

# **OBD & Sulfur Status Report**

Sulfur's Effect on the OBD Catalyst Monitor on Low Emission Vehicles

U.S. Environmental Protection Agency  
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## **Introduction**

This paper presents EPA's views on the issue of gasoline sulfur and its effects on the catalyst monitor of low emission vehicle on-board diagnostic (OBD) systems. This paper presents the pertinent data known to exist at the time of its writing, and EPA's current analysis of that data. This paper also presents EPA's conclusions based on that data, and EPA's suggested policy position at the time of its writing. This paper was originally made available for public review in March of 1997. Subsequent to that review, EPA received input and feedback from interested parties. Copies of all written comments received by EPA on the March 1997 paper can be obtained by contacting one of the contact people listed on the cover page of this paper. This paper should be viewed as a working document subject to change, and not as a final definitive statement by EPA on the OBD and gasoline sulfur issue.

## **Background**

In August of 1995, EPA was approached jointly by domestic auto manufacturers and members of the American Petroleum Institute (API) expressing a mutually held concern that California Low Emission Vehicles (LEV) equipped with On-Board Diagnostic (OBD II) systems operated outside of California on typical federal gasoline, such as those vehicles in the Northeast Ozone Transport Region (OTR) or those designed for the proposed National Low Emission Vehicle (NLEV) program, may experience a proliferation of illuminated Malfunction Indicator Lights (MIL) due to the impact of fuel derived sulfur on the OBD II catalyst monitoring system. If such MIL illumination were to occur, they argued it would result in considerable consumer dissatisfaction and widespread adverse public reaction to OBD. They jointly suggested that adjustments to the OBD II catalyst monitor cut points (i.e., the point at which the OBD II system indicates a malfunction via illuminating the MIL, also known as the malfunction threshold) would alleviate the potential problem and represented the best solution to that potential problem given the short leadtime before implementation of the proposed NLEV program.

In an effort to assess the validity of this potential problem and the appropriateness of the suggested solution, EPA encouraged the auto and oil industries to generate data on the effect of sulfur on LEV catalyst monitoring systems. In response to EPA's request, the Coordinating Research Council (CRC), an organization of auto and oil industry members, performed a laboratory reactor catalyst study to quantify sulfur's effect on catalyst monitoring.

In addition, several auto manufacturers, including the three domestics and one import, separately generated and shared with EPA their confidential sulfur data on LEV-prototype vehicles. During the course of meeting with each manufacturer to review their confidential sulfur data, a separate issue was raised. That issue being the possibility that, due to sulfur's effect on the catalyst and the exhaust gas oxygen sensor, vehicle emissions might increase above NLEV emission standards, and possibly above OBD malfunction thresholds. Additionally, due

to sulfur's effect on the OBD catalyst monitor, the MIL may not illuminate despite the increased emission levels.

This paper discusses EPA's views on the implications of the data and presents EPA's proposed course of action in dealing with OBD II requirements for California LEVs certified under the proposed NLEV program for sale outside of California. Note that this paper does not attempt to address the issue of California LEVs certified for sale inside California and migrating outside California for temporary or permanent reasons.

## **Discussion**

### **OBD Catalyst Monitor**

The OBD threshold is based on emission performance (i.e., 1.75 x NMHC standard for LEV program vehicles). However, the OBD technique used to monitor the catalyst does not directly measure emissions, nor catalyst conversion efficiency. The catalyst monitoring technique used throughout industry measures or infers the oxygen storage capacity (OSC) of the catalyst via oxygen sensors. This is usually accomplished by developing an OSC index, which is a surrogate for actual OSC and is discussed in more detail below. Hydrocarbon (HC) conversion efficiency can be inferred from oxygen storage, although the relationship is nonlinear. Once the HC conversion efficiency level has been established, one can infer whether or not emissions are exceeding the OBD malfunction threshold through knowledge of what the typical HC feedgas (engine-out emissions) levels are for the engine.

