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MY 2006 OBD II Compliance For Aftermarket Light Duty Natural Gas Vehicles

Final Report for:
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EXECUTIVE SUMMARY

In order to encourage increased penetration of natural gas vehicles (NGV's) in the Canadian marketplace, the government of Canada is offering incentives in the form of NGV conversion grants. These grants reduce the cost of converting a vehicle to natural gas, making it more attractive for customers to add more NGV's into their fleet. The government of Canada, however, wishes to ensure that only quality aftermarket NGV conversions are eligible for the grant, so that the expected benefits of reduced greenhouse and toxic gas emissions are realized. To claim eligibility for a conversion grant, the aftermarket NGV converter must therefore produce a valid EPA or CARB certificate of emissions compliance for each model of vehicle to be converted. EPA or CARB certificates must be obtained for each model year. If there have been no changes made to a particular model, certification data may be carried over from one model year to the next, and there are conditions under which data may be carried across from one model to another within the same base vehicle manufacturer.

In the past, aftermarket converters received EPA or CARB certificates based on emissions performance that met the requirements of specific levels of emissions standards. Commencing 2006, however, there are additional requirements that the NGV conversion must also be fully OBD II compliant. (On Board Diagnostics II). The OBD II system has been designed by the OEM to diagnose faults in the emission control system, and illuminate a MIL (Malfunction Indicator Light) on the vehicle's driver information center, when the emissions are exceeding (generally) 1.5 times any of the applicable emissions standards for which the vehicle was originally certified. Various monitors have been designed by the OEM, which have a complex set of fault detection strategies and algorithms contained within the OEM computer. The OEM software therefore contains calibrate-able fault detection thresholds which set the MIL based on a correlation of the fault diagnostic system strategy and the emissions created when the fault is present. When the vehicle is operated on natural gas, this correlation will no longer be valid, and the emissions could be quite different when a fault is detected using the OEM gasoline based diagnostic system. This could place the vehicle out of OBD II compliance when it is operated on natural gas.

Developing OBD II compliance for an aftermarket NGV conversion is a formidable and costly undertaking for converters who have little to no experience with OBD II systems. In 2005 a report was prepared with the support of Natural Resources Canada, entitled "OBD II Certification Impacts on the Aftermarket NGV Conversion Industry", which defined the OBD II problem and informed converters on the nature of OBD II systems. The converter was then faced with learning how to test sophisticated OBD II system performance on natural gas, and developing OBD II compliant systems. The "Showstopper" in all of this was the concern (by both the converter and EPA), that if the gasoline related fault thresholds had to be reset to be compliant with natural gas operation, the converter had no way of achieving that, because he had no access to the OEM computer to make the changes. The OEM, of course, had no interest in making these changes for the NGV converter.

EPA/CARB could do little about this, because they had no data on the OBD II performance of aftermarket NGV conversions when operated on natural gas. Obtaining this data was therefore of paramount importance to help to negotiate a satisfactory solution for the aftermarket NGV converters with EPA and CARB.

This project has therefore focused on obtaining typical OBD II performance data from aftermarket natural gas vehicles. A cooperative development and test program was set up with two major aftermarket converters, BAF Technologies in the USA and ECO Fuel Systems in Canada, who agreed to share OBD II test data. The program was designed to provide EPA and CARB with a wide spectrum of previously unknown OBD II performance data from typical aftermarket NGV converters, tested over a common format, and covering different vehicle classifications from pick up trucks to passenger cars, different base OEMs, dedicated and bi-fuel natural gas conversions, and different levels of certification stringency.

BAF decided to pursue the development of a new technical approach for aftermarket converters, which allowed them to gain access to the OBD II calibration in the OEM computer, which would allow them to make changes to the OEM fault thresholds as required. ECO Fuel Systems continued with the conventional electronic fuel injection approach using their own computer linked to the OEM computer, often referred to as a Master-Slave system. This approach does not allow OEM gasoline thresholds to be reset OBD II test methods were developed, and a test plan formulated.

The results of the OBD II testing proved to be of great interest. A consistent trend emerged across all of the different vehicles tested:

- ECO/GM Bi-fuel pick-up truck certified to a high certification level (EPA Bin 8)
- ECO/Ford B-fuel passenger car certified to a mid certification level (EPA Bin 5)
- BAF/Ford CNG only pass. car certified to a very low certification level (EPA Bin 2)

Provided the certification level of the NGV remained the same as the base gasoline vehicle, the gasoline based diagnostic monitors generally detected faults created in the NGV system, at emissions levels below the malfunction criteria set by the OBD II regulations. In essence this means that the MIL will be illuminated somewhat earlier, or at lower emissions than, MIL illumination on gasoline.

However, when the certification level on CNG was much more stringent than the base gasoline vehicle, then the gasoline based diagnostic monitors generally detected faults created in the NGV system, at emissions levels considerably greater than the malfunction criteria set by the OBD II regulations. In this case, the threshold levels would have to be reset from the gasoline settings in order to be OBD II compliant.

This is a satisfactory result from the perspective of ECO Fuel systems. Since bi-fuel vehicles must be certified to the same emissions standards on both gasoline and natural gas, then ECO Fuel systems should be able to reach OBD II compliance without having to reset monitor thresholds. BAF, on the other hand, has to reset thresholds to be compliant with the more stringent emissions standards for which the dedicated CNG vehicle was certified. Their technical approach, however, allows them to do that.

A White Paper on this study was prepared and presented to EPA for discussion. EPA indicated they were highly appreciative of the study and the results presented, as this is totally new information for them. They agreed with all findings of the study, and were pleased with the results, as it solves one of EPA's concerns on what to do with converters who cannot reset monitor thresholds. EPA, however, voiced concern that fault detection at lower emissions than the criteria of 1.5 times the applicable emissions standards could constitute a false MIL, and is not in compliance with their regulations. CARB on the other hand requires the MIL to be illuminated at emissions levels less than 1.5 times the standards. They seem to care less about how low the emissions levels are when fault detection occurs. EPA will accept CARB OBD II approval, (< 1.5 times) but if a company certifies only with EPA, then they must abide with the EPA regulations (> 1.5 times). EPA has, therefore recognized that they have a dilemma to resolve, as a result of the findings of this work The dilemma arises because the data shows that aftermarket conversions will generally set the MIL to illuminate at < 1.5 times the standards using the gasoline monitors. In order to reach the level required for approval, converters will have to "dirty up" the calibration, increasing the NGV emissions, so that the MIL will be illuminated at 1.5 times the applicable standards. However, EPA does not want converters to make their emissions worse, and prefers to have the lower emissions created by the NGV. Hence the dilemma, which needs to be tracked and resolved with EPA.

EPA also agreed to review the need for costly catalyst monitor tests as a result of the data obtained in this study. The data showed that NMHC may be an inappropriate criterion for detecting faults in the catalyst monitor for an NGV, due inherently low NMHC emissions. The study showed that the gasoline catalyst monitor thresholds will still detect catalyst failure on an NGV, but on the basis of high CO or NOx emissions, not on the basis of hydrocarbon emissions. EPA will therefore likely pursue a less costly approach to catalyst monitor tests, involving use of gasoline thresholds, and some minimum test of emissions from a worst case catalyst. However, since they only have one set of data on threshold catalysts, provided by BAF, more data will be required for EPA to follow this path.

Applicability of OBD II data across a range of different vehicles was clarified by EPA The OEMs generally form OBD II groupings which could cover perhaps 10 or 12 models with the same OBD II system. EPA agreed to provide information on the extent of carry over and carry across of OBD II data which could be permitted from one model to another in order to reduce the cost of testing. Future testing should therefore be carried out on the worst case vehicle in the OBD II grouping, in order to maximize use of the same data over a range of vehicle models.

Much has been learned from this study. The major obstacle, involving the inability of the aftermarket converter to shift thresholds to reach compliance, has been removed. New technical approaches are becoming apparent which could allow some converters to shift OEM thresholds as required. The converter will still be faced with OBD II testing each model year, depending on the extent permitted for carry across and carry over from previous model years, but he now has experience on what to do, and the extent of testing may be minimized as a result of the findings of this project.

Continued support from NRCAN will likely be required to deal with additional requirements in MY 2007, and to nurture the maturing capability in aftermarket NGV compliance.

Achieving OBD II compliance with aftermarket NGV’s is a significant milestone which will benefit the industry, improving the image of quality natural gas vehicles. Having a fully functional OBD II system provides assurance that the aftermarket NGV’s have durable emissions components, and are complying in use. In this respect they have matured to the same standing as an OEM vehicle.

1. INTRODUCTION

At the present time, most of the major OEMs in North America have largely abandoned the NGV market. The Canadian NGV Alliance (CNGVA), and the Canadian Government, would like to see increased penetration of NGVs in Canada, because of their beneficial effect in reducing greenhouse gases, and other toxic emissions. Since the major OEM marketing strategies are based in the USA, Canada must rely on advanced aftermarket natural gas vehicles, (ANGVs), to build the NGV market in Canada and the USA, to a level that will encourage the OEMs to re-enter the marketplace. The Canadian government has made a substantial investment in the NGV business, over the years, and as a result, there are several Canadian companies who have developed the experience to produce OEM type, quality aftermarket NGV conversions. In order that NGV conversions in Canada receive a conversion incentive grant, the Canadian government wishes to ensure that only these quality NGV conversions enter the market place. This can be achieved if the conversion company produces an EPA or CARB certificate of compliance, for the converted ANGV, to provide the confidence level that the converted vehicle emissions performance is satisfactory, and that the expected greenhouse gas emissions reduction is being achieved.

As of 2006, however, EPA and CARB certification of ANGVs have new requirements that the vehicles must be fully OBD II compliant. This has been achieved in the past through cooperative ventures between the converter and the OEM. Without the help of an OEM, the ANGV converter will have to develop alternative solutions for OBD II compliance which are acceptable to EPA and CARB. This is a formidable and costly undertaking for the ANGV converter, who must climb a significant learning curve to develop sophisticated technology to interface with existing gasoline OBD II systems, and obtain data to demonstrate OBD II compliance when operating on natural gas. This must be done without any assistance from the OEM, which presents significant difficulties for the converter.

While EPA has acknowledged that such difficulties exist, they did little initially to alleviate the OBD II problem. They did, however, in 2005, send staff to Technical Forums to state the need to comply with OBD II requirements for aftermarket alternative fuels conversions. (See Appendix IV for EPA Guidance Letter on Approval of OBD II Systems for Aftermarket Alternative Fuel Converters). While they were somewhat lenient in approving OBD II systems in 2005, they indicated that in 2006 they would hold aftermarket alternative fuel converters to the same regulatory requirements that OEMs meet, in order to maintain compliance equity among manufacturers. Having a fully functional OBD II system provides EPA with some assurance that alternative fuel converted vehicles have durable emissions components and are complying in use. This, however, was an onerous requirement for an industry that had no experience in OBD II compliance.

EPA was also silent on the fundamental problem facing the aftermarket converter. Typically, they had no access to the fault thresholds contained within the OEM computer, which triggered the Malfunction Indicator Light (MIL) when the gasoline emissions reached the malfunction criteria of 1.5 times the emissions standard as a result of the fault. If the vehicle, operating on natural gas, encountered the same fault, and triggered the MIL at a different emissions level, the MIL threshold would have to be reset in order to be OBD II compliant, and the converter had no way of doing that inside the OEM computer.

In many respects, EPA took this position because they had no data on the OBD II performance of aftermarket NGV conversions when operated on natural gas. Obtaining this data was therefore of paramount importance to help to negotiate a satisfactory solution for the ANGVM converters with EPA and CARB.

There were many questions to be answered. What were the natural gas emissions at the gasoline fault threshold level? Were they much greater than required by the OBD II malfunction criteria set by the regulations, or perhaps much less? Did the monitor threshold levels require resetting on natural gas, to meet the malfunction criteria, and how would that be done? Were they close enough that EPA or CARB would not require thresholds to be reset? Did the fault threshold emissions performance relative to the emissions standards vary from monitor to monitor? If the natural gas vehicle was certified to a lower certification level than that for which the vehicle was originally certified on gasoline, how did that affect the fault threshold emissions performance relative to the required malfunction criteria of 1.5 times the applicable emissions standards? (1.75 times hydrocarbons for the catalyst monitor, and 2.5 times the CARB SULEV standard). Also, how would the aftermarket converter carry out this testing without the help of the OEM?

It was agreed by two ANGV converters, ECO Fuel Systems, (ECO) in BC, Canada, and BAF Technologies, (BAF) in Texas, USA, that a cooperative program, to share OBD II data from their respective vehicle test programs, would benefit all parties. This project has therefore allowed a number of goals to be achieved. Alex Lawson Associates (ALA) has worked closely to assist ECO in developing an OBD II compliant system for 2006. As a result, ECO has greatly improved their level of understanding of OBD II systems, both testing and compliance, compared to when the project commenced. In addition, it has been possible to put together a program test matrix, covering a number of test vehicle categories, including a spectrum of manufacturers, vehicle types (dedicated and bi-fuel), and different stringencies of certification levels. The different categories are:

- BAF Dedicated Ford CNG passenger car, certified to a much lower emissions standard than that for which the vehicle was originally certified on gasoline. The original gasoline vehicle was certified to EPA Tier 2 Bin 5, while the CNG conversion is to be certified to Tier 2 Bin 2 with EPA and SULEV II with CARB.

- ECO Bi-fuel Ford CNG passenger car certified to the same level as the original gasoline vehicle, that is EPA Tier 2 Bin 5

- ECO Bi-fuel General Motors CNG Pick-up truck, certified to the same level as the original gasoline vehicle, that is EPA Tier 2 Bin 8.

This provides EPA and CARB with a wide spectrum of previously unknown OBD II performance data from aftermarket NGV converters, tested over a common format, and covering different vehicle classifications from pick up trucks to passenger cars, different OEMs, dedicated and bi-fuel natural gas conversions, and different levels of certification stringency.

EPA will now have a better understanding of typical OBD II performance of ANGV conversions, and a common trend is emerging which suggests that gasoline OBD II calibrations may in fact be adequate for natural gas operation, provided that the certification level is not changed. This data will therefore assist negotiations with EPA and CARB to develop guidelines to reduce the complexity of testing and cost of compliance, leading to NGV conversions which are both technically and economically viable.

2. OBJECTIVES

- To provide advice to EcoFuels on the technology, test program, and data required to make their NGV conversion system OBD II compliant.
- To analyse the OBD II data, and prepare a report on the ECO system OBD II performance, for presentation to EPA/CARB. Reporting will be in a broader context than that used for certification purposes, and will include OBD II performance data from other after market systems such as the BAF system, presented in a common format for comparison purposes.
- To provide EPA/CARB with a better understanding of the typical OBD II performance of aftermarket NGV conversion systems.
- To discuss with EPA/CARB opportunities for streamlining the OBD II certification process, based on the data presented, to reduce the financial burden of OBD II compliance presently placed on aftermarket converters.
- To acquire a better understanding of the system changes required to make the CNG vehicle OBD II compliant, which will allow future strategies to be developed for certifying aftermarket NGVs on an economic basis.

3. BACKGROUND REGULATIONS

In 1991, California introduced OBD I regulations, for which the NGV conversion industry was able to respond, as it involved simple checks which would alert the driver, if a sensor was inoperative. In 1996, OBD II regulations were introduced by EPA and CARB for gasoline vehicles. The regulation actually required alternative fuel vehicles to comply with OBD II requirements, but annual waivers were granted by EPA and CARB up until the 2005 model year. An extension of the waiver process was successfully negotiated in 2004, which provided a one year extension to the NGV industry. In 2006, however, all alternative fuel vehicles had to be fully OBD II compliant.

The CARB OBD II regulations are contained in the California Code of Regulations Title 13, Division 3, Chapter 1, Article 2, Section 1968.1 "Malfunction and Diagnostic System Requirements for 1994 and subsequent vehicles". A revised version of the OBD II regulations was issued by CARB for 2004 and subsequent vehicles under CFR Section 1968.2. There is a three year phase in for these regulations, so that ANGV converters will not have to comply with the additional requirements in 1968.2 until the end of the phase in period, that is, 2007. However, we were informed by CARB that ANGV converters have to work with the new 1968.2 regulations, even although certain segments do not apply until 2007. The reference to the 1968.2 regulations is "California Code of Regulations, Title 13, Division 3, Chapter 1, Article 2, Section 1968.2 "Malfunction and Diagnostic System Requirements – 2004 and Subsequent Model Year Passenger Cars, Light Duty Trucks, and Medium Duty Vehicles and Engines". These can be found at the website http://ccr.oal.ca.gov/linkedslice/default.asp?SP=CCR-1000&Action=HOME.

The additional requirements which ANGV converters will have to face in 2007 include NOx monitoring (probably the biggest challenge), cold start monitoring, and a reporting of the frequency with which the monitors are run on the vehicle. This is as a result of the finding by CARB that some manufacturers were not running the monitors very often, probably to reduce the frequency of false MILs occurring. If you do not run the monitor, then you will not get a false MIL. The new requirements involve Ratio Monitoring Requirements, and involve reporting a ratio of N/D, where N is defined as the number of times a vehicle has been operated such that all monitoring conditions necessary for a specific monitor to detect a malfunction have been encountered. D is defined as a measure of the number of times the vehicle has been operated. Ratios must not exceed defined values for a certain number of monitors.

Another feature of the 1968.2 regulations affects NOx monitoring. If an ANGV converter elects to be compliant with NOx monitoring in 2006, for LEV II, ULEV II and SULEV II vehicles, the malfunction criteria is 3.5 times the applicable standard, and he may carry that over into the 2007 model year. If he does not elect to comply with NOx monitoring requirements in 2006, then in 2007 he must meet the more stringent malfunction criteria of 2.5 times the applicable standard.

Clarification of EPA OBD II requirements also occurred in 2005 and 2006. On September 1st 2005, EPA issued the guidance letter (Appendix IV) to clarify EPA approval of OBD II systems on aftermarket alternative fuel conversions. Further discussion of this will be found in Section 8 – Progress Made with Regulatory Agencies. EPA has been aware of the current study, and that data of value to them will be forthcoming. In fact, they called to check on the status of the project, and that it was still moving ahead. Recognizing the need for data, they issued an updated Certification Guidance for Alternative Fuel Converters on February 3rd 2006. (See Appendix V) This was very helpful, benefiting aftermarket converters, in that it defined clearly suggested methods for showing OBD compliance, and did not require converters, in 2006, to reset fault thresholds to meet malfunction criteria. It required converters to measure the emissions operating on CNG, at the point where the MIL was illuminated by the gasoline MIL threshold settings, and report the emissions in the application for OBD II approval. For 2006, the converter would not have to reset the MIL threshold if it was greater than the malfunction criteria, and deficiencies would be granted. EPA wants to see the OBD II performance data of CNG aftermarket conversions, and will look for improvements in future model years. Catalyst test requirements, however, remained a difficult issue to deal with, and are discussed later in this report.

