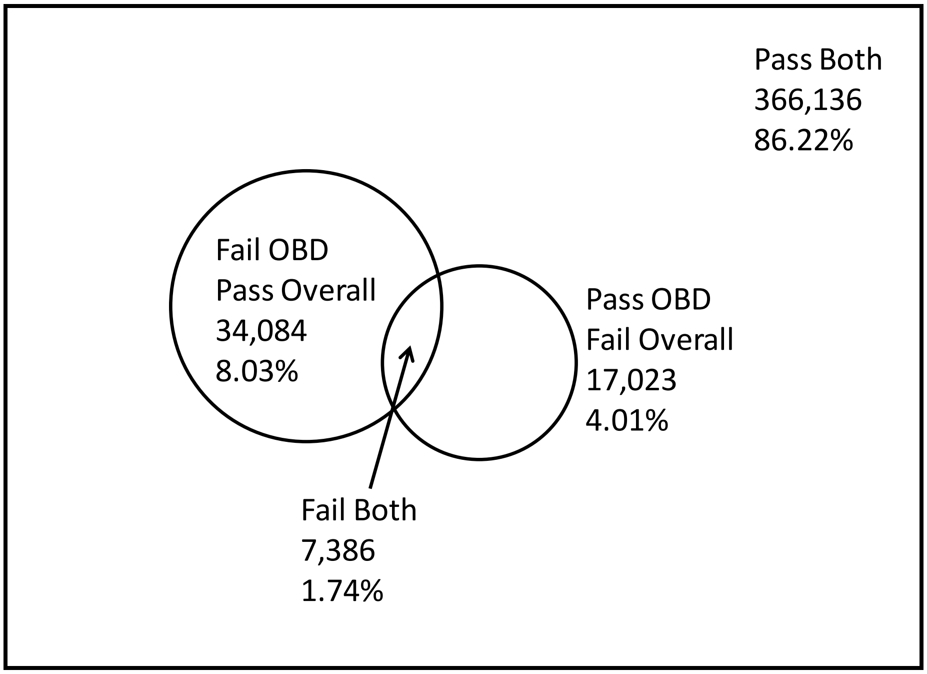
A comparison of IM240 results by individual gas (HC, CO, and NOx) is displayed in Table A-8. The fraction of vehicles failing the IM240 for HC or CO separately is slightly lower than the fraction failing NOx (0.6% vs. 0.8%). When considered together (failing either HC or CO) the fraction is nearly the same (0.8%). The ratio between passing and failing OBD results is about the same in any case, with a generally higher fraction failing the OBD test whenever a vehicle fails an IM240 test for any gas. The number of vehicles passing the OBD inspection while failing the IM240 test is due to the lack of perfect overlap between the two procedures.

Table A-8 IM240 Individual Gas Comparison to OBD Results						
IM240 Result		**OBD Result (N)**			**OBD Result (%)**	
		F	**P**	**Total**	**F**	**P**
HC	F	2,474	2,049	4,523	0.6%	0.5%
	P	38,996	381,110	420,106	9.3%	90.7%
CO	F	2,330	1,912	4,242	0.6%	0.5%
	P	39,140	381,247	420,387	9.3%	90.7%
HC or CO	F	3,184	2,850	6,034	0.8%	0.7%
	P	38,286	380,309	418,595	9.1%	90.9%
NOx	F	3,404	3,690	7,094	0.8%	0.9%
	P	38,066	379,469	417,535	9.1%	90.9%

Colorado performs a variety of different visual and functional tests during their vehicle inspection, including the IM240 procedure. Their overall pass/fail results depend on the results all of the tests. A vehicle must pass all individual tests to receive a passing result for the overall test. Table A-9 and Figure A-5 compare the overall pass/fail results to the OBDII results. In this comparison, the percent of vehicles failing the I/M test rises from 2.42% for exhaust emissions only to 5.75% for all tests combined. The largest contributor to the increase is the pressure test, with a failure rate of 4.33% in this sample. All remaining tests fail less than 0.1% of the vehicles in this sample. The poorer correlation between the OBD result and the overall result is due in part to the fact that the fuel system pressure test used in the Colorado program is more stringent than the leak detection criteria required for the OBD system.