There are currently two feasible OBD methods for monitoring catalyst performance using the oxygen storage technique. These are the "dual sensor" method, which compares output signals from the main fuel system control oxygen sensor and a second oxygen sensor located downstream from the monitored catalyst; and, the "time-delay" method, which relies solely on the output signal from an oxygen sensor located downstream from the monitored catalyst. The "dual sensor" method measures the amount of oxygen storage in the catalyst via the OSC index. The OSC index for the "dual sensor" method compares the differences in voltage signals, such as switching frequency or amplitude, between the main fuel system control oxygen sensor and the downstream oxygen sensor. An example of an OSC index can be the ratio of rear sensor voltage to the front sensor voltage. A noticeable difference in the voltage signals indicates a high level of oxygen storage from which one can infer a high conversion efficiency. In contrast, a downstream sensor voltage signal mimicking the front sensor signal indicates a lack of oxygen storage and an apparent reduction in conversion efficiency.

The "time-delay" method evaluates the catalyst by measuring the time it takes for the downstream oxygen sensor to respond to a rich or lean signal from the main fuel control sensor. The fuel system is artificially commanded to switch rich and lean by a predetermined, carefully calibrated amount. A measurement is then made of the time delay that occurs for the downstream oxygen sensor to respond to the known rich and lean conditions. The OSC index for

the “time-delay” method can be the actual time delay itself. A time delay exceeding a predetermined value indicates a high level of oxygen storage, and thus a highly efficient catalyst. A time delay shorter than the predetermined value indicates a low level of oxygen storage, and thus a poorly performing catalyst.

### **Oxygen Storage and Sulfur’s Effect**

Oxygen storage is the ability of the catalyst to store excess oxygen during lean conditions and then release it during rich conditions where there is limited oxygen to oxidize HC and CO. In addition to oxidizing HC and CO, the storage and release of oxygen also helps reduce NO<sub>x</sub>. The main oxygen storage agent in the catalyst is the metal oxide ceria (CeO<sub>2</sub>). Ceria is dispersed throughout the catalyst washcoat during the production process. Also, in addition to promoting oxygen storage, ceria also helps maintain the dispersion of the catalyst’s noble metal particles. This dispersion of particles increases the noble metal surface area within the catalyst and, therefore, the availability of noble metal sites to carry out the catalytic activity. The ceria also serves to stabilize the surface area of the catalyst's alumina support, increasing its durability against high temperature excursions, one of the primary causes of catalyst deterioration.

Sulfur interferes with ceria’s oxygen storage function by adsorbing onto the catalyst surface under lean and stoichiometric conditions and forming ceria sulfite and ceria sulfate, both of which inhibit oxygen storage. As the catalyst ages (i.e., thermal aging), precious metal particles agglomerate, regardless of the sulfur content of the fuel. As a result, surface area is reduced, decreasing catalyst efficiency and oxygen storage. Under high concentrations, sulfur worsens this thermal effect by covering noble metal and ceria particles, further reducing surface area thereby decreasing conversion efficiency and oxygen storage.

The data generated by CRC and the vehicle manufacturers suggest that sulfur's effect on catalyst conversion efficiency and oxygen storage is reversible. This is consistent with information found in the available literature. All of the data seen by EPA also suggests that for today’s catalyst technology, and that expected for at least the near future, exposure to sulfur can result in a loss of catalyst performance. However, the catalyst can regain *most* of its original performance by again operating on low sulfur fuel. There is some debate as to how much operation on low sulfur fuel is required to reverse sulfur's effect, but the consensus seems to be that as little as one tankful of low sulfur fuel will return *most* of the catalyst's original performance. It also appears that some catalysts operated on high sulfur fuel experience a "memory effect." In other words, the catalyst does not fully regain all of its original performance by simply operating on low sulfur fuel. The "memory effect" can be erased, thereby returning the catalyst to its pre-sulfur exposed performance, by operating the vehicle under rich air-fuel and high temperature conditions. This appears to be true regardless of sulfur content in the fuel. However, rich air-fuel and high temperature operating conditions occur infrequently in-use.

Sulfur's impact on LEVs is greater than its impact on Tier 0 and Tier 1 vehicles. The bench data presented by CRC and several vehicle manufacturers indicate that sulfur has a greater effect on catalyst conversion efficiency and oxygen storage for LEVs than for Tier 0 and Tier 1

vehicles. The two most significant reasons are: (1) that many LEV designs are expected to employ much tighter air-fuel ratio control (i.e., fewer rich and lean excursions); and, (2) LEV designs are expected to use the noble metal palladium in their catalysts, sometimes in conjunction with the traditional platinum and rhodium noble metals, and sometimes exclusively.

