State of California
AIR RESOURCES BOARD

STAFF REPORT: INITIAL STATEMENT OF REASONS FOR PROPOSED RULEMAKING

Technical Status and Revisions to Malfunction and Diagnostic System Requirements for Passenger Cars, Light-Duty Trucks, and Medium-Duty Vehicles and Engines (OBD II) and the Emission Warranty Regulations

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I. SUMMARY OF STAFF PROPOSAL AND RELATED POLICY ISSUES

Background

Second generation on-board diagnostics (OBD II) systems consist mainly of software designed into motor vehicle on-board computers that detect emission control system malfunctions as they occur. The OBD II system monitors virtually every component and system that can cause increases in emissions. The system generally relies on information from sensors already available on the vehicle and rarely requires an additional sensor just for OBD II monitoring. When an emission-related malfunction is detected, the OBD II system alerts the vehicle operator by illuminating the malfunction indicator light (MIL) on the instrument panel. By alerting the driver of malfunctions as they occur, repairs can be made promptly, which results in fewer emissions from the vehicle. The OBD II system also stores important information that identifies the faulty component or system and the nature of the fault, which allows technicians to quickly diagnose and properly repair the problem. It also results in less expensive repairs and promotes repairs done correctly the first time, resulting in less costs to the vehicle owners.

With OBD II systems having been required on 1996 and newer vehicles, including most vehicles sold nationwide, more than 110 million vehicles are currently equipped with them. Input from manufacturers, service technicians, inspection and maintenance (I/M) programs, and in-use evaluation programs indicate that OBD II systems are very effective in finding emission problems and facilitating repairs. Accordingly, the U.S. EPA issued a final rule indicating its confidence in the performance of OBD II systems by requiring states with I/M programs to perform OBD II checks for these newer cars and allowing them to be used in lieu of current tailpipe tests. The California I/M program (Smog Check) has adopted these provisions.

The Air Resources Board (ARB or the Board) originally adopted OBD II requirements in 1989 and required all passenger cars, light-duty trucks, and medium-duty vehicles and engines to be equipped with the systems by the 1996 model year. The Board has modified the regulation in regular updates since initial adoption to address manufacturers' implementation concerns and, where needed, to strengthen specific monitoring requirements. Most recently, the Board updated the OBD II requirements in 2002 to address several concerns and issues regarding the regulation (section 1968.2, title 13, California Code of Regulations (CCR)) and establish enforcement requirements (section 1968.5, title 13, CCR). The Board also adopted heavy-duty on-board diagnostic system (HD OBD) requirements in July 2005 that will become applicable to 2010 and later heavy-duty engines. This proposal does not amend the HD OBD regulation.

Since 2002, based on its experience and input from industry, ARB staff has identified several areas in the OBD II regulation in which additional modifications would be appropriate to provide for improved emission control monitoring. The proposed changes to section 1968.2 are included herewith as Attachment A, while the proposed changes to section 1968.5 are included herewith as Attachment B. The most significant proposed modifications for gasoline and diesel vehicles are reviewed below.

Gasoline Vehicles

Staff is proposing several revisions to the OBD II requirements for gasoline vehicles. In general, the changes refine existing monitoring requirements to improve the effectiveness of OBD II systems or revise implementation dates to provide manufacturers with additional time to meet the final, more stringent requirements.

Air-Fuel Cylinder Imbalance Monitoring

The key emission control elements of current low emission gasoline vehicles are precise fuel control systems working in conjunction with very capable advanced technology catalyst systems. The fuel system must provide a single specific air-fuel mixture ratio to the catalyst under all engine operating conditions in order to achieve the low emissions required by current emission standards. Recognizing the importance of proper operation of the fuel system, the current OBD II regulation requires malfunctions to be detected when the fuel system cannot maintain emissions below 1.5 times the emission standards.

Recent field testing of vehicles, however, has revealed an in-use fuel system-related malfunction that existing OBD II systems generally cannot identify or detect even when emissions exceed 1.5 times the standards. Moreover, the current OBD II regulation has not identified such a malfunction as a specific failure mode requiring detection. The problem has been traced to cylinder-to-cylinder variations in air-fuel mixture ratio that are not properly corrected by the fuel control system. This type of malfunction or system deterioration can have a significant impact on emissions. The imbalances can be caused by fuel injector variation, unequal airflow into the cylinders, uneven exhaust gas recirculation (EGR) distribution across the engine cylinders, or effects of oxygen sensor placement in the exhaust system. The impact of these variations is that the air-fuel mixture arriving at the catalyst is not at the optimum ratio to achieve maximum efficiency of the catalyst, thereby resulting in higher emissions without detection of a malfunction because the monitors have not been designed to detect such an imbalance. Staff is proposing that manufacturers be required to detect an air-fuel cylinder imbalance in one or more cylinder that causes the fuel delivery system to be unable to maintain emissions below a specified emission level. Staff has outlined one monitoring approach in this report that relies on closer examination of oxygen sensor signals to identify when this anomaly is taking place. Appropriate lead time is being provided to phase in this new monitoring provision.

Oxygen Sensor Monitoring

The OBD II regulation currently contains monitoring requirements for oxygen sensors, which provide critical inputs to the fuel control system in order to achieve lowest emissions. One of the oxygen sensor parameters currently required to be monitored is the response rate, which is the ability of the sensor to respond quickly to changes in air-fuel mixture ratios. While the current regulation requires response rate monitoring, staff is proposing changes to the regulatory language that would more specifically identify the kinds of response rate deterioration that would need to be detected. The changes would ensure that all manufacturers are implementing the monitor uniformly and completely so that all possible means of oxygen sensor deterioration would be detected prior to emissions exceeding 1.5 times the standards. Beginning in the 2009 model year, manufacturers would need to submit data or other documentation demonstrating they have used a calibration method that would ensure that the response rate criteria are satisfied.

Results from in-use testing of vehicles by ARB staff have also reinforced the need for more rigorous monitoring of the secondary oxygen sensors used both to adjust and fine-tune the fuel control over time and to monitor the catalyst for proper operation. For secondary oxygen sensors, the regulation currently requires the diagnostic system to detect a fault, to the extent feasible, when the sensor can no longer reliably monitor the catalyst. Given the location of the sensor downstream of the catalyst, stringent monitoring of the sensor has been difficult to achieve or isolate from other effects. Accordingly staff has been accepting fairly simple “activity” diagnostics that verify minimal operation of the sensor as acceptable monitoring techniques. Unfortunately, in-use vehicles with deteriorated secondary oxygen sensors and deteriorated catalysts have been found to have high emissions and no malfunction indication. Replacement of the secondary oxygen sensor subsequently allowed the diagnostic system to detect the malfunctioning catalyst and illuminate the malfunction light. Ideally, manufacturers’ secondary oxygen sensor monitors should be able to detect and illuminate the MIL for this fault. Unfortunately, most current monitors have a “gap” in the degree of sensor deterioration between where the sensor is no longer sufficient for proper catalyst monitoring and where the sensor itself can be detected as malfunctioning. Considering that catalyst fault codes are a significant percentage of the failures found in high-mileage vehicles, the regulation needs to be modified to better inform manufacturers of what is expected of secondary oxygen sensor monitors and to avoid problems like these in the future. Improved monitoring techniques for the rear sensor have been identified as well as improved monitoring techniques for the catalyst monitor that are less sensitive to secondary sensor performance degradation. Manufacturers would be required to implement these improvements on 2009 and later model year vehicles.

Catalyst Monitoring

In the 2002 OBD II update, the Board approved the addition of a requirement to monitor the catalyst for increases in oxides of nitrogen (NOx) emissions, and lead time was provided to develop the monitoring technique. Manufacturers, however, have contended that implementing improvements to meet the final threshold of 1.75 times the NOx standard are taking longer than originally anticipated. While some manufacturers are on track to meet the original phase-in, several have discovered that more significant changes to their monitoring strategies or catalyst formulations and/or configurations are needed. Staff is, therefore, proposing to extend the intermediate malfunction threshold of 3.5 times the NOx standard for an additional two years to allow more development time needed to meet the final threshold for signaling a catalyst malfunction relative to NOx emissions.

Permanent Fault Codes

Based on feedback and experience gained from incorporating OBD II inspections into the Smog Check program and other nationwide I/M programs, staff is proposing a requirement to make it easier to distinguish vehicles that have been properly repaired from vehicles undergoing fraudulent actions aimed at avoiding a proper inspection. Currently, a technician or vehicle owner can erase all fault codes and extinguish the MIL by issuing a command from a generic scan tool plugged into the vehicle or, in many cases, simply by disconnecting the vehicle battery. These actions reset internal flags known as the "readiness status" that determine if a vehicle is ready for a Smog Check inspection. They also remove all traces of previous faults that the OBD II system had detected on the vehicle. With some minimal additional vehicle operation, the internal flags can be partially reset before a fault is re-detected. In some cases, this approach had been used to pass inspections without needed repairs being performed.

For vehicles that have a MIL illuminated for one or more faults, the staff proposal would require manufacturers to store "permanent" fault codes. Vehicle owners and technicians would not be able to clear or erase permanent fault codes by any generic or manufacturer-specific scan tool command (or by disconnecting the battery). Instead, these fault codes would only be allowed to be self-cleared by the OBD II system itself, once the monitor responsible for setting that fault code has run and passed enough times to confirm that the fault was no longer present. Permanent fault codes would allow the Smog Check program to target and reject or fail those vehicles that have recently had the malfunction light illuminated and have not subsequently been driven enough to know if the fault has been repaired correctly. While this change may not seem noteworthy on its face, the problem being addressed is a source of major lost emission reductions in Smog Check.

<u>Light-Duty Diesels</u>

Currently no light-duty diesel vehicles are sold in California, because manufacturers have not been able to comply with current low emission vehicle emission standards. However, progress in reducing diesel engine emissions is occurring, and several manufacturers have expressed a desire to introduce diesel vehicles in California as early as next year.

Current OBD II Requirements for Light-Duty Diesels

In adopting the Low Emission Vehicle II (LEV II) emission standards in 1998, the Board rejected a proposal to establish a less stringent emission standard that could be met by higher emitting light-duty diesel vehicles. This action set the precedent that all light-duty vehicles, regardless of the fuel or technology used, must meet the same emission standards. The LEV II emission standards are based on the capabilities of gasoline engines, which in general are the lowest emitting technology currently available. The current OBD II regulations also embrace this precedent by requiring diesel vehicles to meet the same monitoring requirements as gasoline vehicles.

Since the OBD II requirements were adopted, advances in diesel engine emission control technology have occurred, and vehicle manufacturers believe they can comply with the same emission standards as gasoline engine vehicles. The newly developed emission control technology, such as particulate filters and NOx selective catalytic reduction, differ greatly from the emission controls used on gasoline engines. Thus, new OBD monitoring methods have to be developed for diesels, and these have lagged the development of the emission control technology itself. As a result, light-duty diesel vehicles cannot meet the current, stringent monitoring thresholds, and thus the OBD II requirements would prevent the introduction of light-duty diesel vehicles for some time to come.

Proposed OBD II Requirements for Light-Duty Diesels

Staff believes that the goal of requiring all light-duty vehicles to comply with the same OBD II requirements is appropriate and consistent with the principle that has been applied to light-duty tailpipe emission standards. However, staff also believes that additional time is required to develop monitoring methods for new emission technologies such as those expected to be used on light-duty diesel vehicles. Thus staff has developed a set of interim monitoring thresholds (the multiple of the emission standard at which the MIL is lit) for new technologies used on diesel vehicles. The interim thresholds would end in 2013, the same year full compliance with HD OBD is required. In 2013 and beyond, light-duty diesels would have to meet the same stringent monitoring thresholds as gasoline vehicles.

Staff consulted with vehicle manufacturers regarding the technical challenges and time needed to develop fully capable OBD II monitors for light-duty diesel vehicles. Based on information received, staff has identified several pathways that should allow compliance with the proposed intermediate monitoring thresholds. For the 2007 to 2009 model years, staff is proposing monitoring thresholds that it believes are consistent with the capabilities of the vehicle manufacturers. These include thresholds as high as five times the emission standard for particulate filters and oxidation catalysts, and thresholds around three times the emission standard for many other monitors. Staff is proposing more stringent interim thresholds for 2010. These are based on projected refinement of monitoring methods learned from assessing the capabilities of the heavy-duty engine manufacturers during development of the HD OBD regulation last year and projected capability of sensor technology learned from meetings with suppliers of sensors needed for monitoring (e.g., particulate matter (PM) and NOx sensors). Staff believes that compliance with monitoring thresholds equivalent to those required of gasoline vehicles can be achieved by the 2013 model year, although the vehicle manufacturers believe they cannot be achieved before the 2016 model year. The interim thresholds have been set with an eye towards monitoring technologies that can meet the 2010 model year thresholds and be further developed in the 2010 to 2013 time frame to achieve the more stringent thresholds.

Table 1
Light-Duty Diesel OBD II Thresholds
(multiple of emission standard)

		ARB proposal
Monitor	**Model Year**	**NMHC**
NMHC catalyst	2007-2009	5.0
	2010-2012	3.0
	2013+	1.75
NOx SCR catalyst/adsorber		**NOx**
	2007-2009	3.0
	2010-2012	2.5
	2013+	1.75
PM filter		**PM**
	2007-2009	5.0
	2010-2012	4.0
	2013+	1.75

Recognizing that higher intermediate OBD II thresholds risks the possibility of increased emissions without malfunctions being detected, the amendments would require manufacturers of 2007 through 2012 model year light-duty diesel vehicles to perform emission testing on actual production vehicles to verify their compliance with the emission standard. Having the manufacturers perform this testing on all diesel vehicle models (which would be equivalent to the in-use tailpipe compliance testing done by ARB on a limited number of vehicle models each year) will provide some assurance that the vehicles, as a whole, do not have a design defect that causes them to fail to meet the base emission standards. However, it is important to note that this type of testing is intended to catch systematic failures or design defects that cause the vehicle to fail to meet the tailpipe standards during the first 120,000 miles whereas OBD II systems are intended to identify each and every vehicle in need of an emission repair for the entire life of the vehicle. Accordingly, this testing does not directly offset the reduced capability of the OBD II system. Similarly, ARB will begin to work with the Bureau of Automotive Repair (BAR) to investigate subjecting light-duty diesel vehicles to biennial SmogCheck inspections like their gasoline counterparts. Again, this would not make-up for the interim reduced OBD II system capability but would provide additional assurance that faults eventually detected by the OBD II system would be repaired.

<u>Medium-Duty Diesels</u>

Unlike the light duty vehicle class, there already is an established presence and market demand for diesels in the medium-duty segment of the market, which includes the heavier pick-up trucks and vans up to 14,000 pounds gross vehicle weight. When the OBD II regulation was first adopted in 1989, they contained provisions that all light- and medium-duty diesels would need to meet comprehensive monitoring requirements starting with the 1997 model year. Thus, medium-duty diesels have been subject to OBD II requirements for 10 years. The current OBD II regulation already contains stringent thresholds for medium-duty diesel emission control systems, including aftertreatment components that were in the early stages of development when the regulations were last updated in 2002. Continuing development of medium-duty diesel aftertreatment systems has closely followed similar efforts well underway for heavy-duty vehicle classes since engines used in medium-duty diesels are generally certified under heavy-duty engine certification procedures. Both classes need to meet very stringent emission standards, especially for PM and NOx, that take effect in the 2007 – 2010 timeframe. As stated, the Board adopted HD OBD requirements in July 2005 that are applicable starting with the 2010 model year.

To better harmonize the medium- and heavy-duty requirements, staff is proposing to amend the medium-duty requirements. Following the HD OBD regulation, the staff proposal includes more specificity in the OBD II regulation to ensure robust and uniform monitoring strategies across all manufacturers but also provides, in most cases, a relaxation in the emission malfunction thresholds.

The OBD II requirements for medium-duty diesel vehicles, which began in 1997, generally reflected the same level of stringency as that for gasoline vehicles, although there were significantly fewer emission-related monitors because diesels had fewer emission controls. At the time of the 2002 Board hearing update, relatively little was certain about the emission control technologies that manufacturers would incorporate on diesel engines to meet the newly adopted 2007 emission standards; accordingly, OBD II thresholds continued to be patterned largely after the relative stringency used for gasoline vehicles. In order to set emission thresholds for the 2005 HD OBD rulemaking, staff worked with industry to better understand the technologies that were maturing and becoming more likely to be placed into production to meet the new stringent 2007 heavy-duty tailpipe standards. With the information gained, staff proposed, and the Board adopted, technically feasible emission malfunction thresholds appropriate for the new emission controls and the resources available to industry that ended up being less stringent than those originally projected in 2002 (and currently adopted) for medium-duty diesels. Since the emission control technologies will be similar for diesels in both the medium- and heavy-duty classes, staff concluded that the medium-duty OBD II thresholds should be consistent with those adopted for HD OBD. As a result, staff is proposing less stringent thresholds for medium-duty diesels than were adopted in the 2002 rulemaking. On the other hand, staff is also proposing substantially more detailed and rigorous monitoring requirements. For example, rather than specifying the fuel system to be monitored for faults that could cause emissions to increase beyond 1.5 times the standard, the proposal would require OBD II systems to specifically evaluate fuel injection pressure, timing, and quantity for malfunctions that would cause increases in emissions above specified thresholds to ensure uniform and complete fuel system evaluation among all manufacturers.

While heavy duty manufacturers will first be incorporating OBD systems in 2010, medium-duty diesel manufacturers have been implementing OBD II systems for a decade. As such, the OBD II proposal includes threshold monitoring requirements for the major emission related components starting in the 2007 model year rather than in the 2010 model year. Medium-duty manufacturers argue that these thresholds should be delayed until 2010 to match the HD OBD phase-in. However, the medium-duty manufacturers have had greater experience in developing OBD II systems and should have been working on solutions to monitoring requirements for some time given the existing OBD II regulations and the pending 2007 emission standards that drive new emission control technologies. Therefore, staff is proposing that medium duty engines comply with monitoring requirements for the technologies needed to meet the 2007 standards, but is proposing significantly less stringent thresholds for the 2007 through 2009 model years. Staff expects most manufacturers would be able to meet these less stringent thresholds in the early years based on initial certification information that has been received for the 2007 model year. In 2010, medium-duty diesels would be required to generally meet the same thresholds that are required for the first year phase-in of HD OBD.

Other Diesel Vehicle Issues

Staff's proposed amendments also include two other noteworthy items that apply to both light- and medium-duty diesel vehicles. The first item pertains to adjustment factors that are required for diesel emission testing and the second item involves tracking and reporting of particular engine operating conditions. Both items have been subject to additional discussions with manufacturers and are generally opposed in some form or another by the manufacturers.

Emission Adjustment Factors

A unique feature of several of the new emission controls evolving for diesel vehicles in the 2007 and subsequent model year time frame is the requirement of infrequent, but periodic, activation under specific conditions to regenerate or purge stored emissions. The most common of these is the PM filter which typically requires an active regeneration event every 300 to 500 miles to burn off the accumulated soot. Other examples include NOx aftertreatment emission controls such as NOx adsorbers which periodically require a desulphurization event. When these active events occur, tailpipe emissions can increase dramatically, exceeding the allowable tailpipe standards. However, since these events occur infrequently, the emission test procedures proscribe a method to account for the additional emissions. Essentially, the procedures require a manufacturer to determine the frequency of the events, to measure the incremental emissions from the event, and to add the appropriate fraction of the incremental emissions to all emission tests conducted without the event. For example, an event may happen once every ten emission tests and cause incremental emissions of 1.3 g/bhp-hr NOx. The emission test procedures would require one-tenth of the 1.3 g/bhp-hr increase, or 0.13 g/bhp-hr, to be added to emission test results obtained without the event, and this total would be compared to the tailpipe emission standard.

This method allows the excess emissions generated during the event to be spread out across all emission tests between successive events to provide a representative average emission level from the vehicle.

Under the staff's proposal, vehicle manufacturers would need to also utilize this adjustment procedure when calibrating OBD II monitors that are tied to emission thresholds. This ensures that when a manufacturer calibrates a system to detect a fault at 1.5 times the standard, for example, the actual average emissions from the vehicle at the point it detects the fault would indeed be at or below 1.5 times the standard. If manufacturers did not include the adjustment factor in determining the calibration, the actual average in-use emissions when the fault is detected would be at some unknown level greater than 1.5 times the standard.

As an additional complication, the component for which the manufacturer is developing the calibration (e.g., a malfunctioning fuel system) could cause an appreciable change to the infrequent event (either increasing or decreasing the frequency with which the event occurs or altering the incremental emissions generated during the event). Using the PM filter regeneration event example described above, a manufacturer working on a fuel system pressure malfunction calibration may find that engine-out PM emissions are greatly increased when the failure occurs. Consequently, the PM filter will accumulate soot at a much higher rate, thus triggering the regeneration event to occur more frequently. If the event were to now occur once every five emission tests instead of once every ten, the adjustment factor would increase from one-tenth of 1.3 g/bhp-hr to one-fifth of 1.3g/bhp-hr, or 0.26 g/bhp-hr. Accordingly, the manufacturer would not only have to use the adjustment factors when calibrating OBD II emission threshold monitors but would also have to recalculate the appropriate adjustment factor for the specific component being calibrated.

For some monitors, staff expects that this calibration scenario will not occur and accordingly will have no impact on the infrequent events (and thus, no recalculation of the original adjustment factors). For other monitors, staff expects this may alter the frequency of the event or the incremental emissions generated during the event. In rare cases, it may even affect both the frequency and the incremental emissions. In any case, failure to properly account for the infrequent events would result in the systems being calibrated at unrepresentative emission levels, so actual average in-use emission levels when faults are detected would be unknown. Proper determination of adjustment factors is also necessary to be able to effectively perform enforcement testing. Use of incorrect adjustment factors would lead to incorrect emission measurements and incorrect findings of compliance (or noncompliance).

While manufacturers have agreed that, technically, it is appropriate to account for such events in the manner noted above, manufacturers have argued that the additional testing time and resources to properly determine the adjustment factors are significant and that they do not have any available time or resources to devote to it. Given that the impact of the adjustment factors on the emission results can be very large and that a consistent policy for effective enforcement testing is needed, staff's proposal does require the use of adjustment factors for OBD II thresholds for all 2007 and subsequent model year vehicles. However, to provide manufacturers with interim relief to be able to better utilize available resources, several changes are proposed.

First, for the 2007 model year, manufacturers would be allowed on all emission threshold monitors to utilize the baseline adjustment factors that they were required to calculate for determining compliance with the tailpipe standards. Thus, manufacturers would not incur any additional time or resources in recalculating the adjustment factors and would simply need to add in the adjustment factor when calibrating the OBD II monitors.

Second, starting in the 2008 model year, manufacturers would be able to continue to use the baseline adjustment factors for all monitors except the oxidation catalyst monitor. For this catalyst monitor, manufacturers would be required to recalculate the adjustment factors appropriate for a malfunctioning catalyst. Staff selected this monitor because the catalyst can have an extremely large impact on the incremental emissions generated during a regeneration event and almost no impact on the emission tests between events. Further, most manufacturers are designing this monitor to run and complete during a PM filter regeneration event and, thus, are already focusing their calibration and testing of the catalyst on emission tests with a regeneration event occurring (which are the exact data predominantly needed to be able to properly recalculate the adjustment factors).

Lastly, manufacturers would be required to determine appropriate adjustment factors for all OBD II emission threshold monitors starting with the 2010 model year. As noted before, staff expects some monitors will have no, or a negligible impact on the regeneration events and thus require no recalculation of adjustment factors. Others will require manufacturers to either measure emission during a regeneration event (to determine if the incremental emissions are changed) and to assess engine out emission levels (to determine if regeneration frequency is likely to be impacted). Manufacturers will likely be able to achieve much of this by engineering evaluation with their knowledge of the triggers for the regeneration events and comparison measurements or calculations to the baseline system. This would ensure that, from 2010 on, in-use emission levels when a fault is detected will actually be at the required levels.

Tracking of Engine Run Time

Another item in the proposed amendments requires tracking of various engine operating conditions in the engine computer itself and reporting out of the stored data to a standardized scan tool (used by technicians, inspectors, etc.). Under the current emission standards and certification procedures, manufacturers are allowed to implement auxiliary emission control devices (AECDs) that are typically software strategies that alter the way the engine or its emission controls work when specific conditions are met. Manufacturers are required to seek ARB approval of all of their AECDs and submit details of the strategies during certification including a subset of AECDs which are justified by the manufacturer as necessary to protect the vehicle, engine, or other emission control components from damage. Often times, these protection AECDs deactivate or substantially diminish the effectiveness of the emission controls, leading to large increases in tailpipe emissions when they are activated. To minimize any adverse emission impact in-use, ARB certification staff must thoroughly evaluate the submitted AECDs, understand all the nuances of the strategy, and ensure that activation of the AECDs are limited to only those conditions where it is absolutely necessary. Further, staff must ensure that the system is robustly designed and is not using or relying on protection AECDs to bolster an otherwise under-designed or “frail” system. To aid the certification staff in consistent evaluation and usage of such AECDs especially as new emission controls emerge at such a rapid pace, the proposed amendments would require the OBD II system to keep track of how often the subset of AECDs with the most potential for adverse emission impact are activated.

Specifically, the system would only need to track operation of AECDs that are: (a) justified by the manufacturer as necessary to avoid vehicle, engine, or emission control component damage; (b) that are not activated substantially during the emission test; and (c) that reduce the effectiveness of the emission control system. For each such “emission-increasing” AECD (EI-AECD), the system would keep track of the cumulative engine run time that the strategy has been activated. During inspections or other programs, the data could be read-out from the vehicle’s computer and staff would be able to see the actual in-use frequency of operation of these strategies that increase emissions. Strategies that are activated more frequently than originally estimated by the manufacturer (and documented at the time of certification) would warrant further investigation and trigger the need to be re-evaluated prior to approving future model year vehicles using the same strategy. Large differences in activation time between various manufacturers’ EI-AECDs would also warrant further investigation to determine if the inequity is a result of a manufacturer using a system that is inadequately designed and is utilizing an EI-AECD to make-up for it.

Manufacturers have voiced considerable objection to this requirement. Manufacturers have stated that the OBD II regulation is an inappropriate regulation to include such a requirement. While staff believes it is the appropriate place for it as it is the only regulation that proscribes information that must be stored and read-out from the on-board computer in a standardized format, staff has also offered to rename the regulation and/or create a unique regulation in title 13 during this rulemaking. Manufacturers have rejected such alternatives as not solving the concern.

Manufacturers have also argued that AECD strategies are highly confidential and this requirement will make it easier for competitors to reverse engineer the strategies. However, the proposed requirement is to keep track of cumulative time when such strategies are active and, at the end of each driving cycle, update the counters. There is no real-time indication during vehicle operation as to when such strategies are or are not active. Accordingly, the most a competitor can do is look at the counters at the end of each trip and determine how much total time during the previous trip an EI-AECD was active—but not any idea of when it actually happened. Further, the tracking will be reported as “EI-AECD #n”, giving the competitor no knowledge as to what the system actually sensed or what action it took (e.g., sensed that engine oil temperature exceeded xxx°F and closed the EGR valve as a result). The competitor would be better able to reverse-engineer the system by simply measuring tailpipe emissions (and looking for spikes when they happen in real-time) or by monitoring the emission controls for deactivation (e.g., watching for the EGR valve to close).

