The Alliance, CVMA, AIAM Emissions and Durability Study

Design of the Experiment

The program was statistically designed to determine whether or not MMT causes vehicle emissions to change or has any effect on engine component durability or OBD II systems. Among the questions the program sought to answer were the following:

- Does MMT cause vehicle emissions to increase and/or impair the performance of any emission control device?
- Does MMT cause spark plugs to misfire?
- Does MMT degrade oxygen sensor performance?

Testing involved a large fleet of vehicles of various models and emission control levels, extensive mileage accumulation on a test track with controlled fueling and periodic exhaust emission testing according to emission certification protocols. Analysis of previous MMT vehicle test programs led to a program design that involved pairs of vehicles (one on clear fuel the other on MMT fuel) and duplicate emission tests at each mileage interval with a third test criteria based on the variability of the first two tests.

<u>Vehicles</u>
At the outset of the program planning, which began in 1996, it was desired to test only production vehicles that were representative of high volume models with a cross section of vehicle makes and engine types. Previous experience with prototype vehicles has indicated that no matter how advanced the prototype is, it is never exactly the same as the vehicle that is eventually released for production and ultimately makes up the on- road vehicle fleet. The first part of the program involved forty vehicles (two pairs of each of ten models), which were products of five different manufacturers. All vehicles were new 1996 or early production 1997 models provided by the manufacturers. The vehicle fleet contained domestic and import model cars and light-duty trucks with 4, 6 and 8 cylinder engines. Two vehicle models were certified to Tier 1 levels, seven models to TLEV (Transition Low Emission Vehicle) levels and one model to LEV (Low Emission Vehicle) levels. More LEV models were desired, but only one model certified to California's LEV standards was available at the start of the program. The second part of the program, run later, included four additional 1998-99 LEV models (16 vehicles, two pairs of each model). These additional LEV models became available for sale in California in 1998 and 1999.

Throughout both parts of the program, exhaust emissions were compared to the regulatory levels that each vehicle was certified to meet. To encourage early introduction of LEV models, California allowed in-use emission levels that were somewhat higher than certification levels for the early model years, but those only applied for 1998 and 1999, after which in-use standards became identical to certification standards. Regardless of the interim standards, manufacturers were still required to design and certify their vehicles to comply with certification standards for the full useful life of the vehicle, so those are the standards chosen for comparison in this test program.

EPA's traditional test protocol for assessing fuel effects calls for assigning fuels to vehicles after some break-in period such as 4000 miles. This was discussed during program planning, but because of concern about initial deposit buildup in combustion chambers, the protocol was modified. If vehicles were allowed to accumulate 4000 miles with a clear fuel, an initial layer of carbon deposits inside the combustion chamber could affect subsequent accumulation of manganese oxide deposits during mileage accumulation and thus affect hydrocarbon emission results. Furthermore, it is unrealistic to believe that new vehicles would only see clear fuel for the first 4000 miles in a market such as Canada where most fuel contains MMT. Therefore, the decision was made to randomly assign fuels to vehicles prior to running the zero mile tests and maintain that assignment throughout the entire program. Advice from the statistical consultant was to statistically randomize vehicle/fuel assignments to the greatest extent possible as the best way to minimize any emissions bias that might exist among vehicle/fuel combinations.

Fuels

Since the primary objective of this study was to determine the effect of the fuel additive MMT, the most straightforward comparison that can be made is to accumulate mileage with one vehicle of each pair on a clear base fuel and the other on the same base fuel containing MMT. In this case, the clear base fuel was an unleaded certification quality fuel normally used by auto manufacturers to accumulate mileage during emission certification tests. The MMT fuel was that same base fuel with the addition of MMT at a level of 0.031 g Mn/gal, the maximum legal limit in the U.S. These fuels were used for mileage accumulation. Emissions testing on all vehicles, both MMT-fueled and Clear-fueled, was done with the same California Phase 2 fuel used by auto manufacturers for emission certification tests.