With the strict LEV standards, vehicles will have to maintain very tight air-fuel ratio control around stoichiometry because allowing too many periods of rich operation could result in an exceedance of the HC and CO standards, while too many periods of lean operation could result in an exceedance of the NO<sub>x</sub> standard. Tighter air-fuel ratio control can exacerbate sulfur's effect because, as discussed earlier, sulfur adsorbs onto the catalyst surface during lean/stoichiometric operation. With tighter air-fuel ratio control, the fuel system maintains an air-fuel ratio very close to stoichiometry, thus increasing the opportunity for sulfur to adsorb to the ceria in the catalyst. In addition, tighter air-fuel ratio control may result in less rich operation which limits the ability of such operation to reverse or reduce sulfur's impact.

The use of palladium in LEV catalysts presents problems for a couple of reasons despite its attractiveness as a catalytic noble metal. Palladium is attractive because of its thermal tolerance and the need to control cold start emissions to comply with the stringent LEV standards. To better control cold start emissions, many manufacturers are moving their catalysts closer to the exhaust manifold to take advantage of the extra heat which helps the catalyst "light-off" and perform at its maximum level much more quickly. An unfortunate result of moving the catalyst closer to the engine is that under normal operating conditions, the catalyst will be exposed to higher temperatures not only during the vehicle warm-up phase but during all modes of vehicle operation. These higher temperatures increase the possibility of thermally degrading the catalyst. Because palladium is more thermally tolerant than platinum or rhodium, it becomes increasingly attractive for LEV applications. Unfortunately, palladium is more susceptible to sulfur contamination than platinum or rhodium. Furthermore, there is a significant amount of literature that suggests sulfur's effect on palladium catalysts is not completely reversible (i.e., the "memory effect" is worse with palladium than with platinum/rhodium)

California's supplemental FTP requirements could exacerbate the effect of sulfur on LEVs.<sup>1</sup> For example, the US06 cycle is a new cycle that contains aggressive accelerations and high speeds (up to 80 mph). The proposed LEV standards for the US06 cycle, which are separate from the existing LEV standards, are considerably stringent. The tight US06 standards will require that many vehicles rarely enter a temporary enrichment (rich air/fuel excursions) mode, a strategy often used to cool the catalyst by reducing the available oxygen for combustion, thereby reducing combustion temperatures. As a result, thermal degradation becomes a greater concern and palladium catalysts become even more attractive. The end result being an increased dependence on palladium and tighter air-fuel control, both of which increase the potential

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<sup>1</sup>EPA's supplemental FTP requirements could have the same effects. However, the issue discussed in this paper is that of California LEVs sold nationally. Therefore, such vehicles will be certified to California's supplemental FTP requirements rather than EPA's.

concerns over sulfur.

### **False MIL**

As stated earlier, the concern of some industry parties with LEVs equipped with OBD II operated outside of California on typical federal gasoline, is that a proliferation of illuminated MILs may occur due to the impact of sulfur on the OBD II catalyst monitoring system. The potential illumination of the MIL due to sulfur has sometimes been incorrectly characterized as a “false MIL.” A false MIL is a situation where the MIL is illuminated even though a monitored component or system is operating such that emission levels are below the malfunction trigger. If sulfur alone causes the OBD system to illuminate the MIL, the OBD system should not be considered malfunctioning; the sulfur has caused an actual degradation of the catalyst's performance, and the OBD catalyst monitor has properly identified the loss in catalyst performance. Clearly, the sulfur in this case has not caused a “false MIL,” but rather a “sulfur induced MIL.” The concern with "sulfur induced" MILs is that sulfur's effect is largely reversible. A catalyst exposed to high sulfur fuel resulting in degraded performance and appropriate MIL illumination, could potentially perform well enough to comply with emission standards after sufficient exposure to lower sulfur fuel. The real question becomes that of whether or not such a catalyst should be considered malfunctioning.

However, while EPA shares this potential concern, there was no convincing data supporting the likelihood of its occurrence, nor did any of the existing data answer several questions, such as:

- Is sulfur is going to cause MIL illumination? If so, how quickly will it occur? Upon leaving the dealership? At 10,000, 50,000, or 100,00 miles?
- What will be the public's reaction to the need for catalyst replacement, especially if vehicle owners replace their catalyst only to have it fail again due to sulfur? Will the public lose faith in OBD before having a chance to gain faith in OBD?