Lastly, manufacturers have argued that this is a "data-logging" experiment that is not needed to be installed on every vehicle and could just as effectively be gathered with special equipment on a few vehicles. Staff's experience with the strategies being used and planned for many of the new diesel emission control technologies is that they are very difficult to assess as to expected in-use frequency and can vary greatly based on driver habits, vehicle usage patterns (e.g., trucks used for towing or delivery or as a daily commuter), and even atmospheric conditions (e.g., temperature, elevation, terrain). In fact, the manufacturers themselves have often argued that such wide variances in usage patterns and driver habits have justified the need for less stringent monitoring requirements and/or larger tolerances. Accordingly, the same representative data could not be gathered from a few trucks with data-logging equipment. Further, many of the on-board computers used with diesel engines already keep track of items like total engine run time, engine idle time, and various other subsets of engine run time. Adding additional counters for each EI-AECD is a relatively insignificant additional burden on the engine computer software and hardware.

Other Items

Staff is proposing to amend the OBD II enforcement regulation (section 1968.5, title 13, CCR), which is included herewith as Attachment B, to align the enforcement provisions, as necessary, with the proposed changes to the OBD II regulation (section 1968.2, title 13, CCR). Additionally, the staff is proposing to delete reference to the "procedures of the California I/M program" from the mandatory recall provisions related to I/M testing and instead list the specific criteria of OBD II noncompliances related to conducting Smog Check inspections that would result in mandatory recall. The staff is also proposing more appropriate in-use thresholds (i.e., thresholds at which a vehicle would be found to have a nonconforming OBD II system and would be subject to possible enforcement action) for OBD II emission testing of diesel vehicles certified to the higher interim malfunction thresholds required for the 2007 through the 2012 model years.

Staff is also proposing to revise the emission warranty regulations, which are included herewith as Attachment C, to update references to "emission-related parts" to better account for changing emission control technology over time. Current warranty provisions have both a "performance" and a "defects" provision for warranty coverage. Under the "performance" provision, any vehicle that fails a Smog Check test within 3 years/50,000 miles would receive repairs covered by the vehicle manufacturer. Under the "defects" provision, vehicles that have defects in emission components or that cause the OBD II MIL to illuminate would also be repaired by the manufacturer for 3 years/50,000 miles. Further, under the "defects" provision, any vehicle that has an emission defect before 7 years/70,000 miles would be covered under warranty if the defect meets specific inflation-adjusted cost limits to repair. To be eligible for this "high cost" warranty provision, however, the defective part must be contained on a warranty parts list maintained by the Board staff. Unfortunately, the list is often not up to date and may not include new technologies that should be on the list. Therefore, staff is proposing to eliminate the out-of-date warranty parts list and simply extend the "high cost" warranty to parts that exceed the specific inflation-adjusted cost limits to repair and are covered by the 3 year/50,000 mile "defect" warranty coverage. What this means is essentially any defective part that turns on the OBD II malfunction light and is a "high cost part" would automatically receive warranty coverage for 7 years/70,000 miles. Consumers would benefit from simplifying the eligibility determination since there would be less doubt about what parts are covered under the proposed revision. Additionally, manufacturers could no longer deny warranty coverage on newer technology vehicles such as hybrid vehicles simply because parts that should have been on the parts list were not present or the company name of a part was slightly different than the description of the part contained on the list, etc.

<u>Summary of Impacts</u>

Environmental Impacts and Environmental Justice Issues

Staff anticipates that the proposed amendments to the regulations will help ensure that measurable emission benefits are achieved both statewide and in the South Coast Air Basin. Monitoring of a motor vehicle's emission control system through the use of OBD II systems helps ensure that vehicles initially certified to the very low and near-zero emission standards maintain their performance throughout the entire vehicle life. Since the amendments are designed to reduce emissions statewide, it should not adversely impact any community in the State, including low-income or minority communities.

Cost Impact

Regarding costs, staff does not expect the proposed revisions will result in any adverse economic impacts. Compliance costs for gasoline light- and medium-duty vehicles should not be affected by the proposed amendments as they generally restructure and clarify currently adopted OBD II requirements. Further, several of the proposed amendments might lessen the overall cost impact of the current regulation by providing additional lead time to manufacturers. The compliance costs for light-duty diesel vehicles were not estimated because gasoline engines provide the basic compliance path, and light-duty diesels are an alternative technology that will be used only if the manufacturer finds it cost-effective. Compliance costs for diesel medium-duty engines have been estimated by staff to add $153 to the retail price of a new vehicle, while compliance costs for light-duty diesel vehicles have been estimated to add $140 to the retail price of a new vehicle. Considering the minimal cost per vehicle increase, the proposed amendments are not expected to significantly alter previously calculated emission benefits or findings. Therefore, the combined benefit of the LEV II and OBD II programs that was estimated in 2002 to result in 57 tons per day reduction of reactive organic gases (ROG) + NOx in the South Coast Air Basin and cost $2.18 per pound of ROG + NOx should still apply.

Economic Impact

Overall, the proposed amendments to the regulations are expected to have no noticeable impact on the profitability of automobile manufacturers. These manufacturers are large and are mostly located outside California although some have some operations in California. The proposed changes involve minimal development and verification of software, minimal hardware modifications, and staff has provided adequate lead times to implement the requirements. Staff believes, therefore, that the proposed amendments would cause no noticeable adverse impact in California employment, business status, and competitiveness.

II. TECHNICAL STATUS AND PROPOSED REVISIONS TO MONITORING SYSTEM REQUIREMENTS FOR GASOLINE/SPARK-IGNITED ENGINES

Since its inception on 1996 model year vehicles, OBD II systems on gasoline vehicles have matured greatly and have proven very effective in finding emission problems in-use and facilitating repairs. Accordingly, the staff is proposing minimal revisions to the current gasoline OBD II system requirements. These proposed changes consist primarily of one new monitoring requirement (air-fuel ratio cylinder imbalance), one new feature for I/M testing, extension of leadtimes and phase-in schedules for a few of the current requirements, and enhancements and clarifications of the current language where needed to help manufacturers better understand the requirements and ensure consistency between manufacturers' diagnostic system capability.

A. <u>CATALYST MONITORING</u>

Virtually all OBD II-equipped vehicles use three-way catalysts (i.e., catalyst systems that simultaneously convert hydrocarbons (HC), carbon monoxide (CO), and NOx). The regulation currently requires monitoring of HC and NOx conversion efficiency on all LEV II vehicles. Regarding NOx conversion efficiency monitoring, manufacturers are required to indicate a malfunction before NOx emissions exceed 3.5 times the standard for 2005 and 2006 model year vehicles and before NOx emissions exceed 1.75 times the standard for 2007 and subsequent model year vehicles (except for passenger car/light-duty truck SULEV II vehicles, which have a threshold of 2.5 times the NOx standard). When this requirement was adopted in 2002, ARB had provided industry with what it considered sufficient leadtime to meet this requirement. Manufacturers, however, have contended that implementing improvements to meet the threshold of 1.75 times the NOx standard is taking longer than originally anticipated. While some manufacturers are still on track to meet the original phase-in, several have discovered that more significant changes to their monitor strategies and/or catalyst formulations are necessary than their early development suggested. As such, changes to extend the phase-in have been proposed. Specifically, these changes would allow the higher interim threshold of 3.5 times the NOx standard to be used for an additional two model years (i.e., 2007 and 2008 model years) and to allow carry-over of those calibrations until the 2010 model year. This additional phase-in time should allow all manufacturers to make any further changes needed to comply with the final threshold of 1.75 times the NOx standard in the 2009 and 2010 model years.

B. EVAPORATIVE SYSTEM MONITORING

The OBD II regulation currently requires monitoring of the complete evaporative system for vapor leaks to the atmosphere as well as verification of proper function of the purge valve. Traditionally, vehicles have used a single purge path to purge vapor from the system to the engine. However, some newer engines, especially turbo-charged engines, have implemented two paths to ensure sufficient purge during boost operation. For vehicles that rely on the proper function of both paths to maintain in-use emission levels, the requirement has been clarified to ensure that both purge paths are monitored.

C. SECONDARY AIR SYSTEM MONITORING

Secondary air systems are used on vehicles to reduce cold start exhaust emissions and typically consist of an electric air pump, hoses, and a check valve(s) to deliver outside air to the exhaust system upstream of the catalytic converter(s). The OBD II regulation currently requires manufacturers to monitor the “air flow” delivered by the secondary air system and, in cases where there are more than one delivery hose (e.g., one to each side, or bank, of a V-6 engine), to verify that the proper amount of air is delivered through each hose. Industry, however, questioned the necessity of monitoring the air flow to each bank of the engine in cases where complete blockage of air delivery to one bank does not affect emissions. Thus, the staff is proposing modified language to exempt detection of flow to both banks if the manufacturer can show that complete blockage of air delivery to one bank does not cause a measurable increase in emissions.

D. AIR-FUEL RATIO CYLINDER IMBALANCE MONITORING

An important part of the emission control system on gasoline vehicles is the fuel system. Proper delivery of fuel is essential to maintain stoichiometric operation, maximize catalytic converter efficiency, and minimize tail pipe emissions. As such, the OBD II regulation has always required fuel system malfunctions to be detected when the fuel system cannot maintain emissions below 1.5 times the standards.

Recently, field testing has revealed in-use fuel system-related malfunctions that OBD II systems generally cannot identify but which can cause emissions to exceed 1.5 times the standards with no detection of a malfunction. Additionally, this failure mode is not specifically identified in the current OBD II regulation. Manufacturers investigated this problem and found the cause to be cylinder-to-cylinder differences or imbalances in the air-fuel ratio that are not properly corrected by the fuel control system. As stated, this type of malfunction or system deterioration can have a significant impact on emissions. The imbalances can be caused by fuel injector variation, unequal airflow into the cylinders, or uneven EGR distribution across the cylinders. In many cases, the front oxygen sensor, which is located in the manifold collector and is used for feedback fuel control, does not equally sense all cylinders and may cause the feedback fuel control system to be blind or overly sensitive to specific cylinders. This can result in improper fuel system corrections (i.e., the fuel system under-compensates or overcompensates for the imbalance) and higher emissions without detection of a malfunction.

To address this, the staff is proposing that manufacturers be required to detect an air-fuel cylinder imbalance in one or more cylinders that causes the fuel delivery system to be unable to maintain emissions below a specified emission level. To provide manufacturers sufficient leadtime to comply with the new requirements, staff is proposing a phase-in during the 2011-2013 model years with a malfunction threshold of 3.0 times the standards. For most vehicles, 100 percent of the vehicles would be required to meet the final threshold of 1.5 times the standards in the 2014 model year. However, to allow additional flexibility in phasing in the final malfunction threshold, a manufacturer may continue to use 3.0 times standards for any applications that were certified in the 2011, 2012, or 2013 model year to 3.0 times the applicable FTP standards and carried over to the 2014 model year.

The staff is proposing a different phase-in schedule for vehicles equipped with certain types of EGR systems that have been found to be more prone to causing cylinder imbalance as the system deteriorates. The staff is proposing cylinder imbalance malfunctions be detected on all 2011 and subsequent model year vehicles equipped with EGR systems that have separate flow delivery passageways (internal or external) that deliver EGR flow to individual cylinders (e.g., an EGR system with individual delivery pipes to each cylinder).

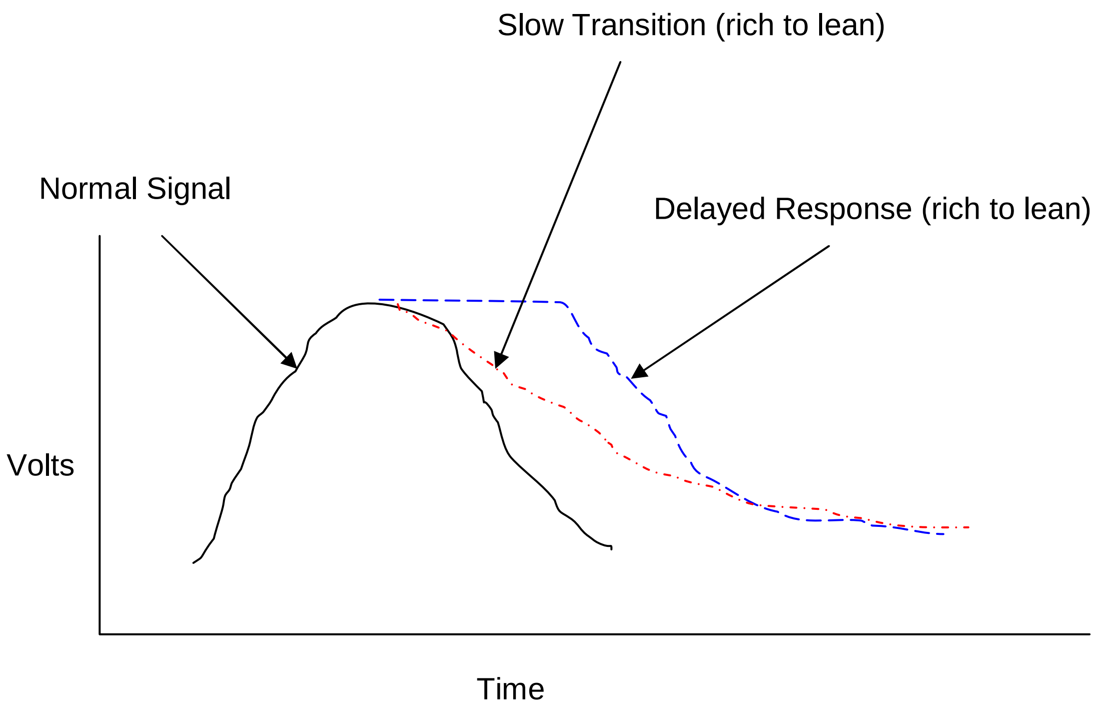
There are a number of monitoring strategies that may be used to detect cylinder imbalances. Monitoring of these types of failures may be accomplished by evaluating the front and/or rear oxygen sensor signals. During in-use testing of vehicles with cylinder imbalance malfunctions by ARB staff, one vehicle had a cylinder imbalance caused by intake valve deposits. The valve deposits caused an EGR effect in that cylinder which resulted in a rich air-fuel ratio relative to the other cylinders. Coincidentally, the oxygen sensor was oversensitive to the malfunctioning cylinder and the fuel system overcompensated by leaning out all the cylinders yielding an overall lean bias for the engine. The lean bias caused NOx emissions to significantly exceed the emission standards. The vehicle manufacturer analyzed the vehicle using special engineering tools to obtain a high-speed signal from the oxygen sensors. With the high speed data, the manufacturer observed that front oxygen sensor signal was noisy (i.e., there were rich spikes in the exhaust signal due the relatively rich air-fuel ratio in the cylinder that had the valve deposits). The noisy signal was an indicator that something was wrong with the system. Fuel system monitors generally use filtered or slower speed oxygen sensor signals to determine the average fuel system error caused by malfunctions that uniformly affect all cylinders. Therefore, typical fuel system monitors would not detect a noisy sensor as malfunctioning fuel system behavior. However, monitoring of the high-speed signal of the front sensor for this kind of behavior could be used to detect a cylinder imbalance fault. Additionally, the rear oxygen sensor signal also could show signs of cylinder imbalance. In the example discussed above, the rear oxygen sensor indicated a lean signal throughout the emission test cycle. However, depending on the fuel control strategy and the catalyst and sensor configuration, analysis of the rear sensor alone may not be sufficient for cylinder imbalance monitoring, nor would analysis of the rear oxygen sensor fuel control values be sufficient to cover all cases. (Monitoring of the downstream fuel control values will therefore remain a separate requirement in the regulation.)

E. OXYGEN SENSOR MONITORING

The OBD II regulation currently details specific monitoring requirements for conventional oxygen sensors, which have traditionally been used as one of the primary emission controls for feedback fuel control systems. Further, manufacturers using other types of exhaust gas sensors are required to submit a monitoring plan for approval to ensure newer technology sensors that may replace oxygen sensors are adequately monitored. Since the last regulatory update in 2002, there has been an increased use of wide-range, or universal, air-fuel (A/F) sensors in lieu of conventional oxygen sensors. With increased usage and gained experience, ARB staff is proposing that the regulation be amended to more specifically detail minimum monitoring requirements for A/F sensors. This would eliminate the need for manufacturers to submit a case-by-case monitoring plan for approval.

The OBD II regulation currently requires oxygen sensors to be monitored for response rate malfunctions. The staff is proposing to clarify what is expected of manufacturers when developing response rate monitors for primary oxygen and A/F sensors. Specifically, manufacturers would be required to detect both asymmetric malfunctions (i.e. faults that affect only the lean-to-rich response rate or only the rich-to-lean response rate) and symmetric malfunctions (i.e., faults that equally affect both the lean-to-rich and rich-to-lean response rates). Further, as has been required since the 1996 model year, manufacturers would continue to be required to detect faults that affect the response either by delaying the initial reaction of sensor to an exhaust gas change (e.g., “delayed” response) or by delaying the transition from a rich reading to a lean reading (or vice-versa) (e.g., “slow transition”) (see Fig. 1 below). While all manufacturers are currently capable of detecting each of these types of faults, not all of them have rigorously calibrated the monitors to ensure proper detection of the faults before emissions exceed 1.5 times the standards. Accordingly, the proposed changes would identify the failure modes for response that should be considered by manufacturers in calibrating the response diagnostic. Under the proposal, manufacturers would be required to consider six different response fault conditions when determining the worst case failure mode necessary for calibration: asymmetric lean-to-rich delayed response, asymmetric rich-to-lean delayed response, asymmetric lean-to-rich slow transition, asymmetric rich-to-lean slow transition, symmetric delayed response, and symmetric slow transition. Manufacturers would be expected to determine an appropriate response monitor threshold(s) to ensure that all response failures are detected prior to exceeding 1.5 times the standards. Further, beginning with a phase-in starting in the 2009 model year, manufacturers would be required to submit data and/or documentation demonstrating that they have used a calibration method that ensures that these criteria have been satisfied.

Fig. 1: O2 Sensor Deterioration Sketch



Results from testing in-use vehicles by ARB staff have also reinforced the need for more rigorous monitoring of the secondary sensors used primarily to monitor the catalyst for proper operation. For secondary oxygen sensors, the regulation currently requires the diagnostic system to detect a fault, to the extent feasible, when the secondary oxygen sensor is no longer reliable for monitoring. Given the location of the sensor downstream of the catalyst, stringent monitoring of the sensor has been difficult to achieve or isolate from other effects (e.g., oxygen storage in the catalyst). Accordingly, staff has been accepting fairly simple “activity” diagnostics that verify minimal operation of the sensor as acceptable monitoring techniques. Unfortunately, in-use vehicles with deteriorated secondary oxygen sensors and deteriorated catalysts have been found to have high emissions and no MIL illumination. Staff found that replacement of the secondary oxygen sensor resulted in the diagnostic system being able to detect the malfunctioning catalyst and illuminate the MIL. Ideally, manufacturers’ secondary oxygen sensor monitors should be able to detect and illuminate the MIL for this fault (i.e., detect a malfunction for deteriorated sensors that cannot robustly detect a “threshold” catalyst). However, very few manufacturers currently have monitors that meet this ideal situation. Most current monitors have a gap in the degree of sensor deterioration between where the sensor is no longer sufficient for catalyst monitoring and where the sensor itself can be detected as malfunctioning. Considering that catalyst fault codes are a significant percentage of the failures found in high-mileage cars in I/M programs, the staff believes the regulation needs to be modified to make manufacturers better understand what is expected of the secondary oxygen sensor monitors and to avoid problems like these in the future. Further, recent improvements in monitoring techniques for the rear sensor have been identified that enable more stringent monitoring of the sensor as well as improved monitoring techniques for the catalyst monitor that are less sensitive to secondary sensor performance degradation.

Thus, the proposed amendments would require better monitoring of the secondary sensors to ensure “sufficient” sensor performance for other monitors. Specifically, the amendments would require the OBD II system be designed such that the worst-performing acceptable secondary sensor is able to detect the best-performing unacceptable system or component (e.g., catalyst) that uses the secondary sensor for monitoring. In other words, in the case of the catalyst monitor, the worst-performing secondary oxygen sensor that could “pass” the secondary sensor monitor should be able to detect a deteriorated catalyst that just barely “fails” the catalyst monitor (i.e., a catalyst deteriorated right to the threshold). If the OBD II system is technically unable to meet this requirement, manufacturers would be required to submit a plan detailing how they will proposed to ultimately close the gap, and the proposed amendments would prescribe the minimum acceptable level of monitoring required of secondary oxygen sensors in the interim. Specifically, the OBD II system would be required to detect a slow rich-to-lean response malfunction of the sensor during a fuel shut-off event (e.g., deceleration fuel cut event). This monitor would be required to monitor the response time during the following periods: (1) from a rich condition (e.g., 0.7 Volts) at the start of fuel shut-off to a lean condition (e.g., 0.1 Volts) expected during fuel shut-off conditions, and (2) the response time of the sensor in the intermediate sensor range (e.g., from 0.55 Volts to 0.3 Volts). In order to develop a robust monitor, manufacturers would need to isolate the sensor response from catalyst effects and transport time as much as possible. Most manufacturers are already implementing some form of this monitor. However, not all manufacturers use fuel shut-off during deceleration to the degree or frequency that is necessary for the monitoring defined above. Therefore, in developing the proposed diagnostics, some manufacturers will also have to make changes to their fuel control strategies to ensure that fuel shut-off is initiated from a rich condition (i.e., a sensor voltage that is greater than voltages necessary to make the response time measurements defined above) and occurs with sufficient in-use frequency to meet the minimum required monitoring frequency specified in the regulation.

To allow time for manufacturers to make these changes across their product lines, the proposal would phase-in this requirement starting with the 2009 model year, with all 2011 and subsequent model year vehicles required to meet this requirement. The OBD II system would be required to track and report the in-use monitoring frequency of this monitor starting with the 2010 model year. Additionally, prior to certification of 2009 model year vehicles, the manufacturers would be required to submit a comprehensive plan demonstrating the their efforts to minimize any gaps remaining between the worst-performing acceptable sensor and a “sufficient” sensor.

F. COLD START EMISSION REDUCTION STRATEGY MONITORING

In order to meet the LEV standards, manufacturers have to design emission control system and control strategies to minimize emissions during and after a cold engine start. The vast majority of emissions during an FTP emission test are generated during the short period after engine start before the catalytic converter “lights off” (i.e., reaches the operating temperature where it begins to achieve high conversion efficiency). In order to minimize these cold start emissions, manufacturers use special strategies to maximize the heat transferred through the exhaust to the catalytic converter to accelerate light off. The most common elements of cold start strategies are modifications to engine speed and ignition timing. The idle speed is increased over the speed that is normally used, or is necessary, for a start-up. Increased idle speed increases exhaust mass flow. Ignition timing is also retarded from normal timing which makes the engine run less efficiently. Retarded ignition timing increases the exhaust temperature and further increases exhaust mass flow. Combined, the two elements generate hotter exhaust temperatures and more thermal mass that can be used to accelerate the light off of the catalyst.

During the last regulatory update in 2002, ARB adopted requirements for monitoring of the cold start emission reduction strategies to ensure these strategies were properly executed on in-use vehicles. Manufacturers have since implemented cold start monitors strategies beginning with the 2006 model year. The cold start monitoring requirements have been a difficult requirement for staff to administer. It requires a detailed disclosure by the manufacturers on how their cold start strategy works. At the same time, it requires an in depth understanding by both ARB staff and the manufacturers’ staff of how malfunctions, drivers’ actions, and vehicle operating conditions (e.g., fuel quality) can affect the proper execution of the cold start strategy.

In reviewing the cold start monitoring strategies that manufacturers have implemented, the staff has concluded that, in some cases, the monitors do not sufficiently ensure that the cold start strategies are successfully executed. For example, some monitors evaluate the combined effects of idle speed and ignition timing and only detect a malfunction when both elements (i.e., engine speed and ignition timing) of the emission reduction strategy have failed. The staff believes this is an inappropriate way to design the monitor because the OBD II system will not detect a malfunction until two failures have occurred. Other manufacturers have calibrated their monitors such that a malfunction will not be detected until the performance of the cold start system has deteriorated beyond what is required for normal warmed-up engine operation. For example, most manufacturers require increased idle speed during cold start. Some manufacturers, however, have implemented malfunction thresholds for the cold start monitor that require the engine speed to be less than the normal warmed up idle speed for a malfunction to be detected. While such an approach does indeed verify that the engine starts and idles, it does not verify that some amount of increased idle speed was achieved during the cold start.

To address these issues, the staff is proposing changes to the cold start monitoring requirements to ensure more consistent implementation of the requirements by all manufacturers. Specifically, the staff is proposing more specific malfunction criteria for the elements of the cold start monitoring strategy. Under the proposed changes, the OBD II system would detect a malfunction if either of two malfunction criteria is satisfied.

For the first proposed malfunction criterion, the OBD II system would be required to detect a cold start malfunction if any single commanded element of the cold start strategy does not properly respond to the commanded action while the cold start strategy is active. A cold start strategy element has proper cold start response if the following conditions are satisfied: (i) the element responds by a robustly detectable amount; (ii) the element responds in the direction of the desired command; and (iii) the magnitude of response is above and beyond what the element would achieve on start-up without the cold start strategy active. For example, if the cold start strategy commands a higher idle engine speed, a fault must be detected if there is no detectable amount of engine speed increase above what the system would achieve without the cold start strategy active. For elements involving spark timing (e.g., retarded spark timing), the monitor may verify final *commanded* spark timing in lieu of verifying actual *delivered* spark timing.

For the second proposed malfunction criterion, the OBD II system would detect a cold start malfunction when any failure or deterioration of the cold start emission reduction control strategy causes a vehicle's emissions to be equal to or above 1.5 times the applicable FTP standards. For this requirement, the OBD II system shall either monitor all elements of the system as a whole (e.g., measuring air flow and modeling overall heat into the exhaust) or the individual elements (e.g., increased engine speed, commanded final spark timing) for failures that cause vehicle emissions to exceed 1.5 times the applicable FTP standards.

The staff is proposing implementation of these requirements on 30 percent of 2010, 60 percent of 2011, and 100 percent of 2012 and subsequent model year vehicles. Manufactures will satisfy these proposed requirements by enhancements to their existing cold start strategy monitors.

G. COMPREHENSIVE COMPONENT MONITORING

One of the most important elements of the OBD II system is that it requires comprehensive monitoring of all electronic powertrain components or systems that either can affect vehicle emissions or are used as part of the OBD II diagnostic strategy for another monitored component or system. This includes input components such as sensors and output components or systems such as valves, actuators, and solenoids. Monitoring of all these components is essential since their proper performance can be critical to the monitoring strategies of other components or systems.

However, as vehicles have become increasingly sophisticated, there has been a proliferation of electronic components much beyond the traditional electronic powertrain components that existed when OBD II was started. Many of these components are peripheral components not related to fuel or emission control of the engine. Yet, by the most stringent of interpretations, these ancillary components could be considered subject to OBD II because they are powertrain-related and could affect emissions indirectly by increasing electrical demand or load on the engine when malfunctioning.