Table A-9 Comparison of Overall I/M Results to OBD Results (Number of Tests and per cent of Total Tests)			
Overall Result	**OBD Result**		
	F	**P**	**Total**
F	7386 1.74%	17023 4.01%	24409 5.75%
P	34084 8.03%	366136 86.22%	400220 94.25%
Total	41470 9.77%	383159 90.23%	424629 100.00%

Figure A-5
Overall Program Results Compared to OBD Results



The Colorado program employs a "fast-pass" system that short circuits tests before completion if initial results are low enough to warrant the conclusion that additional testing is not required to assign a passing result to the vehicle. Many vehicles are only tested for the first 30 seconds of the 240 second test, with additional vehicles dropping out over the course of the test as soon as a passing result can be assumed. In addition, vehicles failing the first IM240 test are permitted a "second chance" test. The emission results recorded for a vehicle cannot be compared to those that would be expected for a full duration test on a fully warmed up vehicle. This makes it unreliable to correlate the gram per mile emission results of the program to the lean DTCs recorded in the advisory OBD program currently in use.

Identification of Ethanol Sensitive Vehicles from I/M Results

The primary purpose of the project E-90-2a was to identify vehicles that are sensitive to changes in fuel ethanol content using OBDII results obtained in I/M programs. OBDII systems monitor vehicle fuel system operation, and report, among others, if the fuel mixture control part of the system exceeds manufacturer specified limits for long term fuel trim. The system reports this condition with DTCs P0171 and P0174. Groups of vehicles with similar characteristics were identified using the first eight characters and the tenth character of the VIN. The results of OBD tests on these groups were tabulated, with reports of the number of tests performed and the number of tests with a report of either a P0171 or P0174 (lean DTCs). To determine the change between reporting periods, the difference in the reported fraction for the groups between the reporting periods was calculated.

The group definition included make, model, engine size, and model year. It is recognized that the VIN does not provide enough information to differentiate between different certification levels (Federal versus California, for example) of a given engine displacement. The groups typically included more than one VIN pattern, which might differ by one or more characters by trim level, or body design. Previous work and the reported description from the I/M programs were used to define the groups.

Description groups included, for example, “Chevrolet Cavalier 2.2 2001”, “Ford Focus 2.0 2003” or “Honda Civic 1.7 2002”. Only a single model year was included in a group.

The number of I/M tests on each group was tabulated by I/M program calendar year. The number of tests that included a lean DTC was also counted. For example, in 2006 there might be 1,650 tests performed on a group, with 12 lean DTCs reported for the group. The fraction lean codes for that group and calendar year would be 12/1650 = 0.0073.

Two calendar years representing the periods before and after ethanol change were selected. The impact of the ethanol change was represented by the change in the lean fraction. For example, if the year before the ethanol change included the 0.0073 fraction, and the year with the ethanol change reported a fraction of 0.0273 for the same group, the reported difference would be 0.0273 – 0.0073 = 0.0200, or 2.0%.

The Atlanta program reported a DTC only if the MIL light was commanded on. The other programs report all DTCs, with a separate report of MIL-commanded-on. Only changes for lean codes with MIL commanded on were used for this (Colorado program) analysis.

Each of the programs selected for analysis had undergone changes in ethanol levels. In Colorado, the ethanol content was not mandated in the summer of 2006, but many suppliers chose to sell an E10 blend in this period, resulting in an average ethanol level of 6.8%. By 2008, E10 was required during all seasons in Colorado, providing a period for comparison to the summer 2006 period (summer 2006 versus summer 2008).

More than 5,000 vehicle groups were identified. The change in lean DTC fraction was calculated for each group. Most of the groups did not reflect any significant change in lean DTC rates (i.e., the difference between the two calendar years was close to 0.000). The number of vehicles within groups varied from 1 to several thousand. An initial approach, found to be satisfactory with use, was to concentrate on vehicle groups with 100 or more samples in the baseline group. The vehicle groups with more than 100 samples were then sorted by decreasing change in lean DTC rate. Focus was then placed on the samples with a change in a lean DTC rate greater than 0.01, or 1.0%.