It was recognized that in the real world, MMT used at a refinery would displace some high octane components such as aromatics to arrive at the same octane level as a clear fuel sold without MMT. However, to test fuels at the same octane level, the MMT fuel would have a different hydrocarbon composition from a clear fuel which would likely affect deposit formation in the engine and hydrocarbon emissions. A comparison of emissions, fuel economy and durability could not be made with MMT as the only fuel variable. Consequently, the program was run with MMT "splash blended" into the base fuel with the result that the octane quality of the MMT fuel was likely about one octane number higher than that of the Clear fuel, but all other fuel properties remained identical. All vehicles except one model had knock sensor systems that were not capable of advancing the spark timing to take advantage of higher octane quality fuel. There was no evidence that the difference in fuel octane quality between Clear and MMT fuels had any effect on test results during this program.

Driving Cycle

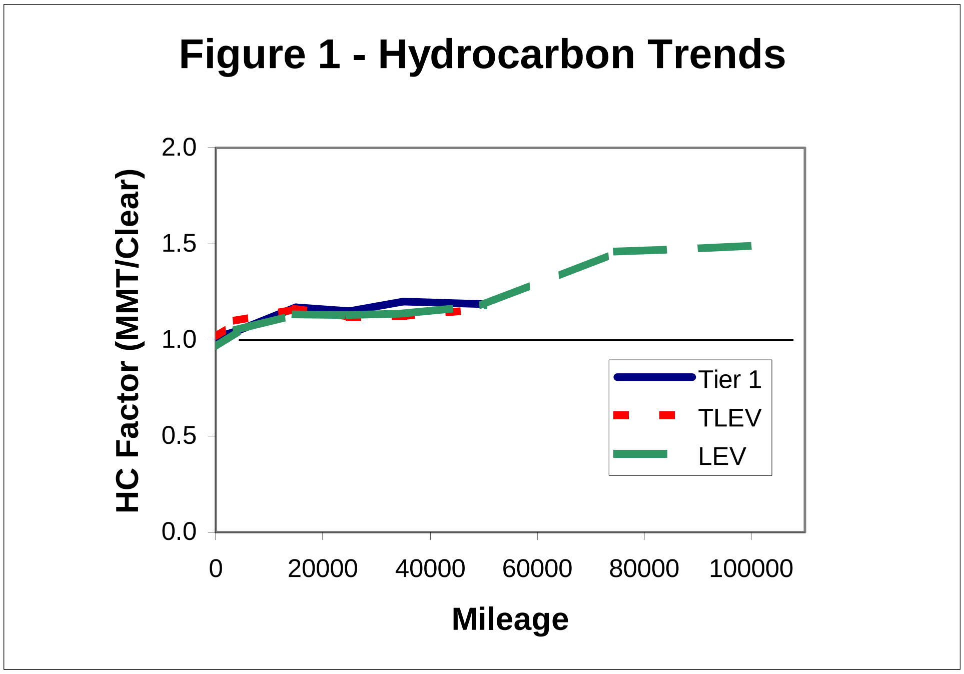
During the planning of the program, there was much discussion about what driving cycle should be used for mileage accumulation. The cycle commonly used to certify vehicles up to this point had been the AMA cycle, which is widely recognized as quite mild service and not really representative of the way customers drive vehicles today. There was a desire to use a cycle that was more severe than "average" to stress the vehicles and emission control systems. This is a common approach by auto makers because they have to insure that their products perform well under all kinds of driving, including that which is more severe than "average". Each automaker had their own proprietary cycles to represent various severities of customer driving and used those cycles for vehicle development, but were not willing to make the cycles publicly available. In 1994 EPA proposed a new cycle, based on customer driving habits, and more aggressive than the AMA cycle. The Standard Mileage Accumulation (SMA) cycle was developed by EPA as an alternative to the AMA cycle and to improve testing of catalytic converter durability during a vehicle's in-use period. This cycle was selected for the study, but modified prior to starting the program in response to criticism ***by Ethyl*** of being too severe. The cycle's top speeds were reduced from 70 to 60 mph and from 80 to 70 mph and the most aggressive acceleration was reduced from wide-open throttle to moderate throttle. Subsequently, this modified SMA cycle has been used for several vehicle deposit and emission test programs by the Coordinating Research Council, an organization composed of representatives from the auto and oil industries.