In order to keep OBD II systems containable and focused on identifying the powertrain components more directly related to fuel or emission control, the staff is proposing changes to exclude certain types of powertrain components. Specifically, the proposed changes would exclude components that are driven by the engine or can increase emissions only by increasing electrical demand or load on the vehicle and are not related to fuel or emission control. Examples of such excluded components could include electric power steering systems or intelligent vehicle charging systems.

Additionally, while hybrid vehicle powertrain components are subject to monitoring, the current regulation does not have very specific guidelines aimed at hybrid components, and some manufacturers have been unsure as to how to design their hybrid component diagnostics to be acceptable under the regulation. Ideally, the regulation would provide specific performance and diagnostic requirements for each and every hybrid component. Unfortunately, hybrids are still rapidly evolving and neither the staff nor manufacturers have developed sufficient experience to detail monitoring requirements for all hybrid components that would properly comprehend how they are used in all applications. Thus, the staff has proposed the inclusion of general guidelines specifying that monitoring would be required for (1) all components/systems used as part of the diagnostic strategy for other monitored component/systems, (2) all energy input devices to the electrical propulsion system, and (3) battery charging system performance, electric motor performance, and regenerative braking performance, and has added a provision that would require manufacturers to submit a monitoring plan for ARB's review and approval.

H. EXCEPTIONS TO MONITORING REQUIREMENTS

Currently, under the OBD II regulation, malfunction thresholds for gasoline vehicles are set to a multiple of the applicable emission standards for chassis-certified vehicles. However, there is a small segment of medium-duty vehicles that are designed and certified to engine dynamometer emission standards. Given the limited number of vehicles and products in this segment, the staff has included proposed language that would allow manufacturers to submit a plan for approval of how they will establish malfunction criteria on engine dynamometer-certified products that are equivalent to the specified malfunction criteria. In practice, manufacturers have been doing this since the start of OBD II, and the proposed language simply codifies what has become industry practice.

III. TECHNICAL STATUS AND PROPOSED REVISIONS TO MONITORING SYSTEM REQUIREMENTS FOR DIESEL/COMPRESSION-IGNITED ENGINES

The staff recently adopted OBD requirements for heavy-duty gasoline and diesel vehicles and engines (HD OBD). The HD OBD requirements were established in the context of heavy-duty engine manufacturers having to meet significantly more stringent tailpipe emission standards for the 2007 through 2010 model years and having to introduce a significant number of new emission controls to meet those requirements. During the rulemaking process for the HD OBD regulation, the staff gained an increased understanding of emission controls used on diesel engines, the types of malfunctions that could lead to emission increases, and the types of monitors needed to ensure robust effective detection of these faults.

It has always been the intention of staff to revise the OBD II requirements for light-duty and medium-duty diesel vehicles once it had adopted the comprehensive OBD requirements for heavy-duty diesel vehicles. Thus, as part of the ARB's biennial review of the OBD II regulation, the staff is proposing several amendments to the monitoring requirements for diesel/compression-ignited engines. For increased clarity, staff has separated the monitoring requirements for gasoline vehicles and diesel vehicles in the revised regulation.

Summaries of the proposed diesel malfunction thresholds are shown below in Tables 2 and 3. Table 2 summarizes the thresholds for light-duty vehicles and Table 3 summarizes the thresholds for medium-duty engines. While the malfunction thresholds are summarized in the tables, the details of the diesel monitoring requirements are discussed in later sections. Tables 2 and 3, notably, do not include malfunction thresholds for medium-duty diesel vehicles certified to a chassis dynamometer tailpipe emission standard. Staff has not proposed specific thresholds for these vehicles. Rather, as discussed below in section III.M, the monitoring requirements applicable to medium-duty diesel vehicles certified to an engine dynamometer tailpipe emission standard shall apply, and the manufacturer is required to use manufacturer-specified chassis-based thresholds that have been approved by the Executive Officer as equivalent to those proposed for each engine dynamometer-based malfunction criterion.

Table 2: Light-Duty Diesel Emission Thresholds

		OBDII Thresholds--g/mile			
Monitor	MY	NMHC	CO	NOx	PM
NMHC catalyst	2007-2009	5.0x	--	---	---
	2010-2012	3.0x	--	--	--
	2013+	1.75x	---	---	--
NOx SCR cat/Adsorber	2007-2009	3.0x	--	3.0x	--
	2010-2012	2.5x	--	2.5x	--
	2013+	1.75x	--	1.75x	--
fuel system-pressure	2007-2009	3.0x	3.0x	3.0x	3.0x
	2010-2012	2.0x	2.0x	2.0x	2.0x
	2013+	1.5x	1.5x	1.5x	2.0x
fuel system-timing/quantity	2010-2012	3.0x	3.0x	3.0x	3.0x
	2013+	1.5x	1.5x	1.5x	2.0x
A/F sensor-upstream	2007-2009	2.5x	2.5x	2.5x	2.5x
	2010-2012	2.0x	2.0x	2.0x	2.0x
	2013+	1.5x	1.5x	1.5x	2.0x
A/F sensor-downstream	2007-2009	3.5x	3.5x	3.5x	5.0x
	2010-2012	2.5x	2.5x	2.5x	4.0x
	2013+	1.5x	1.5x	1.75x	2.0x
PM/NOx sensor	2007-2009	3.5x	3.5x	3.5x	5.0x
	2010-2012	2.5x	2.5x	2.5x	4.0x
	2013+	1.5x	1.5x	1.75x	2.0x
EGR- flow, response, cooler	2007-2009	3.0x	3.0x	3.0x	3.0x
	2010-2012	2.5x	2.5x	2.5x	2.5x
	2013+	1.5x	1.5x	1.5x	2.0x
Boost pressure- control, cooling	2007-2009	--	---	---	---
	2010-2012	2.0x	2.0x	2.0x	2.0x
	2013+	1.5x	1.5x	1.5x	2.0x
PM filter-efficiency	2004-2009	--	---	---	5.0x
	2010-2012	--	---	---	4.0x
	2013+	--	---	---	1.75x
PM filter-regeneration frequency	2007-2009	functional	--	--	---
	2010-2012	3.0x	3.0x	3.0x	---
	2013+	1.5x	1.5x	1.5x	---
VVT	2007-2009	3.0x	3.0x	3.0x	3.0x
	2010-2012	2.5x	2.5x	2.5x	2.5x
	2013+	1.5x	1.5x	1.5x	2.0x
Cold-start strategy	2007-2009	--	---	---	---
	2010-2012	2.5x	2.5x	2.5x	2.5x
	2013+	1.5x	1.5x	1.5x	2.0x

Table 3: Medium-Duty Diesel Emission Thresholds

			OBDII Thresholds--g/bhp-hr			
Monitor	MY	cert std.	NMHC	CO	NOx	PM
NMHC cat	2007-2012		2.5x	--	---	---
	2013+		2.0x	---	---	--
NOx cat/Adsorber	2007-2009		3.5x	--	+0.5	--
	2010-2012		2.5x	--	+0.3	--
	2013+		2.0x	--	+0.2	--
fuel system-pressure	2007+	> 0.50 NOx	1.5x	1.5x	1.5x	0.03/+0.02
	2007-2012	</= 0.50 NOx	2.5x	2.5x	+0.3	0.03/+0.02
	2013+	</= 0.50 NOx	2.0x	2.0x	+0.2	0.03/+0.02
fuel system-timing/quantity	2010-2012		2.5x	2.5x	+0.3	0.03/+0.02
	2013+		2.0x	2.0x	+0.2	0.03/+0.02
A/F sensor-upstream	2007+	> 0.50 NOx	1.5x	1.5x	1.5x	0.03/+0.02
	2007-2012	</= 0.50 NOx	2.5x	2.5x	+0.3	0.03/+0.02
	2013+	</= 0.50 NOx	2.0x	2.0x	+0.2	0.03/+0.02
A/F sensor-downstream	2007-2009		2.5x	2.5x	+0.5	0.05/+0.04
	2010-2012		2.5x	2.5x	+0.3	0.05/+0.04
	2013+		2.0x	2.0x	+0.2	0.03/+0.02
PM/NOx sensor	2007-2009		2.5x	--	+0.5	0.05/+0.04
	2010-2012		2.5x	--	+0.3	0.05/+0.04
	2013+		2.0x	--	+0.2	0.03/+0.02
EGR- flow & cooler	2004-2006		1.5x	1.5x	1.5x	1.5x
	2007-2012		2.5x	2.5x	+0.3	0.03/+0.02
	2013+		2.0x	2.0x	+0.2	0.03/+0.02
Boost pressure	2010-2012		2.5x	2.5x	+0.3	0.03/+0.02
	2013+		2.0x	2.0x	+0.2	0.03/+0.02
PM filter-efficiency	2004-2009		--	---	---	0.09
	2010-2012		--	---	---	0.05/+0.04
	2013+		--	---	---	0.03/+0.02
PM filter-frequent regen	2007-2009		functional	--	--	---
	2010-2012		2.5x	---	+0.3	---
	2103+		2.0x	---	+0.2	---
VVT	2006-2012		2.5x	2.5x	+0.3	0.03/+0.02
	2013+		2.0x	2.0x	+0.2	0.03/+0.02
Cold-start strategy	2010-2012		functional	--	--	---
	2013+		2.0x	2.0x	+0.2	0.03/+0.02

A. NON-METHANE HYDROCARBON (NMHC) CONVERTING CATALYST MONITORING

Background

Diesel oxidation catalysts have been used on some off-road diesel engines since the 1960s and on some trucks and buses in the U.S. since the early 1990s. Oxidation catalysts are generally used for reducing HC and CO emissions via an oxidation process. Current diesel oxidation catalysts, however, are also optimized to reduce PM emissions. Manufacturers are likely to include oxidation catalysts to enhance the performance of other aftertreatment emission controls while also using them for a small reduction in HC, CO and PM emissions.

With the last amendments adopted in 2002, the OBD II regulation currently requires 2004 and subsequent model year light-duty vehicles and 2007 and subsequent model year medium-duty vehicles to monitor the catalyst for both HC and NOx conversion capability. Manufacturers are required to indicate a catalyst malfunction when the conversion capability of the catalyst system decreases to the point that emissions exceed 1.75 times the applicable HC, NOx, or PM standard. Since adoption of those thresholds, staff has gained considerable experience in expected usage of oxidation catalysts and advancements in monitoring technology through the development of the HD OBD regulation. Monitoring technology has not evolved as well as expected as manufacturers have largely focused on development of emission solutions to meet the tailpipe standards and spent very little time on ensuring diagnostic capability was maturing equivalently.

Accordingly, the staff is proposing to relax the monitoring thresholds for oxidation catalysts and give manufacturers significantly more lead time to incorporate proper monitoring. Manufacturers would still be required to detect a malfunction of the catalyst before emissions exceed specified levels and the specified levels would become increasingly more stringent from the 2007 through 2013 model years. Details of the proposed monitoring thresholds and the phase-ins are provided in Tables 2 and 3 at the beginning of section III. of this report. If a malfunctioning catalyst cannot cause emissions to exceed the applicable emission threshold, a manufacturer would only be required to functionally monitor the system and indicate a malfunction when no NMHC conversion efficiency could be detected. At a minimum, manufacturers would be required to monitor the catalyst once per driving cycle in which the monitoring conditions are met.

The OBD II system would also be required to monitor the oxidation catalyst for other aftertreatment assistance functions. For example, for catalysts used to generate an exotherm to assist PM filter regeneration, the OBD II system would be required to indicate a malfunction when the catalyst is unable to generate a sufficient exotherm to achieve regeneration of the PM filter. Similarly for catalysts used to generate a feedgas constituency to assist selective catalytic reduction (SCR) systems (e.g., to increase NO_2 concentration upstream of an SCR system), the OBD II system would be required to indicate a malfunction when the catalyst is unable to generate the necessary feedgas constituents for proper SCR system operation. Lastly, for catalysts located downstream of a PM filter and used to convert NMHC emissions during PM filter regeneration, the OBD II system would be required to indicate a malfunction when the catalyst has no detectable amount of NMHC conversion capability.

In order to determine the proper OBD II malfunction threshold for the oxidation catalyst, manufacturers would be required to progressively deteriorate or “age” the catalyst(s) to the point where emissions exceed the malfunction threshold (e.g., 1.75 times the standard). The method used to age the catalyst(s) must be representative of real world catalyst deterioration (e.g., thermal and/or poisoning degradation) under normal and malfunctioning operating conditions. For engines with aftertreatment systems that only utilize diesel oxidation catalysts, the catalyst(s) can be aged as a system to the emission threshold for determining the malfunction threshold. However, for engines with aftertreatment systems that utilize multiple catalyst technologies (e.g., an aftertreatment system that includes an oxidation catalyst, catalyzed NOx adsorber, catalyzed PM filter, and lean NOx catalyst), determining the OBD II malfunction threshold for the diesel oxidation catalyst becomes more complex since the aging effects on the catalyst are dependent on many factors, including the location of the oxidation catalyst relative to the other aftertreatment technologies and the synergism between each component in the system. Given that each component in the system is dependent on every other component of the overall catalyst system and deteriorate in-use as a system, it would not be appropriate to treat each component in the system independent of the others.

Since it is uncertain what exhaust configurations and aftertreatment systems manufacturers will use to comply with the future emission standards, it is important for the staff to develop and specify a “one-size-fits-all” aging process that accurately represents every possible future aftertreatment configuration. Once diesel aftertreatment system designs have stabilized to a level similar to gasoline aftertreatment systems (i.e., the variation of aftertreatment systems is limited) defining a generic catalyst aging plan will be more simple and practical. Until then, the staff would require manufacturers to submit a monitoring plan to the Executive Officer for review and approval of the monitoring strategy, malfunction criteria, and monitoring conditions prior to introduction on a production engine. Executive Officer approval would be based on the representativeness of the catalyst system aging to real world catalyst deterioration under normal and malfunctioning operating conditions, the effectiveness of the monitor to pinpoint the likely area of malfunction, and verification that each catalyst component is functioning as designed.

Technical Feasibility of Proposed Monitoring Requirements

To achieve the interim monitoring requirements, or alternatively, if only a functional monitor of the catalyst is required, temperature sensors could be used for monitoring. A functioning oxidation catalyst is expected to provide a significant exotherm when it oxidizes HC and CO. By placing one or more temperature sensors at or near the catalyst, the temperature of the catalyst could be measured during conditions where a large exotherm is expected. This would likely be monitoring during an intrusive event such as PM filter regeneration where fuel is added to the exhaust mixture to create a large exotherm in the catalyst. If the measured exotherm does not exceed a predetermined amount that only a properly-working catalyst can achieve, the diagnostic would fail. With improved temperature sensors, manufacturers may also be able to characterize catalyst light-off characteristics (e.g., after a cold start) and correlate warm-up characteristics with corresponding emission levels.

Monitoring of the oxidation catalysts could also be performed similar to that used on gasoline vehicles for three-way catalysts that use ceria to provide an oxygen storage function. The monitoring concept is based on the principle that the catalyst's oxygen storage capability correlates well with HC and NOx conversion efficiency. Thus, oxygen sensors located upstream and downstream of the catalyst can be used to determine when the oxygen storage capability of the catalyst deteriorates below a predetermined threshold. Determining the oxygen storage capacity would require lean air-fuel (A/F) operation followed by rich A/F operation or vice-versa during catalyst monitoring. Since a diesel engine normally operates lean of stoichiometry, the lean A/F operation portion will be a normal event. However, the rich A/F operation would have to be commanded intrusively when the catalyst monitor is active. The rich A/F operation could be achieved with the engine fuel injectors through late fuel injection or with a dedicated injector in the exhaust upstream of the catalyst. With lean operation, the catalyst will be saturated with stored oxygen. As a result, both the front and rear oxygen sensors should be reading lean. However, when rich A/F operation initiates, the front oxygen sensor would switch immediately to a "rich" indication while the rear oxygen sensor should stay reading "lean" until the stored oxygen in the catalyst is all consumed by the rich fuel mixture in the exhaust. As the catalyst deteriorates, the delay time between the front and rear oxygen sensors reading rich would become progressively smaller. Thus, by comparing the time difference between the responses of the front and rear oxygen sensors to the lean-to-rich or rich-to-lean A/F changes, the performance of the catalyst could be determined. Although conventional oxygen sensors are utilized to illustrate the monitoring method above, these sensors could be replaced with A/F sensors for additional engine control benefits such as EGR trimming and fuel quantity trimming.

For monitoring of the oxidation catalysts capability for other aftertreatment assistance functions (e.g., generating an exotherm for PM regeneration or proper feedgas for subsequent aftertreatment), a functional monitor is all that is required. It is expected that manufacturers would also use the exotherm approach mentioned above to either directly measure the function (e.g., proper exotherm generation) or correlate to the required function (e.g., proper feedgas generation). For catalysts upstream of the PM filter, it is expected that this monitoring would be conducted during an active regeneration event. For catalysts downstream of the PM filter, however, it is likely that manufacturers will have to intrusively add fuel (either in-exhaust or through in-cylinder post-injection) to create a sufficient exotherm to distinguish malfunctioning catalysts.

B. OXIDES OF NITROGEN (NOx) CONVERTING CATALYST MONITORING

Selective Catalytic Reduction (SCR) Catalyst

Background

The SCR catalyst has been used on power plants and stationary engines since the 1970s and is now being developed for use on on-road diesel engines. SCR catalysts are considered one of the most promising exhaust aftertreatment technologies for NOx control. SCR systems use nitrogen-containing compounds such as ammonia or urea, which are injected from a separate reservoir into the exhaust gas stream before the catalyst. Currently the SCR system, with NOx reduction rates of over 80 percent, is one of the more promising catalyst technologies capable of achieving the most stringent NOx emission standards.

SCR catalyst systems require an accurate ammonia control system to inject precise amounts of reductant. An injection rate that is too low may result in lower NOx conversions while an injection that is too high may release unwanted ammonia emissions (referred to as ammonia slip) to the atmosphere. In general, ammonia to NOx ratios of around 1:1 are used to provide the highest NOx conversion rates with minimal ammonia slip. Therefore, it is important to inject just the right amount of ammonia appropriate for the amount of NOx in the exhaust. For stationary source engines, estimating the exhaust NOx levels is fairly easy since the engine usually operates at a constant speed and load and the NOx emission rate is generally stable. However, on-road diesel engines operate over a range of speeds and loads, thereby making NOx exhaust estimates difficult without a dedicated NOx sensor in the exhaust. With an accurate fast response NOx sensor, closed-loop control of the ammonia injection can be used to achieve and maintain the desired ammonia/NOx ratios in the SCR catalyst for high NOx conversion efficiency (i.e., greater than 90 percent) necessary to achieve the stringent NOx emission standards under various engine-operating conditions. Currently, however, such an accurate fast response NOx sensor is not yet available. It has been estimated that achieving the medium-duty 2010 NOx emission standards with SCR systems will require a NOx sensor that can measure NOx levels accurately around the 10 to 20 ppm range with little cross sensitivity to ammonia.[1] Current NOx sensors do not yet meet these specifications, but sensor technology is improving quickly such that zero to 500 ppm resolution sensors have been achieved[2] and zero to 100 ppm sensors are being developed.[3] With further development, sensors are expected to achieve the required NOx sensitivity in time for the 2010 medium-duty emission standards. Regarding cross-sensitivity to ammonia, work has been done that indicates ammonia and NOx measurements can be independently measured by conditioning the output signal.[4] This signal conditioning method resulted in a linear output for both ammonia and NOx from the NOx sensor downstream of the catalyst.

For SCR systems, closed-loop feedback control of the reductant injection could be achieved using one or two NOx sensors. If two are used, the first NOx sensor would be located upstream of the catalyst and the reductant injection point and would be used for measuring the engine-out NOx emissions and determining the amount of reductant injection needed to reduce emissions. The second NOx sensor located downstream of

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[1] Song, Q. and Zhu, G., "Model-based Closed-loop Control of Urea SCR Exhaust Aftertreatment System for Diesel Engine," SAE Paper 2002-01-0287.

[2] Kato, N., Kokune, N., Lemire, B., and Walde, T., "Long Term Stable NOx Sensor with Integrated In-Connector Control Electronics," SAE Paper 1999-01-0202.

[3] Kobayashi, N., et al., "Development of Simultaneous NOx/NH3 Sensor in Exhaust Gas," Mitsubishi Heavy Industries, Ltd., Technical Review Vol.38 No.3 (Oct. 2001).

[4] Schaer, C. M., Onder, C. H., Geering, H. P., and Elsener, M., "Control of a Urea SCR Catalytic Converter System for a Mobile Heavy Duty Diesel Engine," SAE Paper 2003-01-0776.

the catalyst would be used for measuring the amount of ammonia and NOx emissions exiting the catalyst and providing feedback to the reductant injection control system. If the downstream NOx sensor detects too much NOx emissions exiting the catalyst, the control system can inject higher quantities of reductant. Conversely, if the downstream NOx sensor detects too much ammonia slip exiting the catalyst, the control system can decrease the amount of reductant injection. With further development, the staff projects that manufacturers will be able to model the upstream NOx levels (based on other engine operating parameters such as engine speed, fuel injection quantity and timing, EGR flow rate), thereby eliminating the need for the front NOx sensor for both control and monitoring purposes.

Recently, some manufacturers have indicated that they believe 2010 emission standards can be met without utilizing a closed-loop feedback system. Instead, an open-loop control system that is based on the “feed-forward” concept could be used. The open-loop system would only require a single NOx sensor that is located upstream of the SCR catalyst to help determine the amount of NOx in the exhaust stream that must be reduced with urea injection. The location of the NOx sensor upstream of the SCR catalyst has a higher NOx concentration and therefore, does not require as accurate a NOx sensor as a downstream NOx sensor would. Although a downstream sensor would still be required for monitoring purposes, the SCR dosing algorithm could be simplified with this approach. However, staff believes this system design is not as robust as a closed-loop system and could allow substantial emission deterioration to occur as the vehicle ages if the downstream sensor is not used for SCR dosing control purposes.

Production SCR catalyst systems may also contain auxiliary catalysts to improve the overall NOx conversion rate of the system. An oxidation catalyst is often positioned downstream of the SCR catalyst to help control ammonia slip on systems without closed-loop control of ammonia injection. The use of a “guard” catalyst could allow higher ammonia injection levels, thereby increasing the NOx conversion efficiency without releasing un-reacted ammonia into the exhaust. The guard catalyst can also reduce HC and CO emission levels and diesel odors. However, increased N_2O emissions may occur and NOx emission levels may actually increase if too much ammonia is oxidized in the catalyst. Some SCR systems may also include an oxidation catalyst upstream of the SCR catalyst and urea injection point to generate NO_2 for reducing the operating temperature range and/or volume of the SCR catalyst. Studies have indicated that increasing the NO_2 content in the exhaust stream can reduce the SCR temperature requirements by about 100 degrees Celsius.[5] This “pre-oxidation” catalyst also has the added benefit of reducing HC emissions. However, additional sulfate PM emissions can occur when high sulfur fuel is used.[6]

[5] Walker, A. P., Chandler, G. R., Cooper, B. J., et al., “An Integrated SCR and Continuously Regenerating Trap System to Meet Future NOx and PM Legislation,” SAE Paper 2000-01-0188.

[6] "Van Helden, R., van Genderen, M., van Aken, M., et al., "Engine Dynamometer and Vehicle Performance of a Urea SCR-System for Heavy-Duty truck Engines," SAE Paper 2002-01-0286.

Despite its high NOx conversion efficiency, there are several concerns in applying SCR systems to mobile applications. First, proper injection control is difficult under transient conditions. Second, design modifications to accommodate the necessarily large SCR catalysts may be difficult and costly. Further, there are many as yet unresolved issues regarding infrastructure changes that would be necessary to address the storage and refilling of the reductant supply on vehicles. Nonetheless, there is extensive research going on in the development and improvement of applying SCR to diesel vehicles.

Proposed Monitoring Requirements

The currently adopted OBD II regulation requires monitoring of diesel catalysts for malfunctions that would cause NOx emissions to exceed 1.75 times the emission standard. As was stated in the introduction to section III., these requirements were adopted in 2002 with the intent that staff would investigate further into monitoring capability while developing the heavy-duty OBD regulation. In doing so, staff has gained a better understanding of manufacturers' capabilities as they move towards implementation of NOx aftertreatment. With this experience, staff is proposing to relax the monitoring thresholds for catalysts used for NOx conversion to better reflect the technologies, capabilities, and resource constraints of the vehicle manufacturers. Manufacturers would still be required to detect a malfunction of the catalyst before emissions exceed specified levels and the specified levels would become increasingly more stringent from the 2007 through 2013 model years. Details of the proposed monitoring thresholds and the phase-ins are provided in Tables 2 and 3 at the beginning of section III. of this report. As with other monitored components, if a malfunctioning catalyst cannot cause emissions to exceed the applicable malfunction emission threshold, a manufacturer would only be required to functionally monitor the system and indicate a malfunction when no NOx conversion efficiency could be detected. At a minimum, manufacturers would be required to monitor the catalyst once per driving cycle in which the monitoring conditions are met.

Further, the staff is proposing that the mechanism for adding the fuel reductant (e.g., urea) be monitored for proper function. Manufacturers would be required to indicate a malfunction if a failure of the reductant delivery causes the engine's NOx emissions to exceed the malfunction emission thresholds referenced above. If a reductant delivery malfunction cannot cause emissions to exceed the applicable emission threshold, a manufacturer would only be required to functionally monitor the system and indicate a malfunction when the system has reached its control limits such that is it no longer able to deliver the desired quantity of reductant. Additionally, if the reductant tank is separate from the fuel tank, manufacturers would be required to indicate a malfunction when there is no longer sufficient reductant available (i.e., the reductant tank is empty) or when the incorrect reductant is used. Since precise control of reductant addition throughout the engine's operation range is essential for good NOx performance from the system, the reductant delivery performance monitor must be conducted continuously.

Technical Feasibility of Proposed Monitoring Requirements

As mentioned earlier, current NOx sensor technology tends to have a cross-sensitivity to ammonia (i.e., as much as 65 percent of ammonia can be read as NOx). Although this cross-sensitivity can be detrimental to SCR controls (i.e., reductant injection/NOx reduction efficiencies), it is actually beneficial for monitoring purposes. Monitoring of the catalyst can be done by using the same NOx sensors that are used for SCR control. When the SCR catalyst is functioning properly, the upstream sensor should read high (for high NOx levels) while the downstream sensor should read low (for low NOx and low ammonia levels). With a deteriorated SCR catalyst, the downstream sensor should read similar values as the upstream sensor or higher (i.e., high NOx and high ammonia levels) since the NOx reduction capability of the catalyst has diminished. Therefore, a malfunctioning SCR catalyst could be detected when the downstream sensor output is near or greater than the upstream sensor output. A similar monitoring approach can be used if a manufacturer models upstream NOx emissions instead of using an upstream NOx sensor. In this case, the comparison is simply made between the modeled upstream NOx value and the downstream sensor value.