CARB, however, has maintained its position that monitor thresholds would have to be reset in 2006, and subsequent years, if they did not comply with the malfunction criteria.

In 2005, work was conducted for the CNGVA and NRCAN, and a report was issued entitled "OBD II Certification Impacts on the aftermarket NGV Conversion Industry". This report clarified what OBD II is, and defined the compliance requirements, together with the consequent impact on the NGV industry. Possible solutions were explored with EPA and CARB, and it was clear that supporting OBD II performance data from ANGVs was required to proceed further with negotiations. The data gathered in this report is therefore very timely. EPA has recently indicated that this will be the first aftermarket OBD II data they will have seen, as it has not been forthcoming from any other alternative fuel converters. The data is therefore groundbreaking material.

4. VEHICLES AND SYSTEMS

There are three vehicles involved in the test program, two equipped with the ECO Fuel System conversions, and one equipped with the BAF conversion system. The test vehicles are:

- BAF Dedicated Ford CNG passenger car, certified to a much lower emissions standard than that for which the vehicle was originally certified on gasoline. The original gasoline vehicle was certified to EPA Tier 2 Bin 5, while the CNG conversion is to be certified to Tier 2 Bin 2 with EPA, and SULEV II with CARB.

- ECO Bi-fuel Ford CNG passenger car certified to the same level as the original gasoline vehicle, that is EPA Tier 2 Bin 5

- ECO Bi-fuel General Motors CNG Pick-up truck, certified to the same level as the original gasoline vehicle, that is EPA Tier 2 Bin 8.

A technical description of both systems is provided below, as the technologies are different, and reflect different capabilities to meet OBD II requirements.

4.1 **<u>Technical description of ECO Fuel System Conversion Approach</u>**.

Operation of the EDI-PRO

The EDI-PRO is based on the Motorola MPC555 Power PC, which has been designed specifically for automotive power train control. This MPC555 has two embedded sub-processing units (time processing units, or TPU's) that can operate independently of the main processor. The communication channel between the main processor and the TPU's is very fast and transparent, and so the main processor can monitor and control the TPU's with very little delay or overhead.

Injector Control

Because the EDI-PRO needs to control a variety of injectors for different fuels, the alternate fuel injector drive current can be customized to suit a given injector
The EDI-PRO assigns 3 TPU channels to each cylinder, and it can handle a maximum of eight cylinders. Each TPU has 16 channels for a total of 32 channels, but two of the channels of one TPU are used to run the LCD user interface, and one TPU channel is used to track RPM. The remaining 5 TPU channels are reserved for possible Crank/Cam waveform modification. To monitor and control each cylinder, the 3 TPU channels track the gasoline pulse, output the full voltage alternate fuel injector opening pulse, and then output the low voltage hold pulse to complete the fuel delivery.

Operation of the Main Processor

The main controller of the MPC555 is a high-speed 32 bit processor that controls a large array of peripheral hardware, including the two TPU processors. The main processor monitors general engine operation by reading MAP, TPS, O2, fuel temperature, fuel pressure, and other analog variables on its 10-bit analog-to-digital converter, and it reads RPM and gasoline pulse times from the TPU channels. It also controls an eight-channel digital-to-analog converter which can be used to output modified versions of O2 or MAP or fuel rail pressure to help bias the gasoline PCM operation to suit alternate fuel operation.

The main processor can broadcast diagnostic information through a dedicated serial port, and it can also have its variables and calibration tables modified through this serial port. A CANBUS port is available to interface to the vehicle bus, as well as a more limited PWM and VPW interface to interface to older style vehicle busses.

For the most part, the main processor software operates as a supervisor to the TPU's, and it controls fuel switch decisions. This software also compensates for fuel delivery in response to changes in the alternate fuel rail pressure and temperature.

This conversion system was applied to two vehicles, a Ford 500 bi-fuel CNG passenger car, and a General Motors 1500 bi-fuel CNG pickup truck.

As bi-fuel vehicles must be certified to the same level as gasoline, the Ford 500 is being certified with EPA to Tier 2 Bin 5, the same as the original gasoline vehicle

The GMC 1500 vehicle is being certified with EPA to Tier 2 Bin 8, the same level as the gasoline vehicle.

After review of the present status of the ECO technology, and detailed discussions with ECO on how to meet the CARB OBD II requirements, it was agreed that with the present level of their technology, they would be unable to reset monitor thresholds if needed to comply with the CARB malfunction criteria. Since EPA does not require resetting thresholds at the present time, ECO's focus therefore shifted to ensure compliance with EPA requirements in 2006, to allow Canadian vehicles to be converted, supported with an EPA certificate of compliance.

4.2 Technical Description of the BAF Conversion System Approach.

The 2006 Ford Crown Victoria is converted to run on Compressed Natural Gas only, as a dedicated CNG vehicle, and uses a sequential multi point CNG fuelling system. This CNG system includes:

1) CNG Fill Valve rated for 3600 psi
2) 2 or 4 CNG Storage Cylinder options rated for 3600 psi each equipped with solenoid tank valves with integral PRD's
3) 3600 psi rated CNG fuel lines to deliver the CNG to the pressure regulator
4) CNG Pressure regulator which regulates the pressure from the storage pressure (max of 3600 psi) to 150 psig – with integral PRV
5) 150 psig rated CNG fuel lines and CNG filter to deliver CNG from the pressure regulator to the fuel rail lockoff.
6) Fuel rail lockoff which is mounted under the hood on the Bank 1 CNG fuel rail.
7) Fuel rails for each bank of the engine and CNG injectors at each cylinder of the engine.
8) The OEM ECU is used together with an injector driver box, wire harness & engine sensors to control the CNG fuelling.

Since the vehicle runs on CNG only, all gasoline components (gasoline filler, tank, lines, canister, vapour valve, fuel rail & injectors) are removed. The original Ford gasoline ECU remains on the vehicle and continues to perform all tasks it would when running on gasoline except for controlling the natural gas fuelling.

It is interesting to note that BAF recognized the difficulties of calibrating an OBD II system if they could not access the OEM computer. The therefore aligned themselves with a company that can carry out performance enhancements of gasoline vehicles. Such a company, with the right personnel, can access the OEM computer to make calibration changes within the computer. It is becoming clear that the aftermarket conversion industry may be well served in future by aligning with those companies that carry out performance enhancements of gasoline vehicles.

It is apparent that these companies have been capable of dis-assembling the software in the OEM computer, and re-assembling it, so that they have complete access to the 60,000 lines of code, and 10,000 calibratable parameters which can be used to create both an emissions and OBD II calibration. Access to the OBD II monitors in this fashion, now allows manufacturers to reset thresholds to comply with CARB requirements. Some of these companies can also provide re-flashing capability, so that the OEM computer can be re-flashed in production vehicles with the revised calibration compliant for CNG operation. This appears to be a more cost effective approach than using the major companies such as Cosworth, as described in the previous OBD II report for the CNGVA/CANMET. Major companies such as these require on-going licensing fees, re-flashing charges, etc., so the aftermarket company has little control over its destiny.

The dedicated CNG Crown Victoria is to be certified with CARB to a SULEV II level, and with EPA to Tier 2 Bin 2. Since the original vehicle was certified to a less stringent level of Tier 2 Bin 5, this had a significant effect on the OBD II threshold performance using OEM gasoline threshold settings as will be seen from the results in Section 6.

5. TEST METHODS

For MY 2006, there are different test methods required by EPA and CARB to validate the OBD II monitors. CARB requires all validation to be carried out on full useful life catalysts aged to 120,000 miles. This is very time consuming and costly. A set of full useful life catalysts aged to 120K miles costs $30,000, and may take 6 – 8 weeks to prepare. Discussions were held with the EPA OBD II group and the view was put to EPA that components such as oxygen sensors could fail at any time during the useful life of the vehicle, and it would be more cost and time effective if the monitors could be tested on catalysts stabilized to 4000 miles. EPA agreed that this was acceptable, and all testing carried out by ECO Fuels was on 4000 mile stabilized catalysts. BAF, on the other hand had to carry out testing on 120 K catalysts since they wanted to certify with both CARB and EPA. A summary of the EPA test and certification requirements for OBD II approval in MY 2006 is provided below.

5.1 <u>EPA OBD II requirements for MY 2005 and newer vehicles (< 8500 GVW):</u>

Beginning with MY 2005 light-duty vehicles and light-duty trucks (MY 2007 for complete heavy-duty vehicles between 8,500 and 14,000 pounds GVW) all conversions must be OBD II compliant when operating on the alternative fuel. No false OBD codes and/or false MIL illumination should occur. For dual fuel vehicles, the OBD II system must not be affected by the conversion when operating the vehicle on gasoline. Testing for compliance should be conducted by inducing failures to the emission system. EPA may, at its discretion, elect to conduct confirmatory testing at its laboratory to ensure that the OBD II system is functional. A letter describing the OBD II system and requesting approval of the system should be submitted to EPA, in advance of the complete application for certification. In cases where the OBD II system may have deficiencies, the letter should identify the deficiencies and what steps are being taken to correct them for future certifications. A CARB letter of approval, if applicable, will not require a separate EPA OBD II approval. The approval letter issued by EPA or CARB should be incorporated into the Application before it is submitted to EPA.

Suggested methods for showing OBD compliance for aftermarket fuel converters include the following:

Misfire - Determine the rate of misfire that will illuminate the MIL using an electronic misfire generator. Run an FI'P at that threshold to determine the level of exhaust emissions.

Fuel trim - Determine when the MIL is illuminated for lean shift and rich shift fuel trim using an electronic fuel trim generator. Run FTPs at those thresholds to determine the level of exhaust emissions.

Catalyst - Using an aged catalyst, measure emissions when the deteriorated catalyst first illuminates the MIL. Achieving the proper level of catalyst deterioration will be a stepwise process of aging and emission testing.

Oxygen Sensor - Determine the level of oxygen sensor deterioration which first illuminates the MIL by a stepwise process of sensor aging and emission measurement. A slew box can be used to simulate a faulty O2 sensor, by slewing out the O2 signal response rate electronically, slowing down the response rate until the MIL is illuminated by the gasoline threshold setting.

Exhaust Gas Recirculation (EGR) - Determine the level of EGR deterioration which first illuminates the MIL by a stepwise process of restricting EGR flow and emission measurement.

EPA regulations require that a deteriorated catalyst illuminate the MIL when an increase of 1.5 times the non-methane hydrocarbon emission standard above the NMHC level is detected using a representative 4000 mile catalyst system. Malfunctions due to misfire conditions, fuel trim problems, or malfunctions of the oxygen sensor or EGR system must illuminate a MIL when increases in NMHC, CO, or NOx of 1.5 times the respective standard are detected. For two trip monitors (monitors which must detect malfunctions on two successive "trips"), setting a pending code is satisfactory proof that the MIL will be illuminated due to detection of a malfunction.

Data and proof of compliance with OBD requirements should be attached to the letter for OBD approval. Vehicle conversions to dual fuel operation should also provide proof that the OEM OBD system designed for operation on the fuel the vehicle was originally certified with has not been compromised.

Catalyst Monitor Testing

This is the most difficult monitor to test for OBD II compliance, both in terms of technical difficulty, cost and time. As a result, some time was spent with EPA to determine if a more cost effective approach was possible.

The EPA test requirement described above in three lines for the catalyst monitor sounds simple, but is actually very difficult to achieve. The first part of the requirement is to acquire an aged catalyst, aged to 120K mile equivalent. This is normally done on an engine dynamometer, over an accelerated catalyst ageing cycle involving high temperatures to thermally stress the catalyst. ALA suggested contacting Engelhard Prodrive in Wixom, Michigan who carries out this service. A lower cost, and faster, ageing approach uses a catalyst poisoning technique, and costs about $10,000 per catalyst set. However, it was determined that the poisoning technique was not approved by Ford for MY 06, so the thermal ageing technique would have to be used at a cost of $30,000 per catalyst set, and about 6 weeks of ageing. For the GM vehicle, poisoning was also not approved, and Engelhard indicated that they could not run the GM thermal ageing protocol, as it was proprietary to GM, and would require permission from GM for Engelhard to age the catalysts thermally. In order to try to break this deadlock, a recent EPA document was sent to ECO which details new catalyst thermal ageing procedures based on an equation which relates ageing time to catalyst temperature exposure. In the simplest terms, the higher the temperature, the shorter the ageing period. ECO contacted GM to discuss getting approval to use the GM ageing protocol, and reviewed the validity of using the EPA approved catalyst ageing protocol in its place. GM responded that the current catalyst technology is very sensitive to the ageing process, and did not recommend using the EPA Protocol, as it was likely to cause catalyst damage to the extent that the emissions would be meaningless. GM invested over 1000 hours to develop the current catalyst ageing protocol. They indicated they may be able to give Engelhard permission to supply aged catalysts to ECO, but there has been no such approval to date.

Even if aged catalysts are obtained, the process does not stop there. An iterative process then commences, called the cook and look process. The emissions are measured over the FTP cycle, and if less than the required threshold value of 1.75 times the applicable emissions standard, then the catalysts must be aged further on the engine dynamometer, and relocated on the vehicle for further FTP emissions testing. This process continues until the MIL is illuminated with the gasoline threshold setting, and the emissions measured at that point. It is possible, however, to overage a catalyst to the point that the emissions are at, say, 4.0 times the standard, when measured after the most recent ageing period, and it is not known at what point the MIL was illuminated. In this event the aging must be repeated, with another set of catalysts to a lesser extent in an attempt to hit the 1.75 value. When you achieve the right emissions threshold of 1.75 times the applicable standard, you now have what is called a set of threshold catalysts. The MIL should be illuminated at this point.

In view of these difficulties, an alternate catalyst monitor test plan was prepared, and submitted to CARB for review. The alternate test plan used an exhaust by pass to increase emissions downstream of the catalyst in an effort to find out what the emissions were when the MIL was illuminated. The alternate test plan is shown in Appendix III. This plan was, however, rejected by CARB as being non representative.

A discussion was held with EPA on the difficulties of developing threshold catalysts which will illuminate the MIL, and permit emissions to be determined at the gasoline MIL threshold. The first concept was that manufacturers could submit to EPA, emissions data collected from a non-coated catalyst substrate (no washcoat, or precious metal) as a worst case scenario for a failed catalyst. EPA wants worst case emissions data at this stage, and would approve this on the basis of a catalyst monitor deficiency, to be corrected in future years. This is not trivial, however, as it is difficult to purchase an uncoated catalyst, and have it canned in an exhaust system for testing.

It was also recognized that only the close coupled catalysts are monitored with the OEM catalyst monitor on the Ford vehicles. It was therefore agreed that a test should be run with an empty can on the close coupled catalyst location, while maintaining the under floor catalyst, to determine the emissions with this configuration. This, however, will not work with the GM vehicles, as there is no under-floor catalyst. It was decided that for the GM vehicles, we could drill a hole in the catalyst brick to increase emissions to the point where the MIL will illuminate, and test emissions at that point. This will likely get us through 2006, but for 2007, the industry will have to invest more time in developing proper threshold catalysts.

5.2 <u>CARB OBD II requirements for MY 2005 and newer vehicles</u>

A meeting was held with the OBD II Section Head of CARB, Mike McCarthy, in El Monte, Ca, to discuss issues of joint interest to BAF Technologies, and ECO Fuel Systems. This presented a good opportunity to have a general discussion on the specific OBD II data which CARB will expect to see, and the test methods which should be used to generate this data. These requirements are much more detailed and comprehensive than those currently required by EPA as described above.

The objective of the meeting was to clarify the steps required to complete the OBD-II compliance process for 2006 CNG passenger cars and medium duty vehicles. Specifically, there was a need to identify the detailed test work and data which CARB will need to see in order to approve OBD II systems for aftermarket vehicles in 2006. The major focus was on dedicated CNG vehicle conversions, but the same considerations also apply to bi-fuel vehicles.

The detailed requirements and outcome of the meeting are described in Appendix II. They are much more comprehensive than current EPA requirements, and include, in addition to the major monitors, comprehensive component monitor requirements, scan tool requirements for service bay diagnostics, and production vehicle evaluation. This also provides a better understanding of where EPA could end up as they move from their current position of leniency, and required manufacturers to demonstrate progress each year in improving their OBD II system performance. The data in this report may help EPA to maintain a middle of the road approach which will satisfy them, without the need to embrace all of the CARB requirements.

6 OBD II MONITOR TESTS

6.1 Test Plan

In order to understand the significance of the OBD II monitor test results, it is important to be aware of the mechanisms of how each of the monitors works. A detailed description of the monitors as used on Ford vehicles is presented in Appendix I for reference as required.

Testing of each of the monitor thresholds was carried out for both fuels, CNG and gasoline, using the basic methods described for EPA in Section 5, and for CARB in Appendix II. For the major monitor tests, the difference between the EPA and CARB requirements is that EPA wishes to see emissions data at the fault thresholds set by the gasoline calibration. CARB wishes to see the same type of data, but requires the thresholds to be reset for CNG operation, if they are not in compliance with the malfunction criteria set by the CARB regulations.

The initial plan was to carry out most of the testing at the B.C. Air Care Laboratory. ECO Fuels was concerned about the logistics of carrying out testing in Ottawa at the Environment Canada Laboratory because of the distances involved, and supporting staff over an extensive period of time. As a result, they decided to carry out development work at the B.C. Air Care Laboratory, and conduct confirmatory testing in Ottawa at the Environment Canada Lab. The BC Air Care facility is known to have a chassis dynamometer with full FTP 75 emissions test capability, in addition to its IM240 test lanes used for regular car inspections. However, it was agreed that qualification of the lab would be required to ensure that meaningful test data would be accumulated even during the development phase.