Regardless of the severity of the driving cycle, all vehicles (Clear and MMT) were driven the same way, so emissions and other parameters can be legitimately compared over the same type of operation.

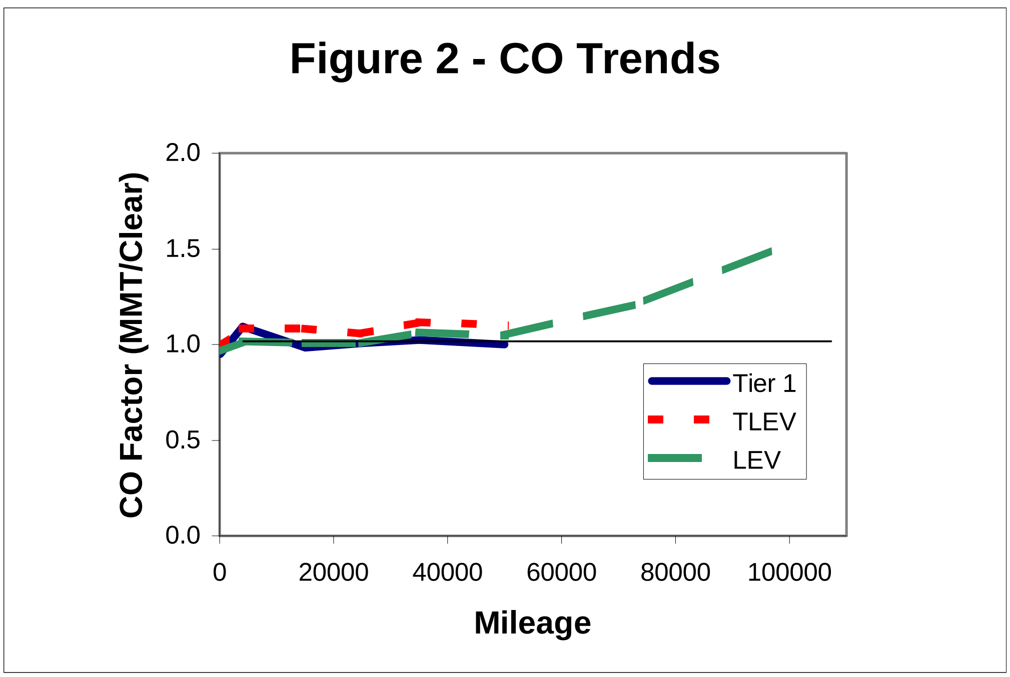
Results from The Study

<u>Hydrocarbon Emissions</u>
The one outstanding result from this study is that MMT consistently increases hydrocarbon emissions for at least one pair and in most cases both pairs of vehicles for each model. The measured emissions data clearly show that MMT-fueled vehicles have higher hydrocarbon emissions than Clear-fueled vehicles when all are driven the same way over extended mileage. Over the entire program involving 56 vehicles and 14 vehicle models, tailpipe hydrocarbon emissions at the end of the mileage accumulation period (50,000 miles for Tier 1 and TLEV; 75,000 or 100,000 miles for LEV) were higher with MMT for all four pairs of Tier 1 vehicles, ten of the fourteen pairs of TLEV vehicles, and eight of the ten pairs of LEV vehicles. None of the Tier 1 or TLEV vehicles exceeded emission certification levels, but seven of the eight light-duty LEV vehicles using MMT fuel exceeded the HC certification standard while only one Clear-fueled LEV vehicle exceeded the certification standard. All medium-duty LEV trucks met the certification standards with both fuels.