Manufacturers have indicated concerns that NOx sensors will not be of sufficient resolution or accuracy to monitor to stringent thresholds. However, if NOx sensor development does not achieve the desired accuracy by 2010, alternative approaches could be pursued. A simple approach that would likely be feasible to meet the interim threshold levels would be to limit monitoring of the catalyst to conditions where engine out NOx concentrations are the highest and, thus, also the highest after the catalyst. Doing so may raise the concentration levels at the tailpipe to high enough levels that the sensor resolution and accuracy may be sufficient. Another approach that can be taken places the downstream NOx sensor at a location in the SCR catalyst that is more ideally suited for the sensor's NOX sensitivity (i.e., where NOx levels are slightly higher than at the SCR catalyst outlet). This new sensor location may require the SCR catalyst substrate to be separated into a front and rear section with the downstream NOx sensor located between the two substrates. This technique has been utilized by gasoline engine manufacturers since 1994 to allow monitoring of three-way catalysts to more stringent emission standards. By monitoring the capability of the front substrate and inferring the capability of the second, the sensor may be operated in a much higher NOx concentration environment that is better suited to the sensor's resolution and accuracy. However, the SCR monitor may require intrusive urea dosing control to reduce the dosing such that the NOx sensor downstream of the first substrate will not detect any ammonia. In such a case, one would have assurance that the NOx concentrations detected by the sensor consist entirely of NOx and not ammonia. By comparing the NOx concentrations at this location to a threshold that infers the performance of the entire catalyst, a deteriorated catalyst can be determined. At least one manufacturer has indicated that it models urea storage in the catalyst and does not inject urea continuously. For such a urea control strategy, the partial volume monitoring method possibly can be integrated with a portion of the non-continuous urea injection periods to reduce the intrusiveness of the monitor.

Monitoring of the reductant injection functionality could also be done with the NOx sensors that are used for control or catalyst monitoring purposes. With a properly functioning injector, the downstream NOx sensor should see a change from high NOx levels to low NOx levels as reductant injection quantities are varied. In contrast, a lack of reductant injection would result in continuously high NOx levels at the downstream NOx sensor. Therefore, a malfunctioning injector could be found when the downstream NOx sensor continues to measure high NOx after an injection event has been commanded.

Reductant level monitoring can also be conducted by utilizing the existing NOx sensors that are used for control purposes. Specifically, the downstream NOx sensor can be used to determine if the reductant tank no longer has sufficient reductant available. Similar to the fuel reductant injection functionality monitor described previously, when the reductant tank has sufficient reductant quantities and the injection system is working properly, the downstream NOx sensor should see a change from high NOx levels to low NOx levels. If the NOx levels remain constant both before and after reductant injection, then the reductant was not properly delivered and either the injection system is malfunctioning or there is no longer sufficient reductant available for injection in the reservoir. Alternatively, reductant level monitoring can also be conducted by utilizing a dedicated "float" type level sensor similar to the ones used on fuel tanks to determine sufficient reductant levels. Some manufacturers may prefer using a dedicated reductant level sensor in the reductant tank to inform the vehicle operator of current reductant levels with a gauge on the instrument panel. If manufacturers use such a sensor for operator convenience, it could also be used to monitor the reductant level in the tank. The level sensor will provide an output (e.g., voltage) that is dependent upon the reductant level. When the output of the level sensor decreases below a calibrated voltage for an empty tank, there is no longer sufficient reductant available for proper function of the SCR system.

Monitoring for incorrect reductant can also be conducted indirectly by utilizing the existing NOx sensors that are used for control purposes. If an improper reductant is utilized, the SCR system will not function properly. Therefore, NOx emissions downstream from the SCR catalyst will remain high both before and after injection. The downstream NOx sensor will see the high NOx levels after injection and inform the OBD II system of a problem. Other approaches being considered include the use of a reductant quality sensor within the reductant tank or the exhaust stream.

C. MISFIRE MONITORING

Background

Misfire, the lack of combustion in the cylinder, causes increased engine-out HC emissions. On gasoline engines, misfire is due to absence of spark, poor fuel metering, and poor compression. Misfire on gasoline engines can be intermittent (e.g., the misfire only occurs under certain engine speeds or loads). Consequently, the OBD II regulation currently requires continuous monitoring for misfire malfunctions on gasoline engines. However, for diesel engines, manufacturers have maintained that misfire only occurs due to poor compression (e.g., worn valves or piston rings, improper injector or glow plug seating), and when poor compression results in a misfiring cylinder, the cylinder will misfire under all operating conditions. Accordingly, for diesel engines, the OBD II regulation currently requires monitoring for misfire that occurs continuously in one or more cylinders at least once per driving cycle in which monitoring conditions (i.e., idle conditions) are met and does not allow the idle period under which misfire monitoring is to occur to require more than 15 seconds of continuous data collection, nor does it allow more than 1000 continuous engine revolutions of data to make a decision. Also, unlike the requirements for gasoline vehicles, the regulation does not require detection of malfunctions before an emission threshold is exceeded (e.g., 1.5 times the standards) on diesel vehicles.

Proposed Monitoring Requirements

The proposed revisions to the regulation would essentially keep the misfire monitoring requirements the same for conventional diesel engines. However, the staff is proposing amendments that would allow manufacturers to conduct this monitoring under conditions other than the idle conditions stated above so long as the general monitoring condition requirements for all monitors are met. This would allow for future innovations or alternate strategies that may more robustly detect misfire under non-idle conditions.

As stated, the current monitoring requirements were based on engine manufacturers' assertions that a misfiring diesel engine will always misfires. However, contrary to manufacturers' assessment, the staff is concerned that real world malfunctions that cause misfires on diesel engines may occur intermittently or only during off-idle conditions. The staff will continue to investigate the possibility of these misfires but currently does not have sufficient information or data to thoroughly validate these concerns. As additional information becomes available for future Board reviews of the OBD II regulation, the staff may propose a more comprehensive requirement.

Additionally, for 2010 and subsequent model year vehicles equipped with sensors that can detect combustion or combustion quality (e.g., for use in homogeneous charge compression ignition (HCCI) control system), the proposed monitoring requirements would be similar to the current requirements for detection of misfire causing emissions to exceed 1.5 times the standards for gasoline vehicles. For these specific diesel vehicles, the OBD system would be required to detect a misfire malfunction prior to emissions exceeding an emission threshold. For light-duty vehicles and medium-duty passenger vehicles certified to a chassis dynamometer tailpipe emission standard, the threshold would be 1.5 times the applicable standards. For medium-duty vehicles (including medium-duty passenger vehicles) certified to an engine dynamometer tailpipe emission standard, the threshold would be 2.0 times the applicable NMHC, CO, or NOx standards or either 0.03 g/bhp-hr PM as measured on a test cycle or 0.02 g/bhp-hr above the applicable PM standard (whichever is higher for PM). Further, this monitoring would be required to be continuous under all positive torque engine speed and load conditions. For these engines, the premise that a misfiring diesel engine misfires under all speeds and loads is clearly not correct. These engines precisely control the combustion process and require additional sensors to accurately measure combustion characteristics. Given the presence of these additional sensors and the likelihood that these types of engines can experience misfire in very specific speed and load regions, continuous monitoring for misfire is appropriate. Staff expects that combustion sensors would only be used on engines that require precise control of air and fuel metering and mixing to achieve proper combustion and maintain low engine-out emission levels.

Technical Feasibility of Proposed Monitoring Requirements

For diesel engines that use combustion sensors, misfire monitoring is feasible because these sensors provide a direct measurement of combustion and, therefore, lack of combustion (i.e., misfire) can be directly measured as well. These sensors are intended to measure various characteristics of a combustion event for feedback control of the precise air and fuel metering. Accordingly, the resolution of sensors that have this capability is well beyond what would be needed to detect a complete lack of combustion.

D. FUEL SYSTEM MONITORING

Background

An important component in emission control is the fuel system. Proper delivery of fuel (in both quantity and injection timing) plays a crucial role in maintaining low engine-out emissions. The performance of the fuel system is also critical for aftertreatment device control strategies. As such, thorough monitoring of the fuel system is an essential element in an OBD II system. The fuel system is primarily comprised of a fuel pump, fuel pressure control device, and fuel injectors. Additionally, the fuel system generally has sophisticated control strategies that utilize one or more feedback sensors to ensure the proper amount of fuel is being delivered to the cylinders. While gasoline engines have undergone relatively minor hardware changes (but substantial fine-tuning in the control strategy and feedback inputs), diesel engines have more recently undergone substantial changes to the fuel system hardware and now incorporate more refined control strategies and feedback inputs.

For diesel engines, a substantial change has occurred in recent years as manufacturers have transitioned to new high-pressure fuel systems. One of the most widely used is a “common-rail” fuel injection system, which is generally comprised of a high-pressure fuel pump, an electronically-controlled pressure regulator, a fuel rail pressure sensor, a common fuel rail that feeds all the individual fuel injectors that directly inject fuel into each cylinder, and a closed-loop feedback system that uses the fuel rail pressure sensor to achieve the commanded fuel rail pressure. Unlike older style fuel systems where fuel pressure was mechanically linked to engine speed (and thus, varied from low to high as engine speed increased), common-rail systems are capable of controlling to any desired fuel pressure independent of engine speed. Increased fuel pressure control allows greater precision relative to fuel quantity and fuel injection timing, and provides engine manufacturers with tremendous flexibility in optimizing the performance and emission characteristics of the engine. The ability of the system to generate high pressure independent of engine speed also improves fuel delivery at low engine speeds.

While most diesel engine manufacturers use common-rail systems, some use improved unit injector systems. In these systems, fuel pressure is generated within the injector itself rather than via an engine-driven high-pressure fuel pump in a common-rail system. Typically, the injector unit is both electrically and hydraulically-controlled. A high-pressure oil pump is used to deliver oil to the injector, which in turn activates a plunger in the injector to increase the fuel pressure to the desired level. Earlier versions of unit injector systems were able to achieve some of the advantages of common-rail systems (e.g., high fuel pressures) but still had limitations on the pressure that they could build based on engine speed. Further, the fuel pressure was a function of engine speed and could not be modified to a lower or higher pressure at a given engine speed. Newer design iterations have created an injector with extra valves that allow the system to deliver higher or lower pressures at a given engine speed. Thus, while there is still some dependence on engine speed for the fuel pressure, it is largely adjustable and can achieve much of the same fuel pressure range a common-rail system is capable of achieving.

Precise control of the fuel injection timing is crucial for optimal engine and emission performance. As injection timing is advanced (i.e., fuel injection occurs earlier), HC emissions and fuel consumption are minimized but NOx emissions are increased. As injection timing is retarded (i.e., fuel injection occurs later), NOx emissions can be dramatically reduced but HC emissions, PM emissions, and fuel consumption increase. Engine manufacturers must continually optimize the system to deliver the desired fuel quantity precisely at the right time.

The common-rail system or improved unit injector system also provides engine manufacturers with the ability to separate a single fuel injection event into discrete events such as pilot (or pre) injection, main injection, and post injection. A system using a pilot injection and a main injection instead of a single injection event has been shown to generate a 16 percent reduction in NOx emissions[7] in addition to providing a substantial reduction in engine noise. Another study has shown that the use of pilot injection versus no pilot injection can lead to a 20 percent reduction in PM emissions and a five percent reduction in fuel usage at a similar NOx level.[8]

Lastly, the high pressures and near infinite control in a common-rail or improved unit injector system begin to open the door for manufacturers to modify the fuel injection pressure during a fuel injection event which results in different fuel quantity injection rate profiles or “shapes.” “Rate-shaping,” as it is commonly known, allows manufacturers to

[7] Tullis, S., Greeves G., 1996. “Improving NOx Versus BSFC with EUI 200 Using EGR and Pilot Injection for Heavy-Duty Diesel Engines”, SAE 960843 (www.dieselnet.com, Diesel Fuel Injection, Common-Rail Fuel Injection).

[8] Greeves, G., Tullis, S., and Barker, B., 2003, “Advanced Two-Actuator EUI and Emission Reduction for Heavy-Duty Diesel Engines”, SAE 2003-01-0698.

begin a fuel injection event with a set injection rate and end the injection at a different injection rate. This could be used to progressively increase the fuel quantity during the injection event and has been shown to lower NOx emissions in laboratory settings.[9]

Given these various aspects of common-rail systems and improved unit injector systems, malfunctions that would affect the fuel pressure control, injection timing, pilot/main/post injection timing or quantity, or ability to accurately perform rate-shaping could lead to substantial increases in emissions (primarily NOx or PM), often times with an associated change in fuel consumption.

The OBD II regulation currently contains general language that requires fuel system monitoring of the performance of all electronic fuel system components to the extent feasible that can cause emission to exceed 1.5 times the applicable standards. With the experience gained from the adoption of the heavy-duty OBD regulation, the staff is proposing more specific monitoring requirements that would delineate malfunctions of the different aspects of the fuel system (e.g., fuel pressure, injection quantity).

Proposed Monitoring Requirements

For diesel engines, the staff is proposing several monitoring requirements to verify the overall fuel system's ability to meet the emission standards and to verify that individual aspects or capabilities of the system are properly functioning.

Fuel System Pressure Control Monitoring

The staff is proposing monitoring requirements that continuously verify whether the system is able to control to the desired fuel pressure. The OBD II system would be required to indicate a malfunction when the system can no longer control the fuel system pressure with the consequence that emissions exceed the thresholds specified in Tables 2 and 3. If no failure of the system can cause emissions to exceed the applicable malfunction emission threshold, then the OBD II system would be required to detect a fault when the fuel pressure control system has reached its control authority limits and can no longer increase or decrease the command to the pressure regulator to achieve the desired fuel system pressure. Similar to the current requirements for fuel system and misfire monitoring on gasoline vehicles, staff is proposing that the OBD II system would be required to store similar conditions (i.e., engine speed, load, and temperature status) when a fuel system pressure malfunction is detected in order to improve the detection capability of faults that only happen in specific speed and load regions of the engine.

Fuel Injection Quantity Monitoring

For 2010 and subsequent model year vehicles, the staff is proposing monitoring requirements that verify the fuel system is able to accurately deliver the proper quantity of fuel required for each injection. The OBD II system would be required to indicate a

[9] "Advanced Technologies: Fuel Injection and Combustion," www.dieselnet.com.

fault when the system is unable to accurately deliver the desired fuel quantity with the consequence that emissions exceed the thresholds specified in Tables 2 and 3. If no failure can cause emissions to exceed the malfunction emission threshold, then the OBD system would be required to detect a fault when the fuel injection system has reached its control authority limits and can no longer increase or decrease the commanded injection quantity to achieve the desired fuel injection quantity.

Malfunctions or deterioration of the system such as injector deposits or injector wear that restrict flow can result in individual cylinder variations that alter the injection quantity or injection profile and lead to increases in emissions. Unlike gasoline engines, diesel engines have no feedback system that directly verifies the proper fuel quantity. While large decreases in the fuel injection quantity can be noticed by the vehicle operator (e.g., reduction in maximum power output of the engine), small changes go unnoticed and may have a substantial impact on emissions by reducing the ability of the system to accurately deliver fuel (through separate pilot, main, or post injections or timing). As an example, pilot injections typically represent only a few percent (e.g., four to five percent) of the total fuel injected for an individual cylinder fueling event but can have a disproportional impact on increases in NOx emissions (e.g., +16 percent). Deterioration or other malfunctions could affect the ability of the system to accurately deliver the pilot injection yet still achieve acceptable performance to the vehicle operator.

Fuel Injection Timing Monitoring

For 2010 and subsequent model year vehicles, the staff is proposing that manufacturers implement monitoring to verify that fuel injection timing is correct; that is, that fuel is injected at the precise time that it is commanded to happen. Small changes in fuel timing (advance or retard) can have significant impacts on emissions. If the injector were to open too soon (due to a deteriorated needle lift return spring, etc.), fuel would be injected too soon and potentially at a lower than desired fuel pressure. If the injector were to be delayed in opening (due to restrictions in the injector body passages, etc.), fuel would be injected later than desired and potentially at a higher fuel pressure than desired. As such, the OBD II system would be required to verify that the fuel injection occurs within a manufacturer-specified tolerance of the commanded fuel timing point and indicate a malfunction prior to emissions exceeding the thresholds specified in Tables 2 and 3.

Feedback Control Monitoring

Regarding feedback-controlled fuel systems, staff is proposing that manufacturers indicate a malfunction if the fuel system fails to begin feedback control within a manufacturer-specified time interval. Manufacturers would also be required to indicate a malfunction if failure or deterioration of components used as part of the feedback control strategy causes the system to go open-loop (i.e., stops feedback control) or default operation of the fuel system. Lastly, manufacturers would also be required to indicate a malfunction if feedback control has used up all of the adjustment allowed by the manufacturer and cannot achieve the feedback target. Malfunctions that cause delays in starting feedback control and malfunctions that cause open-loop operation could either be detected with a fuel-system specific monitor or with individual component monitors.

Technical Feasibility of Proposed Monitoring Requirements

A few passenger cars and several medium-duty applications utilizing diesel engines have been monitoring the fuel system components since the 1997 model year under the OBD II regulation. Recently, this has included vehicles using common-rail fuel injection and improved unit injector systems, the same new technology that staff expects to be used throughout the heavy-duty industry. For some aspects of these high-pressure fuel systems, however, the monitoring requirement amendments proposed by the staff would extend beyond those presently required for existing medium-duty applications.

Fuel System Pressure Control Monitoring

The first fuel system monitoring requirement proposed by the staff is to identify malfunctions that prevent the fuel system from controlling the fuel pressure to the desired level. Manufacturers control fuel pressure by using a closed-loop feedback algorithm that allows them to increase or decrease fuel pressure until the fuel pressure sensor indicates they have achieved the desired pressure level. For the common-rail systems currently certified on medium-duty vehicles, the manufacturers are indeed continuously monitoring the fuel system pressure by comparing the actual fuel system pressure sensed by a fuel rail pressure sensor to the target fuel system pressure stored in a software table or calculated by an algorithm inside the on-board computer. A fault is indicated if too large of a difference exists between the two. The error limits are established by engine dynamometer emission tests to ensure a malfunction will be detected before emissions exceed 1.5 times the applicable emission standards. In some cases, manufacturers have developed separate strategies that can identify small errors over a long period of time versus large errors over a short period of time. In other cases, one strategy is capable of detecting both types of malfunctions at the appropriate level. In cases where no fuel pressure error can generate a large enough emission increase to exceed 1.5 times any of the applicable standards, manufacturers are required to set the threshold at their control limits (e.g., when they reach a point where they can no longer increase or decrease fuel pressure to achieve the desired fuel pressure). Several medium-duty applications already meet this monitoring requirement. By its nature, a closed-loop system is inherently capable of being monitored because it simply requires analysis of the same closed-loop feedback parameter that is also being used by the system for control purposes.

Fuel Injection Quantity Monitoring

The second diesel fuel system monitoring requirement being proposed is that the monitor verify that the proper quantity of fuel is being injected. Again, manufacturers would be required to establish the malfunction criteria by conducting emission tests to ensure a malfunction will be detected before emissions exceed the malfunction emission threshold (e.g., 2.5 times the applicable emission standards). In cases where no fuel quantity error can generate a large enough emission increase to exceed the malfunction emission threshold, manufacturers would be required to set the threshold at their control limits (e.g., when they reach a point where they can no longer increase or decrease fuel quantity to achieve the desired fuel quantity).

As there is no overall feedback sensor to indicate that the proper mass of fuel has been injected, this monitoring would be more difficult. One manufacturer, however, is currently using a strategy that verifies the injection quantity under very specific engine operating conditions and appears to be capable of determining that the system is accurately delivering the desired fuel quantity. This strategy entails intrusive operation of the fuel injection system during a deceleration event where fuel injection is normally shut off (e.g., coasting or braking from a higher vehicle speed down to a low speed or a stop). During the deceleration, fuel injection to a single cylinder is turned back on to deliver a very small amount of fuel. Typically, the amount of fuel would be smaller than, or perhaps comparable to, the amount of fuel injected during a pilot or pre injection. If the fuel injection system is working correctly, that known injected fuel quantity will generate a known increase in fluctuations (accelerations) of the crankshaft that can be measured by the crankshaft position sensor. If too little fuel is delivered, the measured crankshaft acceleration will be smaller than expected. If too much fuel is delivered, the measured crankshaft acceleration will be larger than expected. This process can even be used to “balance” out each cylinder or correct for system tolerances or deterioration by modifying the commanded injection quantity until it produces the desired crankshaft acceleration and applying a correction or adaptive term to that cylinder to compensate future injections of that cylinder to the desired nominal amount. Each cylinder can, in turn, be cycled through this process and a separate analysis can be made for the performance of the fuel injection system for each cylinder. Even if this procedure requires only one cylinder be tested per revolution (to eliminate any change in engine operation or output that would be noticeable to the driver) and requires each cylinder to be tested on four separate revolutions, this process would only take two seconds for a six-cylinder engine decelerating through 1500 rpm.

The crankshaft position sensor is commonly used to identify the precise position of the piston relative to the intake and exhaust valves to allow for very accurate fuel injection timing control and, as such, has sufficient resolution and data sampling within the on-board computer to be able to measure such crankshaft accelerations. Further, in addition to the current use of this strategy by a medium-duty diesel engine manufacturer, a nearly identical crankshaft fluctuation technique has been commonly used on medium-duty diesel engines during idle conditions to determine if individual cylinders are misfiring since the 1997 model year.

Another technique that may be used to achieve the same monitoring capability is some variation on the current cylinder balance tests used by many manufacturers to improve idle quality. In such strategies, fueling to individual cylinders is increased, decreased, or shut off to determine if the cylinder is contributing an equal share to the output of the engine. This strategy again relies on changes in crankshaft/engine speed to measure the individual cylinder's contribution relative to known good values and/or the other cylinders. Such an approach would be viable to effectively determine the fuel injection quantity is correct for each cylinder but has the disadvantage of not necessarily being able to verify the system is able to deliver small amounts of fuel precisely (such as those commanded during a pilot injection).

The staff expects other monitoring techniques will likely surface as manufacturers begin to develop their systems. One other approach that has been newly mentioned but not investigated very thoroughly is the use of a wide-range air-fuel (A/F) sensor in the exhaust to confirm fuel injection quantity. The monitoring concept is that the A/F sensor output can be compared to the measured air going into the engine and calculated fuel quantity injected to see if the two agree. Differences in the comparison may be able to be used to identify incorrect fuel injection quantity.

Fuel Injection Timing Monitoring

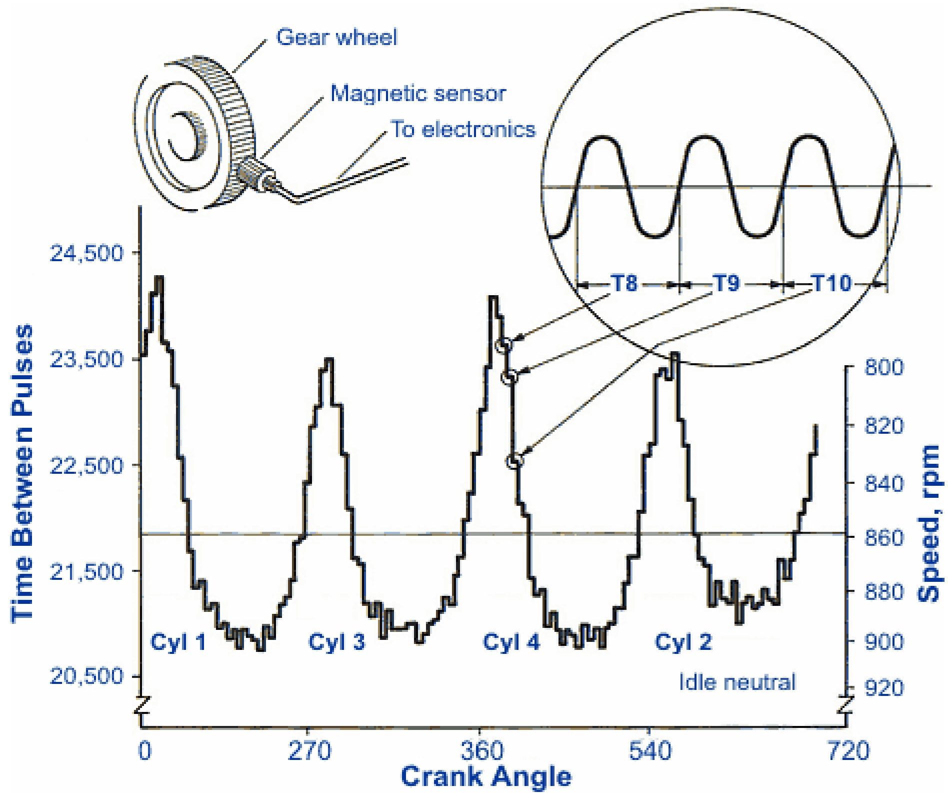
A similar, or even the same, technique could potentially be used to meet this third proposed monitoring requirement. By monitoring the crankshaft speed fluctuation and, most notably, the time at which such fluctuation begins, ends, or reaches a peak, the OBD II system could compare the time to the commanded fuel injection timing point and verify that the fluctuation occurred within an acceptable time delay from the commanded fuel injection. If the system was working improperly and actual fuel injection was delayed relative to when it was commanded, the corresponding crankshaft speed fluctuation would also be delayed and result in a longer than acceptable time period between commanded fuel injection timing and crankshaft speed fluctuation. Mention of this exact method is found in dieselnet.com[10]:

> In fact, some experiments were conducted at the Bendix Diesel Engine Controls in which a signal was obtained and digitized to analyze the impulsive flywheel motion that results from the torque development. Figure 5 shows the results of this experiment which was conducted on a 4-cylinder Volkswagen diesel engine. While the general observation is that in an engine the flywheel is rotating at a steady speed, it is in fact rotating in a pulsating pattern as shown in Figure 5. By referencing the trace in Figure 5, control engineers at Bendix *were able to infer injection timing and fueling for each cylinder*. Analysis of such trace can yield information regarding when the piston began its downward acceleration. From this determination, an injection timing is inferred by referencing the start of piston acceleration to a set top-dead-center reference. Comparative analysis is then conducted by the electronic control unit *to determine the injection timing for each individual cylinder*. In injection systems where individual cylinder control of the fuel injection is available, adjustments can be made to equalize the effective injection timing in all cylinders. *Likewise, the rate and amount of acceleration of each flywheel impulse can be used to infer the fueling in each cylinder*. Once again, the

[10] "Controls for Modern Diesel Engines: Model-Based Control Systems," www.dieselnet.com

electronic control unit is capable to adjust the cylinder-to-cylinder fueling rate for smoother engine operation…[Emphasis added]

Figure 5. Torque Pulses Development in a 4-Cylinder Diesel Engine



Another technique that has been mentioned to the staff but not studied in depth is to confirm fuel injection timing involves an electrical feedback signal from the injector to the computer to confirm when the injection occurred. Such techniques would likely use an inductive signature to identify exactly when an injector opened or closed and verify that it was at the expected timing. The staff expects further investigation would be needed to confirm such a monitoring technique would be sufficient to verify fuel injection timing.

Feedback Control Monitoring

The staff further proposed that the fuel system be monitored for feedback control. The conditions necessary for feedback control (i.e., the feedback enable criteria) are defined as part of the control strategy in the engine computer. The feedback enable criteria are typically based on minimum conditions necessary for reliable and stable feedback control. When the manufacturer is designing and calibrating the OBD II system, the manufacturer would determine how long it takes to satisfy these feedback enable criteria on a properly functioning engine for the range of in-use operating conditions. The OBD II system can evaluate whether it takes too long for these conditions to be satisfied after engine start relative to normal behavior for the system, and a malfunction can be indicated when the time exceeds a specified value (i.e., the malfunction criterion). For example, for fuel pressure feedback control, a manufacturer may wait to begin feedback control until fuel system pressure has reached a minimum specified value. In a properly functioning system, pressure builds in the system as the engine is cranked and shortly after starting, and the pressure enable criterion is reached within a few seconds after engine start. However, a malfunctioning system (e.g., due to a faulty low-pressure fuel pump) may take a significantly longer time to reach the feedback enable pressure. A malfunction would be indicated when the actual time to reach the feedback enable pressure exceeds the malfunction criterion.