A visit to the BC Air Care Facility was made to meet with Dave Gourley, Manager Operations, and Stephen Stewart, Project Engineer. A tour of the facility revealed that the FTP facility was not equipped to provide certification grade data. The areas of concern are lack of precise temperature and humidity control, isolation of test chamber from background hydrocarbon sources, correlation of 20-inch cradle roll dynamometer with certification grade 48-inch single roller, lack of dilution air treatment for the CVS and insufficient resolution in lower detection ranges of the gas analyzers. For example, the most sensitive range for NOx emissions is 100 ppm full scale, whereas the emissions from typical EPA Tier 2 Bin 5 vehicles are closer to 5 ppm. Measurements would therefore be made at the limit of resolution of the analysers. It was decided, therefore, that further testing would be carried out at the Environment Canada laboratories.

Interesting information, however, was obtained from the Air Care facility on the OBD II performance of the vehicles being tested on the vehicle inspection lane. The statistics showed that out of 13,000 vehicles tested, 409 vehicles passed emissions with the MIL illuminated, and 149 vehicles failed emissions without the MIL being illuminated. This shows the degree of fuzziness in the OBD II system, and raises further questions on the stringency being applied to natural gas vehicles.
A meeting was held with Environment Canada (E.C.) and Eco Fuel Systems to go over the test program and familiarize E.C. with the OBD II test requirements. E.C. has no prior experience with OBD II systems, and was interested to learn more about the systems and test methods. It was clear that E.C. has the capability to perform the test program with assistance from ECO engineers, and measure emissions accurately at the emissions certification level targeted by ECO. It was pointed out to ECO, that they would have to plan to test both their Ford and GM products, and submit OBD II data to EPA for both vehicle test groups. ECO had thought previously that they could carry across Ford OBD II data to their GM products, but this is not the case.

The test plan was therefore developed with E.C. which included baseline emissions testing on both CNG and gasoline to compare the emissions data against the standards for which the vehicle is to be certified. Then, each monitor would be tested on both fuels at the gasoline threshold levels set by the OEM where the MIL would be illuminated. It is important to recognize that both of the vehicles being tested by ECO Fuels are certified to different emissions standards. The Ford 500 passenger car is certified on gasoline to EPA Tier 2 Bin 5; the GM 1500 pickup truck is certified on gasoline to EPA Tier 2 Bin 8, a less stringent emissions standard.

The test plan set up for E.C. for the 2 vehicles, 2 fuels and 5 monitors is shown below.

	February			
TASK week of Feb 13 - 17	14 Tues	15 Wed	16 Thurs	17 Fri
Prep Ford 500 for Bi-Fuel Testing	xxx			
Run Ford 500 Gasoline Baseline FTP		am lab		
Test GMC 1500 O2 Slew Limit on Gasoline		pm lab		
Run GMC 1500 O2 Slew Test Gasoline FTP			am lab	
Run Ford 500 CNG Baseline FTP			pm lab	
Run Ford 500 O2 Slew Test Gasoline FTP				am lab
Run GMC 1500 O2 Slew Test CNG FTP				pm lab

	February			
TASK week of Feb 20 - 24	21 Tues	22 Wed	23 Thurs	24 Fri
Run Ford 500 O2 Slew Test CNG FTP, Prep for Fuel Trim Rich CNG	am lab			
Test GMC 1500 Fuel Trim Limits CNG, prep for Fuel Trim Rich CNG	pm lab			
Run GMC 1500 Fuel Trim Rich CNG FTP, prep for Fuel Trim Lean CNG		am lab		
Run Ford 500 Fuel Trim Rich CNG FTP, prep for Fuel Trim Lean CNG		pm lab		
Run Ford 500 Fuel Trim Lean CNG FTP, prep for Fuel Trim Lean Gasoline			am lab	
Run GMC 1500 Fuel Trim Lean CNG FTP			pm lab	
Test GMC 1500 Fuel Trim Limits Gasoline, Prep for Fuel Trim Lean Gasoline				am lab
Run Ford 500 Fuel Trim Lean Gasoline FTP, prep for Fuel Trim Rich Gasoline				pm lab

	February	March		
TASK week of Feb 27 - March 3	28 Tues	1 Wed	2 Thurs	4 Fri
Run Ford 500 Fuel Trim Rich Gasoline FTP, stabilize	am lab			
Run GMC 1500 Fuel Trim Lean Gasoline FTP, Prep for Fuel Trim Rich Gasoline	pm lab			
Run GMC 1500 Fuel Trim Rich Gasoline FTP, Stabilize		am lab		
Test Ford 500 EGR Limit		pm lab		
Run Ford 500 EGR Test Gasoline FTP			am lab	
Run GMC 1500 EGR Test Gasoline FTP			pm lab	
Run Ford 500 EGR Test CNG FTP				am lab
Run GMC 1500 EGR Test CNG FTP				pm lab

	March			
TASK week of March 6 - 10	7 Tues	8 Wed	9 Thurs	10 Fri
Make up FTP if necessary	am lab			
Test Ford 500 Misfire Limit	pm lab			
Run Ford 500 Misfire Test Gasoline FTP		am lab		
Run GMC 1500 Misfire Test Gasoline FTP		pm lab		
Run GMC 1500 Misfire Test CNG FTP			am lab	
Run Ford 500 Misfire Test CNG FTP			pm lab	

	March			
TASK week of March 13 - 17	14 Tues	15 Wed	16 Thurs	17 Fri
Run Ford 500 Blank Cat CNG FTP	am lab			
Run additional HOT505's until MIL sets	pm lab			
Run GMC 1500 Blank Cat CNG FTP		am lab		
Run additional HOT505's until MIL sets		pm lab		

Since the BAF Crown Victoria is a dedicated CNG vehicle, it can be certified to a lower level than gasoline. It should be noted therefore that the BAF Crown Victoria passenger car was certified on gasoline to EPA Tier 2 Bin 5, but the CNG version will be certified to the most stringent level set by EPA which is EPA Tier 2 Bin 2. The plan for testing the BAF vehicle included testing on CNG at the gasoline fault thresholds where the MIL was illuminated. However, since CARB certification is required, the thresholds will be reset for CNG operation, if they are not in compliance with the malfunction criteria set by the CARB regulations.

6.2 OBD II Monitor Test Results

6.2.1 ECO Fuel Systems GMC 1500 Bi-fuel CNG Pickup Truck

The data was packaged into the format shown in Table 1, for the GMC truck. For each of the major emissions components, the emissions standards are shown for the Tier 2 Bin 8 certification level for this vehicle. The target threshold emission level is then shown, beyond which the MIL must be illuminated. This is 1.5 times the emission standard for NOx and CO, and 1.75 times the standard for hydrocarbons. The emissions measured over the FTP cycle on the vehicle for each test are then shown. The emissions were measured with an accumulated mileage of 4000 miles on the vehicle. In order to compare the data against the full useful life emissions standards which are set at 120,000 miles on the vehicle, and to allow for emissions deterioration over the full useful life of the vehicle, the estimated emissions at 4K miles were multiplied by the EPA assigned emissions deterioration factors (shown in column 8) to produce the full useful life emissions shown in column 9. The emissions are then divided by the emissions standards to arrive at an emissions malfunction threshold level relative to the standard, where the MIL was illuminated, (shown in column 10 for CNG and column 11 for gasoline) for comparison against the malfunction criteria of the OBD II standards.

The baseline emissions on gasoline and CNG are shown in the first two rows of Table 1. The NOx and CO emissions for CNG operation are considerably lower than the gasoline results

Fuel trim monitor tests are shown in Table 1, with the fuel trim set to the maximum lean and rich limits permitted by the adaptive fuel control system. The adaptive fuel control system works as follows. As fuel control system component parameters change from nominal with time, the adaptive fuel table contents will reflect the change. As the parameters continue to change, the long term fuel trim (long term average values) will move towards the adaptive limits, and the adaptive table will reach the adaptive tables clip. This means that the adaptive table cannot compensate for any additional changes in fuel control component parameters. Further change in the fuel control system components parameters will cause the short term fuel switch point to move toward its clips. As this trend continues the ability of the fuel control system to control fuel will cease. Beyond this point, emissions increase dramatically. The emissions profile has been described as a bathtub, with the base of the tub being within the control limit, and the sides of the tub representing large increases in emissions outside the adaptive limits of rich and lean operation. The malfunction threshold is set at the corners of the bathtub, to reflect when the emissions control system has reached its limit, and the emissions are about to increase. In this respect, this monitor is unique in that the malfunction threshold is set to indicate when the adaptive fuel control system is railed against its limit, rather than when the emissions are greater than 1.5 times the emissions standard. This was discussed during a review meeting with EPA in Ann Arbor, Michigan, and they agreed that this was the case. Minutes of that meeting have been approved by EPA, and are included in Appendix VII.

The fuel trim emissions results in Table 1 were obtained with the fuel set rich or lean to the point where the MIL was illuminated, as a result of the original gasoline threshold settings in the OEM computer. Codes 0171 and 0174 were set for the rich limits, and 0172 and 0175 for the lean limits. Tests were run on both CNG and gasoline to compare the results against each other, and against the OBD II malfunction criteria limits. The gasoline emissions are higher than baseline, and well within the criteria limits. The CNG emissions for the rich limit are also higher than baseline, and well within the criteria limits. However, when the MIL was set at the lean limit, the emissions were 3.5 times the emissions standard for CO emissions. This is a result of system constraints with the CNG system, resulting in control being compromised, especially at idle and deceleration. This could be accepted by EPA as a deficiency in 2006, but may need to be corrected in future years.

The oxygen sensor monitor test results are shown in Table 2. In this case a slew box was used to slew out the oxygen sensor response rate until a pending MIL was obtained. Pending means that a fault may be present, and the monitor will try again to determine if the same fault occurs. (This is due to the statistical nature of fault detection in an OBD II system). If the fault is not detected again, no hard code or MIL is set. If the fault continues to be detected over a certain number of trips, then a hard code will be set and the MIL illuminated. Initially, the emissions were measured with a MIL pending status. The results for gasoline were marginally acceptable, at 1.0 times the standard, but the CNG result would be considered unacceptable low by EPA at 0.6 times the emission standard for NOx. That is the MIL is set too early when the emissions are still in compliance. This is essentially a false MIL, in that the gasoline threshold setting causes the MIL to illuminate too early when the vehicle is operated on CNG. EPA is strict on there being no false MILs; CARB cares more about emissions exceeding the malfunction criteria when the MIL is illuminated. The OBD II calibrator does indeed walk on a knife edge.

A number of corrective actions were discussed with ECO:

- The false MIL may be a result of the CNG emissions being much cleaner than gasoline, so that the gasoline MIL setting occurs while the CNG emissions are still low. One solution to this would be to dirty up the CNG emissions to a level similar to gasoline, and this would then likely cause the MIL to set at emissions levels similar to gasoline, and hopefully greater than the emissions standards.

TABLE 1

OBD II Monitor Threshold Tests Baseline and Fuel Trim Monitors
ECO GM 1500 Tier 2 Bin 8

Monitor Test Descriptiion	Codes Set	Emission Component	Tier 2 Bin 8 Standards	Malfunction Critera relative to Standard	Target MIL Threshold	4K FTP 75 Emissions at Gasoline Thresholds	EPA Assigned DFs	U/L FTP 75 Emissions at Gasoline Thresholds	MIL Threshold with Gasoline Calibration	
									CNG	Gasoline
Baseline CNG	None	NOx	0.200	1.5 times	0.300	0.017	1.730	0.029	0.15	
No MIL		CO	4.200	1.5 times	6.300	0.614	1.620	0.995	0.24	
9th Feb.		NMHC	0.125	1.75 times	0.218	0.018	1.370	0.025	0.20	
Baseline Gasoline	None	NOx	0.200	1.5 times	0.300	0.068	1.730	0.118		0.59
No MIL		CO	4.200	1.5 times	6.300	1.036	1.620	1.678		0.40
12th Jan.		NMHC	0.125	1.75 times	0.218	0.061	1.370	0.084		0.67
Fuel Trim Max Rich Limit	0171	NOx	0.200	1.5 times	0.300	0.029	1.730	0.050	0.25	
MIL on CNG	0174	CO	4.200	1.5 times	6.300	0.400	1.620	0.648	0.15	
22-Feb		NMHC	0.125	1.75 times	0.218	0.014	1.370	0.019	0.15	
Fuel Trim Max Rich Limit	0171	NOx	0.200	1.5 times	0.300	0.071	1.730	0.123		0.61
MIL on Gasoline	0174	CO	4.200	1.5 times	6.300	0.699	1.620	1.132		0.27
28-Feb		NMHC	0.125	1.75 times	0.218	0.085	1.370	0.116		0.93
Fuel Trim Max Lean Limit	0172	NOx	0.200	1.5 times	0.300	0.008	1.730	0.014	0.07	
MIL on CNG	0175	CO	4.200	1.5 times	6.300	9.111	1.620	14.760	3.51	
23-Feb		NMHC	0.125	1.75 times	0.218	0.040	1.370	0.055	0.44	
Fuel Trim Max Lean Limit	0172	NOx	0.200	1.5 times	0.300	0.090	1.730	0.156		0.78
MIL on Gasoline	0175	CO	4.200	1.5 times	6.300	1.962	1.620	3.178		0.76
24-Feb		NMHC	0.125	1.75 times	0.218	0.094	1.370	0.129		1.03

TABLE 2

OBD II Monitor Threshold Tests O2, Misfire, and Catalyst Monitors
ECO GM 1500 Tier 2 Bin 8

Monitor Test Descriptiion	Codes Set	Emission Component	Tier 2 Bin 8 Standards	Malfunction Critera relative to Standard	Target MIL Threshold	4K FTP 75 Emissions at Gasoline Thresholds	EPA Assigned DFs	U/L FTP 75 Emissions at Gasoline Thresholds	MIL Threshold with Gasoline Calibration	
									CNG	Gasoline
O2 Sensor Response Rate	0133	NOx	0.200	1.5 times	0.300	0.128	1.730	0.221	1.11	
MIL set CNG	0153	CO	4.200	1.5 times	6.300	0.602	1.620	0.975	0.23	
1st March		NMHC	0.125	1.75 times	0.218	0.016	1.370	0.022	0.18	
O2 Sensor Response Rate	0133	NOx	0.200	1.5 times	0.300	0.116	1.730	0.201		1.00
MIL set Gasoline	0153	CO	4.200	1.5 times	6.300	1.281	1.620	2.075		0.49
2nd March		NMHC	0.125	1.75 times	0.218	0.072	1.370	0.099		0.79
Misfire CNG	0300	NOx	0.200	1.5 times	0.300	0.188	1.730	0.325	1.63	
		CO	4.200	1.5 times	6.300	0.284	1.620	0.460	0.11	
		NMHC	0.125	1.75 times	0.218	0.038	1.370	0.052	0.42	
Misfire Gasoline	0300	NOx	0.200	1.5 times	0.300	0.067	1.730	0.116		0.58
		CO	4.200	1.5 times	6.300	1.486	1.620	2.407		0.57
		NMHC	0.125	1.75 times	0.218	0.178	1.370	0.244		1.95
CAT Monitor CNG	no MIL	NOx	0.200	1.5 times	0.300	0.090	1.730	0.156	0.78	
		CO	4.200	1.5 times	6.300	0.914	1.620	1.481	0.35	
		NMHC	0.125	1.75 times	0.218	0.017	1.370	0.023	0.19	
CAT Monitor Gasoline	0420	NOx	0.200	1.5 times	0.300	0.188	1.730	0.325		1.63
		CO	4.200	1.5 times	6.300	1.426	1.620	2.310		0.55
		NMHC	0.125	1.75 times	0.218	0.108	1.370	0.148		1.18

This, however, appears counterproductive for producing a cleaner than gasoline CNG vehicle.

- The low emissions on CNG could support certifying to a lower emissions standard then Bin8. Bin 6 could be supported on CNG, and at this lower emissions standard, the MIL emissions threshold measured on CNG would then be greater than the standard, (1.3 times the standard), which would be ideal. However, bi-fuel vehicles have to be certified to the same levels on both gasoline and CNG, and the gasoline emissions would not support a Bin 6 level, so this would only be an option if the emissions were improved slightly on gasoline.
- The third option was to repeat the O2 monitor testing under conditions where the sensor was slewed out further to a hard code and MIL rather than at a pending MIL status.

Accordingly a repeat test was run but this time a hard code was set by the MIL, and the emissions measured on CNG. The result shown in Table 2 is much better at 1.11 times the emissions standard. This should be acceptable to EPA as the emissions are now greater than the standard, a fault is clearly evident, and the MIL should be set, even although it is less than the 1.5 times standard target. In fact, this presented EPA with a dilemma, which is discussed at the conclusion of this report, and in the appended White Paper.

Similar results were obtained with the misfire monitor with the MIL being set by the gasoline strategy at NOx levels of 1.6 times the standard for CNG, and 1.9 times the NMHC standard for gasoline.

For catalyst monitor testing the catalysts were physically damaged by drilling holes to simulate a failed catalyst. With four 3/16" holes in the catalyst, the MIL was set on gasoline at emissions levels of 1.6 times the NOx standard. On CNG, however, no MIL was set with the same four holes in the catalysts, and the emissions remained low at 0.75 times the NOx standard. More work needs to be done on this catalyst to increase emissions with further damage to the catalyst, but this technique is not a good indicator of what the emissions will actually be when the MIL is set by the gasoline thresholds. A better indication of this is provided with the BAF data below, obtained on Ford supplied OBD II threshold catalysts.

Tests with the EGR monitor showed that emissions remained very low even when the EGR flow rate was almost completely shut off. It is believed that in this case, EGR is used as a means of improving fuel economy, and is not emissions related. EPA also suggested that this may be the case.

6.2.2 ECO Fuel Systems Ford 500 Bi-fuel CNG Passenger Car

Table 3 shows the results of a similar set of tests for the baseline and fuel trim monitors conducted on the Ford 500 passenger car. It should be noted that this vehicle is certified to the lower level of Tier 2 Bin 5, compared with the Bin 8 level of the GMC truck. In this case, the baseline CNG emissions are somewhat higher than the gasoline emissions, measured over the FTP cycle.

The CNG emissions and the gasoline emissions at the rich limit are quite satisfactory. The lean limit emissions tests, however, on both fuels showed very high NOx levels on CNG, and on gasoline, ranging from 4 to 6 times the emissions standard. Again, this is probably a function of how the test was conducted, and will likely be approved by EPA for 2006 on the basis of a deficiency to be corrected is subsequent model years.