As a first step toward properly answering these questions, EPA requested the Auto and Oil industries to gather as much data as possible on sulfur's effect on the OBD catalyst monitors expected for use on LEVs. The focus of this testing was not the sulfur effect on catalyst conversion efficiency or emissions, but rather the sulfur effect on catalyst oxygen storage (i.e., the parameter measured by the OBD catalyst monitor), as only very limited data addressing that effect was available, particularly for LEVs.

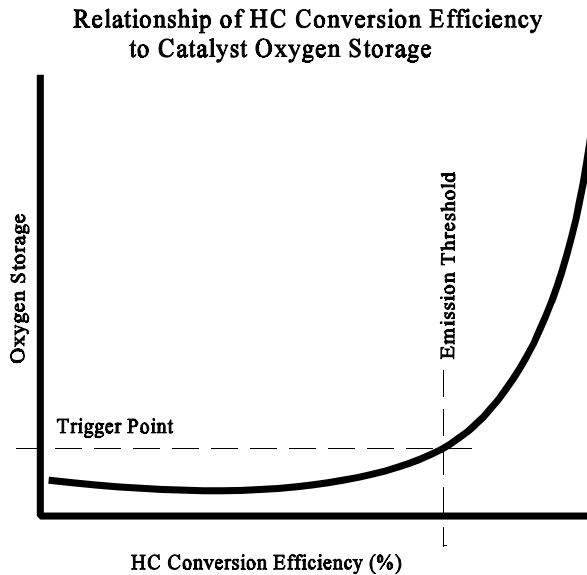
### **Sulfur Data on LEV/OBD II Technology**

The data collected thus far has consisted of bench data provided through the CRC Laboratory Reactor Study and vehicle-derived data from several auto manufacturers. The data generated in the CRC study was for sulfur levels of 40 ppm, 80 ppm, 300 ppm, 600 ppm, and 1000 ppm. With the exception of one manufacturer who tested at 30 ppm, 100 ppm, 350 ppm, and 1000 ppm sulfur levels, the rest of the vehicle manufacturer data was generated at "low

sulfur" levels of 30-50 ppm and "very high" sulfur levels of 900-1000 ppm. Catalysts ranged from LEV prototype to LEV production intent. OBD catalyst monitor designs ranged from experimental non-production intent (CRC Study) to production intent. Catalysts were either bench or oven aged to simulate 100K miles and to the original OBD II LEV threshold of 1.5 x the NMHC standard, which simulates severely aged catalysts.

### CRC Laboratory Reactor Data

The CRC laboratory reactor data suggest that for catalysts aged to 1.5x the NMHC standard, high levels of sulfur suppress oxygen storage such that it could possibly result in illuminated MILs. For catalysts aged to 100K miles, the effect of high sulfur was less significant. CRC concluded that, depending on the catalyst design (e.g., washcoat, noble metal content and loading, etc.) some LEV catalysts will be affected by sulfur, while others will not. Therefore, some catalyst monitoring systems will be affected by sulfur such that MIL illumination may occur and, therefore, OBD threshold cutpoint relief will be required to avoid sulfur induced MIL illumination. However, the CRC laboratory reactor data showed that some catalyst monitoring systems will not be affected by sulfur such that the MIL will illuminate and, as a result, no OBD cutpoint relief will be necessary. The data also suggested that for some catalyst monitors, whether affected by sulfur or not, OBD cutpoint relief may be infeasible because of the nonlinear relationship between oxygen storage and HC conversion efficiency (see graph). Because of this nonlinearity, catalyst monitors calibrated to trigger near the "flat" portion of the relationship have little or no room to "back off" of the cutpoint. For such monitors, manufacturers argue that additional relief to cutpoint thresholds would be useless since they will be unable to move further down the curve.



Even though the CRC laboratory reactor data was very useful in providing insight as to how sulfur interacts with the catalyst monitor; indicating that sulfur affects oxygen storage, it was impossible to determine whether or not sulfur would adversely effect the catalyst monitor for LEVs. Therefore, EPA suggested that actual vehicle data on LEVs (prototype or production) with LEV-intent OBD catalyst monitor systems and catalysts were necessary.