Malfunctions that cause open-loop or default operation can be readily detected as well. As discussed above, the feedback enable criteria are clearly defined in the computer and are based on what is necessary for reliable control. After feedback control has begun, the OBD II system can detect when these criteria are no longer being satisfied and indicate a malfunction. For example, one of the enable criteria could be that the pressure sensor has to be within a certain range. The upper pressure limit would be based on the maximum pressure that can be generated in a properly functioning system. A malfunction would be indicated when the pressure exceeds the upper limit and the fuel system stops feedback control and goes open-loop.

The feedback control system has limits on how much adjustment can be made. The limits would likely be based on the ability to maintain acceptable control. Like the feedback enable criteria, the control limits are defined in the computer. The OBD II system would continuously track the actual adjustments made by the control system and indicate a malfunction if the limits are reached.

E. EXHAUST GAS SENSOR MONITORING

Background

Exhaust gas sensors (e.g., oxygen sensors, A/F sensors, NOx sensors, PM sensors) are expected to be used by light- and medium-duty diesel engine manufacturers to optimize their emission control technologies as well as satisfy many of the proposed OBD II monitoring requirements, such as NOx aftertreatment monitoring and EGR system monitoring. Since an exhaust gas sensor will be a critical component of a vehicle's emission control system, the proper performance of this component needs to be assured in order to maintain low emissions.

The OBD II regulation currently requires the diagnostic system to monitor the output voltage, response rate, and any other parameter that can affect emissions or other diagnostics of the primary and secondary oxygen and A/F sensors, including continuous monitoring of circuit continuity and out-of-range values. Manufacturers are required to indicate a fault prior to emissions exceeding 1.5 times the applicable standards. For heated oxygen sensors, the heater must be monitored for circuit continuity faults and for failures where the current or voltage drop within the circuit deteriorates below the manufacturer's specified limits for proper operation. For these other types of exhaust gas sensors, manufacturers are required to submit a monitoring plan for approval demonstrating that the monitors presented would be as reliable and effective as those for conventional sensors, though they are at a minimum required to be monitored for circuit continuity, out-of-range values, and rationality faults.

Proposed Monitoring Requirements

With further experience, staff is now proposing more detailed requirements specific to each type of exhaust gas sensor and its intended usage in the diesel emission control system. Specifically, staff has detailed separate requirements for upstream A/F sensors, downstream A/F sensors, and PM or NOx sensors. Details of the specific malfunction thresholds are provided in Tables 2 and 3 at the beginning of section III.

For all exhaust gas sensors, the proposed regulation would also require the OBD II system to monitor for circuit continuity and out-of-range faults and faults that would cause the sensor to no longer be sufficient for use for other OBD II monitors (e.g., catalyst monitors). Additionally, since emission control system performance is essential in meeting the emission standards and maintaining low emissions, malfunctions where the system is unable to optimize this should be detected. Thus, the staff is also proposing that for all exhaust gas sensors, the OBD II system would be required to indicate a malfunction when a sensor fault occurs such that an emission control system stops using the sensor as a feedback input. Additionally, for heated exhaust gas sensors, manufacturers would be required to monitor the heater for proper performance as well as circuit continuity faults.

Technical Feasibility of Proposed Monitoring Requirements

The OBD II regulation currently has similar monitoring requirements for oxygen and A/F sensors, though the malfunction emission thresholds being proposed by the staff are different. Nevertheless, the technical feasibility has clearly been demonstrated for these packages.

NOx sensors are a recent technology and currently still being developed and improved. Since NOx sensors are projected to only be used for control and monitoring of aftertreatment systems that reduce NOx emissions (e.g., SCR systems), the OBD II system would have to distinguish between deterioration of the aftertreatment system and the NOx sensor itself for the reasons discussed below. As the aftertreatment deteriorates, NOx emissions will increase (i.e., the NOx concentration levels in the exhaust increase), and assuming there is no attendant deterioration in the NOx sensor, the NOx sensor will read these increasing NOx levels. The increased NOx levels can be the basis for determining a malfunction of the aftertreatment system. However, if the NOx sensor experiences deterioration (has an increasingly slower response rate) along with the aftertreatment system, the sensor may not properly read the increased NOx levels from the malfunctioning aftertreatment system, and the aftertreatment monitor would conclude the malfunctioning aftertreatment system is functioning properly. Similarly, the performance of NOx aftertreatment (i.e., level of deterioration of the after treatment system) could affect the results of the sensor monitor. Therefore, to achieve robust monitoring of aftertreatment and sensors, the OBD II system has to distinguish between deterioration of the aftertreatment system and the NOx sensor. To properly monitor the sensor, it is crucial to account for the effects of aftertreatment performance on the results of a sensor monitor. The NOx sensor monitor has to be conducted under conditions where the aftertreatment performance can either be quantified and compensated for in the monitoring results or its effects can be eliminated.

Using an SCR system as an example, the effects of the SCR performance could be eliminated by monitoring under a steady-state operating condition (i.e., a steady-state engine-out NOx condition). Under a relatively steady-state condition, reductant injection could be “frozen,” that is, the reductant injection quantity could be held constant, which would also freeze the conversion efficiency of the SCR system. With SCR performance held constant, engine-out NOx emissions could be intrusively increased by a known amount (e.g., by reducing EGR flow or changing fuel injection timing and allowing the engine-out NOx model to determine the increase in emissions). The resulting increase in emissions would pass through the SCR catalyst unconverted, and the sensor response to the known increase in NOx concentrations could be measured and evaluated. This strategy could be used to detect both response malfunctions (i.e., the sensor reads the correct NOx concentration levels but the sensor reading does not change fast enough to changing exhaust NOx concentrations) and rationality malfunctions (i.e., the sensor reads the wrong concentration level). Rationality malfunctions could be detected by making sure the sensor reading changes by the same amount as the intrusive change in emissions. Lastly, the sensor response to decreasing NOx concentrations could be also be evaluated by measuring the response when the intrusive strategy is turned off and engine-out NOx emissions are returned to normal levels. Malfunction criteria could then be determined by correlating sensor response and emission levels from conducting emission tests with sensors having various levels of deterioration.

PM sensors are even less developed than NOx sensors; as such, less is certain about the important characteristics of PM sensors relative to their use in emission control or their proper use as monitoring devices. However, staff has had discussions with sensor suppliers about PM sensor development and is encouraged by the early findings. Further, staff has held discussions with these suppliers about the need for diagnostics, and staff expects that basic diagnostics such as circuit checks, out-of-range values, and heater functionality will be easily implemented. For sensor response or other such characteristics, manufacturers may need to implement strategies similar to those discussed above for NOx sensors and require intrusive operation to verify sensor readings or response during known exhaust concentration conditions.

F. EXHAUST GAS RECIRCULATION (EGR) SYSTEM MONITORING

Background

Exhaust gas recirculation (EGR) systems are currently being used to complement advanced fuel injection and turbocharger systems to meet NOx levels of approximately 2.0 g/hp-hr (the 2004 standard is 2.5 g/hp-hr NMHC+NOx with a 0.5 g/hp-hr NMHC cap). Some systems also use an EGR cooler to further reduce NOx emissions. While NOx control technologies have evolved and been refined on gasoline engines over the last 30 years, they had not been as readily adapted to diesel engines. However, as light- and medium-duty diesel engines have been subject to increasingly more stringent emission standards, EGR systems have become more commonplace and will likely be a key emission control component on future diesel engines.

While in theory the EGR system simply routes some exhaust gas back to the intake, production systems can be complex and involve many components to ensure accurate control of EGR flow and maintain acceptable PM and NOx emissions while minimizing effects on fuel economy. To determine the necessary EGR flow rates and control EGR flow, EGR systems normally use the following components: an EGR valve, valve position sensor, boost pressure sensor, intake temperature sensor, intake (fresh) airflow sensor, and tubing or piping to connect the various components of the system. EGR temperature sensors and exhaust backpressure sensors are also commonly used. Additionally, some systems use a variable geometry turbocharger to provide the backpressure necessary to drive the EGR flow. Therefore, EGR is not a stand alone emission control device. Rather, it is carefully integrated with the air handling system to control NOx while not adversely affecting PM emissions and fuel economy.

The OBD II regulation currently requires manufacturers to indicate a malfunction of the EGR flow rate before emissions exceed 1.5 times the applicable standards. If a malfunction of the system could not cause emissions to exceed 1.5 times the standards, manufacturers are required to detect a malfunction if there is no detectable amount of EGR flow. Individual electronic components (e.g., valves, sensors) used by the EGR system are required to be monitored under the comprehensive component monitoring requirements.

Proposed Monitoring Requirements

With staff's gained experience during the heavy-duty OBD regulation work, staff is proposing revisions that better specify the exact types of EGR system malfunctions that must be detected and appropriate thresholds and leadtime for each component. Given the need to accurately control EGR to maintain acceptable emission levels, the staff is proposing monitoring requirements for flow rate and response rate malfunctions. Additionally, on vehicles equipped with EGR coolers, the OBD II system would be required to monitor the cooler for insufficient cooling malfunctions. Details of the exact emission thresholds and phase-in years are included in Tables 2 and 3 at the beginning of section III.

EGR Flow Rate Monitoring

Under the staff's proposal, the OBD II system would be required to indicate an EGR system malfunction before the change (i.e., decrease or increase) in flow from the manufacturer's specified EGR flow rate causes vehicle emissions to exceed a certain threshold. In situations where no failure or deterioration of the EGR system that causes a decrease in flow could result in vehicle emissions exceeding the malfunction emission threshold, the OBD II system would be required to indicate a malfunction when the system has reached its control limits such that it cannot increase EGR flow to achieve the commanded flow rate.

EGR Response Rate Monitoring

Manufacturers will likely use transient EGR control to meet the emissions standards. EGR rates will be varied with transient engine operating conditions to maintain the balance between NOx and PM emissions. Therefore, staff is proposing a response rate diagnostic to verify that the system has sufficient response. Specifically, the OBD II system would be required to indicate a response malfunction of the EGR system if it is unable to achieve the commanded flow rate within a manufacturer-specified time with the consequence that emissions would exceed a certain threshold. These thresholds are the same as those required for EGR flow rate monitoring above.

Feedback Control Monitoring

Regarding feedback-controlled EGR systems, staff is proposing that manufacturers indicate a malfunction if the EGR system fails to begin feedback control within a manufacturer-specified time interval. Manufacturers would also be required to indicate a malfunction if failure or deterioration of components used as part of the feedback control strategy causes the system to go open-loop (i.e., stops feedback control) or default operation of the EGR system. Lastly, manufacturers would also be required to indicate a malfunction if feedback control has used up all of the adjustment allowed by the manufacturer. Malfunctions that cause delays in starting feedback control and malfunctions that cause open-loop operation could either be detected with an EGR system-specific monitor or with individual component monitors.

EGR Cooling System Monitoring

Insufficient EGR cooling can result in higher NOx emissions and can lead to default operation where EGR is shutoff. Accordingly, the staff is proposing monitoring requirements for proper EGR cooling system performance. Specifically, the OBD II system would be required to indicate an EGR cooling system malfunction when the reduction in cooling of the exhaust gas causes emissions to exceed a certain threshold. These thresholds are the same as those required for EGR flow rate monitoring above. For vehicles in which no failure or deterioration of the EGR system cooler could result in a vehicle's emissions exceeding the malfunction emission threshold, the OBD II system would be required to indicate a malfunction when the system has no detectable amount of EGR cooling. Some manufacturers using EGR coolers have indicated that the cooler is not used for emission reduction but rather for EGR valve and system durability. These manufacturers have also requested to forego monitoring of the EGR cooler. If a manufacturer demonstrates that emissions would not be affected under any reasonable driving condition due to a complete lack of EGR cooling, the manufacturer would not be required to monitor the EGR cooler.

Other Monitoring Requirements

Manufacturers would be required to monitor all electronic components of the EGR system (e.g., temperature sensors, valves) for proper function and rationality under the comprehensive component monitoring requirements.

Technical Feasibility of Proposed Monitoring Requirements

EGR Flow Rate Monitoring

The EGR control system has to determine and control the EGR flow. While the system designs from different manufacturers will vary, they will virtually all employ a similar closed-loop control strategy. Under such a strategy, the control system first determines the desired EGR flow rate based on the engine operating conditions. Manufacturers would likely store the desired flow rate/valve position in a lookup table in the engine control module (ECM) (e.g., the desired EGR values, which are based on engine operating conditions such as engine speed and engine load, are established when the manufacturer designs and calibrates the EGR system). The ECM then commands the valve to the position necessary to achieve the desired flow. EGR flow rate and/or valve position is feedback-controlled, and the ECM calculates or directly measures both fresh air charge and total intake charge. The difference between the total intake charge and fresh airflow is the actual EGR flow. The closed-loop control system continuously adjusts the EGR valve position until the actual EGR flow equals the desired EGR flow.

These closed-loop control strategies could be readily monitored and are the basis for many existing monitors on both gasoline and diesel light- and medium-duty vehicles. The OBD II system could evaluate the difference (i.e., error) between the look-up value and the final commanded value to achieve the desired flow rate. When the error exceeds a specific threshold, a malfunction would be indicated. Typically, as the feedback parameter or learned offset increases, there is an attendant increase in emissions, and a correlation could be made between feedback adjustment and emissions. This type of monitoring strategy could be used to detect both high and low flow malfunctions, and is currently in production on a medium-duty vehicle.[11]

While the closed-loop control strategy described above is effective in measuring and controlling EGR flow, some manufacturers are currently investigating the use of a

[11] "2003 MY OBD System Operation Summary for 6.0L Diesel Engine" at website http://www.motorcraftservice.com/vdirs/diagnostics/pdf/Dobdsm304.pdf.

second control loop based on an A/F sensor (also known as a wide-range oxygen sensor or a linear oxygen sensor) to further improve EGR control and emissions. With this second control loop, the desired air-fuel ratio is calculated based on engine operating conditions (i.e., intake airflow, commanded EGR flow and commanded fuel). The calculated air-fuel ratio is compared to the air-fuel ratio from the A/F sensor and refinements can be made to the EGR and airflow rates (i.e., the control can be "trimmed") to actually achieve the desired rates. On systems that use the second control loop, flow rate malfunctions could also be detected using the feedback information from the A/F sensor and by applying a similar monitoring strategy as discussed above for the primary EGR control loop.

The proposed amendments would require two types of leaking valves to be detected. One type is the failure of the valve to seal when in the closed position (e.g., if the valve or seating surface is eroded, the valve could close and seat, yet still allow some flow across the valve). A flow check is necessary to detect a malfunctioning valve that closes properly but still leaks. EGR flow (total intake charge minus fresh air charge) could be calculated with the valve closed using the monitoring strategy described above for high and low malfunctions, and when flow exceeds unacceptable levels, a malfunction would be indicated. Some cooled EGR systems will incorporate an EGR temperature sensor, which could also be used to detect a leaking EGR valve. For a properly functioning EGR valve, EGR temperature should be a minimum when the EGR valve is closed. An elevated EGR temperature when the valve is closed would indicate a malfunctioning valve. A leaking valve can also be caused by failure of the valve to close/seat (e.g., carbon deposits on the valve or seat that prevent the valve from fully closing). The flow check described above would detect failure of the valve to close/seat but would require a repair technician to further diagnose whether the problem is a sealing or seating problem. Failure of the valve to close/seat could be specifically monitored by checking the zero position of the valve with the position sensor when the valve is closed. If the valve position were out of the acceptable range for a closed valve, a malfunction would be indicated. This type of zero position sensor check is commonly used to verify the closed position of valves/actuators used in gasoline OBD II systems (e.g., gasoline EGR valves, electronic throttle) and would be feasible for diesel EGR valves.

EGR Response Rate Monitoring

The EGR response rate diagnostic is similar to the flow rate diagnostic. While the flow rate diagnostic would evaluate the ability of the EGR system to achieve a commanded flow rate under relatively steady state conditions, the response diagnostic would evaluate the ability of the EGR system to modulate (i.e., increase and decrease) EGR flow as engine operating conditions and, consequently, commanded EGR rates change. Specifically, as engine operating conditions and commanded EGR flow rates change, the monitor would evaluate the time it takes for the EGR control system to achieve the commanded change in EGR flow. This monitor could evaluate EGR response passively during transient engine operating conditions encountered during in-use operation. The monitor could also intrusively evaluate EGR response by commanding a change in EGR flow under a steady state engine operating condition and measuring the time it takes to achieve the new EGR flow rate. Similar passive and intrusive strategies have been developed for variable valve control and/or timing (VVT) monitoring on light- and medium-duty vehicles. The staff believes similar approaches can be used for EGR system monitoring.

EGR Cooling System Monitoring

Some diesel engine manufacturers are currently using exhaust gas temperature sensors as an input to their EGR control systems. On these systems, EGR temperature, which is measured downstream of the EGR cooler, could be used to monitor the effectiveness of the EGR cooler. For a given engine operating condition (e.g., a steady speed/load that generates a known exhaust mass flow and exhaust temperature to the EGR cooler), EGR temperature will increase as the performance of the EGR cooling system decreases. During the OBD calibration process, manufacturers could develop a correlation between increased EGR temperatures and cooling system performance (i.e., increased emissions). The EGR cooling monitor would use such a correlation and indicate a malfunction when the EGR temperature increases to the level that causes emissions to exceed the malfunction emission threshold.

While the staff anticipates that most, if not all, manufacturers will use EGR temperature sensors to meet future standards, EGR cooling system monitoring may also be feasible without an EGR temperature sensor by using the intake manifold temperature (IMT) sensor. EGR cooling system performance could be evaluated by looking at the change in IMT (i.e., "delta" IMT) with EGR turned on and EGR turned off (IMT would be higher with EGR turned-on). If there is significant cooling capacity with a normally functioning cooling system, there could be a significant difference in intake manifold temperature with EGR turned on and off. As cooling system performance decreases, the change in IMT would increase. The change in IMT could be correlated to decreased cooling system performance and increased emissions.

G. BOOST PRESSURE CONTROL SYSTEM MONITORING

Background

Turbochargers are used on internal combustion engines to enhance performance by increasing the mass and density of the intake air. Some of the benefits of turbocharging include increased horsepower, improved fuel economy, and decreased exhaust smoke density.[12] Most modern diesel engines take advantage of these benefits and are equipped with turbocharging systems. The power increase associated with turbocharging also brings higher engine stresses, so the robust design of the diesel engine makes the addition of a turbocharger less problematic compared to gasoline engines. While turbochargers increase the efficiency of the diesel engine, exhaust emissions are also improved. Moreover, smaller turbocharged diesel engines can be

[12] Ecopoint Inc., 2000. "Turbochargers for Diesel Engines", DieselNet Technology Guide.

used in place of larger non-turbocharged engines to achieve desired engine performance characteristics.

The most widely used turbochargers utilize exhaust gas to spin a turbine at speeds from 10,000 to over 150,000 rpm. The turbine is mounted on the same rotating shaft as an adjacent centrifugal pump. The energy that would otherwise be exhausted as waste heat is used to drive the turbine, which in turn drives the centrifugal pump. This pump draws in fresh air and compresses it to increase the density of the air charge to the cylinders, thereby increasing power.

A boost pressure sensor is typically located in the intake manifold to provide a feedback signal of the current turbo boost. As turbo speed (boost) increases, the pressure in the intake manifold also increases. Hence, engine designers may compare the boost pressure signal to a target boost for the given engine speed and load conditions. Target boost pressure is then obtained by either modulating a wastegate valve or turbo vanes.

Proper boost control is essential to optimize emission levels. Even short periods of over- or under-boost can result in undesired air-fuel ratio excursions and corresponding emission increases. Additionally, the boost control system directly affects exhaust and intake manifold pressures. Another critical emission control system, EGR, is very dependent on these two pressures and generally uses the differential between them to force exhaust gas into the intake manifold. If the boost control system is not operating correctly, the exhaust or intake pressures may not be as expected and EGR may not function as designed. In high-pressure EGR systems, higher exhaust pressures will generate more EGR flow and, conversely, lower pressures will reduce EGR flow. A malfunction that causes excessive exhaust pressures (e.g., wastegate stuck closed at high engine speed) can produce higher EGR flowrates at high load conditions and have a negative impact on emissions.[13]

Manufacturers commonly use charge air coolers to maximize the benefits of turbocharging. As the turbocharger compresses the intake air, the temperature of the intake air charge increases. This increasing air temperature causes the air to expand, which is directionally opposite of what turbocharging is attempting to accomplish. Charge air coolers are used to exchange heat between the compressed air and ambient air (or coolant) and cool the compressed air. Accordingly, a decrease in charge air cooler performance can affect emissions by causing higher intake air temperatures that can lead to increased NOx emissions from higher combustion temperatures.

One drawback of turbocharging is known as turbo lag. Turbo lag occurs when the driver attempts to accelerate quickly from a low engine speed. Since the turbocharger is a mechanical device, a delay exists from the driver demand for more boost until the exhaust flow can physically speed up the turbocharger. In addition to a negative effect on driveability and performance, improper fueling (e.g., over-fueling) during this lag can cause emission increases (typically PM).

[13] Ecopoint Inc., 2000. “Effects of EGR on Engine and Emissions”, DieselNet Technology Guide.

To decrease the effects of turbo lag, manufacturers design turbos that spool up quickly at low engine speeds and low exhaust flowrates. However, designing a turbo that will accelerate quickly from a low engine speed but will not result in an over-speed/over-boost condition at higher engine speeds is difficult. That is, as the engine speed and exhaust flowrates near their maximum, the turbo speed increases to levels that cause excessive boost pressures and heat that could lead to engine or turbo damage. To prevent excessive turbine speeds and boost pressures at higher engine speeds, a wastegate is often used to bypass part of the exhaust stream around the turbocharger. The wastegate valve is typically closed at lower engine speeds so that all exhaust is directed through the turbocharger, thus providing quick response from the turbocharger when the driver accelerates quickly from low engine speeds. The wastegate is then opened at higher engine speeds to prevent engine or turbo damage from an over-speed/over-boost condition.

An alternative to using a wastegate is to use an improved turbocharger design commonly referred to as a variable geometry turbo (VGT). To prevent over-boost conditions and to decrease turbo lag, VGTs are designed such that the geometry of the turbocharger changes with engine speed. While various physical mechanisms are used to achieve the variable geometry, the overall result is essentially the same. At low engine speeds, the exhaust gas into the turbo is restricted in a manner that maximizes the use of the available energy to spin the turbo. This allows the turbo to spool up quickly and provide good acceleration response. At higher engine speeds, the turbo geometry changes such that exhaust gas flow into the turbo is not as restricted. In this configuration, more exhaust can flow through the turbocharger without causing an over-boost condition. The advantage that VGTs offer compared to a waste-gated turbocharger is that all exhaust flow is directed through the turbocharger under all operating conditions. This can be viewed as maximizing the use of the available exhaust energy.

The OBD II regulation currently requires Individual electronic components (e.g., valves, sensors) used by the boost pressure control system to be monitored under the comprehensive component monitoring requirements.

Proposed Monitoring Requirements

Since boost control systems are a common feature of modern diesel engines and can have a large impact on emissions when they deteriorate, staff is proposing specific monitoring requirements for these systems. The staff is proposing manufacturers be required to monitor boost control systems for proper operation. Manufacturers would be required to continuously monitor for appropriate boost to verify that the turbocharger is operating as designed and conditions of over-boost or under-boost are not occurring. Specifically, the OBD system would be required to indicate a malfunction before an increase or decrease in boost pressure causes emissions to exceed a certain threshold. Details of the specific malfunction thresholds are provided in Table 2 at the beginning of section III.

The staff is also proposing that manufacturers be required to monitor for slow response malfunctions of the VGT system. That is, the OBD system would be required to monitor the time required to reach the desired boost, whether transitioning from high to low boost or low to high, and indicate a malfunction before an increase in the response time causes emissions to exceed a certain threshold. These thresholds are the same as those required for boost pressure monitoring above.

The proposed regulation would also require the OBD II system to monitor the electronic components of the boost control system (e.g., actuators, pressure sensors, position sensors) that provide or receive a signal from the engine control module (ECM) under the comprehensive component requirements for malfunctions such as circuit failures, rationality faults, and functional response to computer commands.

Lastly, the staff is proposing that charge air coolers be monitored for proper cooling of the intake air. That is, the OBD II system would be required to detect a charge air cooling system malfunction before a decrease in cooling from the manufacturer's specified cooling rate causes emissions to exceed a certain threshold. These thresholds are the same as those required for boost pressure monitoring above. If no charge air undercooling malfunction can cause emissions to exceed the malfunction emission threshold, then the cooler would need to be monitored for proper functionality (e.g., verify that some detectable level of cooling is occurring).

Regarding feedback-controlled boost pressure systems, staff is proposing that manufacturers indicate a malfunction if the boost pressure system fails to begin feedback control within a manufacturer-specified time interval. Manufacturers would also be required to indicate a malfunction if failure or deterioration of components used as part of the feedback control strategy causes the system to go open-loop (i.e., stops feedback control) or default operation of the boost pressure system. Lastly, manufacturers would also be required to indicate a malfunction if feedback control has used up all of the adjustment allowed by the manufacturer. Malfunctions that cause delays in starting feedback control and malfunctions that cause open-loop operation could either be detected with a boost pressure system specific monitor or with individual component monitors.

Technical Feasibility of Proposed Monitoring Requirements

To monitor boost control systems, manufacturers are expected to look at the difference between the actual pressure sensor reading (or calculation thereof) and the desired/target boost pressure. If the error between the two is too large or persists for too long, a malfunction would be detected. Manufacturers would need to calibrate the length of time and size of error to ensure robust detection of a fault occurs before the emission malfunction threshold is exceeded. Given the purpose of a closed-loop control system with a feedback sensor is to continually measure the difference between actual and desired boost pressure, the control system is already continually monitoring the difference and attempting to minimize it. As such, a diagnostic requirement to indicate a fault when the difference gets too large and the system can no longer properly achieve the desired boost is essentially an extension of the existing control strategy. Additionally, multiple diesel medium-duty engines are currently certified to the OBD II regulation requirements with OBD II systems that meet these proposed requirements.

To monitor for malfunction or deterioration of pressure sensors, manufacturers could validate sensor readings against other sensors present on the vehicle or against ambient conditions. For example, at initial key-on before the engine is running, the boost pressure sensor should read ambient pressure. If the vehicle is equipped with a barometric pressure sensor, the two sensors could be compared and a malfunction indicated when the two readings differ beyond the specific tolerances. A more crude rationality check of the boost pressure sensor may be accomplished by verifying that the pressure reading is within reasonable atmospheric limits for the conditions to which the vehicle will be subjected.

Rationality monitoring of VGT position sensors may be accomplished by comparing the measured sensor value to expected values for the given engine speed and load conditions. For example, at high engine speed and loads, the position sensor should indicate that the VGT position is open more than would be expected at low engine speed and loads. These rationality checks would need to be two-sided. That is, position sensors would be checked for appropriate readings at both high and low engine operating conditions.