As a result of the CNG emissions being higher than gasoline, the oxygen response rate test results presented in Table 4 showed CNG NOx emissions to be 1.04 times the emissions standard, when the MIL was illuminated by the OEM gasoline calibration settings. This is an excellent result. The corresponding gasoline emissions with the MIL illuminated, showed NOx emissions of 1.16 times the emissions standard. It is interesting that when the emissions are similar between CNG and gasoline, and the standards are the same, the gasoline threshold settings for the Ford oxygen sensor monitor, appear adequate. The threshold response is quite similar, with CNG operation tending to set the MIL earlier (lower emissions) than on gasoline.

Results from testing the misfire monitor on CNG showed NOx emissions of about 2 times the standard. However, this was at about the minimum level of 1% misfire recognized by CARB as the floor for misfire detection. Therefore, this is the best you can do as an emissions level for detecting the minimum 1% misfire rate. Gasoline misfire testing was not conducted.

TABLE 3

OBD II Monitor Threshold Tests Baseline and Fuel Trim Monitors

ECO Ford 500 Tier 2 Bin 5

Monitor Test Description	Codes Set	Emission Component	Tier 2 Bin 5 Standards	Malfunction Critera relative to Standard	Target MIL Threshold	4K FTP 75 Emissions at Gasoline Thresholds	EPA Assigned DFs	U/L FTP 75 Emissions at Gasoline Thresholds	MIL Threshold with Gasoline Calibration CNG	MIL Threshold with Gasoline Calibration Gasoline
Baseline CNG	None	NOx	0.070	1.5 times	0.105	0.029	1.730	0.050	0.72	
No MIL		CO	4.200	1.5 times	6.300	0.425	1.620	0.689	0.16	
		NMHC	0.090	1.75 times	0.158	0.009	1.370	0.012	0.14	
Baseline Gasoline	None	NOx	0.070	1.5 times	0.105	0.016	1.730	0.028		0.40
No MIL		CO	4.200	1.5 times	6.300	0.232	1.620	0.376		0.09
		NMHC	0.090	1.75 times	0.158	0.027	1.370	0.037		0.41
Fuel Trim Max Rich Limit	0171	NOx	0.070	1.5 times	0.105	0.021	1.730	0.036	0.52	
MIL pending on CNG	0174	CO	4.200	1.5 times	6.300	0.303	1.620	0.491	0.12	
3rd March		NMHC	0.090	1.75 times	0.158	0.006	1.370	0.008	0.09	
Fuel Trim Max Rich Limit	0171	NOx	0.070	1.5 times	0.105	0.044	1.730	0.076		1.09
MIL set on Gasoline	0174	CO	4.200	1.5 times	6.300	0.373	1.620	0.604		0.14
28-Feb		NMHC	0.090	1.75 times	0.158	0.056	1.370	0.077		0.85
Fuel Trim Max Lean Limit	0172	NOx	0.070	1.5 times	0.105	0.255	1.730	0.441	6.30	
MIL illuminated on CNG	0175	CO	4.200	1.5 times	6.300	0.363	1.620	0.588	0.14	
2nd March		NMHC	0.090	1.75 times	0.158	0.020	1.370	0.027	0.30	
Fuel Trim Max Lean Limit	0172	NOx	0.070	1.5 times	0.105	0.172	1.730	0.298		4.25
MIL on Gasoline	0175	CO	4.200	1.5 times	6.300	0.738	1.620	1.196		0.28
1st March		NMHC	0.090	1.75 times	0.158	0.043	1.370	0.059		0.65

TABLE 4

OBD II Monitor Threshold Tests O2, and Misfire Monitors

ECO Ford 500 Tier 2 Bin 5

Monitor Test Descriptiion	Codes Set	Emission Component	Tier 2 Bin 5 Standards	Malfunction Critera relative to Standard	Target MIL Threshold	4K FTP 75 Emissions at Gasoline Thresholds	EPA Assigned DFs	U/L FTP 75 Emissions at Gasoline Thresholds	MIL Threshold with Gasoline Calibration	
									CNG	Gasoline
O2 Sensor Response Rate	0133	NOx	0.070	1.5 times	0.105	0.042	1.730	0.073	1.04	
MIL set CNG	0153	CO	4.200	1.5 times	6.300	0.913	1.620	1.479	0.35	
24th Feb.		NMHC	0.090	1.75 times	0.158	0.006	1.370	0.008	0.09	
O2 Sensor Response Rate	0133	NOx	0.070	1.5 times	0.105	0.047	1.730	0.081		1.16
MIL set Gasoline	0153	CO	4.200	1.5 times	6.300	0.813	1.620	1.317		0.31
		NMHC	0.090	1.75 times	0.158	0.040	1.370	0.055		0.61
Misfire CNG		NOx	0.070	1.5 times	0.105	0.084	1.730	0.145	2.08	
		CO	4.200	1.5 times	6.300	0.552	1.620	0.894	0.21	
		NMHC	0.090	1.75 times	0.158	0.005	1.370	0.007	0.08	
Misfire Gasoline		NOx	0.070	1.5 times	0.105	0.000	1.730	0.000		0.00
(Not completed)		CO	4.200	1.5 times	6.300	0.000	1.620	0.000		0.00
		NMHC	0.090	1.75 times	0.158	0.000	1.370	0.000		0.00

6.2.3 BAF Technologies Ford Crown Victoria Dedicated CNG Passenger Car

BAF have completed monitor testing for CARB and EPA with results on Fuel Trim, EGR, O2, Misfire, and Catalyst monitors. Table 5 shows these results as they were initially presented to EPA during a meeting held in Ann Arbor, Michigan.

It should be noted that this is a dedicated CNG Crown Victoria passenger car, certified on CNG to the most stringent level of Tier 2 Bin 2 emissions. The base gasoline vehicle used for conversion to CNG was certified at a much higher level of Tier 2 Bin 5 emissions level, and this is the level for which the OBD II calibration, and threshold levels, would have been set by the OEM. It should also be noted that BAF intends to certify this vehicle with CARB at the SULEV II certification level, which is the equivalent, but not identical, level to EPA's Tier 2 Bin 2. When certifying to the SULEV II standards, CARB has a relaxed set of OBD II malfunction criteria, requiring the MIL to be illuminated at 2.5 times the emissions standards for all emissions components. Since BAF only wants to have one calibration, EPA agreed to accept the 2.5 times malfunction criteria, even although they have 1.5 times criteria on their books for Tier 2 Bin 2. Table 5 reflects the 2.5 times malfunction criteria as a target for OBD II compliance.

Referring to Table 5, it is evident that the CNG emissions, when the MIL is illuminated by the gasoline settings, are now all higher than the standard, with the exception of the EGR result. Fuel trim MIL threshold emissions levels are 1.6 to 1.8 times the standard for lean and rich fuel trim limits respectively, presumably because the emission standard is now much lower than that for which the vehicle was originally calibrated. The oxygen sensor response rate, and misfire monitor emissions levels are about 4.5 times the emission standard when the MIL was illuminated at the gasoline setting. This is just lower than the CARB limit of 5 times the standard, beyond which CARB could not even accept a deficiency, because a level of greater than 5 times the standard triggers a mandatory recall, and CARB cannot legally permit a deficiency if it is in mandatory recall territory. This fact allowed BAF to obtain a conditional certification with CARB in advance of completing all OBD II testing. Although some threshold levels are high as a result of the low certification standards being sought, compared to gasoline, they can be reset by BAF to a lower threshold level, as described in Section 4.2.

EPA's response to these results was interesting in that they focused not on the high threshold emissions numbers, but on the low EGR monitor result of setting the MIL at 0.85 times the emissions standard. This was rejected by EPA on the grounds that a false MIL was being created at that level. Although they would accept the higher numbers, recognizing that improvements would be made in future years, they would not accept the lower emission threshold of 0.85 for approval in MY 2006.

With respect to the catalyst monitor, a test was initially carried out on a thermally damaged catalyst to find out what level of emissions performance would be achieved relative to the MIL. However, the results were inconclusive, in that the MIL was

TABLE 5
OBD II Monitor Threshold Tests
BAF 2006 CNG Crown Victoria

Monitor Test Description	Emission Component	Applicable Emission Standard SULEV II	Target MIL Threshold 2.5 times Standard	CNG FTP 75 Emission Results at gasoline monitor Thresholds	CNG MIL Threshold with gasoline calibration
Fuel Trim Max Lean Limit-25%	NOx	0.020	0.050	0.032	1.6
MIL illuminated	CO	1.000	2.500	0.140	
	NMHC	0.010	0.025	0.005	
Fuel Trim Max Rich Limit +25%	NOx	0.020	0.050	0.022	
MIL not illuminated, Ford sets	CO	1.000	2.500	1.786	1.786
MIL to illuminate at +26%	NMHC	0.010	0.025	0.043	
EGR flow rate restricted 60%	NOx	0.020	0.050	0.017	0.85
until MIL is illuminated	CO	1.000	2.500	0.127	
	NMHC	0.010	0.025	0.001	
Oxygen sensor response rate:	NOx	0.020	0.050	0.091	4.55
MIL set at 10% normal frequency	CO	1.000	2.500	0.130	
of 1.52 Hz	NMHC	0.010	0.025	0.003	
Misfire Monitor	NOx	0.020	0.050	0.085	4.25
MIL set at 1.2% misfire	CO	1.000	2.500	0.270	
	NMHC	0.010	0.025	0.041	4.1
Catalyst Monitor	NOx	0.020	0.050	0.017	0.85
Tests on Ford Threshold Cats	CO	1.000	2.500	2.234	2.234
MIL illuminated	NMHC	0.010	0.025	0.009	0.9

illuminated during the test, but it was not known when the MIL would have been illuminated. Therefore, the high emissions which resulted, about Tier 2 Bin 9, did not indicate that this is the emissions which would have been achieved at the gasoline MIL threshold.

CARB, however, wanted to get a realistic view of the emissions performance of the catalyst monitor at the gasoline threshold level. They therefore requested Ford to cooperate in providing BAF with a set of Ford threshold catalysts which had been used to test the gasoline catalyst monitor, and set the gasoline thresholds on the OEM gasoline Ford Crown Victoria. This provided an excellent opportunity for a direct comparison of the CNG emissions performance of the catalyst monitor at the OEM gasoline fault thresholds.

Table 5 shows the results. The regulations call for the MIL to be illuminated at 2.5 times the applicable NMHC standard. Recognizing that this is a Bin 5 gasoline calibration, and the CNG variant is being certified to Bin 2, the threshold response on CNG is arguably good. While the NMHC threshold sets the MIL at 90 % of the NMHC useful life standard, (somewhat early), the CO emissions when the light was set are 2.2 times the SULEV II standard. It can be argued, therefore, that the fault needed to be detected on a CO emissions basis, and it would be appropriate to turn on the MIL at that point. This raises the question as to whether NMHC emissions are appropriate for monitoring catalyst faults with a CNG vehicle where NMHC emissions are inherently low even with a damaged catalyst. It is clear, however, that running a catalyst monitor on a CNG vehicle with gasoline threshold settings does not create high emissions or a gross polluter. If anything, the MIL will be set earlier than required.

It is also of interest to note that the front and rear oxygen sensor switching ratios were almost the same, indicating that this threshold catalyst was an almost dead catalyst. Yet the NOx and NMHC emissions were still below the standards. This shows how clean CNG vehicles actually are, in that, even with an almost dead catalyst, NOx and NMHC emissions remained good, and less than the SULEV II emissions standards.

7 DISCUSSION OF RESULTS

The data from both of the ECO Fuel’s vehicles, with the exception of a few outliers largely related to methods of testing, is providing a general trend that the gasoline MIL settings for the major monitors are detecting faults at emissions levels which are less than the malfunction criteria set by the regulations. So, this is not a case where the emissions on CNG could be very high before the MIL is illuminated by the gasoline threshold setting. This is an important finding for ECO Fuels, since they may not be required to reset monitor thresholds within the OEM computer to deal with high emissions; a requirement they are unable to achieve with current technology. It is important to recognize, however, that this is related to the certification levels being the same on CNG and gasoline for these bi-fuel vehicles. When a CNG vehicle is calibrated to lower emissions than gasoline, the data appears to show that the MIL will be illuminated too early by gasoline thresholds, and this is of concern to EPA as discussed below.

The BAF vehicle was calibrated to lower emissions levels than gasoline, but was also certified to a lower emissions standard. This resulted in some of the emissions being much greater than the required malfunction criteria before the MIL was illuminated by the gasoline thresholds. These thresholds will have to be reset by BAF to comply with OBD II regulations, but BAF is capable of achieving this with their current technology.

Although this Tier 2 Bin 5 Crown Victoria was calibrated to pass Bin 2 levels on CNG, it is of interest to calculate what the emissions thresholds would be if the vehicle was certified to the same level as gasoline, (as in a bi-fuel vehicle certification) that is Bin 5 on CNG, using the Bin 5 gasoline OBD II thresholds set by the OEM. How would the CNG emissions now stack up against the Bin 5 certification levels, and what will the emissions be when the MIL is illuminated relative to Bin 5 emissions standards.

Table 6 shows this analysis. The Table now shows the Bin 5 standards, with the CNG emissions performance compared against these standards. With the exception of the EGR results, which are now even lower, of course, because of the higher standards, the results are remarkably similar to the ECO Fuel Systems results. Instead of the MIL being illuminated at 4.5 times the Bin 2 standard for the oxygen sensor monitor, the MIL is now seen to be illuminated at 1.3 times the Bin 5 standard. This is an ideal result for this monitor, and provides further evidence that, for the oxygen sensor, the OEM gasoline MIL settings are adequate, without being reset, provided the same certification level is employed. If the certification level is reduced, then the monitors will have to be reset to comply with the OBD II requirements.

The same is true of the misfire monitor, the MIL now being illuminated at 1.2 times the Bin 5 standard, compared with 4.1 times the Bin 2 standard.

The fuel trim monitor results at Bin 5 standards are now also similar to the ECO Fuel Systems data, being 0.3 to 0.4 times the Bin 5 standard for rich and lean limits respectively, compared with 1.6 to 1.8 times the standards when the vehicle is certified to Bin 2 levels.

There is therefore a trend emerging, that, the gasoline OBD II calibration set by the OEM may also be adequate for CNG, with out having to reset threshold levels, providing the certification levels are the same as gasoline, as required for bi-fuel vehicles. When the certification level is made more stringent on CNG than on gasoline, then some monitors will likely have to be reset.

Table 7 shows the results when BAF reset the thresholds to be compliant with the SULEV II certification level. All thresholds are now satisfactory from a CARB perspective. Table 8 shows the same data compared against the EPA Tier 2 Bin 2 standards. The results are again satisfactory, although the oxygen sensor is now marginally low against the higher CO standards for Bin 2 regulations. This is causing EPA some concern, and will need to be resolved. However, since only one calibration is desired for both CARB and EPA, this was considered a good compromise at the present time.

A further analysis can be carried out assuming that ECO Fuels wanted to take the results from the bi-fuel calibration, and certify it as a dedicated CNG vehicle to a lower certification level. Using the Bin 8 GM vehicle as an example, the analysis assumed the vehicle would now be certified to a Bin 5 level, as a dedicated CNG vehicle. The emissions from the GM vehicle were low enough to support a Bin 5 level on CNG. (but not on gasoline). Table 9 shows this analysis. It is now clear that the emissions for the oxygen sensor monitor now exceed the regulatory requirements, being 3 times the standards when the MIL is illuminated by the gasoline threshold settings. This demonstrates that to achieve more stringent certification levels on CNG compared with gasoline, monitor thresholds will have to be reset.

TABLE 6
OBD II Monitor Threshold Tests
BAF Dedicated CNG Crown Vic. if certified to Tier 2 Bin 5 Levels

Malfunction Criteria	**Emission Component**	**Tier 2 Bin 5 Standards**	**Target MIL Threshold**	**U/L FTP 75 Emissions at Gasoline Thresholds**	**MIL Threshold with Gasoline Calibration CNG**
Fuel Trim Max Rich Limit	NOx	0.070	0.105 (1.5X)	0.022	0.31
MIL illuminated CNG	CO	4.200	6.30 (1.5X)	1.786	0.43
	NMHC	0.090	0.158 (1.75X)	0.043	0.48
Fuel Trim Max Lean Limit	NOx	0.070	0.105 (1.5X)	0.032	0.46
MIL illuminated CNG	CO	4.200	6.30 (1.5X)	0.140	0.03
	NMHC	0.090	0.158 (1.75X)	0.005	0.06
Oxygen sensor response rate:	NOx	0.070	0.105 (1.5X)	0.091	1.30
MIL set CNG, 0133, 0153	CO	4.200	6.30 (1.5X)	0.130	0.03
	NMHC	0.090	0.158 (1.75X)	0.003	0.03
EGR Flowrate restricted 60%	NOx	0.070	0.105 (1.5X)	0.017	0.24
MIL illuminated CNG	CO	4.200	6.30 (1.5X)	0.127	0.03
	NMHC	0.090	0.158 (1.75X)	0.001	0.01
Misfire Monitor	NOx	0.070	0.105 (1.5X)	0.085	1.21
MIL set at 1.2% misfire	CO	4.200	6.30 (1.5X)	0.270	0.06
	NMHC	0.090	0.158 (1.75X)	0.041	0.46
Catalyst Monitor	NOx	0.070	0.050	0.017	0.24
Tests on Ford Threshold Cats	CO	4.200	2.500	2.234	0.53
MIL illuminated	NMHC	0.090	0.025	0.009	0.10

TABLE 7

OBD II Monitor Threshold Tests with Thresholds reset for CNG Operation
BAF 2006 CNG Crown Victoria certified to CARB SULEV II Standards

Monitor Test Description	Codes Set	Emission Component	Applicable Emission Standard SULEV II	Target MIL Threshold 2.5 times Standard	CNG FTP 75 Emmissions 120K	MIL Threshold with BAF CNG calibration
Fuel Trim Max Lean Limit -40%	0171, 0174	NOx	0.020	0.050	0.018	0.9
MIL illuminated at -32%		CO	1.000	2.500	0.560	0.56
		NMHC	0.010	0.025	0.002	0.2
Fuel Trim Max Rich Limit +40%	0172, 0175	NOx	0.020	0.050	0.021	1.05
MIL illuminated at +32%		CO	1.000	2.500	0.569	0.569
		NMHC	0.010	0.025	0.003	0.3
EGR flow rate restricted 100%	0401,	NOx	0.020	0.050	0.031	1.55
MIL set to illuminate at this point		CO	1.000	2.500	0.869	0.869
		NMHC	0.010	0.025	0.007	0.7
Oxygen sensor response rate:	0133, 0153	NOx	0.020	0.050	0.019	0.95
MIL illuminated		CO	1.000	2.500	1.328	1.328
		NMHC	0.010	0.025	0.002	0.2
Misfire Monitor	0300,	NOx	0.020	0.050	0.053	2.65
MIL set at 1.0% misfire		CO	1.000	2.500	2.700	2.7
		NMHC	0.010	0.025	0.007	0.7
Catalyst Monitor	0420, 0430	NOx	0.020	0.050	0.017	0.85
MIL illuminated		CO	1.000	2.500	2.234	2.234
		NMHC	0.010	0.025	0.009	0.9