## Vehicle Data

Four auto manufacturers generated confidential data on LEVs and shared the data with EPA. The LEV data seem to support the CRC laboratory reactor data but were much more comprehensive, making it more usable in discerning how a LEV/OBD II catalyst monitor system could be affected by high sulfur fuel. The data from all four manufacturers suggest that sulfur has a negative effect on oxygen storage. However, only one manufacturer's data suggest that there is a possibility of sulfur-induced MIL illumination. That manufacturer tested two vehicles, one equipped with a four cylinder engine and the other equipped with a six cylinder engine. Both vehicles were TLEVs, not LEVs, and they were tested with catalysts aged to three simulated mileages: 100K miles; between 100K miles and the OBD threshold (1.5 x NMHC standard); and, to the OBD threshold. That manufacturer's data for the 100K mile aged catalysts indicate that the effect of sulfur was not sufficient to result in an illuminated MIL for either vehicle. For the catalysts aged between 100K miles and the OBD threshold, the vehicle with the six cylinder engine illuminated the MIL only with 1000 ppm sulfur, although the OSC index values for 29 ppm sulfur and 100 ppm sulfur were extremely close to the failure threshold. Finally, both vehicles illuminated the MIL with the catalysts aged to the OBD threshold, regardless of sulfur level.

Another manufacturer's data indicate that rather than sulfur induced MIL illumination, the MIL will probably *not* illuminate even when emissions may be in excess of the malfunction threshold. This manufacturer's data appear to indicate that, while sulfur adversely impacts the catalyst conversion efficiency and oxygen storage, it also has a similar impact on the downstream oxygen sensor used as part of the OBD catalyst monitor. The effect of sulfur on the downstream sensor is to slow the response rate such that its output signal mimics that of the signal expected from a sensor monitoring a high efficiency catalyst. As a result, the on-board computer interprets the signal as acceptable and fails to flag a poorly performing catalyst. Their data suggest that this could occur at any catalyst aging level: 10K, 50K, or 100K miles, or at the OBD threshold generated at sulfur levels of 30 ppm and 900 ppm.

Another manufacturer's data indicate a similar result: Poor catalyst performance with no MIL illumination, but for a different reason. This manufacturer's data indicate that catalyst performance is being adversely impacted by the sulfur, but its catalyst monitoring strategy is essentially impervious to sulfur's effects. Because of the catalyst monitoring strategy this manufacturer employs, the catalyst performance is temporarily returned to the "non-sulfur exposed" level during the monitoring event. This is done by forcing a rich operating condition for a very brief time during the catalyst monitoring event. This rich condition appears to reverse the sulfur effect such that during the catalyst monitoring event, the catalyst is operating at the



pre-sulfur exposed level. Once the monitor completes its evaluation, sulfur again adsorbs onto the catalyst surface returning the catalyst to its “sulfur exposed” performance.

The final manufacturer’s data indicate an increased variability in the decision making process of the catalyst monitor resulting from sulfur exposure. This manufacturer’s data do not indicate that MIL illumination will occur, but the increased variability causes them to have less certainty in the monitor’s performance. However, EPA believes that by using statistical algorithms in the catalyst monitor (e.g., Exponentially Weighted Moving Average (EWMA) which compares the results of the latest monitoring event with that from several preceding monitoring events in making decisions rather than relying only on the latest monitoring event), as most manufacturers do, the problems of increased variability can be minimized.

### **Data Analysis and Summary**

The data available to EPA at this time suggest that for LEVs with "typically" aged catalysts and mileage at or below 100K miles, sulfur's effects on the OBD catalyst monitor should not cause MIL illumination. While sulfur does appear to introduce variability into the decision making process of the OBD catalyst monitor, EPA believes that using statistical algorithms can reduce the potential for sulfur induced MIL illumination resulting from that variability. For those vehicles with severely aged catalysts due to high mileage, malmaintenance, and/or heavy-duty operation (e.g., trailer towing, mountain driving, etc.) or other potential causes of catalyst deactivation (e.g., poisoning, etc.) it appears that sulfur could cause MIL illumination on some but not all vehicles depending on the catalyst technology (i.e., noble metals, catalyst location) and OBD catalyst monitoring strategy employed.