Lastly, monitoring of boost pressure feedback control could be performed using the same strategies discussed for fuel system feedback control monitoring in section IV.D of this report.

H. NOx ADSORBER MONITORING

Background

NOx adsorbers are another NOx control technology that has been experiencing significant progress in development and optimization. This is one of the newer technologies being optimized for use in diesel vehicles as well as lean-burn gasoline vehicles. The adsorbers chemically bind (i.e., “trap”) the oxides of nitrogen during lean engine operation. Generally, when the storage capacity of the adsorbers is saturated, regeneration occurs and the stored NOx is released and converted. This occurs under rich exhaust conditions and includes the chemical reduction of the released NOx to nitrogen by carbon monoxide, hydrogen, and hydrocarbons on a precious metal site. The rich exhaust conditions, which generally last for several seconds, are typically achieved using a combination of intake air throttling (to reduce the amount of intake air), exhaust gas recirculation, and post-combustion or in-exhaust fuel injection.

NOx adsorber systems have demonstrated NOx reduction efficiencies from 50 percent to in excess of 80 to 90 percent. However, this efficiency has been found to be highly dependent on the fuel sulfur content because NOx adsorbers are extremely sensitive to sulfur. Sulfur compounds can saturate the adsorber and limit the number of active sites for NOx adsorption, thereby lowering the NOx reduction efficiency. Accordingly, low sulfur fuel is required to achieve the greatest NOx reduction efficiencies. Although new adsorber washcoat materials are being developed with a higher resistance to sulfur poisoning and ultra-low sulfur fuel will be required in the future, it is projected that NOx adsorber systems will still be subject to sulfur poisoning and will require a sulfur regeneration mechanism.[14] Sulfur poisoning, however, is generally reversible through a desulfurization process, which requires high temperatures (i.e., 500 to 700 degrees Celsius) accompanied by a rich fuel mixture that can be achieved with post-injection and installation of a light-off catalyst upstream of the NOx adsorber. Because the sulfur regeneration process takes much longer (e.g., several minutes) and requires more fuel and heat than the NOx regeneration step, permanent thermal degradation of the NOx adsorber and fuel economy penalties may result from too frequent sulfur regeneration. However, if regeneration is not done frequently enough, NOx conversion efficiency is compromised and fuel economy penalties will also be incurred from excessive purging of the NOx adsorber.[15]

In order to achieve and maintain high NOx conversion efficiencies while limiting negative impacts on fuel economy and driveability, vehicles with NOx adsorption systems will require precise air-fuel control in the engine and in the exhaust stream. Many of these control strategies are still undergoing rapid development. However, diesel manufacturers are expected to utilize NOx sensors and temperature sensors to provide the most precise closed-loop control for the NOx adsorber system.[16] These sensors will provide the adsorber control system with valuable information regarding the NOx levels, oxygen levels/air-fuel ratio, and adsorber temperatures that are needed to achieve and maintain the highest NOx conversion efficiencies possible with minimum fuel consumption penalties during all types of operating conditions. Further, these same sensors can also be used to monitor the adsorber system as will be described later.

Alternatively, if NOx sensors are not used to control the NOx adsorber system, it is projected that A/F sensors (located upstream and downstream of the adsorber) can be used effectively as a substitute. A/F sensors are currently used by one manufacturer on a gasoline-fueled vehicle equipped with a NOx adsorber system to control and monitor the system. Although manufacturers have previously expressed concerns regarding the durability of A/F sensors in diesel applications, these concerns apparently have been sufficiently addressed since at least one diesel manufacturer is using A/F sensors for EGR control. On diesel applications, A/F sensors have several advantages over NOx sensors including lower cost, wide availability, and a mature technology. However, A/F sensors cannot provide an instantaneous indication of tailpipe NOx levels, which would allow the control system to precisely determine when the adsorber system is filled to capacity and regeneration should be initiated. If A/F sensors are used in lieu of NOx

[14] Bailey, O., H., Dou, D., and Molinier, M., "Sulfur Traps for NOx Adsorbers: Materials Development and Maintenance Strategies for Their Application," SAE Paper 2000-01-1205; "NOx Adsorbers," www.dieselnet.com.

[15] Ingram, G. A. and Surnilla, G., "On-Line Estimation of Sulfation Levels in a Lean NOx Trap," SAE Paper 2002-01-0731.

[16] "NOx Adsorbers," www.dieselnet.com.

sensors, an estimation of NOx engine-out emissions and their subsequent storage in the NOx adsorber can be achieved indirectly through modeling. However, this may require significant development work depending upon the sophistication of the model.

The OBD II regulation currently requires manufacturers to come in with a plan for Executive Officer approval under the “other emission control or source system monitoring” requirements detailing the monitoring strategy, malfunction criteria, and monitoring conditions for the NOx adsorber.

Proposed Monitoring Requirements

In developing the heavy-duty OBD requirements, staff has gained sufficient experience to provide more detailed monitoring requirements for NOx adsorbers. Therefore, the staff is proposing that manufacturers monitor the NOx adsorber for proper performance. The OBD II system would be required to indicate a malfunction when the adsorber capability decreases to a point such that emissions exceed a certain NMHC or NOx emission threshold and that this threshold would become increasingly stringent in the 2007 through 2013 model years. Details of the exact emission levels and model years are provided in Tables 2 and 3 at the beginning of section III. Additionally, if a malfunctioning NOx adsorber cannot cause emissions to exceed the malfunction emission threshold, a manufacturer would only be required to functionally monitor the system and indicate a malfunction when no NOx adsorber capability could be detected.

Additionally, for NOx adsorber systems that use active or intrusive injection (e.g., in-cylinder post-fuel injection) to achieve desorption of the adsorber, the OBD system would be required to indicate any malfunction of the injection system that would prevent proper desorption of the NOx adsorber.

Technical Feasibility of Proposed Monitoring Requirements

As mentioned earlier, either NOx sensors or A/F sensors along with a temperature sensor are projected to be used for controlling the NOx adsorber system. These same sensors could also be used to monitor the adsorber system. The use of NOx sensors placed upstream and downstream of the adsorber system would allow the system’s NOx reduction performance to be continuously monitored. For example, the upstream NOx sensor on a properly functioning adsorber system operating with lean fuel mixtures, will read high NOx levels while the downstream NOx sensor should read low NOx levels. With a deteriorated NOx adsorber system, the upstream NOx levels will continue to be high while the downstream NOx levels will also be high. Therefore, a malfunction of the system can be detected by comparing the NOx levels measured by the downstream NOx sensor versus the upstream sensor. With further development, the staff projects that manufacturers will be able to model the upstream NOx levels (based on other engine operating parameters such as engine speed, fuel injection quantity and timing, EGR flow rate), thereby eliminating the need for the front NOx sensor for both control and monitoring purposes.

Alternatively, if NOx sensors are not used by the adsorber system for control purposes, monitoring of the system could be conducted by using A/F sensors to replace one or both of the NOx sensors. Under lean engine operation conditions with a properly operating NOx adsorber system, both the upstream and downstream A/F sensors will indicate lean mixtures. However, when the exhaust gas is intrusively commanded rich, the upstream A/F sensor will quickly indicate a rich mixture while the downstream oxygen sensor should continue to see a lean mixture in the exhaust due to the release and reduction of NO_2 in the adsorber. Once all of the stored NO_2 has been reduced, the downstream A/F sensor will indicate a rich reading. The more NOx that is stored in the adsorber, the longer the delay before the downstream A/F sensor indicates a rich exhaust gas. Thus, the time differential between the upstream and downstream A/F sensors' lean-to-rich indication is a gauge of the NOx adsorption capability of the adsorber and can be calibrated to indicate different levels of performance. Fresh NOx adsorber systems will have the highest NOx adsorption capability and consequently the longest "lean-to-rich switch" time differential while deteriorated adsorbers with no adsorption capability will have the shortest time differential. Therefore, the NOx adsorber system could be monitored by calibrating the lean-to-rich time differential to indicate a fault when the NOx adsorber system has deteriorated to a level such that the emission thresholds would be exceeded. Honda currently utilizes A/F sensors in a similar manner as described above to monitor the NOx adsorber on a 2003 model year gasoline vehicle.

Since sulfur poisoning reversibly diminishes the performance of the NOx adsorber system, it is imperative that sulfur poisoning be distinguished from a true deteriorated system. Otherwise, perfectly good NOx adsorber systems could erroneously be identified as being bad (i.e., false MILs could occur). Manufacturers of gasoline vehicles with NOx adsorber systems are aware of this issue and are taking various measures to account for adsorber sulfation. These approaches are also being pursued on diesel vehicles. When the NOx adsorption capacity decreases past a predetermined threshold, a desulfation event is intrusively commanded (e.g., with an external heat source or rich fuel mixture) to sufficiently heat up the adsorber for sulfur removal. After desulfation, the adsorber system's NOx capacity is again reevaluated. If the NOx capacity is now below the predetermined threshold, the NOx adsorber is judged good and the previous deteriorated result was due to sulfur poisoning. However, if the NOx capacity is still below the threshold, the NOx adsorber is truly bad and the MIL should be commanded on and a fault code identifying the deteriorated adsorber stored.

The injection system used to achieve desorption of the adsorber could also be monitored with A/F sensors. When the control system injects extra fuel to achieve a rich mixture, the front A/F sensor will respond to the change in fueling and can be used to directly measure whether or not the proper amount of fuel has been injected. If manufacturers employ a NOx adsorber system design that uses only a single A/F sensor downstream of the adsorber for monitoring and control of desorption, the downstream sensor could also be used to monitor the performance of the injection system. As discussed above, the sensor downstream of the adsorber will switch from a lean reading to a rich reading when the stored NO_2 has been released and reduced. If the sensor switches too quickly after rich fueling is initiated, it is an indication that either too much fuel is being injected or the adsorber itself has poor storage capability. Conversely, if the sensor takes too long to switch after rich fueling is initiated, it may be an indication that the adsorber has very good storage capability. However, excessive switch times (i.e., times that exceed the maximum storage capability of the adsorber) would be indicative of an injection system malfunction (i.e., insufficient fuel is being injected) or a sensor malfunction (i.e., the sensor has slow response).

I. PARTICULATE MATTER (PM) FILTER MONITORING

Background

In order to meet the stringent PM standards, manufacturers will generally use aftertreatment devices such as PM filters to achieve the necessary emission levels. PM filters are considered the most effective control technology for reduction of particulate emissions and can typically achieve PM reductions in excess of 90 percent. In general, a PM filter consists of a filter material that permits exhaust gases to pass through but traps the PM emissions. In order to maintain the performance of the PM filter and the vehicle, the trapped PM must be periodically removed before too much particulate is accumulated and exhaust backpressure reaches unacceptable levels. The process of periodically removing accumulated PM from the filter is known as regeneration and is very important for maintaining low PM emission levels. PM filter regeneration can be passive (i.e., occur continuously during regular operation of the filter), active (i.e., occur periodically after a predetermined quantity of particulates has been accumulated), or a combination of the two. With passive regeneration, oxidation catalyst material is typically incorporated into the PM filter to lower the temperature for oxidizing PM. This allows the filter to continuously oxidize trapped PM material during normal driving. In contrast, active systems utilize an external heat source such as an oxidation catalyst that is brought up to temperature at specific intervals by supplemental injected fuel (usually by in-cylinder post fuel injection), a fuel burner or perhaps an electric heater to facilitate PM filter regeneration. It is projected that virtually all PM filter systems will have some sort of active regeneration mechanism.

One of the key factors that needs to be taken into account for a filter regeneration control system is the amount of soot quantity that is stored in the PM filter (often called soot loading).[17] If too much soot is stored in the PM filter when regeneration is activated, the soot can burn uncontrollably and damage the filter. However, activating regeneration when there is too little trapped soot is also undesirable since there is a minimum amount of soot quantity needed to ensure good burn propagation. Another important factor to be considered in the control system design is the fuel economy penalty of filter regeneration. Prolonged operation with high backpressures in the exhaust and too frequent regenerations are both detrimental to fuel economy and durability of the filter. Given these considerations, the control system for the regeneration system is projected to utilize both pressure sensors and temperature

[17] Salvat, O., Marez, P., and Belot, G., “Passenger Car Serial Application of a Particulate Filter System on a Common Rail Direct Injection Diesel Engine,” SAE Paper 2000-01-0473.

sensors to model soot loading among other properties. Sensors that can directly measure the amount of particulate matter in diesel exhaust are also being developed (PM sensors) and can be used in addition to the pressure and temperature sensors to provide a more accurate estimate of the soot loading on the filter. One of these sensors is capable of measuring particulate at engine out levels.[18] Another particulate sensor being developed will be capable of measuring very low particulate concentrations downstream of the particulate filter in order to provide a direct evaluation of the condition of the particulate filtering system. Through the information provided by these sensors, designers can optimize the PM filter for effectiveness and maximum durability while minimizing fuel economy and performance penalties.

The OBD II regulation currently requires the OBD II system to indicate a PM filter performance malfunction prior to emissions exceeding 1.5 times any of the applicable standards for 2004 and subsequent light-duty vehicles and medium-duty passenger vehicles and 2007 and subsequent medium-duty vehicles. If any malfunction of the PM filter cannot cause emissions to exceed 1.5 times any of the applicable standards, the OBD II system would be required to indicate a malfunction when catastrophic failure of the PM filter occurs.

<u>Proposed Monitoring Requirements</u>

The staff is proposing monitoring requirements that would verify the PM filter's filtering, regeneration, and (for catalyzed PM filters) NMHC conversion performances.

PM Filter Monitoring

The OBD II system would be required to indicate a malfunction of the PM filter (e.g., cracks or melting in the filter) when the filtering capability decreases to a point such that PM emissions exceed a specified emission threshold and the specified levels would become increasingly stringent from 2007 through the 2013 model year. Details of the proposed monitoring thresholds and the phase-ins are provided in Tables 2 and 3 at the beginning of section III. of this report. In addition, the proposed regulation would require the OBD II system to indicate a fault for an "empty can" (i.e., completely removed/destroyed substrate) or an inappropriately replaced filter (i.e., PM filter assembly replaced by a muffler or a straight pipe).

Additionally, for catalyzed PM filters that are able to convert NMHC emissions, the proposed regulation would require the OBD II system to indicate a malfunction when the NMHC conversion efficiency decreases to the point that NMHC emissions exceed emission thresholds specified in the regulation. If any malfunction of the NMHC conversion capability cannot cause NMHC emissions to exceed the malfunction emission threshold, the OBD II system would be required to indicate a malfunction when there is no detectable amount of NMHC conversion.

[18] David Kittelson, Hongbin Ma, Michael Rhodes, and Brian Krafthefer, "Particle Sensor for Diesel Combustion Monitoring," Presentation supported under DOE Cooperative Agreement DE-FC04-02AL67636, Honeywell, prime contractor, University of Minnesota, subcontractor.

PM Filter Regeneration Monitoring

Regeneration must be monitored by the OBD II system since this process is vital to maintaining the performance of the PM filter. Thus, staff is proposing that manufacturers monitor PM filters for proper performance of the regeneration process. The OBD II system would be required to indicate a malfunction when the regeneration frequency increases to a level past the manufacturer's specified regeneration frequency such that NMHC, CO (for light-duty vehicles), or, NOx emissions exceed a certain threshold. These thresholds are the same as those required for NMHC conversion monitoring of catalyzed PM filters above. If excess regeneration frequency cannot cause emissions to exceed malfunction emission thresholds, the OBD II system would be required to indicate a malfunction when the regeneration frequency exceeds the manufacturer's specified design limit for allowable regeneration frequency. The proposed requirements would also require the OBD II system to indicate a fault when no regeneration occurs during conditions where the manufacturer designates regeneration to occur.

Additionally, for PM filter systems that use active or intrusive injection (e.g., in-cylinder post-fuel injection) to achieve regeneration of the filter, the OBD II system would be required to indicate any malfunction of the injection system that would prevent regeneration of the PM filter.

Regarding feedback-controlled PM filter regeneration systems, staff is proposing that manufacturers indicate a malfunction if the regeneration control system fails to begin feedback control within a manufacturer-specified time interval. Manufacturers would also be required to indicate a malfunction if failure or deterioration of components used as part of the feedback control strategy cause the system to go open-loop (i.e., cease feedback control) or default operation of the injection system. Lastly, manufacturers would also be required to indicate a malfunction if feedback control has used up all of the adjustment allowed by the manufacturer. Malfunctions that cause delays in starting feedback control and malfunctions that cause open-loop operation could either be detected with a regeneration control system specific monitor or with individual component monitors.

Technological Feasibility of Proposed Monitoring Requirements

It is anticipated that manufacturers will not need additional hardware to meet the PM filter monitoring requirements with the exception of the addition of one PM sensor. The same sensors that are used to control trap regeneration are projected to be used for monitoring. In general, a differential pressure sensor placed across the filter and at least one temperature sensor located near the PM filter are used for the control system. As mentioned earlier, a differential pressure sensor is expected to be used on PM filter systems to prevent damage due to delayed or incomplete regeneration that could lead to excess temperatures. When the sensor senses high pressures, regeneration can be activated. However, while backpressure sensors are a necessary part of the control strategies for the PM filter, pressure sensors alone are not sufficient for proper control and protection of the filter. The staff understands from discussions with engine manufacturers, PM filter suppliers, and consultants, that backpressure by itself does not provide a robust indication of soot loading. To make up for the shortcomings of backpressure sensors, manufacturers will also utilize soot-loading models to predict the loading of the filter and to initiate regeneration. The model will estimate the degree of filter loading by tracking the difference between the modeled engine-out PM (i.e., the emissions that are being loaded on to the filter) and regenerated PM (i.e., the PM that is being burned off the filter due to the vehicle operating conditions and /or active regeneration). If the model indicates the PM filter is heavily loaded but the backpressure sensor does not indicate heavy loading, regeneration will be activated based on the model. As mentioned earlier, particulate matter sensors can also be used upstream of the filter in conjunction with the pressure and temperature sensors to better estimate the PM loading of the filter (i.e., the soot-loading model) and optimize filter regeneration frequency and duration. Currently, the sensitivity of these sensors is not sufficient for measuring the low PM levels downstream of the filter. However, with further development, staff believes that a PM sensor with the necessary sensitivity for measuring PM levels downstream of the filter will be available in the 2010 to 2013 timeframe. With such a sensor available, the proposed final emission thresholds for PM filter monitoring should be achievable.

A comprehensive and accurate soot-loading model is necessary for successful monitoring of the PM filter. The proposed monitoring requirements are feasible with further development of the PM filter soot-loading model to make it sufficiently accurate to detect when the actual filter loading inferred from the pressure sensor does not agree with the predicted loading from the soot loading model. The pressure sensor, in combination with the model, could also be used to determine if regeneration is functioning correctly and to evaluate the suitability of the filter for controlling particulate emissions. For example, after a regeneration event, the backpressure should drop significantly since the trapped soot and particles are removed. If backpressure does not drop within the range expected after a regeneration event as predicted by the model, the regeneration did not function correctly (or the filter could have excessive ash loading) and the OBD II system would alert the vehicle operator of a problem. Also, backpressure on a normal PM filter should progressively increase as the mass of soot and trapped particles increases. In general, the mass of soot and trapped particles should increase as the mileage traveled or time of operation increases. However, a cracked filter or missing filter may not experience increased backpressure as expected. Therefore, a cracked or missing filter can be detected if the backpressure fails to increase at the rate projected by the soot-loading model. Backpressure increases with both increased soot loading on the filter and with increasing exhaust flowrate (i.e., as engine load increases). To optimize comparison between the soot-loading model and the backpressure sensor, it is important to account for this increase in backpressure due to exhaust flow (e.g., by normalizing the backpressure based on exhaust flow rate).

Manufacturers have expressed concern, that over time, ash will accumulate on the PM filter, thus altering the soot-loading characteristics. A PM filter with significant ash loading will not drop to as low backpressure levels immediately following a thorough regeneration event and it will load up quicker (because the soot capacity will be reduced by the accumulated ash). If not accounted for, this ash loading could result in inappropriate indication of a fault. Ash loading is a normal byproduct of engine operation (the ash loading is largely a function of oil consumption by the engine and the ash content of the engine oil). Manufacturers could monitor the ash accumulation rate and include that in their soot-loading model. While the ash accumulation rate varies based on the ash content of the engine oil, one manufacturer has indicated it plans on specifying the type of engine oil that must be used so the ash accumulation rate can be accurately accounted for. If the ash accumulation rate significantly exceeds the normal acceptable rate predicted by the model, or the model has determined that the filter has reached its maximum ash loading and the required maintenance is not performed (manufacturers are investigating maintenance intervals and procedures to remove the ash from the filter), a malfunction could then be appropriately indicated.

Lastly, manufacturers have indicated that they are concerned that small differences in crack size or location may generate large differences in tailpipe emission levels, and they are not confident that they can reliably detect all leaks that would result in the emission levels proposed for the malfunction criteria. Accordingly, the manufacturers have suggested pursuing an alternate malfunction criterion independent of emission level such as a percent of exhaust flow leakage or a specified hole size for a leak. However, staff does not believe that pursuit of such alternate thresholds is appropriate at this time. Manufacturers have not even completed work on initial widespread implementation of PM filters for the 2007 model year, and staff expects substantial refinement and optimization will be made by manufacturers based on their field experience prior to the introduction of this monitor in the 2010 model year. Industry also explained that spontaneous small areas of self regeneration might occur in the PM filter during normal vehicle operation and that such episodes could affect the reliability of the monitoring strategies that have been outlined. Given that monitoring strategies are in their infancy, industry needs to develop their strategies further to overcome some of these possible issues. In any case, a successful downstream PM sensor would provide a direct reading of tailpipe PM and would not be subject to these latter concerns. Staff projects that only one PM sensor located either upstream or downstream of the PM filter will be needed for monitoring purposes.

As mentioned earlier, manufacturers are projected to also use temperature sensors for regeneration control purposes. As an additional benefit, this same sensor could also be used in these systems to monitor active regeneration of the filter. If excess temperatures are seen by the temperature sensor during active regeneration, the regeneration process can be stopped or slowed down to protect the filter. If active regeneration is commanded on and there isn’t a sufficient temperature rise in the PM filter system for the amount of soot stored in the filter, the regeneration system is malfunctioning and the OBD II system would alert the driver of a problem.

Lastly, monitoring of PM filter regeneration feedback control could be performed using the same strategies discussed for fuel system feedback control monitoring in section IV.D of this report.

J. CRANKCASE VENTILATION (CV) SYSTEM MONITORING REQUIREMENTS

Background

During the engine combustion process, some exhaust gases can escape past the piston into the crankcase and subsequently to the atmosphere. The CV system is used to remove exhaust gases (also known as “blow-by”) that have not combusted in the cylinder and direct them to the intake manifold to be burned by the engine. The CV system generally consists of a crankcase vapor outlet hose (through which the exhaust gas is directed from the crankcase to the intake ducting typically upstream of the compressor), and a CV valve to control the flow through the system. Many diesel systems also include a filter and/or oil separator to reduce the amount of oil and/or particulate matter that exits the CV system. As with CV systems on gasoline vehicles, staff believes the likely cause of CV system malfunctions and excess emissions is improper service or tampering of the CV system. These failures include misrouted or disconnected hoses, and missing or improperly installed valves, filters, or oil separators. Of these failures, hose disconnections on the vapor vent side of the systems and/or missing valves can cause emissions to be vented to the atmosphere.

For vehicles with diesel engines, the OBD II regulation currently requires (under the “Positive Crankcase Ventilation (PCV) System Monitoring” requirements) manufacturers to submit a plan for Executive Officer approval of the monitoring strategy, malfunction criteria, and monitoring conditions prior to introduction on a production vehicle. Executive Officer approval is based on the effectiveness of the monitoring strategy to monitor the performance of the CV system to the extent feasible with respect to the proposed malfunction criteria detailed in the current regulation, which essentially requires the OBD II system to monitor for disconnections between the crankcase and the CV valve and between the CV valve and the intake ducting. The regulation also does not require the stored fault code to specifically identify the disconnection if additional hardware would be required for this purpose, and provided service information generated by the manufacturer directs technicians to examine the connection as a possible cause of the indicated fault.

Proposed Monitoring Requirements

Instead of continuing to use the provision to allow manufacturers to submit a monitoring plan for ARB approval, the staff is proposing to apply essentially the same monitoring requirements that are currently being required for gasoline vehicles.
Thus, the staff is proposing that manufacturers be required to monitor the CV system for disconnections between the crankcase and the CV valve and between the CV valve and the intake ducting. Regarding disconnection between the CV valve and the crankcase, detection would likely be significantly more difficult, and could require additional hardware such as a pressure switch to ensure flow in the system. However, in order to

facilitate cost-effective compliance, the staff proposes to exempt manufacturers from detecting this type of disconnection if certain system design requirements are satisfied. Specifically, manufacturers can be exempted from monitoring in this area if the CV valve is fastened directly to the crankcase in a manner that makes technicians more likely to disconnect the intake ducting hose from the valve rather than disconnect the valve itself from the crankcase during service or if disconnection of the CV valve results in a rapid loss of oil such that the vehicle operator is certain to respond and have the vehicle repaired. Staff believes that this would eliminate most of the disconnected hose and valve events because technicians who do not reconnect the intake ducting hose when the service procedure is completed will be alerted to a diagnostic fault or oil leak that will lead the technician back to the improperly assembled component.

For CV system designs that utilize tubing between the crankcase and the valve or any additional tubing or hoses used to equalize pressure or to provide a ventilation path between various areas of the engine (e.g., crankcase and valve cover), the proposed regulation would allow for an exemption from detecting disconnection in this area. This exemption would be obtained if it is demonstrated that all of these connections are resistant to deterioration or accidental disconnection, are significantly more difficult to remove than the connections between the intake ducting and the valve, and are not subject to disconnection during any of the manufacturer's repair procedures for non-CV system repair work. Again, the staff believes these safeguards will eliminate most of the disconnected hose and valve failures previously observed in the field on gasoline systems while still providing manufacturers with adequate design flexibility to meet the requirement.

Under the existing certification requirements for medium-duty diesel engines, manufacturers are allowed to implement open CV systems (i.e., systems that release crankcase vapors to the atmosphere without routing them to the intake ducting or to the exhaust upstream of the aftertreatment) if the manufacturer accounts for the crankcase emissions to the atmosphere in the tailpipe certification values. Currently, all manufacturers will be implementing closed CV systems (i.e., systems that route crankcase vapors to the intake or exhaust upstream of the aftertreatment). As such staff is not proposing specific monitoring requirements for open systems at this time. However, the proposal would still require manufacturers to submit a monitoring plan for Executive Officer approval. The plan would be approved based on the effectiveness of the proposed monitor to detect disconnections and malfunctions in the system that prevent proper control of crankcase emissions (e.g., if the system is equipped with a filter to reduce crankcase emissions to the atmosphere, the OBD II system shall monitor the integrity of the filter).