Results from Atlanta, Georgia from 2005 through 2009 provided a significant baseline to compare program results from other areas. The sample size increased steadily from about 1.1 million to 1.7 million initial vehicle tests per year over the period studied. Ethanol content changed during the period reviewed, rising from approximately 2% in 2007 to a nominal 10% level in 2009. This robust sample identified 137 vehicle groups for additional study, using the 100 vehicle sample and the change in Lean DTC rate of at least 0.01.

The State of California underwent a change from nominally 2.0% oxygen content in 2009 to 3.5% oxygen content in January of 2010. Fuel provided in the Los Angeles area reflected this change in the Alliance fuel survey. Initial tests from the area yielded more than 1.2 million initial test samples for comparison. Many of the same vehicle groups identified in the Georgia program were identified in the California program, reinforcing confidence in the procedure used. The procedure developed with the Georgia data appeared to work with a smaller change in ethanol (6% to 10% versus 2% to 10%) with 111 vehicle groups identified.

A change from 0% ethanol to 10% ethanol occurred in the much smaller Vancouver, British Columbia program in January 2010. Less than 100,000 vehicle test results were collected from comparable periods of 2009 and 2010. Only eight candidate groups were identified from Vancouver, far fewer than the number found in the Georgia and California programs. Only three of these were also detected in the larger programs. It appears as if 100,000 initial tests is too small a sample for efficient use of the procedure.

About 175,000 initial tests were drawn from the Colorado I/M program results for the summertime periods of 2006, 2007, and 2008. The wintertime periods of 2007 and 2008 yielded much smaller samples of about 70,000 and 75,000 initial tests respectively. While the winter periods are closer in time to the summer 2006 period of interest, the smaller samples obtained apparently diminished the efficiency of the procedure. A comparison of the 2006 and 2008 summer time frames, however, did identify 124 groups for additional study. Several of these groups repeated the groups identified in the Georgia and California data.

The cut points of a 100 vehicle sample and a 0.01 change in lean DTC rate were not intended to eliminate every group that random variation might identify. With 100 vehicles, only 1 reported lean DTC is required to achieve the 0.01 change. Many of the groups, however, had many more samples and higher lean DTC rates, and additional manual examination could be used to include or exclude specific groups from further consideration.

While one approach would be to sort the remaining groups by decreasing DTC rates, it was more informative to sort the remaining groups by description groups, resulting in similar make/model/engine size groups arranged by model year. Examining the groups revealed patterns by engine displacement. While there might be a “missing” model year in a series, review of the original data might reveal a group slightly under the 100 vehicle sample cut, or a fraction slightly below the 0.01 cut.

It was also useful to compare results between state programs. While not every group identified appeared in every program, again there are groups of vehicles that appear across two or three programs. These are the groups that merit consideration for inclusion in potential follow-up testing programs.

Colorado Program Results

A table of the results of the Colorado program analysis was prepared using the same procedures described for the California and Georgia programs. A total of 179,171 initial complete tests were extracted from CY2006 and 174,601 tests from CY2008. 1,440 lean DTCs were found in 2006 compared to 1,773 in 2008. The overall increase in fraction lean code was 0.0020.

The groups that included more than 100 initial tests in 2006 and which also yielded an increase in lean DTCs greater than 0.01 were segregated. The 16,361 tests in this subgroup (9%), accounted for 959 of the 1,773 lean DTCs found in 2008, (54%). The results were provided to the CRC committee in spreadsheet form.

Three I/M programs were studied in detail—California and Georgia in the base CRC program and Denver in this effort sponsored by NREL. Each analysis identified groups of vehicles with more than 100 samples and which resulted in an increase of lean DTCs greater than 0.01. These three special groups were merged into a single dataset by vehicle group. The merged table further reinforced the findings for the first two groups. Many of the vehicle groups identified in one program were also identified in a second independent program, supporting the conclusion that the identified vehicles are more sensitive to elevated ethanol fuel levels, and that the increases observed were more than random chance.