Based on the data reviewed in this document, EPA does not believe there will be a proliferation of illuminated MILs due to sulfur. The data presented to date suggest that MIL illumination due to sulfur is only a potential issue for high mileage vehicles (beyond their useful life) and those lower mileage vehicles having severely aged catalysts that are most likely on the verge of needing replacement independent of sulfur. As discussed above, different catalysts are affected by sulfur in different ways. Predicting how many LEVs with high mileage or severely aged catalysts would actually be affected by sulfur is very difficult if not impossible at this time, but it appears that not all of these vehicles will be affected. It is important to note that the MOBILE5 model predicts that 24% of all LDVs have over 100K miles. Therefore, the fact that sulfur would only be a potential problem for high mileage vehicles in no way minimizes the concerns surrounding sulfur’s impacts on catalyst performance or OBD monitoring. However, it should be pointed out that of the four manufacturers who supplied LEV data, only one had data indicating sulfur-induced MIL illumination, and those vehicles were TLEVs. Also, it should be noted that the OSC indices for the two vehicles were very close to the failure threshold at low sulfur levels (20 ppm & 100 ppm) with catalysts aged between 100K miles and the OBD threshold, and were actually below the failure threshold at all sulfur levels for the catalysts aged to the OBD threshold (1.5x the NMHC standard). This suggests that these vehicles could possibly illuminate the MIL at 1.5x the NMHC standard, regardless of sulfur. Note that the OBD threshold is being revised from the current 1.5x the NMHC standard to 1.75x the NMHC

standard.

Perhaps of more concern than the potential for sulfur-induced MIL illumination, is the possibility of sulfur affecting vehicles such that emissions increase but the MIL is *not* illuminated (i.e., “false-passes”). Data from two of the four manufacturers suggest that this could be a more likely scenario. One of these two manufacturers stated that their catalyst monitor design was very sound and would still be capable of detecting the “normal” types of catalyst deterioration and failure that the system was designed to detect, such as thermal deterioration, but would be unable to detect any loss in catalyst efficiency resulting from high sulfur fuel. Both of the manufacturers with false-pass data contend that, since many other manufacturers use catalyst monitoring strategies similar to theirs, the possibility of other manufacturers experiencing similar results is high; EPA has seen no data to support this contention.

## **Analysis of OBD II/NLEV Implementation**

Gasoline sulfur clearly causes emissions to increase when using past catalyst technology and the catalyst technology currently expected for use in LEV applications. The data presented to date indicate that sulfur-induced MILs are possible on some TLEV and LEV vehicles, while sulfur may mask catalyst failures on other LEV vehicles. OBD is in its infancy, and discounting concerns voiced quite strongly by industry is not going to help EPA achieve long term goals such as OBD based I/M, ever increasing vehicle durability, positive public reaction to illuminated MILs and overall confidence in OBD. It is imperative that EPA work together with industry to ensure that the OBD program continues to be a success. If a party can provide conclusive data demonstrating sulfur effects, or other effects, on OBD and/or emission control system performance, EPA should remain open to reviewing that data and taking necessary steps to address the problem.

Based on the data available to date, EPA sees two potential short term courses of action in dealing with the issue of sulfur-induced MILs for OBD catalyst monitors for vehicles designed to the California LEV standards but certified under the pending NLEV program. EPA can provide up-front regulatory relief by relaxing the OBD monitor threshold, or EPA can address manufacturer concerns on a case-by-case basis similar to how the Agency currently deals with OBD issues.

By publishing a regulatory revision to the pending NLEV regulations, EPA could revise the OBD catalyst monitor thresholds such that a MIL illumination would be required at some appropriately increased multiple of the standard (e.g., 2.0x, 2.5x, 3.0x, etc.). Alternatively, the regulatory revision could be such that following the catalyst monitor demonstration based on use of California Phase II gasoline, the catalyst monitor trigger level for NLEVs could be adjusted such that MIL illumination will not occur when operating on fuel with some appropriately chosen sulfur level (e.g., 100 ppm, 300 ppm, 1000 ppm). This could potentially result in a different OBD catalyst monitor trigger point for every engine family utilizing this demonstration option, and it would impose a significant burden on vehicle manufacturers.