Technical Feasibility of Proposed Monitoring Requirements

In general, diesel engine manufacturers would be required to meet design requirements for most of system in lieu of actually monitoring many of the hoses for disconnection. Specifically, the proposed regulation would allow for an exemption for any portion of the system that is resistant to deterioration or accidental disconnection and not subject to disconnection during any of the manufacturer's repair procedures for non-CV system repair work. These safeguards should eliminate most of the disconnected or improperly connected hoses while allowing manufacturers to meet the requirements without adding any additional hardware solely to meet the monitoring requirements. Where monitoring is required between the CV and the intake ducting, it is possible to use monitoring strategies similar to those used on gasoline vehicles. For example, if the components of the CV system are properly sized, a disconnected line will cause a large source of unmetered air to be inducted into the engine which can be detected by EGR or intake air mass flow rationality monitoring.

K. ENGINE COOLING MONITORING REQUIREMENTS

Manufacturers generally utilize engine coolant temperature (ECT) as an input for many of the emission-related engine control systems. Diesel engines generally use ECT to initiate closed-loop control of some emission control systems, such as EGR systems. Similar to closed-loop fuel control on gasoline engines, if the coolant temperature does not warm up, closed-loop control of these emission control systems will usually not begin, which will also result in increased emissions.

The OBD II regulation currently requires the OBD II system on diesel applications to indicate a fault when the ECT sensor does not achieve the stabilized minimum temperature needed for “warmed-up fuel control” within an Executive Officer-approved time interval after starting the engine. The staff is proposing to modify this language to require the OBD II system to indicate a fault when the ECT sensor does not achieve the stabilized minimum temperature needed “to begin closed-loop or feedback operation of emission-related engine controls (e.g., feedback control of fuel pressure, EGR flow, boost pressure)” within an Executive Officer-approved time interval after starting the engine. In other words, manufacturers would be required to monitor the ECT sensor to ensure that the vehicle achieved the highest minimum temperature needed for closed-loop control of all emission control systems (e.g., fuel system, EGR system) on diesel vehicles. The technical feasibility of the proposed amendments has already been demonstrated on other light- and medium-duty vehicles under the OBD II regulation.

L. VARIABLE VALVE TIMING AND/OR CONTROL (VVT) SYSTEM MONITORING REQUIREMENTS

The OBD II regulation currently requires the OBD II system to indicate a target error or slow response malfunction of the VVT system before emissions exceed 1.5 times the applicable standards. Based on experience gained during development of the heavy-duty OBD regulation, the staff is proposing to revise the malfunction emission threshold for diesel vehicles. Specific emission thresholds for the phase-in years are provided in Tables 2 and 3 in the beginning of section III.

VVT systems are in general use in light- and medium-duty gasoline applications, and under the OBD II regulation, such systems have been monitored for proper function on the applications that have used VVT systems since the 1996 model year. Most recently, these manufacturers have designed monitoring strategies to detect VVT system malfunctions that cause emissions to exceed an emission threshold, which is currently required in the OBD II regulation for all 2006 and subsequent model year Low Emission Vehicle II applications. Thus, technical feasibility has been demonstrated on these vehicles.

M. COMPREHENSIVE COMPONENT MONITORING REQUIREMENTS

The OBD II regulation currently requires the monitoring of comprehensive components, which covers all other electronic powertrain components or systems not mentioned above that either can affect vehicle emissions or are used as part of the OBD II diagnostic strategy for another monitored component or system. They are generally identified as input components, which provide input directly or indirectly to the on-board computer, or as output components or systems, which receive commands from the on-board computer. Typical examples of input components on diesel vehicles include the exhaust temperature sensor and the fuel pressure sensor. Typical examples of output components/systems on diesel vehicles include the idle governor, the wait-to-start lamp, and cold start aids (e.g., glow plugs). Monitoring of comprehensive components is essential since the proper performance of these components can be critical to the monitoring strategies of other components or systems. Generally, these components are also essential for proper fuel control or driveability, and malfunctions of them often cause an increase in emissions or impact fuel economy and/or vehicle performance.

The staff is proposing a few amendments to the comprehensive component monitoring requirements for diesel vehicles. The proposed changes mentioned for gasoline comprehensive component monitoring (i.e., electronic powertrain components driven by the engine, hybrid components) in section III.F of the Staff Report also apply to diesel vehicles. Additionally, the staff is revising the language for idle control system monitoring. Specifically, for diesel vehicles, manufacturers would be required to indicate a malfunction of the idle control system if either of the following occurs: (1) the system cannot achieve the target idle speed with a fuel injection quantity within +/-30 percent of the manufacturer-specified normal fuel quantity at idle and engine speed tolerances, or (2) the system cannot achieve the target idle speed or fuel injection quantity within the smallest engine speed or fueling quantity tolerance range required to enable other OBD II monitors.

N. EXCEPTIONS TO MONITORING REQUIREMENTS

While the proposed monitoring requirements in section 1968.2(f) detail malfunction criteria for medium-duty vehicles certified to an engine dynamometer tailpipe emission standard as all medium-duty diesel vehicles are and have been for the last 10 years, the requirements do not specify numeric malfunction criteria for chassis-certified medium-duty vehicles even though there are allowances for medium-duty vehicles to be certified to a chassis dynamometer tailpipe emission standard. The staff is proposing that these vehicles be required to follow the monitoring requirements and malfunction criteria applicable to diesel vehicles certified to an engine dynamometer tailpipe emission standard. However, because the malfunction emission thresholds specified in the regulation for engine dynamometer products are on a different basis (e.g., g/bhp-hr) than the emission standards for chassis certified vehicles (e.g., g/mile), manufacturers would be required to submit a proposal and request approval for a malfunction criterion that is equivalent to that required in section (f) for engine-certified products.

IV. PROPOSED REVISIONS TO STANDARDIZATION REQUIREMENTS

One of the most important and successful aspects of OBD II has been the requirement for manufacturers to standardize certain features in the OBD II system. Effective standardization assists all repair technicians by providing equal access to essential repair information, and requires structuring the information in a consistent format from manufacturer to manufacturer. With continual evolution of technology and the extensive feedback received from technicians in the field and I/M programs around the nation, ARB is proposing to clarify and update existing requirements and modify others as necessary to assist technicians in the repair industry and in OBD II-based I/M programs.

A. Reference Documents

The staff is proposing amendments that would update the list of Society of Automotive Engineers (SAE) documents that are incorporated by reference into the regulation. As is common practice with technical standards, industry periodically updates the standards to add specification or clarity. The current regulation incorporates the 2001 version of technical standard SAE J1939 and associated documents. The proposal would update the regulation to incorporate the March 2005 version of J1939. The current regulation also incorporates the 2001 version of ISO 15765-4 which has been subsequently updated in 2005. The proposal would also update the regulation to include the 2005 version. Several other SAE standards including SAE J1978 and SAE J1979 are currently being prepared for ballot and adoption. As these documents are only updated every few years, staff will monitor the progress of adoption of these updates and include them in this rulemaking (through staff suggested changes presented at the Board Hearing) if they are adopted within time. Furthermore, the staff is proposing to incorporate two additional SAE technical standard documents to the regulation. Specifically, the staff is proposing to add: (1) SAE J1699-3 – “OBD II Compliance Test Cases”, May 2006; and (2) SAE J2534 – “Recommended Practice for Pass-Thru Vehicle Programming”, February 2002. SAE J1699 and SAE J2534 are currently used by manufacturers for production vehicle evaluation (PVE) testing of standardized requirements (section 1968.2(j)(1)).

B. MIL Illumination Protocol

In many of today’s advanced vehicles, the OBD II system illuminates the MIL by sending a command from the engine’s on-board computer to the instrument panel’s computer and then the instrument panel computer actually turns the MIL on. If a malfunction occurs in the connection between the engine computer and the instrument cluster computer, the MIL may not be illuminated even though it is commanded on. To ensure more consistent performance by all manufacturers in this scenario, proposed language is added that would require the instrument panel computer to default to a MIL on configuration if communication between the two computers is lost. As not all manufacturers are currently configured to meet this requirement, the proposed language requires this capability on all 2010 and subsequent model year vehicles.

C. Medium-Duty Diesel Protocol

The OBD II regulation currently allows manufacturers to use one of four protocols for communication between a generic scan tool and the vehicle's on-board computer until the 2008 model year, after which, all vehicles are required to utilize a single protocol. The current regulation, however, also allows medium-duty vehicles with engines certified on an engine dynamometer to use whatever protocol is designated as acceptable by the heavy-duty OBD requirements to allow commonality between engines that are used in both medium-duty and heavy-duty vehicles. In 2002 when this allowance was adopted, the heavy-duty OBD regulation had not yet been adopted. Since then, the heavy-duty OBD regulation was adopted and the protocols required on heavy-duty vehicles have been identified. Accordingly, the staff is proposing amendments to the current OBD II regulation language to reflect this and refer specifically to the adopted heavy-duty OBD regulation for allowable alternate protocols.

D. Permanent Fault Codes

Based on feedback and experience gained from the incorporation of OBD II inspections in the Smog Check program and other nationwide inspection and maintenance (I/M) programs, the staff is proposing a requirement to make it easier to distinguish vehicles undergoing recent repair from vehicles undergoing fraudulent actions to try and slip through the Smog Check program. Currently, a technician or vehicle owner can erase all fault codes and extinguish the MIL by issuing a command from a generic scan tool plugged into the vehicle or, in many cases, simply by disconnecting the vehicle battery. While this does reset internal flags known as the "readiness status" that are currently recorded in Smog Check, it also removes all trace of the previous fault that was detected on the vehicle. With some minimal additional vehicle operation, some of these internal flags can be reset before a fault is re-detected and, in some cases, the vehicle can erroneously pass a Smog Check inspection.

For vehicles that have the MIL on for one or more faults, the staff's proposal would require manufacturers to be able to store "permanent" fault codes. The system would be required to be capable of storing a minimum of four confirmed fault codes that are presently commanding the MIL "on" in non-volatile memory (NVRAM) at the end of every key cycle. By requiring these "permanent" fault codes to be stored in NVRAM, vehicle owners and technicians would not be able to erase them simply by disconnecting the battery. Further, manufacturers would not be allowed to clear or erase these "permanent" fault codes by any generic or manufacturer-specific scan tool command. Instead, these fault codes would only be allowed to be self-cleared by the OBD II system itself, once the monitor responsible for setting that fault code had indeed run and passed enough times to confirm that the fault was no longer present. Since not all manufacturers currently have sufficient NVRAM memory available in their on-board computers to store permanent fault codes, a phase-in implementation of permanent fault codes would be required starting in the 2010 model year and ending with all vehicles required by the 2012 model year (including 2012 model year medium-duty vehicles with 2011 model year engines certified on the engine dynamometer).

Permanent fault codes would allow the Smog Check program to target and reject for fail only those vehicles that have recently had the MIL illuminated and have not subsequently been driven enough to know if the fault has been repaired. The permanent fault code method also has advantages for a technician attempting to repair a vehicle and subsequently prepare it for inspection or proof of correction. The permanent fault code would identify the specific diagnostic that would need to be exercised after repair and prior to inspection to remove the permanent fault code. By combining this information with the vehicle manufacturer's service information, technicians could identify the exact conditions necessary to operate a particular monitor. As such, technicians could more effectively target after-repair verification and would be able to verify that the specific monitor that previously illuminated the MIL has run and confirm the repair has been made correctly. This also provides added incentive for the technician to "fix it right the first time" and reduces vehicle owner "come-backs" for incomplete or ineffective repairs.

E. Access to Additional Data through a Generic Scan Tool

Currently, manufacturers are required to report certain “real-time” data parameters in a format that a generic scan tool can process and read so technicians can access the data for trouble-shooting malfunctions. In recent years, feedback from technicians in the field has identified the need for additional parameters to be made available by the vehicles’ OBD II system to assist them in effective repair. Thus, the proposed amendments define some additional parameters (data stream and freeze frame values) that manufacturers would be required to report. Further, the proposed amendments better address diesel vehicles by requiring many new diesel engine specific parameters to be reported on all diesel vehicles.

While the data parameters are generally used for technicians to assist them in repairs, some of the data is also used for the Smog Check program and for compliance or enforcement testing by ARB staff. An example of one of the parameters that manufacturers would be required to report to facilitate in-use emission compliance testing by ARB staff is the real-time status of the NOx and PM “not-to-exceed” (NTE) control areas. These parameters were previously included and adopted in heavy-duty OBD and are being copied for medium-duty applications because they are also tested for compliance in the same manner as the heavy-duty engines. Without this parameter, emission testing by ARB and U.S. EPA would be significantly more difficult to accomplish (e.g., by requiring off-board duplication of the internal engine computer’s proprietary algorithms, models, and calculations). It is also expected that continued improvement and development in the in-use emission testing procedures and equipment currently being established for heavy-duty engines may identify the need for additional standardized parameters and/or modifications to proposed parameters that can be incorporated during a future regulatory revision.

F. Software Calibration Identification Number (CAL ID) and Calibration Verification Number (CVN)

OBD II systems have been required to support two additional parameters identifying the current software “version” or calibration (CAL ID) and an internal calculated result to verify the integrity of the software (calibration verification number (CVN)) since the 2002 model year. These two parameters are intended to be used during Smog Check to help verify that valid software is installed in the on-board computer and that the software has not been corrupted or tampered. As various states around the nation have begun to collect this data, the need for further revisions have become apparent. At the last rulemaking, staff had already revised the requirements for CVN and extended the phase-in to allow manufacturers to accommodate the revisions. Now, continued feedback from the field has identified even more necessary revisions to facilitate usage of these two parameters in Smog Check. As such, the proposed language includes several minor changes to the CAL ID and CVN requirements.

First, by 2009 model year, all vehicles are required to respond with an equal number of CAL IDs and CVNs and in the same order such that off-board equipment used during Smog Check could match up each CAL ID with its corresponding CVN. Further, manufacturers are required to either design the vehicles to respond with a single CAL ID and CVN combination for each on-board computer or to respond with them in a fixed order of importance (from most critical for proper emission control to least critical). These two changes will allow reasonable size databases to be established to gather and use the CAL ID and CVN data in Smog Check. Lastly, the staff had previously adopted documentation and reporting requirements for the CVN and CAL ID information with the assumption that a U.S. EPA workgroup would have developed a “standardized electronic format” by the 2005 model year. However, no “standardized electronic format” has yet been developed. Thus, the staff is planning to develop such a standardized template to be included in a future ARB mail-out and is proposing that this document be referenced in the regulation (the specific mail-out number will be made available at the Board Hearing and as part of the subsequent 15-day changes to the regulations). This will provide a uniform format to receive the data from all manufacturers and facilitate further testing to incorporate usage of the data in Smog Check.

G. Tracking Requirements

Engine Run Time, Idle Time, and PTO Activation Time

Consistent with what was already adopted for heavy-duty OBD, the staff is proposing requirements for manufacturers to track and log engine operating time in various operating conditions for all 2010 and subsequent model year diesel vehicles. First, for light-duty diesel vehicles, manufacturers would be required to track and log cumulative engine run time. For medium-duty diesel vehicles, manufacturers would be required to track and log cumulative engine run time, cumulative engine on idle time, and power take-off operation time. These parameters would provide basic information about how often the engine is operated and are commonly available on most medium- and heavy-duty diesel engines. They also provide a baseline for making percentage of time comparisons to other tracked data (described below). The proposed requirements would set a minimum resolution for each of these counters and require all these counters to be stored in non-volatile memory (NVRAM) so that vehicle owners or operators would not be able to erase them simply by disconnecting the battery or clearing codes with a scan tool.

Emission-Increasing AECD Activation Time

An additional important item relative to the effectiveness of diesel emission controls in-use is the usage of auxiliary emission control devices (AECDs). Typically, auxiliary emission control devices (AECDs) consist of alternate control strategies or actions taken by the engine controller for purposes of engine, engine component, or emission control component protection or durability. In some cases, activation of an AECD has been justified by the manufacturer as needed to protect the engine and it can result in substantial emission increases while the AECD is activated. AECDs have been an essential part of the certification process and the subject of numerous mail-outs and guidances by U.S. EPA and ARB to help ensure consistent interpretation and equity in usage among all manufacturers. Approval usually involves lengthy review and considerable scrutiny by ARB staff to try and understand the complex algorithms and strategies used by various manufacturers and additionally relies on data supplied by manufacturers as to the expected occurrence/operation of these items in-use. However, such data is often based on the operation of one or two trucks for a few hours of operation and are not likely to be representative of the extreme variances in engine duty cycles and vehicle operator habits that the diesel engines are exposed to in the real world. Further, the complicated algorithms and calculations used by manufacturers to activate such strategies are not easily decipherable nor comparable from one manufacturer to another, making consistent policy decisions and equity among all manufacturers extremely difficult, if not impossible, to achieve.

To help alleviate this issue, staff is proposing requirements for the vehicle's on-board computer to keep track of cumulative time that a subset of these AECDs is active. Specifically, the proposed language only requires tracking of AECDs that cause an emission increase (i.e., emission increasing AECDs or EI-AECDs). Further, the language only requires tracking of EI-AECDs that are justified by the manufacturer as needed for engine protection and are not related to engine starting or operated substantially during the emission test cycles. Additionally, there is a provision for some AECDs to be approved as not-to-exceed (NTE) deficiencies and any such AECDs is automatically excluded from being considered an EI-AECD. AECDs that are only invoked as a result of high altitude operation (above 8000 feet in elevation) would also be excluded from being considered an EI-AECD. Lastly, in the rare instance (if any) that there is an EI-AECD that is justified as needed for engine protection but it actually is comprised of no sensed, calculated, or measured value and no corresponding commanded action by the on-board computer to act differently as a result, it would also be excluded from being tracked as an EI-AECD.

For those strategies that meet all the requirements above to be considered an EI-AECD, the on-board computer would be require to count cumulative time each one is operated and update the stored counter at the end of each driving cycle with the total cumulative time during the driving cycle. Further, each EI-AECD would be counted and reported separately (EI-AECD #1, etc.). ARB staff would be able to use this data to confirm or refute previous assumptions about expected frequency of occurrence in-use and use the data to support modifications to future model year applications and better ensure equity among all manufacturers. This data will also help ARB staff identify "frail" engine designs that are under-designed relative to their competitors and inappropriately relying on EI-AECD activation to protect the under-designed system.

Manufacturers have raised several concerns regarding this required tracking citing technical concerns, confidentiality concerns, and the inappropriateness of including such a requirement in the OBD II regulations. Regarding technical concerns, manufacturers have argued that determination of which AECDs are emission-increasing will require additional emission testing time. However, staff has revised the provision to define emission-increasing as reducing the emission control system effectiveness and thus, make the determination based on engineering analysis, not any emission test data. Industry has also argued that many EI-AECDs have varied levels of emission increase and they are not simple on/off switches, thereby complicating the counting process and making no distinction between items with a large emission impact and those with only a minor emission impact. To address this, staff modified the proposal to split tracking of each EI-AECD that is not a simple on-off decision into two separate counters and separately track time spent with "mild" EI-AECD activation (defined as action taken up to 75 percent of the maximum action that particular EI-AECD can take) and "severe" EI-AECD activation (defined as action taken from 75 to 100 percent of the maximum action that particular EI-AECD can take). As an example, an EI-AECD that progressively derates and eventually shuts off EGR when the engine overheats would be tracked in the "mild" counter for time spent commanding EGR derating of 1 to 75 percent and tracked in the "severe" counter for time spent commanding EGR derating of 75 to 100 percent (fully closed). Manufacturers have also expressed concern about the complexity of tracking two EI-AECDs that may be overlapping and both commanding action. After further discussion with individual manufacturers about how their strategies were structured, staff modified the proposal to require independent tracking of the EI-AECDs and not require the software to decipher which of the overlapping EI-AECDs was actually having the bigger impact and only accumulate time in that counter.

Regarding confidentiality, manufacturers have indicated that their algorithms and strategies that compromise their EI-AECDs are extremely confidential and do not want their competitors to know the details. Manufacturers have indicated that they believe staff's proposal would provide competitors with more detail of their EI-AECDs and make reverse-engineering easier. Staff's proposal, however, does not provide any additional information to make it easier to reverse-engineer a competitor's strategies nor does it provide any detail about the strategies or algorithms used. The only data staff's proposal would make available is cumulative time an engine is operated with a specific numbered EI-AECD active (eg.., EI-AECD #6). Only the certifying manufacturer and ARB would know for any particular engine what strategy or algorithm a particular EI-AECD corresponded to. Further, since the cumulative time data is only update at the end of a drive cycle, a competitor could only ascertain that, at some previous time in the operation of this engine, a particular EI-AECD was activated a cumulative amount of time. The data would not indicate at what time during any previous drive cycles the EI-AECD was active, whether it was active for one long period or many short bursts of time, or the severity of the action (or even what action) was taken during the EI-AECD activation. As can be done today, a manufacturer would be better served emission testing the engine, identifying real time spikes in emissions, and analyzing the engine operating condtions where the spikes actually occurred to reverse engineer his competitor's products rather than looking at data that does not tell him when the actual activation may have occurred. Lastly, given that the only items of discussion here are EI-AECDs justified by the need to protect the engine, a manufacturer's desire for confidentiality can be motivated by only one concern—that it is currently activating an EI-AECD (and thus, protecting its engine) during conditions that its competitors are not (and thus, not equally protecting their engine) thereby giving the manufacturer a competitive advantage in engine durability. By definition, this means that the manufacturer is activating its EI-AECDs more often (in conditions where its competitors are not). But this is also some of the very same inequity that ARB staff struggle to eliminate in certification in cases where a manufacturer is overly conservative in concluding engine "protection" is necessary and/or staff use to distinguish a "frail" engine design relative to competitors' engines.

Regarding industry's argument that such a tracking requirement is a "test program" or doesn't belong in the OBD II regulation because it isn't directly related to diagnostics, staff has discussed this with the industry many times. The OBD II regulation is the only regulation where ARB specifies data that must be available in a standardized format and protocol through the OBD II vehicle connector and thus, it is the appropriate regulation to include the standardized data. Already, the regulation contains data not directly related to diagnostics but instead used by ARB staff or Smog Check to inspect vehicles or facilitate compliance testing. Further, staff has indicated to industry that it would be willing to rename the regulation or place it in a separate title 13 section during this rulemaking and industry has rejected those solutions as not addressing the real problem. Industry is also the first to point out the myriad of ways diesel engines are used in vehicles and the differences in vehicle operator habits and usage patterns. These points are often used by industry to justify why solutions that work for one type of engine or vehicle are unlikely to work for other engines or vehicles. However, in this case, the manufacturers are arguing that tracking and logging of data in all vehicles is unnecessary and a test program or data logging of a few vehicles would provide just as much data. By the manufacturer's own arguments in other areas, data from a few vehicles clearly would not be representative of the fleet as a whole and any data logging or test program involving a few trucks would provide very little insight as to the real world activation of EI-AECDs.

H. Service Information

At the last regulatory update in 2002, ARB had not yet finalized and put into effect a service information rule requiring disclosure of necessary OBD II diagnostic and repair information to the service community. As such, the current OBD II regulation contains language that details types of service information that must be made available and includes a provision that any ARB-adopted service information rule would supersede the service information requirements contained within the OBD II regulation. Since the last rulemaking, the ARB service information regulation has gone into effect and, accordingly, staff has removed the redundant (and now superseded) service information requirements in the OBD II regulation.

V. PROPOSED REVISIONS TO DEMONSTRATION TESTING REQUIREMENTS

The OBD II regulation requires manufacturers to submit emission test data demonstrating that the emission threshold-based monitors are able to detect a fault and illuminate the MIL before emissions exceed the malfunction criteria (e.g., 1.5 times the standards). Currently, each manufacturer performs demonstration testing on one to three test groups per model year depending on the number of test groups certified by the manufacturer for that model year. ARB adopted the requirement to demonstrate more than one test per model year at the 2002 Board hearing. At that time, staff's intent was to have "medium-sized" manufacturers conduct demonstrating testing on two test groups per year. However in implementing this requirement over the last few model years, medium-sized manufacturers typically have had more than eleven test groups per year, and as such, have been required to perform testing on three test groups. Some medium-sized manufacturers have approached staff about the workload burden needed to test the number of vehicles required, and ARB has considered their concerns and is proposing adjustments. Specifically, the proposed amendments would require manufacturers certifying six to fifteen test groups in a given model year to conduct testing on vehicles from two test groups and would require manufacturers certifying sixteen or more test groups in a given model year to conduct testing on vehicles from three test groups.

Staff is also proposing changes to the demonstration procedures for engine certified products. For medium-duty vehicles certified to an engine dynamometer tailpipe emission standard, the staff is proposing to allow manufacturers, with Executive Officer approval, use an alternate engine dynamometer test cycle or a chassis test cycle to demonstrate proper MIL illumination if the emission test cycle does not allow all of a monitor's enable conditions to be satisfied.

In addition to the general changes discussed above, staff is also proposing specific demonstration testing requirements for diesel vehicles to complement the proposed monitoring requirements detailed for diesels detailed under section IV of the Staff

Report. Consistent with the existing demonstration requirement for gasoline vehicles, demonstration testing for diesel vehicles would be performed for all of the emission threshold-based monitors.

When diesel manufacturers perform tailpipe emissions certification testing, they are required to adjust the test results to account for the emissions impact from regeneration events. The adjustments are required by the exhaust test procedures and are necessary when aftertreatment regeneration causes an increase in emissions and regeneration does not occur on every test cycle (i.e., the test results do not always include the impact of regeneration emissions). For example, PM filter regeneration commonly occurs every few hundred miles. In order to achieve PM filter regeneration, engine control has to be altered to generate the high exhaust temperatures necessary for regeneration to occur. This is achieved by using different fuel injection, EGR and boost control strategies which generate the high exhaust temperatures but can cause an attendant increase in HC and NOx emissions. A manufacturer determines the emission impact from regeneration by conducting an emissions test during which regeneration occurs. The manufacturer then determines how frequently regeneration occurs (e.g., once every ten emission tests). Using the test results from the regeneration emission test and the regeneration frequency, the manufacturer calculates an adjustment factor to be applied to emission tests where regeneration does not occur to yield the adjusted emission results. For certification, the adjusted results have to meet the certification standards.

The adjusted emission results are representative of average emissions from an engine equipped with aftertreatment that has infrequent regeneration and, as such, are required (and appropriate) for emissions certification testing. Similarly, OBD II calibration and demonstration test results need to be adjusted to assess compliance with the OBD II malfunction thresholds. Staff has proposed requirements for determining the adjustment factors in section (d)(6.2) of the regulation. Engine dynamometer emission test results would be adjusted using the methods specified in the Code of Federal Regulations (CFR). Manufacturers of light-duty vehicles and chassis certified medium-duty vehicles would be required to submit a plan for Executive Officer approval to adjust the emission results using an approach similar to that defined in the CFR for engine dynamometer certified products.

When calibrating their monitors and performing this demonstration testing, diesel manufacturers would use the adjusted emission value to determine whether or not the specified emission threshold is exceeded (e.g., is the malfunction detected before the adjusted emission value exceeds 1.5 times the standard) just like the adjusted values are used for determining whether or not the engine meets the tailpipe standards. However, because the malfunctioning component can cause an increase in regeneration frequency or an increase in regeneration emissions relative to a properly functioning emission control system, the adjustment factors need to be recalculated for each OBD II monitor calibrated to an emission threshold. For example, a fuel system pressure malfunction may cause increased engine-out PM emissions which are trapped by the PM filter (thereby avoiding/minimizing an immediate tailpipe emission increase).