TABLE 8

OBD II Monitor Threshold Tests with Thresholds Reset for CNG Operation
BAF 2006 CNG Crown Victoria Certified to EPA Tier 2 Bin 2 Standards

Monitor Test Description	Codes Set	Emission Component	Applicable Emission Standard Tier 2 Bin 2	Target MIL Threshold 2.5 times Standard	CNG FTP 75 Emissions 120K	MIL Threshold with BAF CNG calibration
Fuel Trim Max Lean Limit -40% MIL illuminated at -32%	0171, 0174	NOx CO NMHC	0.020 2.100 0.010	0.050 5.250 0.025	0.018 0.560 0.002	0.90 0.27 0.20
Fuel Trim Max Rich Limit +40% MIL illuminated at +32%	0172, 0175	NOx CO NMHC	0.020 2.100 0.010	0.050 5.250 0.025	0.021 0.569 0.003	1.05 0.27 0.30
EGR flow rate restricted 100% MIL set to illuminate at this point	0401,	NOx CO NMHC	0.020 2.100 0.010	0.050 5.250 0.025	0.031 0.869 0.007	1.55 0.41 0.70
Oxygen sensor response rate: MIL illuminated	0133, 0153	NOx CO NMHC	0.020 2.100 0.010	0.050 5.250 0.025	0.019 1.328 0.002	0.95 0.63 0.20
Misfire Monitor MIL set at 1.0% misfire	0300,	NOx CO NMHC	0.020 2.100 0.010	0.050 5.250 0.025	0.053 2.700 0.007	2.65 1.29 0.70
Catalyst Monitor MIL illuminated	0420, 0430	NOx CO NMHC	0.020 2.100 0.010	0.050 5.250 0.025	0.017 2.234 0.009	0.85 1.06 0.90

TABLE 9

OBD II Monitor Threshold Tests Baseline and Fuel Trim Monitors

ECO GM 1500 Tier 2 Bin 5 Certification Level

Monitor Test Description	Codes Set	Emission Component	Tier 2 Bin 5 Standards	Malfunction Criteria relative to Standard	Target MIL Threshold	4K FTP 75 Emissions at Gasoline Thresholds	EPA Assigned DFs	U/L FTP 75 Emissions at Gasoline Thresholds	MIL Threshold with Gasoline Calibration	
									CNG	Gasoline
O2 Sensor Response Rate	0133	NOx	0.070	1.5 times	0.300	0.128	1.730	0.221	3.16	
MIL set CNG	0153	CO	4.200	1.5 times	6.300	0.602	1.620	0.975	0.23	
1st March		NMHC	0.090	1.75 times	0.218	0.016	1.370	0.022	0.24	
O2 Sensor Response Rate	0133	NOx	0.070	1.5 times	0.300	0.116	1.730	0.201		2.87
MIL set Gasoline	0153	CO	4.200	1.5 times	6.300	1.281	1.620	2.075		0.49
2nd March		NMHC	0.090	1.75 times	0.218	0.072	1.370	0.099		1.10
Fuel Trim Max Rich Limit	0171	NOx	0.070	1.5 times	0.300	0.029	1.730	0.050	0.72	
MIL on CNG	0174	CO	4.200	1.5 times	6.300	0.400	1.620	0.648	0.15	
22-Feb		NMHC	0.090	1.75 times	0.218	0.014	1.370	0.019	0.21	
Fuel Trim Max Rich Limit	0171	NOx	0.070	1.5 times	0.300	0.071	1.730	0.123		1.75
MIL on Gasoline	0174	CO	4.200	1.5 times	6.300	0.699	1.620	1.132		0.27
28-Feb		NMHC	0.090	1.75 times	0.218	0.085	1.370	0.116		1.29
Fuel Trim Max Lean Limit	0172	NOx	0.070	1.5 times	0.300	0.008	1.730	0.014	0.20	
MIL on CNG	0175	CO	4.200	1.5 times	6.300	9.111	1.620	14.760	3.51	
23-Feb		NMHC	0.090	1.75 times	0.218	0.040	1.370	0.055	0.61	
Fuel Trim Max Lean Limit	0172	NOx	0.070	1.5 times	0.300	0.090	1.730	0.156		2.22
MIL on Gasoline	0175	CO	4.200	1.5 times	6.300	1.962	1.620	3.178		0.76
24-Feb		NMHC	0.090	1.75 times	0.218	0.094	1.370	0.129		1.43

8. PROGRESS MADE WITH REGULATORY AGENCIES

8.1 EPA

EPA has been cooperative in showing a degree of leniency with aftermarket alternative fuel converters at the present time. Discussions have resulted in progress in a number of fronts, and clarification of requirements has also been very helpful.

In the previous report for the Canadian NGV Alliance, dated 10th May 2005, entitled "OBD II Certification Impacts on the Aftermarket NGV Conversion Industry" it was reported that there was language in the EPA regulations which indicated that the OBD II requirements should be met "to the extent feasible" by manufacturers as approved by the Administrator. It was thought that this would alleviate the ANGV converter from having to reset monitor thresholds, as it was not feasible at that time for him to access the OEM computer in order to change the thresholds, and that waivers could be granted on the basis that compliance had been achieved to the extent feasible.

EPA agreed to clarify this language and the use of waivers, which they did in the EPA Guidance document issued in September 1, 2005 (Appendix IV). They reported as follows.

It is important that aftermarket alternative fuels converters correctly interpret the last sentence in 986.1806-05(i), which states:

> "At a minimum, alternate fuel vehicles shall be equipped with an OBD system meeting OBD requirements to the extent feasible as approved by the Administrator."

The wording "to the extent feasible", are referenced in the preamble language from 65 Federal Register 59918, dated October 6**,** 2000. In the preamble EPA the words "to the extent feasible" apply only to the criteria for issuing waivers (emphasis added). The preamble states that waivers from full OBD II compliance are to be based upon "technological infeasibility, not resource reasons." Waivers from OBD II compliance for manufacturers of alternative fueled vehicles officially expired with the end of the **2004** model year for light-duty vehicles and trucks.

It was therefore clear that this avenue was not one which aftermarket NGV converters could profitably explore.

EPA, however, went on to offer a significant benefit to converters with the issue of guidelines (Appendix V) requiring converters to report emissions performance of the major monitors at the gasoline MIL threshold levels, without the need to comply with malfunction criteria, should there be a need to reset threshold levels on CNG to achieve full compliance. If the emissions exceed the malfunction criteria, then a deficiency will be issued in 2006, but progress will be expected in future years to attempt to meet the requirements. EPA has no fines for deficiencies, so there is no financial penalty imposed on the converters with this process.

Further progress was evident in that EPA agreed that monitor testing could be conducted on 4000 mile stabilized catalysts, rather than follow the CARB requirement that all testing must be conducted on 120,000 mile full useful life aged catalysts. The latter are very costly to obtain; typically $30,000 per set. So, there is real economic benefit to converters in obtaining data on 4000 mile catalysts.

A meeting was held with EPA in Ann Arbor to review the BAF threshold data, and decide if we were on the right track. There was also an opportunity to discuss some of the ECO Fuel Systems issues. Minutes of this meeting are included as Appendix VII as reference, as they have been approved by EPA.

EPA has indicated they intend to be lenient in 2006, but expect to see improvements in 2007 and beyond. They are therefore interested in the emerging OBD II data, which will help them to decide what to do in future years. They are less interested at present in data which exceeds the malfunction criteria, as they can grant deficiencies without penalty. They are very concerned, however, about low emissions threshold results which can be considered false MILs. This is a major concern for EPA, as customers, observing such a MIL illumination, would take their vehicle in for repair, and be informed that there is nothing wrong with the vehicle, as it still meets the emissions standards. EPA will not approve MIL settings at this level, as the vehicles, in use, would likely be subject to defect reporting and recall, as a result of customer complaints of false MIL settings.

In general, EPA wants to see OBD II emissions thresholds at 1.5 times the applicable standard, or greater. This contrasts with CARB who require thresholds to be less than 1.5 times the standard, to allow for vehicle to vehicle variability, and ensure that emissions at the fault threshold never exceed 1.5 times the emissions standards. This needs to be resolved, as CARB will not accept greater than 1.5 times the standard, and EPA does not want to accept less than 1.5 times the standard. The knife edge is getting sharper.

Although the malfunction criteria are set at 1.5 times the emissions standards, the issue of the fuel trim monitor was raised, and it was argued that this monitor is unique in that the 1.5 times malfunction criteria will never be reached at the limits of the fuel system adaptive control. It was agreed that the fuel trim monitor thresholds are set at the limits of rich and lean adaptive control, because once the long term and short term fuel trims are railed at the adaptive limits, a fault has occurred, and must be detected with the MIL at that point. Any excursion beyond these limits will cause loss of fuel control and excessive emissions. Because adaptive control is still functional at the limits, the emissions will not appear to be excessive at that point, although a fault has definitely occurred, and has to be flagged, because loss of fuel control is imminent with consequences of high emissions levels. A customer, having a vehicle repaired under these circumstances, as a result of the fuel trim MIL being illuminated, will not be observing a false MIL in this circumstance, even although the emissions are below the standards, because the fault is real, and has to be repaired to prevent future emissions degradation.

A discussion ensued on the difficulties of developing threshold catalysts which will illuminate the MIL, and permit emissions to be determined at the gasoline MIL threshold. Three alternative methods of measuring catalyst monitor performance emerged from these discussions which EPA will temporarily accept for MY 06.

1. Manufacturers could submit emissions data collected from a non-coated catalyst substrate (no washcoat, or precious metal) as a worst case scenario for a failed catalyst. They want worst case emissions data at this stage, and would approve this on the basis of a catalyst monitor deficiency, to be corrected in future years.
2. It was recognized that only the close coupled catalysts are monitored with the OEM catalyst monitor on the Ford vehicles. It was therefore agreed that a test should be run with an empty can on the close coupled catalyst location, while maintaining the under floor catalyst, to determine the emissions with this configuration.
3. This, however, will not work with the GM vehicles, as there is no under-floor catalyst. It was decided that for the GM vehicles, we could drill a hole in the catalyst brick to increase emissions to the point where the MIL will illuminate, and test emissions at that point.

This will likely get us through 2006, but for 2007, the industry will have to invest more time in developing proper threshold catalysts.

Another point of discussion related to the use of generic scan tools used by service personnel to detect fault codes, and trouble shoot the vehicle. ECO Fuel systems has indicated that they can output CNG specific codes from their computer, but they have no control over the scan tool manufacturers, who are not motivated to develop a reading capability for CNG specific faults, for what is perceived by them to be a small market. EPA responded that, while they insist that manufacturers must offer compatibility with generic scan tools, they do not need manufacturer specific codes to be read by the generic scan tool. This is good news for ECO Fuel Systems.

8.2 CARB

CARB does not appear to be in any position to offer any degree of leniency in meeting the OBD II requirements, and levies penalties for each deficiency granted. In order to obtain a deficiency, however, you must provide an emissions result which does not meet the malfunction criteria, and demonstrate good reason why it cannot be met at the present time. If the emissions for any monitor exceed the malfunction criteria, they must be reset inside the OEM computer in order to be in compliance.

CARB has, however, been cooperative in providing advice to aftermarket converters, facilitating access to Ford threshold catalysts, and recognizing a market timing issue, described below, which has been a significant impediment to the aftermarket NGV converter. This issue was resolved, and a precedent was created to allow converters to obtain conditional certification prior to completion of all OBD II testing. This precedent has spilled over into Canada, in that the Canadian government is also willing to consider grants for vehicle conversions to be conditionally approved subject to completion of all OBD II testing and final EPA certification. The issue and solution is described below.

Market timing is a major problem for Small Volume Manufacturers (SVM) to bring a product to market. SVMs are charged with the not insignificant task of re-designing OEM gasoline vehicles to operate cleaner on natural gas. OEM engineers have at least a year to conduct the proper calibrations for a new model year. SVMs don't get to see the vehicle they intend to convert to natural gas until the current model year is delivered to dealers. SVMs then need to convert the vehicle to natural gas, get control of the system, calibrate for low emissions, and perform the OBDII compliance testing and calibration. First time around, the OBDII compliance testing involves many months of effort. Unfortunately, by this time, the OEMs will be at, or near the close of their production window on these target alternative fuel vehicles. Additionally, fleets purchase their vehicles in the first months of the year. Consequently, the process to finalize OBDII compliant certifications places the vehicle order outside the purchase window for fleets. With input from ALA, a letter was prepared by the California NGV Coalition, requesting a more flexible OBD II approval process to shorten the time for certification and allow fleet sales to proceed within the allotted time window. A copy of this letter is included in Appendix VI.

This request was rejected because CARB was not comfortable with the aftermarket industry's basic capability to succeed in being OBD II compliant in 2006, or even 2007.

A meeting was therefore held with senior CARB representatives to discuss this issue in more detail, provide CARB with a better understanding of current aftermarket capabilities, and determine what CARB would need to see in order to develop a higher comfort level for facilitating the OBD II certification process for aftermarket converters. A number of interesting points arose from the meeting.

Present at the meeting were Bob Cross, Chief, Mobile Source Control Division, Steve Albu, Chief Advanced Systems, Mike McCarthy Head OBD II Section, Mike Eaves, California Natural Gas Vehicle Coalition, and representatives from BAF Technologies. Andre Padovani, Eco Fuel Systems was unable to be present, and was represented by Alex Lawson. The main issue for discussion is described below.

The proposal was that CARB should permit conditional approval of an OBD II system, based on a technical review, to allow manufacturers to meet the fleet order window, and then the manufacturer would continue to calibrate the OBD II system over the coming months, to collect all data necessary to satisfy CARB that the system is compliant, after which the condition would be removed from the Executive Order.

Having heard a presentation on current aftermarket capabilities, CARB agreed in principal that a conditional approval was possible on a case by case basis, depending on their assessment of the manufacturer's capability to make their system OBD II compliant. However, Steve Albu indicated that one approach that could facilitate certification would be to provide some initial preview testing for each of the monitors using the OEM's current thresholds to determine the scope of effort needed in terms of calibration effort before launching into actual development for the manufacturer's package. This would enhance CARB's ability to provide some form of advanced certification approval. This preview testing could probably be accomplished in a two to three week period. Again, it is clear that having data on OBD II threshold performance will greatly improve CARB's comfort level. At present there is no track record by the industry. The data in this report will continue to build a confidence level with CARB.

8.3 White Paper

A White Paper has been prepared for discussion with EPA and CARB. The purpose of the White Paper is:

- To provide EPA and CARB with information on the typical OBD II threshold performance of aftermarket NGVs, when the gasoline monitor thresholds are not altered.
- To explore opportunities, based on this knowledge, to further facilitate the OBD II approval process in future model years, and reduce compliance costs.

The White Paper summarizes the test vehicles, test methods employed, and test results, including all of the emissions data contained in this report, and threshold levels achieved. A discussion of the implications of the results is presented, together with a set of conclusions. The White Paper concludes with a number of points for discussion, which have arisen from this work, which need resolution, and could facilitate future OBD II approval with a reduced cost of compliance.

The White Paper is included as Appendix VIII.

8.4 Where Do We Go From Here With Future Model Year Certifications

Each model year, the OEMs certify vehicles by including them in a number of durability test groups according to various parameters of engine displacement, vehicle technology, and emission control systems, which will exhibit similar durability characteristics. A worst case vehicle is selected as a durability vehicle, and emissions deterioration factors (DFs) are determined. These DFs will be applied across the durability test group. An emissions data vehicle is also selected from which worst case emissions are determined for certification. For example, emissions data from a Chrysler 3.8 L minivan, can be used to obtain an EPA certificate which will also cover the 3.3 L minivan. The OEM must also obtain OBD II certification each year, by carrying out a set OBD II compliance tests, and OBD II groupings will exist depending on the OBD II technology and calibration employed.

As of 2005, the aftermarket converter must carry out emissions tests as he has always done to comply with emissions certification, but he must now also carry out additional OBD II tests to comply with OBD II requirements for each vehicle to be certified. So, each vehicle has to have its emissions data and OBD II data in order to be certified. Just as with emissions certification, there will be "Carry Across" opportunities to carry across OBD II data from one vehicle to another in any model year if they are within the same OBD II grouping. There will also be "Carry Over" opportunities to carry over OBD II data from one model year to the next, for the same vehicle, provided that the system or vehicle does not change in the ensuing model year. The carry across and carry over opportunities must be assessed on a case by case basis with input from EPA on what vehicles are included in the same test groups.

For MY 2007, direct carry over of OBD II compliance is unlikely, because additional OBD II requirements are implemented at the end of the phase in period for the additional regulations, for which small volume manufacturer must then comply. These are described in Section 3, and in the Recommendations below. It is likely, therefore, that in 2007, carry over of existing OBD II data from the GM 1500 will be possible from 2006, but further OBD II testing will be required on the GM 1500, and additional data will be necessary to satisfy the new requirements for that vehicle in 2007. If a different GM model from the 1500, for example, is selected for conversion in 2007, it will have to be determined through consultation with EPA whether the existing OBD II test data from the GM 1500 test vehicle, can be carried across for use with the new model, or whether a set of new OBD II test data will have to be gathered for that vehicle.

Therefore, each vehicle to be converted and certified in any model year, must have it own emissions certification data, and its own OBD II test data, obtained either through carry across, carry over, or through new testing. The first round of obtaining OBD II compliance will obviously be the most costly in terms of time and money, as the learning curve is ascended. Having gained experience in how to perform OBD II testing, future testing on other vehicles should be less costly, to achieve OBD II compliance, based on experience, know how, and having the equipment to do the job. Progress made with facilitation of the EPA OBD II approval process, as achieved in this study, also reduces certification costs.