EPA believes, at this time, it would be inappropriate to permit any relief unless a manufacturer were able to supply data indicating that the catalyst monitoring system(s) of a specific engine family or families have been adversely affected by sulfur. Based on this, EPA sees no reason to provide up-front regulatory relief to address the OBD related sulfur concern. EPA believes the only acceptable demonstration of need for OBD catalyst monitor relief is that generated using in-use or production-ready vehicles operating on commercial fuels and using production-ready OBD catalyst monitor algorithms.

While up-front regulatory relief is not being provided, EPA remains open to manufacturer concerns regarding sulfur. Should a manufacturer approach EPA with conclusive data (preferably in-use data, but data such as that from production-intent vehicles would also be considered) demonstrating that a significant number of MILs are illuminating on a specific set of vehicles (i.e., identical catalyst configurations, identical catalyst formulations, etc.) due solely to sulfur exposure, then EPA would consider allowing a modification of the OBD catalyst monitor in such a way as to eliminate the sulfur induced MIL illumination. The Clean Air Act Amendments of 1990 state that all LDVs and LDTs will monitor, at a minimum, the catalyst and oxygen sensor. Therefore, EPA does not foresee allowing a manufacturer to disable the catalyst monitor. Instead, should the manufacturer have a proposed calibration that eliminates the MIL concern yet provides effective detection of all other forms of catalyst degradation, such a calibration will be considered. EPA does not see this option as applicable for carryover from model year to model year; however, if it appears that manufacturers are still having problems with sulfur and there are no other resolutions, EPA will consider allowing such a carryover.

EPA hopes to replace the emission testing portion of current Inspection and Maintenance (I/M) programs with a check of the OBD system, at least for those vehicles equipped with OBD (i.e., 1996+ model year). EPA is concerned that any policy offering general sulfur-related relief for catalyst monitoring could jeopardize the emission benefits that OBD based I/M is expected to provide. Since sulfur appears to negatively impact only some OBD catalyst monitors, only those vehicles affected should receive relief.

EPA also believes the potential benefits of OBD could be jeopardized if sulfur-induced MILs, or “false-passes” (MIL *not* illuminated), are ignored. OBD is an emission control strategy unlike anything ever proposed by industry or mandated by government. It doesn't control emissions; instead it monitors the components and systems that *do* control emissions and alerts the driver if and when something is wrong with those components or systems. In addition, OBD stores all critical emission control and engine control information at the point of detecting any malfunctions, thereby helping technicians diagnose the problems and make the appropriate repairs.

The potential of OBD to help identify and reduce excess emissions is very high and rivals other emission control strategies current or past. The Agency anticipates that OBD will identify at least as many, if not more, high emitting in-use vehicles as existing emission test based I/M programs. The OBD system's potential to diagnose failed and/or deteriorated emission-related components and systems that result in proper repairs is unparalleled. Furthermore,

manufacturers have shown that OBD's greatest attribute may be its influence toward improving vehicle design and durability, since manufacturer incentive to avoid illuminating MILs is very high.

While OBD shows great promise, it has a potential shortfall; it's an interactive system whose benefits are enhanced by vehicle owners responding to the MIL by promptly taking the vehicle to the repair shop for appropriate action. If the public were to lose faith in OBD, because the MIL illuminates too often, rightly or wrongly, they may become frustrated and start to ignore the MIL. If this were to happen, OBD's effectiveness could be reduced because vehicles would be taken for service only after required annual or biennial trips to I/M stations, rather than being taken for repair shortly following MIL illumination.

Furthermore, some higher mileage vehicles will, for a variety of reasons, be fitted with aftermarket catalyts following MIL illumination and repair. There is no known data showing the effect of sulfur on aftermarket catalyts designed for use on LEVs. Aftermarket catalyts are designed to last approximately 25K miles, or about a quarter of the expected design life of the original equipment catalyts. In addition, to minimize costs, aftermarket catalyts are not designed to perform as efficiently as original equipment catalyts. Therefore, if sulfur causes MIL illumination on a high mileage vehicle (i.e., beyond the emission warranty period) and the original equipment catalyts is subsequently replaced with an aftermarket catalyts, the possibility exists that the combination of sulfur and the lesser performing aftermarket catalyts could result in MIL illumination and catalyts replacement within 25K miles. Presumably, not many vehicle owners would be happy with a need to replace their catalyts every year or two, particularly at their expense. This is a concern shared by auto manufacturers, the oil industry, and EPA alike. In order to prevent a scenario like this from occurring, a joint industry-EPA effort must be undertaken to ensure that OBD systems are accurate and reliable. Anything that could cause the public to potentially lose faith in OBD is a concern, and thought must be given as to how to avoid or resolve such a scenario.