Table A-10 displays samples from the merged data sets. It should be emphasized again that the groups identified are not "Failing" or otherwise defective, but appear to be more sensitive to increases in fuel ethanol content. Each row identifies results for a single group defined by make, manufacturer, engine displacement, and model year. A key describing the column headings follows the table.

In the first row of the sample, 658 vehicles in one vehicle description group (Make/Model/Displacement/Model Year) were tested in the low ethanol year in Atlanta, 459 from the same group in the high ethanol year, with lean DTC fractions of 0.021 and 0.07—a difference of 0.053. An increase of 0.065 was found in the California program for the same vehicle description group. The Denver results for this group did meet the 100 vehicle/0.010 increase requirement.

Table A-10 highlights the correlation between the three programs. The appearance of a given vehicle group in two or three different I/M programs is a strong indication that the difference in OBDII results between the low and high ethanol time periods is more than random chance. Table A-10 is only a subset of the results—the merged table includes 124 different vehicle groups. In both the sample and the final table, however, fewer groups are found in the Colorado sample. This is a result of both the smaller number of vehicle tests performed and because of the discretionary use of E10. The majority of the vehicles in Colorado’s low ethanol period were operated on E10—the effects found are believed to result from the minority vehicles operated on E0 or low levels of ethanol.

The complete results are to be provided to CRC for use in their selection of vehicles for additional testing.

Table A-10
Selected Samples of Merged Results from Three I/M Programs Meeting Special Criteria

	Atlanta, Georgia							California							Denver, Colorado						
Group	**AN1**	**AN2**	**AC1**	**AC2**	**AP1**	**AP2**	**Adiff**	**CN1**	**CN2**	**CC1**	**CC2**	**CP1**	**CP2**	**Cdiff**	**DN1**	**DN2**	**DC1**	**DC2**	**DP1**	**DP2**	**Ddiff**
1	658	459	14	34	0.021	0.074	0.053	89	684	2	60	0.022	0.088	0.065							
2								266	338	6	14	0.023	0.041	0.019							
3	260	170	11	14	0.042	0.082	0.040	286	154	10	7	0.035	0.045	0.010							
4								99	124	2	4	0.020	0.032	0.012							
5	807	652	6	17	0.007	0.026	0.019								110	96	9	10	0.082	0.104	0.022
6	1300	1077	24	35	0.018	0.032	0.014								151	120	7	17	0.046	0.142	0.095
7								3096	714	14	11	0.005	0.015	0.011							
8	1465	1154	26	41	0.018	0.036	0.018								297	225	21	33	0.071	0.147	0.076
9	1510	1397	7	46	0.005	0.033	0.028	2524	820	33	21	0.013	0.026	0.013	137	104	0	5	0.000	0.048	0.048
10	3184	2502	53	81	0.017	0.032	0.016								548	380	11	22	0.020	0.058	0.038
11	3380	2614	163	163	0.048	0.062	0.014	3087	1686	124	85	0.040	0.050	0.010	431	376	32	35	0.074	0.093	0.019
12	842	635	7	12	0.008	0.019	0.011	443	296	4	8	0.009	0.027	0.018							
13								723	225	2	6	0.003	0.027	0.024							
14	514	380	25	25	0.049	0.066	0.017	549	257	24	15	0.044	0.058	0.015							
15	1587	1369	10	30	0.006	0.022	0.016	1256	601	27	19	0.021	0.032	0.010	232	214	6	8	0.026	0.037	0.012
16								93	110	0	2	0.000	0.018	0.018							
17	317	244	4	9	0.013	0.037	0.024														
18								147	271	2	8	0.014	0.030	0.016							
19								20	137	0	2	0.000	0.015	0.015							

xN1 = Sample size for the group before the change in ethanol content, where x = identifies the state program A, C, or D
xN2 = Sample size for the group after the change in ethanol content
xC1 = Number of vehicles found with lean DTCs in XN1 sample
xC2 = Number of vehicles found with lean DTCs in XN2 sample
xP1 = xC1 divided by xN1 (ex. 14 / 156 = 0.021)
xP2 = xC2 divided by xN2 (ex. 34 / 459 = 0.074)
xDIFF = xP2 minus xP1 (ex 0.074 – 0.021 = 0.053)