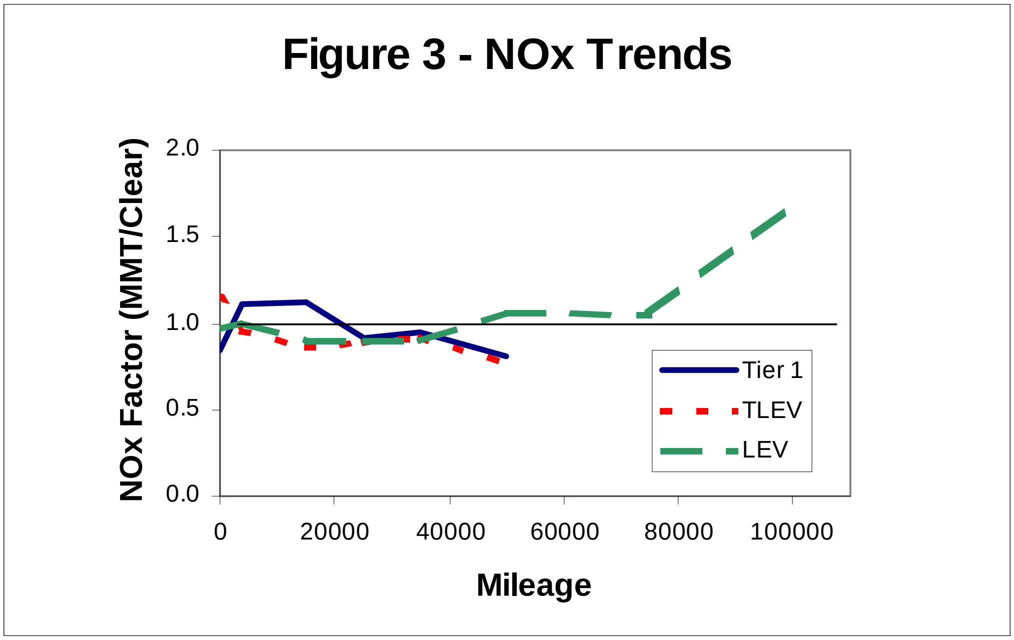
The trends in tailpipe HC emissions with mileage for each emissions class of vehicles are shown in Figure 1. The "HC Factor" is calculated by dividing the measured HC emissions from the MMT-fueled vehicle by those from the Clear-fueled vehicle of each vehicle pair, so a ratio greater than one means that emissions were higher with MMT than with Clear fuel.



<u>CO and NOx Emissions</u>
None of the vehicles on either fuel exceeded the appropriate certification levels for CO or NOx. For Tier 1 and TLEV vehicles, tailpipe CO emissions were about the same with both fuels at the end of the program, but for LEV vehicles CO was higher with MMT fuel. These trends are shown in Figure 2.