EPA realizes that controlling gasoline sulfur levels represents a potential strategy to resolving the issue of sulfur's effect on catalyts efficiency and OBD catalyts monitoring. However, for several reasons such a strategy cannot be implemented quickly. These reasons include lack of sufficient data on the impacts of intermediate sulfur levels on OBD system operation, inability to implement new fuel requirements in less than several years time frame, and lack of data on the cost effectiveness of sulfur control versus options for more sulfur resistant catalyts technologies. Therefore, such a strategy represents a long term strategy while providing no short term solutions.

## **Short-Term Solutions**

### **Sulfur-Induced MILs**

There are several ways EPA envisions the previously discussed case-by-case determination being implemented. First, the manufacturer must provide EPA with definitive

data demonstrating that sulfur alone is causing MIL illumination on in-use or production intent vehicles. The manufacturer may want to increase the catalyst monitor trigger point on affected vehicles; or they may want to revise the calibration such that monitoring occurs during a different set of operating conditions; or they may want to deactivate the catalyst monitor or deactivate any MIL associated with catalyst malfunctions; etc. Following are two scenarios for consideration.

#### A. Revised Catalyst Monitor Threshold Calibration

EPA could allow the manufacturer to revise the catalyst monitor threshold calibration provided the calibration effectively identifies a catalyst degraded for all other reasons while decreasing the incidence of MIL illumination resulting from sulfur exposure. This could happen as either a field fix or running change.

#### B. Revised Catalyst Monitor Operating Conditions

EPA could allow the manufacturer to recalibrate the operating conditions under which the catalyst monitor evaluates the catalyst. For example, the manufacturer may want to revise the operating conditions such that the catalyst monitor activates during a 50 to 60 mph cruise following a 65 mph to 50 mph deceleration rather than monitoring at a 40 to 50 mph cruise following a gradual acceleration from 10 mph to 40 mph. The known data to date suggests that the operating conditions chosen for activating the catalyst monitor can have a definite impact on the reliability and accuracy of the monitor. With experience and in-use feedback, manufacturers may learn that different operating conditions are more effective than others for minimizing the sulfur effect (or other effects). This is an attractive implementation scenario as EPA has already allowed for such revisions to catalyst monitors after in-use data have demonstrated poor reliability of monitoring under some operating conditions. Therefore, this implementation approach is in place and represents a status quo approach to OBD implementation rather than the introduction of new policy.

#### **False-Passes**

There are no known short-term software or hardware fixes to address this issue. While this issue does not represent a customer “inconvenience,” it does potentially complicate the use of the OBD catalyst monitor in an I/M program since the monitor will most likely be unable to detect the increase of emissions above the OBD threshold due to operation on higher sulfur fuel. As discussed earlier, the catalyst monitor should still be capable of detecting normal catalyst deterioration or failure, just not the loss of catalyst efficiency resulting from high sulfur. EPA is left with no option in the short-term but to accept that this possibility exists.

#### **Conclusion**

EPA believes that it should go forward with the approach of addressing the sulfur induced MIL issue on an in-use, case-by-case basis, with an emphasis on the second implementation

scenario (revised catalyst monitoring conditions), but openness to the first scenario (revised catalyst monitor threshold).

Recognizing that this approach represents a short term solution, EPA believes that further study should occur toward developing a long term resolution. Investigations should continue to look into the effect of sulfur on exhaust emissions, the effect of intermediate sulfur levels on the OBD catalyst monitor, and the cost effectiveness of fuel related control measures such as a sulfur cap or tighter performance standards. There should also be further study to determine the feasibility and cost effectiveness of developing sulfur-tolerant emission control technology for vehicles.

This paper has focused on the possibility of MIL illumination resulting from high sulfur levels in gasoline. As mentioned in the discussion, some of the manufacturer vehicle-derived data suggested that, rather than sulfur induced MIL illumination, the MIL would probably *not* illuminate even when emissions may be in excess of the malfunction threshold. Therefore, it is recommended that further discussion on this issue occur and more data be generated to fully characterize this potential concern.