8.5 Final Review Meeting with EPA on All Data.

A meeting was held with EPA to review the findings and conclusions from this study. In attendance were the Canadian NGV Alliance, BAF Technologies, ECO Fuel systems, and Alex Lawson Associates. Representing EPA were Marty Reineman, responsible for aftermarket certifications, Russel Banush, certification rep., Ted Trimble, who approves OBD II aftermarket applications, and Arvon Mitcham, OEM OBD II approvals, and in use compliance.

The key points from the meeting are summarized as follows.

- EPA is very appreciative of the data provided as a result of this work. It has provided them with unique data, and a much better understanding of the OBD II performance of typical aftermarket conversion systems. They accept that fact that converters may not have to shift monitor thresholds in order to be compliant, provided the certification level remains the same as gasoline. They are, in fact, relieved that the data has provided them with this opportunity, as they were previously uncertain on what course to take to deal with converters who could not shift the monitor thresholds in order to be compliant.

- EPA also recognizes the difficulties facing aftermarket converters to test the catalyst monitor with threshold catalysts. BAF were the only company to provide data on OEM threshold catalysts supplied by Ford Motor Company, in response to a CARB request. More data is needed on threshold catalyst tests of the catalyst monitor. If the data supports the BAF conclusion, that NMHC may be an inappropriate criterion to measure catalyst damage in an NGV, then in the future, EPA may accept that the gasoline catalyst monitor does an effective job in alerting the driver of a catalyst failure. Some tests would still have to be conducted to satisfy regulatory requirements, but these could be reduced to some simple test such a worst case test with an empty can, followed by approval to use the gasoline monitor system to detect catalyst failures on the NGV.
- A discussion was held on the potential for carry across of OBD II data to other engine test groups. EPA indicated that manufacturers had OBD II test groups in which the same OBD II data was used across a number of different engines. For example, Ford might have up to 9 different engines contained within one OBD II grouping. EPA can advise the aftermarket converter of these groupings, within which carry across provisions may be used. However, it is important that the test vehicle selected as a data vehicle should be a worst case vehicle in order to carry across data to other vehicles. Aftermarket converters should submit a plan to EPA at the beginning of each model year, identifying the range of vehicles to be converted, and they should receive confirmation that the selected test vehicle is, in fact, considered by EPA to be worst case.
- EPA has, however, recently indicated that they have a dilemma to resolve, as a result of the findings of this work, and they have also entered into discussions with CARB in this respect. The issue is that the EPA regulations required the MIL to be illuminated at emissions levels greater than 1.5 times the applicable emissions standards. CARB on the other hand requires the MIL to be illuminated at emissions levels less than 1.5 times the standards. EPA will accept CARB OBD II approval, (< 1.5 times) but if a company certifies only with EPA, then they must abide with the EPA regulations (> 1.5 times). The dilemma arises because the data shows that aftermarket conversions will generally set the MIL to illuminate at < 1.5 times using the gasoline monitors. In order to reach the level required for approval, converters will have to “dirty up” the calibration, increasing the NGV emissions, so that the MIL will be illuminated at 1.5 times the applicable standards. However, EPA does not want converters to make their emissions worse, and prefers to have the lower emissions created by the NGV. Hence the dilemma. This needs to be tracked in the future. EPA is considering whether they can certify at lower emissions levels, but approve OBD II compliance at higher emissions thresholds. How this would be done is not clear, however, as more than one calibration would be required. This dilemma needs to be tracked and resolved with EPA.

9 CONCLUSIONS AND RECOMMENDATIONS

9.1 CONCLUSIONS

- The project has allowed ECO Fuel Systems to considerably expand their knowledge in testing OBD II systems, use of equipment required to evaluate monitors, validity of the data obtained and its relevance to OBD II compliance.

- For natural gas vehicles certified to the same level as the original gasoline vehicle, there is an emerging trend that the gasoline MIL settings of the major monitors are detecting faults at emissions levels which are less than the malfunction criteria set by the regulations. It is clear that this is not a case where the MIL is illuminated on a CNG vehicle by gasoline threshold settings at higher emissions levels than gasoline. This appears true across different OEM vehicles having different levels of OBD II sophistication. It is believed that GM has a higher level of OBD II sophistication than Ford.

- There is probably a greater concern that the gasoline MIL setting is illuminated too early during natural gas operation, raising EPA's concern that false MIL illumination may occur without resetting monitor thresholds.

- It is likely that false MIL illumination can be accommodated through appropriate calibration changes to the CNG vehicle. In essence, however, this amounts to "dirtying up" the CNG emissions to a level similar to gasoline in order to satisfy the gasoline OBD II threshold settings, which is counterproductive to the concept of producing a clean natural gas vehicle. An alternative approach would be to decrease the certification level on CNG by one level of stringency, provided that the gasoline emissions would support it.

- If the natural gas vehicle is to be certified to a much lower level of stringency than the original gasoline vehicle, then the gasoline thresholds will likely have to be reset for some of the major monitors. Otherwise the emissions at the gasoline threshold settings will be considerably greater than the OBD II malfunction criteria permit.

- It is interesting to note that even with a severely deteriorated threshold catalyst, the NOx and NMHC emissions were still below the useful life standards, demonstrating the robust cleanliness of the natural gas vehicle.

- Testing of OEM threshold catalysts for the catalyst monitor, has shown that CO emissions reach levels that would normally trigger a malfunction with monitors other than the catalyst monitor. The catalyst monitor is unique in that only NMHC emissions are used as the malfunction criteria for MIL illumination. (1.75 times the NMHC standard). While the CO emissions indicate that a catalyst malfunction has occurred with this CNG vehicle, the NMHC emissions remain below the applicable useful life standard. This suggests that while NMHC emissions may be appropriate for monitoring the health of the catalyst in gasoline operation, they may not be appropriate malfunction criteria for CNG operation due to inherently low NMHC emissions.

- The BAF approach to conversion systems allows them to shift the monitor thresholds required for certification of dedicated CNG vehicles to very stringent emissions standards. The ECO Fuel System approach should be capable of reaching OBD II compliance with EPA in the 2006 model year. The data from the bi-fuel vehicles is showing that the thresholds do not need to be shifted when the certification level remains the same as gasoline. Some concern remains about early MIL illumination (false MILS) which may need to be accommodated through CNG fuel system calibration adjustment for some monitors as required.

- In discussions with CARB, a precedent was created which, on a case by case basis, allows aftermarket NGV converters to obtain conditional certification in California prior to completion of all OBD II testing. The condition will be removed when final OBD II approval is granted (normally 30 – 45 days after conditional certification). This allows converters to offer vehicles for sale before final OBD II approval is granted, in order to meet the fleet buying cycle before order windows are closed in March of any model year.

- Progress has been made through discussions with EPA on methods of facilitating the OBD II testing process for aftermarket alternative fuel converters. This will greatly assist aftermarket converters in reaching OBD II compliance in 2006, but EPA expects to see improvements in OBD II performance in future model years.

9.2 RECOMMENDATIONS

- Much has been learned from this study, but there are a number of gaps in the knowledge base which need to be filled.

- The catalyst monitor needs more work. EPA will want to see progress in 2007. While testing of blank or damaged catalysts will satisfy 2006 requirements, testing of properly aged catalysts to the threshold level (development of threshold catalysts) should be conducted in 2007 to provide valid data to EPA of the emissions performance at the threshold where the MIL is illuminated by the gasoline setting. If, as we suspect, the NMHC emissions are too low, and the MIL is set at emissions levels considerably below the NMHC malfunction criteria (false MIL), then negotiations should take place with EPA to discuss the appropriateness of NMHC as the malfunction criteria for natural gas vehicles. We need to secure agreement with EPA that a different set of malfunction criteria should be accepted for catalyst monitoring of natural gas vehicles, or (ideally) the catalyst monitor test should be scrapped for natural gas vehicles.

- 2007 is the end of the phase in period for OEMs to meet additional OBD II monitoring and test requirements. Small Volume Manufacturers (Aftermarket NGV converters) do not have to meet the new requirements until the end of the phase in period. Commencing MY 2007, they will have to become conversant with the new requirements, and develop appropriate test methods for the additional monitoring requirements, in order reach OBD II compliance in that model year. 2007 will not therefore be a simple carry over of data from 2006. Some of the monitor data may be carried over, but new tests will also have to be conducted and added to the list. The new requirements include NOx monitoring, cold start testing, and Monitor Performance Ratio Definition. There needs to be a clear definition of "What's new for 2007", so that appropriate action can be taken.

- A better understanding needs to be developed with EPA of the "Carry Across" potential of an approved OBD II system from one model vehicle to another in the same model year, and the "Carry Over" potential of approved systems from one model year to the next, in order to minimize the amount of testing required. Testing should also be performed on the worst case vehicle of an OBD II test grouping in order that carry across requests will be accepted.

- A rationalization needs to take place between EPA and CARB to get agreement on different interpretations of the OBD II malfunction criteria. EPA requires emissions data demonstrating thresholds greater than 1.5 times the emissions standards, while CARB will only accept data showing thresholds less than 1.5 times the standards. EPA has a dilemma to resolve in this regard, as they do not want converters increasing their NGV emissions in order to comply with the 1.5 times requirements. This dilemma needs to be tracked and resolved with EPA.

- The aftermarket conversion industry may be well served in future by aligning with those companies that carry out performance enhancements of gasoline vehicles, in order to gain access to the OEM computer. This will allow development of the capability to change monitor thresholds for MIL illumination to meet the malfunction criteria as required in the regulations. The result will be greater flexibility to deal with threshold values which may need to be changed as EPA gradually tightens up on malfunction criteria requirements

- Continued support from NRCAN will likely be required in this area to deal with the issues described above, and to nurture the maturing capability in aftermarket NGV OBD II compliance.

A final consideration:

Aftermarket NGVs frequently use EPA assigned emissions deterioration factors to calculate useful life emissions, and there has always been some doubt about their real world emissions durability over the vehicle useful life. Having a fully functional OBD II system provides assurance that the aftermarket NGVs have durable emissions components, and are complying in use. In this respect they have matured to the same standing as an OEM vehicle.

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MY 2006 OBD II Compliance
For Aftermarket Light Duty Natural Gas Vehicles

Appendix I to IX

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31st March, 2006

APPENDIX I

Description of Typical OEM Major Monitors and Test Procedures

Catalyst Monitor

The Catalyst Monitor is an algorithm designed to detect when the catalyst is displaying poor emission conversion efficiency. On Ford vehicles, the detection capability is based on the premise that the ratio, of rear HEGO to front HEGO voltage signal lengths, is related directly to catalyst efficiency. As the catalyst efficiency reduces, the ratio of REAR to FRONT HEGO length increases. The monitor collects HEGO switch data, and after a sufficient number of switches are collected it calculates the REAR/FRONT length ratio. When the ratio exceeds a pre-determined value the catalyst is considered to be exceeding the threshold emissions limit. This sets a Catalyst Failed Flag, which is used to light the MIL.

The catalyst monitor logic processes the raw HEGO voltage data and generates switch flags, which correspond to HEGO voltage swings/switches. This then detects voltage maxima-minima and corresponding voltage amplitude changes. This data is used to confirm that a true HEGO voltage switch has occurred. Then the logic sets up an air mass cell array and indicates in which cell of the array that the test is currently operating. Once this is set up, the logic counts the front and rear HEGO switches. The switches are stored in different air mass cell registers. These registers are used to ensure that sufficient number of switches have been collected in all air mass cells before a trip is considered complete and a switch ratio is calculated. Finally the logic then determines that a sufficient number of switches have been collected. It then takes a rear to front ratio of the HEGO switches, and it indicates whether or not the catalyst is good or bad - based on that ratio.

To run the catalyst monitor test, there are several conditions that have to be met. The vehicle must be operating in a specific window for engine load, vehicle speed, inferred catalyst temperature, EGR flow rate, coolant temperature, inlet air temperature and air flow. Once all of these criteria are met, the catalyst monitor will begin running. Once the test is running, a failure is determined if the average switch ratio exceeds a calibrated ratio. This ratio is determined using threshold catalysts and monitoring the average switch ratio. A value is then chosen that will indicate failure with these catalysts.

Misfire Monitor

The Misfire Monitor system requirements are defined by CARB regulations. Here are the key points:

* Requirement: "System shall monitor engine misfire and shall identify the specific cylinder experiencing misfire." If more than one cylinder is misfiring, then "a separate code will indicate that multiple cylinders are misfiring."
* Malfunction criteria (Type A): "The percent misfire evaluated in 200 revolution increments for each engine speed and load condition which would result in catalyst damage" - AND - the catalyst temperature exceeds its calibrated damage threshold.
* Malfunction criteria (Type B): "The percent misfire evaluated in 1000 revolution increments, which would cause emissions from a durability demonstration vehicle, to exceed 1.5 times any of the applicable FRP standards." Four separate 1000 block tests may fail per trip before setting a

pending code, except for the first 1000 block test after startup in which case a pending code must be set based on this single test.
* Monitoring conditions: "... monitoring will be continuous and under all positive torque engine speeds and load conditions." (Full Range) Misfire is a phase in requirement, which starts in 97MY with 50% of the total vehicle fleet sales, and it continues (through 2002MY) with 50/50/75/90/100 percentages.
* Negative Torque: The positive torque line extends from the engine load at neutral idle to neutral 3000 rpm. The monitor must run during the California Inspection Maintenance Test. From neutral 3000, it extends to the engine load at red-line with 4" of Hg manifold vacuum less than the engine load at neutral red-line.
* MIL Illumination (Type A): "... MIL will blink once per second during actual (Type A) conditions" and a pending code stored. If fuel shutoff is activated, then the MIL need not blink. If the fault clears, then the MIL need not be continuously lit, unless the fault occurs, over two driving cycles.
* MIL Illumination (Type B): MIL will be illuminated and a fault code stored if misfire is detected, over two driving cycles.
* Clearing pending codes: If "similar conditions" are encountered without seeing misfire, or if "similar conditions" are not encountering within the next 80 drive cycles, then pending codes may be cleared.
* Extinguishing the MIL: 3 consecutive trips must occur with "similar conditions" and no misfire, before the MIL will be turned off and code cleared.
* Similar Conditions Criteria: Speed within 375 rpm, and load within +/- 20%, of the speed load conditions stored at the time of misfire.

The misfire monitor calculates misfire rates for each cylinder per every 200 and 1000 engine revs. Also it calculates running averages for the misfire rates per cylinder, and for the total misfire rate. In addition to this it calculates a Type A misfire rate threshold, as a function of current RPM and load conditions. A Type A misfire condition indicates the catalyst can be damaged from overheating due to unburned fuel. The misfire monitor works by looking at the profile from the crankshaft sensor and determining if that profile shows whether or not a misfire has happened.

To calibrate the misfire monitor there are several things that are used. There is a table that is used to set the allowable misfire rate based on engine RPM and load. If the total number of calculated misfires exceeds a certain value, the vehicle is considered misfiring. All of these thresholds can be changed to ensure that the misfire monitor is set at the correct time. In testing, a misfire generator is employed so that the correct misfire rate can be induced to calibrate the thresholds.

Fuel Trim Monitor

As fuel control system component parameters change from nominal with time the adaptive fuel table contents will reflect the change. As the parameters continue to change the adaptive table will reach the adaptive tables clip. This means that the adaptive table cannot compensate for any additional changes in fuel control component parameters. Further change in the fuel control system components parameters will cause the short term fuel switch point to move toward its clips. As this trend continues the ability of the fuel control system to control fuel will cease.

Once these limits are reached the MIL light is turned on at the correct threshold.

O2 Monitor

The following is the sequence when the O2 sensor monitor is running;
During normal operation of the vehicle, the EGO monitor will follow the execution sequence:

High frequency fuel modulation begins. After a number of engine revolutions, sampling of the upstream EGO sensors occurs every 16 milliseconds. Upstream EGO sensor voltage and frequency statistics are computed. After a number of commanded O2 sensor cycles occur, high frequency fuel modulation is disabled, and 16 millisecond sampling is disabled. EGO signal amplitude and frequency response is calculated for each of the upstream sensors. These statistics are compared to calibrated limits and a decision is made as to the health of the upstream EGO sensors. The voltage envelope of the downstream EGO sensors is checked, and if it not sufficiently large because a minimum rich voltage on bank 1 or a minimum lean voltage on bank 2 has not been observed, then the fuel control is forced into open loop and a rich A/F ratio is commanded for bank 1. After the calibrated number of seconds times out or the required rich voltage is seen the rich A/F excursion is discontinued. If a required minimum lean EGO sensor voltage has not been seen up to this point then the fuel control is forced into open loop operation and a lean and A/F ratio is commanded for a calibrated number of seconds for the appropriate bank. After the calibrated number of seconds times out or the required lean EGO sensor voltage is seen, the lean A/F excursion is discontinued. A decision is made on the relative health of the downstream EGO sensors based on the voltage envelope attained on the downstream EGO sensors.

There are three primary tests to the O2 Sensor Monitor

- Overvoltage Test

In this test, O2 sensor voltage is continuously monitored for an over-voltage condition. When one is encountered a malfunction is flagged, and no further testing of the upstream sensors is done.

- Upstream Response Test

The O2 sensor upstream response test samples the sensor a-to-d readings and stores them to determine if it’s in the steady state window for the test, and process the information based on the results of the test. The O2 sensor voltage samples are taken in at a high rate in order to capture the peak rich and lean voltages during the rich or lean excursion from stoichiometry.

- Bias Shift Test

In this test, the rear O2 sensors are checked against a pair of limits. If the voltage is found to exceed these limits, then all further testing of the sensor is stopped.

There is a minimum frequency that, if the O2 switches less than this frequency, the O2 sensor is considered to be malfunctioning, and the MIL light will be set.

A slew box is used to simulate a slow switching O2 sensor, and calibrate the thresholds against emissions.

EGR Monitor

The EGR monitor consists of several subtests within the overall monitor. The EGR monitor checks for the following issues;

Code	Description
P0401	Insufficient EGR flow
P0402	EGR valve stuck open
P0405	EPT sensor signal out of range low
P0406	EPT sensor signal out of range high
P1405	EPT upstream hose disconnected or plugged
P1406	EPT downstream hose disconnected or plugged
P0403	Output driver fault

The following describes how each of these sections work and is calibrated.