However, the PM filter will load up faster with the increased engine-out PM and could cause regeneration to occur more frequently. If the baseline (i.e., tailpipe certification) adjustment factors were used, they would be underestimating actual in-use emissions because the adjustment factors are based on less frequent regeneration than what would actually occur when the fault was present. Therefore, to accurately assess the emission impact from a malfunction, it is necessary to determine a malfunction-specific adjustment factor. Manufactures will have to perform additional emission test during their OBD II calibration and demonstration testing to determine the malfunction-specific adjustment factors. To allow time to develop these additional factors, staff's proposal allows the use of the certification adjustment factors for the 2007 through 2009 model year vehicles, in lieu of establishing and using a specific adjustment factor for each monitor. However, for NMHC (or oxidation) catalyst malfunctions, staff's proposal requires the use of a malfunction-specific adjustment factor starting with the 2008 model year. This one component is singled out for earlier use of a specific adjustment factor because its primary function on many diesel applications is to facilitate PM filter regeneration. Accordingly, when it deteriorates or malfunctions, it can have a very large impact on regeneration emissions while having minimal impact on non-regeneration emissions. Using the certification adjustment factors for this component would greatly underestimate the true emission level when the component malfunctions.

VI. PROPOSED REVISIONS TO CERTIFICATION REQUIREMENTS

A. Certification Application

Based on the staff's reviews of manufacturers' applications in the past years, minor changes are being proposed to the OBD II certification submittal requirements to expedite the OBD II review and approval process. The regulation currently requires manufacturers to submit data identifying all disablement of misfire monitoring that occurs during the FTP and US06 cycles. Proposed amendments would require these data to be submitted in a standardized format that will be detailed in a future ARB mail-out to facilitate consistent and quick review by staff (the specific mail-out number will be made available at the Board Hearing and as part of the subsequent 15-day changes to the regulations). The staff is also proposing to require manufacturers to include a cover letter with each test group application identifying the deficiencies and concerns (if any exist) that apply to the equivalent test group in the previous model year and the changes and/or resolution of each concern or deficiency for the current model year. This would allow the ARB staff to spend less time determining if past problems have been corrected.

B. Model Year Designation for Certification

The OBD II regulation currently requires that the OBD II system on medium-duty vehicles utilizing engines certified on an engine dynamometer be certified to the OBD II requirements applicable to the designated vehicle model year, not engine model year. As explained in more detail in the previous 2002 OBD II Staff Report, this was intended to prevent confusion during certification as well as avoid difficulty in including medium-duty vehicles into the California Smog Check program, which typically tests vehicles based on the model year of the vehicle, not the engine. Medium-duty manufacturers have argued that it is more appropriate to align the OBD II requirements with the engine model year, as is done with the tailpipe emission standards especially when considering the great changes being made in engine emission control hardware in the 2007 and 2010 timeframes. Subsequent discussions with medium-duty manufacturers have identified a modification that would address both staff's and industry's concern. Specifically, the proposed amendments would allow engine manufacturers to meet the OBD II requirements applicable to the model year of the engine except in cases where the OBD II requirement is specifically intended for use in the California Smog Check program. In such cases, medium-duty manufacturers must meet the Smog Check requirements on a vehicle model year basis and the requirements where this exception apply are specifically identified in the regulation.

VII. PROPOSED REVISIONS TO PRODUCTION VEHICLE EVALUATION AND VERIFICATION TESTING

The current regulation includes three specific classes of vehicle testing that must be done by manufacturers on actual production vehicles each year. Since the testing began in the 2004 and 2005 model years, staff and manufacturers have gained experience in the testing and identified areas where further refinement could be applied. First, one of the testing elements verifies vehicles communicate properly to off-board equipment using the standardized protocol and messages required by the OBD II regulation. Since this testing requirement was first adopted, SAE has developed a specification and software for off-board equipment that can be used to conduct the testing. Accordingly, the proposed amendments would provide specific reference to the use of equipment meeting these SAE specifications (SAE J1699-3 and SAE J2534). Staff is also proposing changes to the reporting requirements for the results of standardized communications testing. Manufacturers are currently required to submit a report only when problems are identified during the testing. The proposal would require manufacturers to also submit a report of passing test results within three months of conducting the tests.

Secondly, manufacturers are required to test from two to six vehicles per year to verify all monitors have been correctly implemented in software. Staff's original intent was to structure the testing requirements to require small manufacturers to test two vehicles per year, medium size manufacturers to test four per year, and large manufacturers to test six per year. However, further analysis has shown that most medium size manufacturers are required to test six vehicles per year based on the rules previously established. As such, staff has revised the regulation to require manufacturers certifying 6 to 15 test groups per year (revised from 6 to 10) to test only four vehicles per year.

Lastly, manufacturers are required to collect actual monitoring frequency data from in-use vehicles within the first six months after they are introduced into commerce. An additional six months can be granted by ARB if the manufacturer has difficulty in gathering sufficient data within the six months. To date, most manufacturers have experienced difficulty in gathering the required data in the first six months and accordingly, staff is proposing changes that would change the timeframe to 12 months to better correspond to what manufacturers are typically achieving. A few manufacturers have also expressed difficulty in obtaining a sufficient number of vehicles for their low sales volume test groups. As such, staff is expanding a current provision that allows manufacturers to request a reduced sample size for these test groups to automatically approve such requests if the manufacturer uses the same sampling and vehicle procurement method as is used for higher sales volume test groups that do meet the minimum sample size. This should provide manufacturers more flexibility in collecting the data on these small volume test groups.

VIII. PROPOSED REVISIONS TO STANDARDIZED METHOD TO MEASURE REAL WORLD MONITORING PERFORMANCE

The OBD II regulation requires manufacturers to design their OBD II monitors to robustly detect malfunctions and to run frequently during real world driving. With a phase-in from 2005 through 2007 model year, manufacturers are required to implement software in the on-board computers to track how many times each of the major monitors has executed as well as how often the vehicle has been driven. By measuring both these values, the ratio of monitor operation relative to vehicle operation can be calculated to determine monitoring frequency (i.e., the in-use performance ratio). The regulation also establishes a minimum acceptable in-use performance ratio that many of the major monitors are required to meet in-use.

The current requirement began as a phase-in from 2005 to 2007 model year and established lower (less stringent) minimum ratios for the first few years to allow manufacturers to gain experience from vehicles in the field. However, since implementation of in-use performance tracking only recently begun with the 2005 model year, manufacturers have argued that they have not had enough experience with this requirement to ensure that their monitors will indeed meet the required minimum in-use ratios. As projected by the staff during the 2002 rulemaking, initial data from real world vehicles provided by manufacturers have shown that manufacturers are virtually all meeting the interim lower ratio and generally meeting the final higher ratios for a great majority of their monitors. However, industry is still concerned about the in-use data and the possibility of remedial action (e.g., recall) if they fail to meet the target. Specifically, industry has stated that more time is needed to collect sufficient in-use data and, where necessary, make modifications to ensure that their vehicles are indeed able to meet the final ratios.

Given that it appears the majority of vehicles are already meeting the final requirements and only a few are in need of significant improvements, and recognizing that it does take a significant amount of time to collect meaningful in-use data to determine what impact changes or improvements will have, the staff is proposing to extend the use of the lower interim ratios for an additional year. For newly adopted monitors for gasoline (i.e., cylinder air-fuel imbalance) and for all monitors for diesel, the amendments also provide longer usage of the lower interim ratios to give manufacturers experience with the new requirements.

While the current language requires this logging and reporting of in-use frequency for only five major monitors, additional review by the staff has identified the need to include one additional monitor to be tracked for gasoline vehicles. Specifically, manufacturers would be required to track secondary oxygen sensor monitors given their importance in ensure proper catalyst fault detection. The staff is also proposing to add additional diesel engine monitors that manufacturers would be required to track and report in-use performance. In addition to the currently required tracking for catalysts (oxidation, SCR NOx, and NOx adsorbers) and EGR monitors, the proposal includes tracking, beginning in the 2010 model year, of the PM filter, exhaust gas sensors, and some boost pressure control system component monitors. Consistent with draft SAE standards, the proposal would require separate tracking for oxidation catalysts and NOx aftertreatment (SCR NOx catalysts and NOx adsorbers). Like gasoline, this will ensure that the most critical emission control monitors (and usually the most difficult to run in-use) will indeed be operated with sufficient frequency in-use.

Finally, the staff is proposing alternate criteria to be used in tracking the frequency of operation of some of the diesel emission control monitors. Unlike gasoline where minimum acceptable frequency is generally in the magnitude of two monitoring events in a two week period, the staff has been discussing the allowance of much longer time periods between monitoring events for some diesel emission controls (e.g.. PM filter and oxidation catalysts). Given the relative infancy of development for several of these components, the staff has been receptive to discussions with manufacturers that would tie these monitoring events to an intrusive PM filter regeneration. Conversations with manufacturers have confirmed that these intrusive events are expected to occur every 300 to 500 miles and accordingly, the proposed language tracks the monitors for the PM filter and oxidation catalyst on a 500 mile interval. Specifically, it requires the counter tracking vehicle operation for these monitors to only increment once every 500 miles making the in-use ratio relative, not to the number of trips the vehicle has made, but to the number of 500 mile accumulations the vehicle has made. This will allow manufacturers to use the normally occurring intrusive events to also achieve monitoring (instead of invoking additional intrusive events on a more frequent basis). However, the staff is concerned that this may ultimately result in an insufficient frequency (e.g., monitoring to occur potentially once per month or much less) given that the proper operation of the emission controls are needed at all times the vehicle is operated. As such, the staff will continue to watch progress with monitoring techniques and real world data to determine the actual in-use frequency and may revisit the criteria at future regulatory reviews if the in-use frequency can be significantly improved.

IX. PROPOSED REVISIONS TO THE EMISSION WARRANTY REGULATIONS

In 1979, ARB originally adopted sections 2035 through 2041, title 13, CCR that contain the warranty requirements for passenger cars, light-duty trucks, and medium-duty vehicles. The regulations established requirements for manufacturers to warrant emission-related parts for both defects and performance for a period of three years and 50,000 miles. Additionally, a subset of “high-cost” emission-related parts was eligible to be warranted for seven years and 70,000 miles if they met specific inflation-adjusted cost numbers. The sections were subsequently amended in 1990 and minor changes were made in 1999 regarding the timing of submittal of information required under these sections.

ARB is proposing further amendments to the warranty regulations, specifically sections 2035, 2037, and 2038, to update the references to emission-related parts to account for emission control technology that is used today and to simplify the requirements, where possible. For section 2035, which details the purpose and definitions, and section 2038, which details warranty requirements for “performance” (e.g., I/M fails), the staff is proposing non-substantive changes to reformat and clean up the language. For section 2037, which details the warranty requirements for “defects” (e.g., faults that cause the MIL to be illuminated), the staff is proposing to eliminate the outdated emission-related parts list used to identify components eligible for the high-cost warranty and instead require high-cost warranty coverage for any component that is subject to warranty for 3 years and 50,000 miles and meets the inflation-adjusted cost limit. With this modification, the parts subject to the “high-cost” warranty will truly become a subset of the parts subject to the comprehensive 3 year/50,000 mile warranty. Several, but not all, manufacturers have indicated that they already have such a policy implemented. As such, the proposed revisions are primarily expected to ensure consistent emission warranty policy from manufacturer to manufacturer and provide a more consistent message to vehicle owners in directly relating MIL illumination to warranty repair. As the emission-related parts list currently used is quite outdated, this revision would also better comprehend newer vehicle technologies such as hybrid vehicles and the emission-related components on those vehicles to ensure expensive emission-related component repairs that happen within the first 7 years and 70,000 miles are not inappropriately passed on to the vehicle owner.

X. ANALYSIS OF ENVIRONMENTAL IMPACTS AND ENVIRONMENTAL JUSTICE ISSUES

As the OBD II requirements for gasoline vehicles are fairly mature and the proposed revisions are minor and mostly clarifications, the changes are not expected to significantly alter previously calculated emission benefits or findings. Regarding diesels, though higher interim malfunction emission thresholds are being proposed for light-duty diesel vehicles during the 2007 through 2012 model years, the staff believes these higher thresholds are necessary considering the diesel emission control technologies involved are new and evolving and have never previously existed on diesel vehicles. Additionally, given the limited number of diesel vehicles that are projected to be introduced into the state during these years, staff believes any adverse emission impact from the higher thresholds will be minimal.

For reference, during the 2002 OBD II regulatory update, staff calculated a combined benefit for OBD II and LEV II of 57 tons per day of ROG + NOx in the South Coast Air Basin alone. Details of the methodology can be found in the 2002 OBD II staff report. Given the substantial shortfall in emission reductions still needed to attain the National and State Ambient Air Quality Standards and the difficulty in identifying further sources of cost-effective emission reductions, it is vital that the emission reductions projected for the LEV II program be achieved. The proposed OBD II regulatory revisions apply almost exclusively to LEV II vehicles and better ensure these vehicles will contain to operate at the expected emission levels, a necessary step towards achieving this goal.

Having identified that the proposed amendments to the regulations will not result in any adverse environmental impacts but rather will help ensure that measurable emission benefits are achieved both statewide and in the South Coast Air Basin, the amendments should not adversely impact any community in the State, especially low-income or minority communities.

XI. COST IMPACT OF THE PROPOSED REQUIREMENTS

A. Cost of the Proposed Requirements

For light-duty vehicles, the proposed amendments to the OBD II regulation consist primarily of clarifications of existing requirements. In the very limited cases where a new monitor is required (i.e., cylinder air-fuel imbalance), lead time is provided to allow manufacturers to implement necessary changes in conjunction with scheduled vehicle upgrades. Currently, the light-duty vehicle sector in California consists entirely of gasoline vehicles. For these vehicles, staff projects that manufacturers will comply with the requirements by revising existing computer software and will not need additional new hardware. Additionally, it is expected that the proposed requirements would be addressed primarily with the existing motor vehicle manufacturer workforce. Considering that no additional hardware and staff are projected to be required for compliance with the proposed modifications, staff has estimated that light-duty gasoline vehicles will not incur any additional costs to the consumer.

However, several manufacturers have recently expressed an interest in introducing diesel vehicles into this sector. Therefore, staff has conducted a separate cost analysis for light-duty diesel vehicles. The cost analysis utilizes a similar methodology as used for ARB's heavy-duty OBD program that was adopted by the Board in July 2005.

In adjusting the analysis previously done for heavy-duty engines to account for light-duty diesel vehicles, staff made several assumptions:

1. An average light-duty diesel vehicle (LDDV) manufacturer has two engine families with a total annual U. S. engine production of 183,000 in the 2013 model year.
2. LDDV manufacturers are primarily horizontally integrated manufacturers with high efficiencies.
3. Proposed OBD II revisions for LDDVs represent a smaller incremental increase in monitoring capability relative to the current OBD II system

capability than the heavy-duty OBD requirements for HDDEs represented above their previous capability.

4. A PM sensor will be needed to comply with the final OBD thresholds for PM filter monitoring.
5. The baseline system for this cost estimate is a title 13, CCR, section 1968.1 compliant system.

Utilizing the above assumptions, staff has revised the cost analysis used for HD OBD. Similar to the HD OBD costs analysis, the goal of this analysis is to estimate the "learned-out" costs of the program in the form of a retail price increase to light-duty diesel vehicle purchasers for a "typical" vehicle. The analysis estimates the incremental costs of implementing the proposed OBD II revisions for an average light-duty diesel engine manufacturer. Based on adjustments to the analysis done for heavy-duty OBD for these light-duty vehicles, the incremental retail cost to the engine purchaser for a typical light-duty vehicle in 2013 is projected to be $140.64 per vehicle. Details of the cost analysis methodology are described in the heavy-duty OBD staff report of July 2005, which is incorporated by reference herein (a copy of which may be found at http://www.arb.ca.gov/regact/hdobd05/hdobd05.htm). Table 4 below summarizes the results of the costs analysis.

Table 4

Incremental Consumer Cost of Light-Duty Diesel OBD System

		LDDV (in dollars)
Variable costs	Component	124.63
	Assembly	0.78
	Warranty	3.16
	Shipping	1.50
Support costs	Research	0.43
	Engineering Support	0.00
	Legal	0.04
	Administrative	0.22
Investment recovery costs	Mach. & equipment	0.00
	Assembly plant changes	0.00
	Development/Testing	0.00
Capital recovery (a)		7.85
Manufacturer costs	Cost of capital recovery (b)	2.03
Total cost		140.64

(a) Cost of capital recovery was calculated at 6% of the total incremental costs.
(b) Cost of capital recovery was calculated at 6%. Vehicles are assumed to remain in inventory for 3 months.

For medium-duty vehicles, the current vehicle fleet consists of both gasoline and diesel vehicles. As such, staff has separately estimated the cost of compliance for each of these vehicle types. Similar to the light-duty vehicle cost assessment described earlier, gasoline vehicles are expected to comply with the requirements by revising existing software and will not require additional hardware or staff. Therefore, staff has not associated any additional costs for medium-duty gasoline vehicles. For diesel vehicles, staff has performed a cost analysis similar to the LDDV analysis above.

The assumptions used for medium-duty diesel vehicles are similar to the LDDV analysis. The assumptions are:

1. An average medium-duty diesel vehicle (MDDV) manufacturer has two engine families and one rating/engine family with a total annual U. S. engine production of 183,000 in the 2013 model year.
2. MDDE manufacturers are primarily horizontally integrated manufacturers with high efficiencies.
3. Proposed OBD II revisions for MDDV represent a smaller incremental increase in monitoring capability relative to the current OBD II system capability than the heavy-duty OBD requirements for HDDVs represented above their previous capability.
4. A PM sensor will be needed to comply with the final OBD thresholds for PM filter monitoring.
5. The baseline system for this cost estimate is a title 13, CCR, section 1968.1 compliant system.

The results of the analysis indicate the "learned-out" costs of the program in the form of a retail price increase to medium-duty diesel vehicle purchasers for a "typical" vehicle in 2013 is projected to be $153.19 per engine. Table 5 below summarizes the results of the costs analysis.

Table 5

Incremental Consumer Cost of Medium-Duty Diesel OBD System

		MDDV (in dollars)
Variable costs	Component	129.63
	Assembly	0.78
	Warranty	3.16
	Shipping	1.50
Support costs	Research	1.58
	Engineering Support	0.00
	Legal	0.14
	Administrative	0.82
Investment recovery costs	Mach. & equipment	0.00
	Assembly plant changes	0.00
	Development/Testing	4.83
Capital recovery (a)		8.55
Manufacturer costs	Cost of capital recovery (b)	2.21
Total cost		153.19

(a) Cost of capital recovery was calculated at 6% of the total incremental costs.
(b) Cost of capital recovery was calculated at 6%. Engines are assumed to remain in inventory for 3 months.

B. Cost Effectiveness of the Proposed Requirements

As stated above, the proposed OBD II revisions are not expected to add any significant cost to gasoline vehicles. Further, medium-duty diesel vehicles represent less than five percent of the current OBD II fleet so even an incremental increase of $153 per medium-duty vehicle only corresponds to an average increase of slightly more than $7 per OBD II vehicle. Additionally, the current light-duty segment consists solely of gasoline vehicles and thus, the incremental cost of $140 per light-duty diesel is not assigned to any portion of the light-duty fleet. Manufacturers choosing to introduce light-duty diesels in lieu of gasoline vehicles in the future would be doing so by their own choice and for economic reasons specific to that manufacturer. Accordingly, the cost-effectiveness numbers calculated from the 2002 regulation update are still applicable. For reference, in 2002 staff calculated two separate cost-analyses for OBD II systems. The first covered the useful life period of the vehicle (typically the first 120,000 miles) and combined with the LEV II program, was $2.18 per pound of ROG + NOx reduced. The second analysis was for the second phase of the vehicle's life, from 120,000 to 230,000 miles, when increased reliance on OBD II is necessary to maintain low in-use vehicle emissions. That cost effectiveness was calculated to be $4.57 per pound of ROG + NOx reduced. The methodologies for both analyses were detailed in the 2002 OBD II staff report, which is incorporated by reference herein (a copy of which may be found at http://www.arb.ca.gov/regact/obd02/obd02.htm).

XII. ECONOMIC IMPACT ANALYSIS

Overall, the proposed amendments to the regulations are expected to have no noticeable impact on the profitability of automobile manufacturers. These manufacturers are large and are mostly located outside California. There is only one motor vehicle manufacturing plant located in California, the New United Motor Manufacturing, Inc. (NUMMI), which is a joint venture between Toyota Motor Corporation and General Motors Corporation. No LDDVs or MDDVs are manufactured at this facility. The proposed changes involve minimal development and verification of software above what is already incorporated into OBD II systems. Additionally, because manufacturers would be provided sufficient lead time to incorporate the minimal proposed changes, incorporation and verification of the revised OBD II software would be accomplished during the regular design process at virtually no additional cost. Any additional engineering resources needed to comply with the proposed program would be small, and when spread over several years of vehicle production, these costs would be negligible. Staff believes, therefore, that the proposed amendments would cause no noticeable adverse impact in California employment, business status, and competitiveness.

A. Legal Requirements

Section 11346.3 of the Government Code requires State agencies to assess the potential for adverse economic impacts on California business enterprises and individuals when proposing to adopt or amend any administrative regulation. Section 43101 of the Health and Safety Code similarly requires that the Board consider the impact of adopted standards on the California economy. This assessment shall include a consideration of the impact of the proposed regulation on California jobs, business expansion, elimination, or creation, and the ability of California business to compete.

B. Affected Businesses and Potential Impacts

Any business involved in manufacturing, purchasing or servicing passenger cars, light-duty trucks and medium-duty vehicles could be affected by the proposed amendments. Also affected are businesses that supply parts for these vehicles. California accounts for only a small share of total nationwide motor vehicle and parts manufacturing. There are 34 companies worldwide that manufacture California-certified light- and medium-duty vehicles and heavy-duty gasoline engines. As stated, only one motor vehicle manufacturing plant is located in California, the NUMMI facility.

C. Potential Impacts on Vehicle Operators

The proposed amendments would provide improved OBD II information and encourage manufacturers to build more durable vehicles, which should result in the need for fewer vehicle repairs and savings for consumers. Additionally, as stated above, the proposed amendments are anticipated to have a negligible impact on manufacturer costs and new vehicle prices.

D. Potential IMpacts on Business Competitiveness

The proposed amendments would have no adverse impact on the ability of California businesses to compete with businesses in other states as the proposed amendments are anticipated to have only a negligible impact on retail prices of new vehicles.

E. Potential Impacts on Employment

The proposed amendments are not expected to cause a noticeable change in California employment because California accounts for only a small share of motor vehicle and parts manufacturing employment.

F. Potential Impact on Business Creation, Elimination or Expansion

The proposed amendments are not expected to affect business creation, elimination or expansion.

XIII. PROPOSED REVISIONS TO OBD II ENFORCEMENT PROVISIONS

The staff is proposing minor changes to the OBD II-specific enforcement regulation (title 13, CCR section 1968.5) to be consistent with the amendments being proposed for the OBD II regulation, including malfunction thresholds and applicability dates. The staff is proposing more appropriate in-use thresholds (i.e., thresholds at which a vehicle would be found to have a nonconforming OBD II system and would be subject to possible enforcement action) for OBD II emission testing of diesel vehicles certified to the higher interim malfunction thresholds required for 2007 through 2012 model year vehicles. Consistent with past ARB policy for both tailpipe emission standards and OBD II emission threshold standards, these interim higher in-use standards allow manufacturers some relief in-use during initial or phase-in years of more stringent emission levels. This provides manufacturers a small amount of latitude to cover cases where the vehicle was designed and certified to the actual standard but unexpected factors caused the vehicle to slightly exceed the standards in-use. Over time, manufacturers gain experience with design changes, if any, needed to maintain the standards in-use and the interim higher in-use thresholds phase-out.

The staff is also proposing changes to criteria listed under the mandatory recall section. Specifically, the enforcement regulation currently states that vehicles fall under mandatory recall if “the motor vehicle class cannot be tested so as to obtain valid test results in accordance with the procedures of the California Inspection & Maintenance (I/M) program applicable at the time of vehicle certification.” The staff is proposing to delete references to “the procedures of the California I/M program” because that document is outside of ARB’s control and has not been updated to keep pace with OBD II technology nor reflect the planned inspection methods for future OBD II vehicles (and those currently being used by many other states in the nation). Instead, the proposed amendments would provide vehicle manufacturers with a single document/source of criteria that could result in non-compliance or a finding of recall related to the OBD II system. The proposed changes list every parameter that vehicles would be required to communicate properly to ensure valid testing results in the California I/M program. Specifically, staff analyzed the parameters currently being used in California, those that are recommended to be used by the U.S. EPA, those that are currently being used by other states, and those that have been included in the OBD II requirements for the primary or sole purpose of facilitating Smog Check. The criteria have been scrutinized to ensure only those that are necessary to accurately determine the pass/fail status of the vehicle or to detect a fraudulent test are included in the mandatory recall criteria. Other criteria that may be used in I/M but are not essential for pass/fail would still be considered noncompliant and appropriate enforcement action, including and up to recall, could be taken.

REFERENCES

Below is a list of documents and other information that the ARB staff relied upon in developing the Staff Report.

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5) Walker, A. P., Chandler, G. R., Cooper, B. J., et al., “An Integrated SCR and Continuously Regenerating Trap System to Meet Future NOx and PM Legislation,” SAE Paper 2000-01-0188.

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7) Tullis, S., Greeves G., 1996. “Improving NOx Versus BSFC with EUI 200 Using EGR and Pilot Injection for Heavy-Duty Diesel Engines”, SAE 96084319 (www.dieselnet.com, Diesel Fuel Injection, Common-Rail Fuel Injection).

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9) “Advanced Technologies: Fuel Injection and Combustion,” www.dieselnet.com.

10) “Controls for Modern Diesel Engines: Model-Based Control Systems,” www.dieselnet.com

[19] Copies of Society of Automotive Engineers (SAE) papers are available through the SAE at:
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E-mail: CustomerService@sae.org
Website: http://www.sae.org

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18) David Kittelson, Hongbin Ma, Michael Rhodes, and Brian Krafthefer, "Particle Sensor for Diesel Combustion Monitoring," Presentation supported under DOE Cooperative Agreement DE-FC04-02AL67636, Honeywell, prime contractor, University of Minnesota, subcontractor.

19) Staff Report: Initial Statement of Reasons (ISOR): Technical Status and Revisions to Malfunction and Diagnostic System Requirements for 2004 and Subsequent Model Year Passenger Cars, Light-Duty Trucks, and Medium-Duty Vehicles and Engines (OBD II), March 8, 2002.

20) Staff Report: Initial Statement of Reasons (ISOR): "Malfunction and Diagnostic System Requirements for 2010 and Subsequent Model Year Heavy-Duty Engines (HD OBD)," June 3, 2005.

Below is a list of documents newly incorporated by reference in the OBD II regulation.

21) SAE J1939 March 2005 -"Recommended Practice for a Serial Control and Communications Vehicle Network" and the associated subparts included in SAE HS-1939, "Truck and Bus Control and Communications Network Standards Manual", 2005 Edition.

22) SAE J1699-3 – “OBD II Compliance Test Cases”, May 2006.

23) SAE J2534 – “Recommended Practice for Pass-Thru Vehicle Programming”, April 2004.

24) ISO 15765-4:2005 "Road Vehicles - Diagnostics on Controller Area Network (CAN) - Part 4: Requirements for emission-related systems.