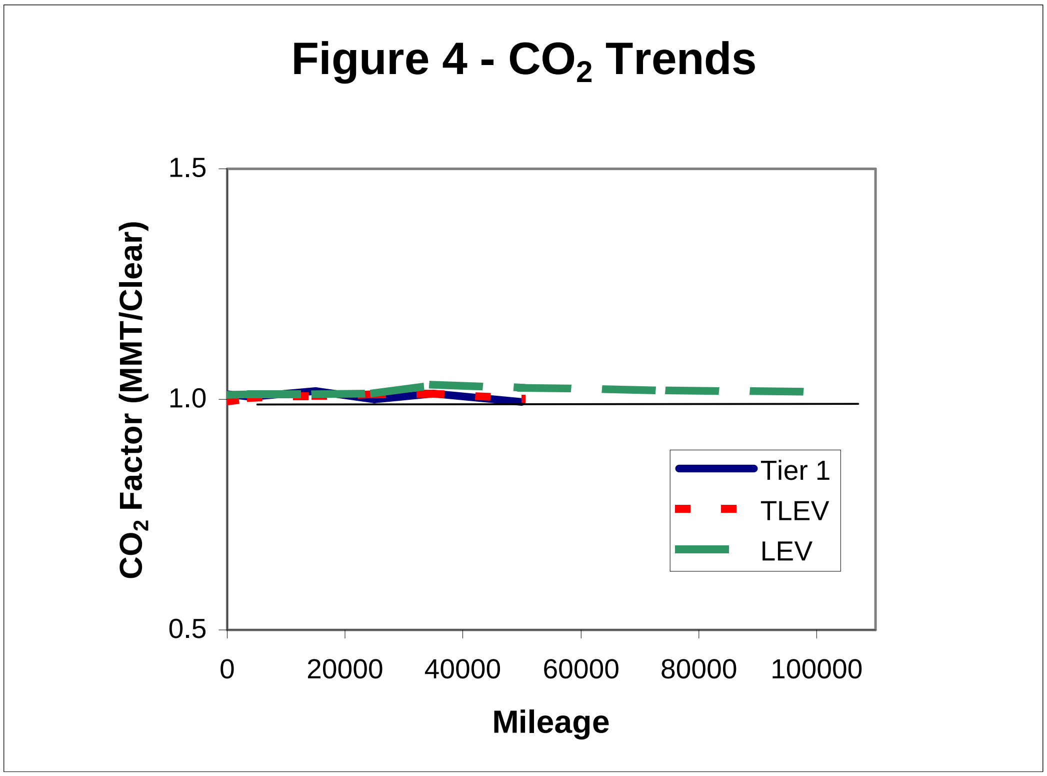


NOx emissions were generally lower at the end of the program with Tier 1 and TLEV vehicles, but higher with LEV vehicles as shown in Figure 3.



CO$_2$ Emissions

CO2 emissions were essentially the same with both fuels for Tier 1 and TLEV vehicles, but somewhat higher with MMT fuel for LEV vehicles at higher mileages as shown in Figure 4.



Fuel Economy

Both city fuel economy and on-road fuel economy was consistently lower with MMT fuel at the end of the program with all classes of vehicles. The effect was greatest with LEVs where the MMT penalty was between 0.5 and 0.6 mpg.

Statistical Analyses

A comprehensive statistical analysis, using several different approaches, was performed on the results from the program and the findings are detailed in the final reports for Parts 1 and 2 of the study (36). A summary of the significant MMT effects at the end of the program for Part 1 (Tier 1, TLEV, one LEV model) and Part 2 (four LEV models) is shown in Table 1. A positive effect means that the measured quantity was higher with MMT fuel and a negative means it was lower. The symbol NS indicates that there was no statistically significant difference between the two fuels.

Table 1
Summary of Significant MMT Effects

Tailpipe Measurements	Part 1 (50,000 miles)	Part 2 (100,000 miles)
HC	+	+
CO	+	+
NOx	-	+
CO_2	NS	+
City FE	NS	-

The important conclusion from this analysis is that for advanced technology LEV vehicles at high mileages, MMT significantly increases all emission constituents, including CO_2, and significantly decreases fuel economy.

Spark Plug and Oxygen Sensor Fouling

Both MMT-fueled vehicles of one TLEV model, a Cavalier, experienced spark plug misfire between 30,000 and 40,000 miles, but the matching Clear-fueled vehicles did not. Upon examination, the plugs were fouled with reddish brown deposits, presumably manganese oxide. After Part 2 of the program was completed, one pair of each model of LEV vehicles was returned to its manufacturer for a post-mortem analysis. It was discovered during that testing that the MMT-fueled Escort LEV was misfiring due to fouled spark plugs with reddish brown deposits while the Clear-fueled vehicle of the pair was not. Further examination of the other pair of Escort LEV vehicles at the end of the program revealed that the MMT-fueled vehicle of that pair was also misfiring due to fouled spark plugs. So, for at least two vehicle models, MMT fuel caused spark plug fouling and engine misfire.

At the end of Part 1, an extensive investigation was made comparing the performance of oxygen sensors from the Tier 1, TLEV and LEV models. No differences in performance could be attributed to the use of MMT fuel.

Implications from the Study Results

Based on results from this comprehensive study, it is likely that the use of MMT fuel will increase HC and CO emissions from both old and new technology vehicles and the impact becomes greater at higher mileages and as vehicle technology advances to meet more strict exhaust emission standards. The increases in HC are expected to cause LEV vehicles to exceed certification standards. Although NOx emissions may decrease somewhat with the use of MMT fuel for older technology vehicles (Tier 1 and TLEV), the opposite is true for LEV technology vehicles - NOx increases with MMT fuel compared to Clear fuel at higher mileages. In addition, for LEV vehicles, the use of MMT fuel causes a small but significant increase in CO_2 emissions and a corresponding decrease in fuel economy.