EPT upstream hose disconnected or plugged
EPT downstream hose disconnected or plugged
This test is run when the EGR valve is closed. When the EGR valve is closed, the EPT pressure should approach zero. Once all the entry criteria are met for this test, the test itself can begin. To determine if the EGR hose is disconnected or not, there are two lookup functions that use air flow and what the pressure drop should be at that air flow.

Insufficient EGR flow
This test infers the pressure difference between the inlet manifold and the exhaust back pressure. This is used to determine a minimum allowed EGR delta pressure during high EGR. The test is performed when the EGR duty cycle is above a minimum value and a comparison is made between actual pressure drop to the expected pressure drop for the current system pressure and a calibrated EGR valve duty cycle. Should the actual pressure drop be less than the estimated pressure drop then a fault exists. The point at which a fault is detected is calibrated using a simple function of the allowed difference between actual pressure drop and how much of a difference is allowed from this to the expected pressure drop.

The EPT sensor signal out of range low/high is a check of the signal coming from the sensor. If the A-D counts of the sensor (or voltage) is too high or too low, then this code will bet set.

For CNG operation, the insufficient flow threshold is the only area of this monitor that may need to be modified to meet the malfunction criteria.

Comprehensive Component Monitor

Most A/D inputs and some outputs, do not have a specific monitor flag for input into the OBD-II Trip flag. However all of these inputs and outputs have min and max values to determine if a sensor is good or bad. A time is given for all of these inputs and outputs to determine if they are working correctly.

APPENDIX II

CARB Test Methods

Early in the project, a meeting was held with Mike McCarthy of CARB to clarify the steps required to complete the OBD-II compliance process for 2006 CNG passenger cars and medium duty vehicles. Specifically, there was a need to identify the detailed test work and data which CARB will need to see in order to approve OBD II systems for aftermarket vehicles in 2006. While the major focus was on dedicated CNG vehicle conversions, the same requirements applied to bi-fuel vehicles. The discussion centered around vehicles certified to ULEV levels and greater. SULEV vehicles have a different set of malfunction criteria.

The majority of the meeting was spent discussing OBD-II related testing and data that CARB requires to issue an OBD-II compliancy certificate. It was decided that the best use of the time would be to take each compliancy issue in order and document the specific testing and data required. OBD-II is categorized under (11) major monitors, with each monitor established to target a specific system or component that can have an effect on tailpipe emissions. Major OBD-II monitors are as follows:

1. Catalyst
2. Misfire
3. EVAP
4. Secondary air
5. Fuel trim
6. Oxygen sensor
7. EGR
8. PCV
9. Thermostat
10. Cold Start
11. Comprehensive Component

NOTE – Items 4, and 10 are not applicable at the present time; and items 8 and 9 are only applicable if any changes are made to threshold enabling criteria.

Below are the results of discussions of the required testing for those remaining monitors for which compliancy must be demonstrated:

Catalyst Monitor

The catalyst monitor is designed to monitor NMHC hydrocarbon emissions only, and must alert the driver when a fault occurs which will cause the NMHC emissions to exceed 1.75 times the applicable NMHC emissions standard. Natural gas vehicles typically have very low NMHC emissions (most of the hydrocarbons are methane), so it is possible that even with a dead catalyst, the NMHC emissions may never exceed the 1.75 times emissions threshold. Therefore, the first thing to do, was to test whether this threshold can ever be exceeded, and provide necessary emissions data to CARB.

Run a complete FTP-75 test cycle on a vehicle outfitted with a non-precious-metal-coated catalyst to determine whether a completely non-functioning catalyst will reach an emission level that exceeds 1.75 times the non-methane hydrocarbon (NMHC) standard. If it is determined that NMHC emissions do not exceed 1.75 times the standard, then at a minimum the Malfunction Indicator Lamp (MIL) must illuminate to warn the vehicle operator of a complete catalyst failure. (worst detectable catalyst). If however the test indicates there are NMHC emissions above 1.75 times the standard, then the manufacturer must age a set of catalytic converters to a failing threshold and reset the MIL to illuminate near, 1.75 times the standard. MIL illumination at 1.74 times the standard, for example, would not be acceptable to CARB. A setting of 1.7 times, or less, would be acceptable to allow for vehicle to vehicle variations.

When running the vehicle on natural gas to age the catalysts, it is important to monitor the emissions as the catalyst ages to determine at what natural gas emissions level the MIL is illuminated with the gasoline monitor threshold setting. For example the MIL may be illuminated before the 1.7 emissions level is reached when operating the vehicle on natural gas. This is a critical data point to obtain with this project, as an early setting of the MIL may indicate that monitors do not need to be reset when operating on natural gas. On the other hand, the 1.7 emissions point may be reached before the MIL is set. The data necessary to reset the MIL at that point should be noted, but the threshold should not be changed at that point. Instead, catalyst ageing should continue until the gasoline MIL threshold is reached and the MIL is illuminated, and the emissions data obtained at that point. The latter will determine what would happen to the natural gas emissions, if the vehicle was left as is until the MIL was illuminated with the gasoline threshold.

NOTE -- The process of aging is expensive and time consuming. It is possible to overage a catalyst to a point that when tested the emissions are at, say, 4.0 times the standard. In this event, the aging must be done over with another set of catalysts to a lesser extent in an attempt to hit the 1.7 value. It is more likely, however, that the overshoot will be smaller, say 2 times the standard. In this event it should be possible to recalibrate the fuel management system to bring the emissions below the 1.75 target, without having to age another set of catalysts. If this cannot be achieved, then another set of catalysts may have to be aged. Once the data is obtained, the MIL should be set to illuminate at 1.7 times the standard, and supporting emissions data submitted to CARB, demonstrating that the MIL is illuminated at 1.7 times the emissions standard

MISFIRE MONITOR

Run a complete FTP-75 test cycle with a misfire generator attached to the vehicle that causes one spark plug in the ignition system to cut-out for a certain % of the cycle. An alternative approach is to modify the ECU to create misfire. However, final demo tests must be run with a misfire generator. The % misfire should be increased until the gasoline MIL setting is reached and the emissions measured at that point. If the emissions are less than 1.5 times the standard, (for all emissions), then no change to the gasoline threshold setting is necessary. If, however, the emissions are greater than 1.5 times the standard, then the misfire rate should be reduced until the emissions are 1.5 times the standard, at which point the MIL needs to be illuminated. The differences between the gasoline and CNG monitor settings needs to be noted with the corresponding emissions values. There is a floor of 1% misfire, below which a manufacture does not need to go. (CARB's position is that requiring a manufacturer to set this monitor to warn an operator of misfires that occur for anything less than 1% of the cycle would be overly burdensome and potentially inaccurate.) Additionally, it is required that manufacturer verify when a misfire condition is introduced the PCM is able to detect with some degree of accuracy how much misfire is present. For example, if the misfire generator is set to a level of 3%, then the misfire monitor in the PCM must detect that value fairly accurately.

EVAP MONITOR (Dedicated CNG vehicles).
In removing the entire gasoline system from the vehicle, including all the components of the EVAP system, there would normally be several DTCs stored in the PCM and the MIL illuminated regarding those missing/nonfunctioning components. However, manufacturers may decide to modify the PCM or ECU software to prevent those codes from setting. CARB will allow the monitors to run in the background, in case there are other aspects of this monitor used by other diagnostic sequences. However, the scan tool must be altered to ensure that the diagnostic results are not reported. NOTE – This is a programming change only, requiring no emission tests.

FUEL TRIM

The fuel trim should be biased rich until the MIL is illuminated, and the FTP 75 emissions measured at that point using the gasoline MIL setting. If the emissions are greater than 1.5 times the emissions standard, then the fuel trim should be reduced until the emissions are slightly below the 1.5 times threshold, and the MIL should be commanded on at that point. The difference in emissions values should be noted between the gasoline and NG settings. The same procedure should be repeated with both banks of the engine biased to a too lean setting, and the same set of data obtained for the too lean condition.
NOTE – Modern fuel injection systems can correct for variances within the fuel delivery system up a certain tolerance. This test monitor will determine what that tolerance is for the CNG system.

OXYGEN SENSOR RESPONSE RATE.

The oxygen sensor response rate should be slewed out (either with an external device, or by making changes within the ECU) until the MIL is illuminated with the gasoline threshold setting. The FTP emissions should be noted at that point for both upstream oxygen sensors in a V-8 engine. Both the rich to lean transition rate and the lean to rich transition rates should be measured against the FTP emissions. If the emissions exceed the 1.5 times threshold, then the response rate needs to be adjusted until the 1.5 threshold is reached, and the MIL should be reset to illuminate at that setting. The differences in emissions data between the gasoline and CNG threshold settings should be noted, as this will be important data to communicate to CARB and EPA. It would also be interesting to test an unmodified vehicle to determine the emissions when the MIL is illuminated on gasoline. This will confirm if the base gasoline vehicle is in compliance with the requirement to illuminate the MIL at 1.5 times the emissions standards.

NOTE – This monitor is used to ensure that a degraded or failed oxygen sensor is detected by the PCM and the operator is warned by illuminating the MIL. All of the other oxygen sensor diagnostics do not require testing for emissions compliance.

EGR MONITOR

This will only need to be done if EGR is used in the CNG vehicle. If EGR is disabled from the base vehicle, then this information needs to be available to the scan tool.
If EGR is used to obtain lower emissions, then a restrictor plate (orifice control) needs to be installed in the EGR passage to cause the emissions to increase until the gasoline MIL is illuminated. The FTP emissions should be measured at that point. If they are greater than the 1.5 target threshold, then they need to be reduced until the 1.5 threshold is reached, at which point the MIL should be reset to illuminate at that point. The difference in emissions needs to be noted.
NOTE – Ford uses a dual-port feedback EGR valve to control the flow of EGR to the engine. This monitor establishes a value that represents when a restriction, such as a failed EGR valve, would cause the tailpipe emissions to exceed 1.5 times the standard.

COMPREHENSIVE COMPONENT MONITOR

The CCM is present to test the operation and functionality of electronic components on the vehicle that can effect tailpipe emissions. In adapting gasoline vehicles to CNG operation, additional CNG specific components need to be added. These typically include the Fuel Rail Pressure and Fuel Rail Temperature sensors, NG injectors, and a fuel storage pressure sensor. These sensors may be connected to the PCM or ECM. If connected to the PCM, it may be possible to use the original electrical circuits and PCM pins used by the gasoline sensors. However, it will be necessary to verify the original diagnostic processes within the PCM are still capable of diagnosing a failure of these sensors and setting the proper Diagnostic Trouble Code (DTC). Mike McCarthy was concerned that the gasoline fuel pressure and fuel temperature sensors are not monitored, and will not have any diagnostic strategies. This would need to be checked. Alternatively, the sensors may be connected to the add-on ECM, and monitoring strategies developed to detect failure modes, and set appropriate DTC's. Additionally a Fuel Storage Pressure sensor is normally installed in the high-pressure line to display the fuel storage value of the CNG tanks using the original dash-mounted gasoline gauge. It may be necessary to consider reporting a fixed value of the NG fuel level to the gasoline PCM, so that monitors will continue to run. Otherwise the gasoline misfire monitor strategy in the PCM may detect a low fuel level, and turn off monitors when in fact the CNG fuel storage is not near empty. This is acceptable to CARB provided there is not another rationality diagnostic which detects that the fuel level has not changed with mileage accumulation, and sets a false code. The mechanical pressure regulator does not require monitoring, as faults are already detected by fuel rail pressure or fuel trim. If no changes are made to the IAT or ECT sensor circuits, which are normally the case, then no change to monitors is required. The same applies to the MAF monitor, which is normally not affected by CNG operation.

SCAN TOOL DATA

In addition to the above monitor resets, OBD-II regulations also require vehicles to provide diagnostic readouts using established SAE protocols through the means of a generic scanner. Generic scanners display vehicle/system information for up to nine modes (determined by the actual equipment installed on the vehicle). It was noted that only three of the display modes would likely require modifications. Mode 1, which displays the readiness status of the OBD-II monitors; Mode 6 which provides information from the last time each OBD-II monitor was run; and Mode 9 which provides information on how often the OBD-II monitors are run. Mode 9 support for small volume manufacturers is not required until 2007. However, it will be necessary to check that there is not some other information reported such as EVAP monitoring which needs to be changed to indicate not supported in a CNG vehicle. Basically the manufacturer must verify that information from all three of these modes is displayed accurately on the scanner. In particular it was noted that our removal of the EVAP system would require that Mode 1, 6, and 9 clearly state that the EVAP monitor is “Not Supported”. Mode #01 probably requires the most changes. The PID for FRT and FRP may need a change in scaling. PID 41 mirrors PID 1, but may need to have “Evap not supported” identified. There are three different PIDs for rail pressure, so it may be possible to turn one off, and the other may be in right range for a CNG sensor. PID 3F probably needs to indicate “Not supported”. In Mode #06 some OEMs report oxygen switching ratios as a number between 0 and 1, with 0 being a perfect catalyst, and 1 being a damaged catalyst. The catalyst threshold number needs to be checked. For example, a bad cat. threshold may be set to 0.75 with a number of 0.55 being acceptable.

Also levels on misfire may need to be changed. EGR needs to be picked up and displayed, if used, and oxygen sensor threshold may need to be changed in the Mode #06 read out.

NOTES – Generic scan tools are used by Inspection/Maintenance technicians during a smog check. Resetting scan tool data is a software change requiring no emission testing.

PRODUCTION VEHICLE EVALUATION

In addition to the above testing and software changes which are required to be done on an engineering/development vehicle, there is a requirement that the manufacturer perform at least one Production Vehicle Evaluation (PVE) as an end-of-line test to verify the vehicle is capable of performing all the required diagnostic readouts using a generic scan tool. Test equipment is available for purchase (Dearborn Group, or check Sourceforge.net) that will perform a full system diagnostic using SAE J-1699-3 guidelines and provide a printout of the results. (This data must be provided to CARB within the first 60 days of production.)

PVE test guidelines also require that the manufacturer cause the tested vehicle to set every DTC capable of being set on the vehicle; and when the fault criteria is introduced, that fault must be stored within the PCM.
NOTE – During our discussions of PVE tests it was recognized that meeting this phase of the requirements would be a significant challenge for an aftermarket converter. In order to set every

fault code capable of being set on the vehicle an OEM breakout box would be required (normally used by the OEM, but not available to converters), and this would require that the converter have knowledge of how Ford enables each of their fault codes. The dilemma is, when Ford submitted their certification application to CARB for the original gasoline certification, they stipulated the information in that portion of the application as “CONFIDENTIAL”. This means CARB has the information, but cannot release it to the manufacturer without Ford’s permission; and of course Ford has the information we would need, but they have no incentive to share it with the manufacturer. In the end Mike McCarthy indicated he would take this issue to his supervisor for further discussion as to how the situation might be resolved. (Apparently this issue has been faced before.)

APPENDIX III

Alternate Test Plan for the Catalyst Monitor

Conventional Testing

The conventional method of setting the catalyst monitor threshold, is to carry out accelerated catalyst ageing, in order to illuminate the MIL when the NMHC emissions reach 1.75 times the applicable standard. Threshold catalysts are aged beyond the 120 K mile equivalent to reach the level where the catalyst efficiency has decreased to the point where NMHC emissions are now 1.75 times the standard. The difficulty with this approach is finding out when you have reached the threshold value. As the catalyst is progressively aged with periodic emissions testing, over-aging of the catalyst beyond the required threshold level is a real possibility, requiring the manufacturer to start again to age a new set of catalysts. Multiple aged catalysts are therefore developed to deal with this contingency, which adds cost.

Alternate test plan

Catalyst thermal degradation (the most common cause of loss of catalyst efficiency) results in loss of oxygen storage capacity in the catalyst washcoat. The oxygen sensor detects oxygen in the exhaust, and the feedback system switches the fuel/air ratio rich and lean of the stoichiometric value. The switching frequency is high upstream, and low downstream of the catalyst. The oxygen content of the exhaust is normally 0.7% upstream of the catalyst, and 0.1% downstream of the catalyst, if the catalyst efficiency is high, and the catalyst is performing normally. As the catalyst degrades, and oxygen storage capacity is lost, the oxygen content of the exhaust downstream of the catalyst rises, the switching frequency increases, and the NMHC emissions approach those upstream of the catalyst.

In order to simulate degradation of the catalyst, a small bypass tube could be routed around say a 120K catalyst, so that a small (controlled with a valve) portion of the exhaust could be taken from a point upstream of the catalyst, but downstream of the oxygen sensor, and fed into the exhaust pipe downstream of the catalyst, but upstream of the second oxygen sensor. In this way, the oxygen content, and NMHC emissions of the exhaust from this natural gas engine, could be progressively increased downstream of the catalyst, just as would have occurred if the catalyst had degraded. The downstream oxygen sensor will detect the change in oxygen concentration (just as it would do if loss of oxygen storage occurred in the catalyst), the switching frequency will increase, and the monitor will respond to illuminate the MIL according to the set threshold value. When the NMHC emissions from this natural gas engine reach 1.75 times the applicable emission standard, the monitor threshold value can be set to illuminate the MIL.

The attractive feature of this approach is that the threshold value can be set more precisely, by varying the amount of bypass exhaust on either side of the required threshold. Since the emissions are created by the natural gas engine, the correlation between the monitor detection system, and the presence of NMHC emissions, is being validated by this method.

The alternate test plan was discussed with Engelhard Pro-drive in Detroit, who carry out catalyst ageing for the OEMs, and they believed the approach was a reasonable one. The alternated test plan was then submitted to CARB for comment. The result was negative and the alternate plan was rejected by CARB on the basis that it would not provide a sufficiently accurate failure threshold setting.

APPENDIX IV

EPA Guidance Letter CCD 05-16

September 1st, 2005

EPA Approval of OBD II Systems on Aftermarket Alternative Fuel Conversions

Dear Manufacturer:

This letter provides guidance for aftermarket alternative fuel converters on how to obtain EPA approval of the on-board diagnostics (OBD) **II** system. This guidance applies to converters who certify 2005 and later model year (MY) light-duty vehicles, light-duty trucks, and medium-duty passenger vehicles, and 2007 and later MY heavy-duty vehicles Background The EPA OBD 11requirements are presented in 40 **CFR** @36.1806-05. Section 86.1806-05(b) describes which emission control related malfunctions must be detected and identified. The components and conditions which must be monitored include: catalysts (detection of an increase in NMHC of 1.5 times the standards), engine misfire, oxygen sensors, evaporative leaks (does not apply to closed fueling systems such as liquefied petroleum gas (LPG) or compressed natural gas (CNG)), other emission control systems (includes EGR if so equipped, secondary air systems if so equipped, and the fuel control system, which singularly result in exhaust emissions exceeding 1.5 times the applicable standards for NMHC, CO, NOx, or diesel PM), and other emission-related powertrain components which have a measurable impact on emissions.

EPA guidance letters CCD-02-12 dated August 29**,** 2002, and CCD-04-20 dated October 2004, describe EPA policies pertaining to certifying aftermarket alternative fuels conversions. Question No. 30 in the October 1,2004 letter and its answer describe EPA policy regarding OBD requirements. The guidance letter states:

"For dual fueled vehicles, the original equipment manufacturer (OEM) OBD system must remain completely functional when operating on the fuel on which the vehicle was originally certified. Operation on alternative fuels must not falsely register diagnostic trouble codes or illuminate a malfunction indicator light (MIL). Dedicated alternative fueled vehicles and dual fuel conversions operating on the alternative fuel must have functional OBD II systems beginning with 2005 MY light duty vehicles and trucks."

It is important that aftermarket alternative fuels converters correctly interpret the last sentence in 986.1806-05(i), which states:

> "At a minimum, alternate fuel vehicles shall be equipped with an OBD system meeting OBD requirements to the extent feasible as approved by the Administrator."

The wording “to the extent feasible", are referenced in the preamble language from 65 Federal Register 59918, dated October 6**,** 2000. In the preamble EPA the words “to the extent feasible” apply only to the criteria for issuing waivers (emphasis added). The preamble states that waivers from full OBD II compliance are to be based upon “technological infeasibility, not resource reasons." Waivers from OBD II compliance for manufacturers of alternative fueled vehicles officially expired with the end of the **2004** model year for light-duty vehicles and trucks.

EPA's requirements for receiving a federal approval of an OBD **II** system are similar to, but not identical to what the California Air Resources Board (CARB) is requiring when they approve the OBD **II** system for a 50 state certificate of conformity. One significant difference between California and EPA's approval process is that EPA does not impose fees for deficiencies while CARB does.

Discussion

Fully functional OBD **II** systems are part of the requirements for obtaining a certificate of conformity. The basic purpose of the OBD 11system is to illuminate the malfunction indicator lamp (MIL) when required and assist service repair mechanics in diagnosing and repairing the vehicle. EPA has provided considerable time for manufacturers of alternative fuel systems to comply with the regulatory requirements for OBD II. EPA's requirements for vehicles operating on alternative fuels were most recently published in the Federal Register on October 6, 2000. The regulations published at 40 **CFR** $86.1806-05 allowed manufacturers of alternative fuel systems for light-duty vehicles, light-duty trucks, and medium-duty passenger vehicles until the 2005 model year to produce fully functional OBD **II** systems. Prior to model year 2005, EPA allowed aftermarket alternative fuel converters to certify vehicles with a desensitized OBD **II** system during vehicle operation on the alternative fuel. Additionally, in the last two years EPA staff have appeared at three technical forums and each time have stated the need to comply with OBD **II** requirements for aftermarket alternative fuels conversions.

By holding aftermarket alternative fuels converters to the same regulatory requirements that OEMs meet, EPA is maintaining compliance equity among manufacturers. In fact, converters already have regulatory relief in the form of an exemption from the OEM requirements to conduct durability and in-use verification testing. Having a fully functional OBD system provides EPA with some assurance that alternate fuel converted vehicles have durable emission components and are complying in use. In addition, it is important for alternate fuel converted vehicles to have fully functional OBD **II** systems in order to allow states with inspection and maintenance programs which rely solely on monitoring the OBD **II** system to be able to assess the performance of the emission control system on the aftermarket conversions at the time of inspection.

EPA OBD **II** Policy for Aftermarket Alternative Fuels Conversions

- EPA will accept a CARB approval of the OBD **II** system for an aftermarket fuels conversion. However, a federal approval of the OBD **II** system does not imply that CARB would also approve the OBD 11 system should the fuels converter wish to sell vehicles in California, or in states which have adopted California emission standards.

- Waivers from complying with the OBD **II** requirements in **@36.1806-05**are no longer applicable effective with the aftermarket fuels conversions of 2005 and later model year light-duty vehicles, light-duty trucks, and medium-duty passenger vehicles. Waivers continue to apply to aftermarket fuels conversions through the 2006 MY for chassis certified heavy-duty vehicles.

- Federal OBD **II** approval will be based on EPA analysis of the fuels converter's OBD **II** system. The application for certification must include the documentation specified in paragraphs §86.1844-01(d)(9)(i), (ii), and (iii). Those paragraphs are re-stated below: (i) A description of the functional operation characteristics of the diagnostic system; (ii) The general method of detecting malfunctions for each emission-related powertrain component; (iii) Any deficiencies, including resolution plans and schedules.
- EPA will permit deficiencies but there must be a schedule for resolution and a demonstration that progress has been made in resolving deficiencies.
- There must be no false MIL illumination when operating on the alternative fuel, or on the fuel used by the OEM to obtain the original certificate if the vehicle is converted to dual fuel operation.
- All recommended practices from the Society of Automotive Engineers (SAE) and the International Organization for Standardization (ISO) referenced in EPA's OBD regulations are required to be followed in order to gain OBD approval, including the requirements for a single 16 pin OBD diagnostic link connector and five character alpha- numeric diagnostic trouble codes.
- EPA may request some aftermarket fuels converters to submit a vehicle for EPA inspection, at which time EPA may check for the detection of any of the malfunctions listed in §86.1806-05, such as electrical continuity, misfire detection, oxygen sensor malfunction, and fuel control system problems resulting in emission increases of more than 1.5 times the applicable standards. Interrogation of the OBD 11system will be done with a generic scan tool using current SAE data transfer protocols.

If you have questions concerning this letter please contact Martin Reineman at 734-214-4430 or by e-mail at reineman.martin@epa.gov.

Sincerely,

Merrylin Zaw-Mon, Director

Certification and Compliance Division.

APPENDIX V

EPA Guidance Letter CCD 06-02

February 3rd, 2006

Updated Certification Guidance for Alternative Fuel Converters

APPENDIX VI

Letter to CARB from the California NGV Coalition

California
Natural Gas Vehicle Coalition

Michael Eaves

President

January 23, 2006

Mr. Robert Cross
Chief, Mobile Source Control Division
California Air Resources Board
9528 Telstar Avenue
El Monte, CA 91731

Subject: OBDII Requirements for Small Volume Manufacturers

Dear Mr. Cross:

I am sorry that we haven't been able to connect by phone over the last week. After several messages, I thought I'd put my request in writing to facilitate a discussion. Concurrently, we are seeking a meeting with Robert Sawyer and Alan Lloyd to discuss this same subject.

The NGV industry certainly appreciates the assistance that Mike McCarthy has given to BAF Technologies to review their OBDII compliance plan for the 2006 Ford Crown Victoria and provide further guidance on how BAF Technologies should handle the requirement to set every fault code on the vehicle since much of this information is Ford confidential with little or no prospect of BAF Technologies obtaining. BAF Technologies is committed to performing the testing and calibrations required to conform to CARB's OBDII requirements. BAF's plan is to submit their data for full OBDII certification within the next few months.

The issue requiring your senior level attention is in recognizing the process and market timing associated with Small Volume Manufacturers (SVM) bringing product to market and to request the certification process be modified to support the introduction of alternative fuel product in a more timely fashion while remaining CARB compliant.

As you know, SVMs are charged with a Herculean task of re-designing OEM gasoline vehicles to operate cleaner on natural gas. OEM engineers have 3-4 years to conduct the proper calibrations for a new model year. They can take advantage of all the prior history of a given model and are aware of model year system changes. SVMs don't even get to see the vehicle they intend to convert to natural gas until the current model year is delivered to dealers. SVMs then need to convert the vehicle to natural gas, get control of the system and tune the engine to SULEV emissions, as is the case with BAF. A Ford consultant recently pointed out that what BAF Technologies has done in three months (achieve SULEV emissions whereas the gasoline product is ULEV) would have taken Ford 2 years.

Having achieved SULEV emissions results, SVMs have to perform the rigorous OBDII compliance testing and calibration. This OBDII compliance testing should be completed in a few months and submitted for certification by several SVMs. Unfortunately, by this time, the OEMs will be at or near the close of their production window on these target alternative fuel vehicles. Additionally, fleets purchase their vehicles in the first months of the year. Consequently, the process to finalize OBDII compliant certifications places the vehicle order outside the purchase window for fleets.

We would like CARB to consider a more flexible yet compliant SVM vehicle certification / approval for sale process. The concept is that following submittal of certified vehicle emissions data, along with CARB staff discussion with the SVM on OBDII certification plans, CARB quickly grant vehicle certification / approval for sale. The certification would also carry requirements for re-flashing the computer with the final OBDII protocols, retroactively paying for any delinquencies, and limiting the total potential sales to 750 vehicles until OBDII approval is granted. This process will enable the sale of clean, alternative fuel vehicles NOW but still allow for appropriate CARB oversight and approval.

It is requested that this flexibility be granted to the BAF Technologies application for the 2006 dedicated natural gas Crown Victoria. As described above, with submittal of the SULEV emissions results, CARB would grant permission to immediately sell 750 2006 dedicated natural gas Ford Crown Victoria's with the stipulation that BAF Technologies would pay any deficiencies for these vehicles noted upon completion of the OBDII certification process and upgrade all vehicle software on vehicles sold to the final OBDII calibrations.

SVMs are playing an important role in providing alternative fuel product that addresses key state goals and objectives such as fuel diversity for California, reducing greenhouse gases (light duty NGVs reduce GHG emissions by 20% over gasoline products), and reducing emissions (SULEV vs. ULEV). In fact, supporting this BAF request will ensure that hundreds of cleaner – high mileage – taxis are operating in California thereby further encouraging the OEMs to re-enter the market. The NGV industry agrees with the concept of OBDII and having control systems that properly monitors emissions for the life of a vehicle. But we believe that CARB and SVMs should work to identify a less onerous process for SVMs, as suggested, that will allow both a timelier introduction of products to the marketplace and preserve the emission goals of CARB.

Finally, as you recognize, this request for permission to sell vehicles is linked but not totally tied to OBDII. SVMs will give CARB the systems that they require. However, for the sake of the product as well as the SVM, time is of the essence for your approval of this more flexible process.

We would welcome an opportunity to discuss this further with you at your earliest possible convenience. I can be reached at 562/708-7240 (cell) or 562/697-9646 (office).

Sincerely,

Michael L. Eaves
President, California NGV Coalition

cc: Alan Lloyd
Robert Sawyer

APPENDIX VII

Minutes of EPA Meeting with ALA and BAF Technologies To Review BAF OBD II Data on a Dedicated CNG Crown Victoria

Dated 8th March 2006

BAF Technologies meeting with EPA Ann Arbor 8th March 2006

Present:

Roger Galloway	BAF Technologies
Alex Lawson	Alex Lawson Associates Inc (consultant for BAF)
Ted Trimble	EPA
Arvon Mitcham	EPA
Russell Banush	EPA

Subject:

Review of BAF Application for Approval of OBD II Compliance for a MY 2006 Dedicated CNG Crown Victoria – Test Group 6BAFV04.61NN

An Application for OBD II approval for the referenced Test Group was tabled for discussion. The format of the application, and technical description of the OBD II system employed, was considered satisfactory.

A review was made of the emission threshold levels achieved when the vehicle was operated on CNG under conditions where the MIL was illuminated with the OEM gasoline MIL threshold settings.

The fuel trim monitor rich and lean test results were considered excellent. It was agreed that since CARB requires thresholds to be 2.5 times the standards for a SULEV application, EPA would consider this acceptable at this time for a Tier 2 Bin 2 application.

The EGR monitor test result was considered too low, at 0.85 times the emissions standard, as it would create a condition where a false MIL could occur. This is a major concern for EPA, as customers, observing such a MIL illumination, would take their vehicle in for repair, and be informed that there is nothing wrong with the vehicle, as it still meets the emissions standards. EPA will not approve MIL settings at this level, as the vehicles, in use, would likely be subject to defect reporting and recall, as a result of customer complaints of false MIL settings. BAF and EPA agreed that there was no benefit to pursuing this path. It was therefore agreed that the EGR threshold would either be set to a higher level, or EGR would be disabled completely, as there seems to be only a minor emissions improvement with use of EGR in this case. BAF will determine if EGR can be disabled while maintaining emissions compliance at the Bin 2 level. As a result of the very low emissions required to meet the Bin 2 standards, compliance headroom may be compromised to the extent that some EGR may be required, or it could be argued that EGR is required to improve fuel efficiency and vehicle range. EGR may have been implemented on the base gasoline vehicle for fuel efficiency reasons and not emissions reasons. EPA will consider the results of the BAF investigation into use of EGR on the basis of being the best you can do, if it cannot be removed entirely.

In general, EPA wants to see OBD II emissions thresholds at 1.5 times the standard, (as applicable) or greater, to ensure that the viability, and customer confidence, in the OBD II system is maintained. This contrasts with CARB who require thresholds to be less than 1.5 times the standard, to allow for vehicle to vehicle variability, and ensure that emissions at the fault threshold never exceed 1.5 times the emissions standards.

It was also agreed that the fuel trim monitor thresholds are set at the limits of rich and lean adaptive control, because once the long term and short term fuel trims are railed at the adaptive limits, a fault has occurred, and must be detected with the MIL at that point. Any excursion beyond these limits will cause loss of fuel control and excessive emissions. Because adaptive control is still functional at the limits, the emissions will not appear to be excessive at that point, although a fault has definitely occurred, and has to be flagged, because loss of fuel control is imminent with consequences of high emissions levels. A customer, having a vehicle repaired under these circumstances, as a result of the fuel trim MIL being illuminated, will not be observing a false MIL in this circumstance, even although the emissions are below the standards, because the fault is real, and has to be repaired to prevent future emissions degradation.

The oxygen sensor and misfire monitor results, although higher than required, were considered satisfactory for this year. Improvements in threshold response are expected to be made in the 2007 model year. It is interesting to note that if the vehicle was certified to the same level for which the vehicle was originally certified on gasoline, the thresholds would be satisfactory. This suggest that operation on natural gas may not be having a significant impact on the validity of gasoline monitor thresholds, and the changes observed may solely be due to the lower certification level of the natural gas version of the vehicle.

A discussion ensued on the difficulties of developing threshold catalysts which will illuminate the MIL, and permit emissions to be determined at the gasoline MIL threshold. It was also recognized that only the close coupled catalysts are monitored with the OEM catalyst monitor on the Crown Victoria. It was therefore agreed that a test should be run with an empty can on the close coupled catalyst location, while maintaining the under floor catalyst, to determine the emissions with this configuration.

If a vehicle is required by EPA for confirmatory testing, then OBD II testing will be included. This will involve creating faults to ensure that the MIL is illuminated, and that the system is compatible with generic scan tool communication. Only generic codes will be tested, not manufacturer specific codes.

APPENDIX VIII

WHITE PAPER

ALEX LAWSON ASSOCIATES INC.
===

WHITE PAPER

OBD II PERFORMANCE OF TYPICAL AFTERMARKET NATURAL GAS VEHICLE CONVERSIONS

For Discussion with:

US Environmental Protection Agency
2565 Plymouth Road, Ann Arbor, Michigan 48105-2498

Attention: Marty Reineman
Ted Trimble
Arvon Mitcham

Alex Lawson Associates Inc
The Canadian Natural Gas Vehicle Alliance
ECO Fuel Systems
BAF Technologies

30th March 2006.

INTRODUCTION

Alex Lawson Associates Inc. has been contracted by the Canadian Natural Gas Vehicle Alliance, and Natural Resources Canada, to investigate MY 2006 OBD II compliance of aftermarket light duty natural gas vehicles. The Government of Canada provides incentive grants for aftermarket NGV conversions provided that they hold a valid Certificate of Conformity from EPA, or a CARB Executive Order.

The benefits of NGVs in reducing greenhouse gases, toxic pollutants, reactive hydrocarbons, and other criteria pollutants, as well as addressing conventional fuel displacement, is well known. However, there is a concern that the cost of OBD II compliance is not aligned with the current sales volume of aftermarket NGVs, as the industry strives to increase sales to a level where the OEMs re-enter the market.

At the same time it is recognized that a fully compliant OBD II NGV provides assurance that the converted vehicles are durable, and complying in use.

Since there is little, if any, data presently available on how present generation aftermarket NGV systems perform with respect to OBD II compliance, it was agreed that OBD II data would be shared in a cooperative venture between BAF Technologies and ECO Fuel Systems, so that an industry standard would become evident, trends would be observed, and commonality of results may appear which would indicate where the conversion performance is the same across different OEM manufacturers, different certification levels, and different conversion systems.

PURPOSE

The purpose of this White Paper is:

- To provide EPA and CARB with information on the typical OBD II threshold performance of aftermarket NGVs, when the gasoline monitor thresholds are not altered.
- To explore opportunities, based on this knowledge, to further facilitate the OBD II approval process in future model years, and reduce compliance costs.

TEST VEHICLES AND CONVERSION SYSTEMS

Three different types of test vehicles were employed in the study covering a spectrum of different conversion systems, different OEM vehicles converted, bi-fuel and dedicated CNG conversions, and different levels of certification stringency. The test vehicles are:

- BAF Dedicated Ford CNG passenger car, certified to a much lower emissions standard than that for which the vehicle was originally certified on gasoline. The original gasoline vehicle was certified to EPA Tier 2 Bin 5, while the CNG conversion will be certified to Tier 2 Bin 2 with EPA and SULEV II with CARB.

- ECO Bi-fuel Ford CNG passenger car certified to the same level as the original gasoline vehicle, that is EPA Tier 2 Bin 5

- ECO Bi-fuel General Motors CNG Pick-up truck, certified to the same level as the original gasoline vehicle, that is EPA Tier 2 Bin 8.

TEST METHODS

The basic method of testing for each monitor was to create a fault during CNG operation, which set the appropriate code and illuminated the MIL based on the gasoline threshold settings. The FTP emissions were then measured with the MIL illuminated to determine how the CNG emissions compared with the malfunction criteria. This would show what the CNG emissions level would be when the MIL was illuminated by the gasoline threshold settings, and how close these emissions would be to the malfunction criteria. For bi-fuel vehicles it was also possible to obtain the same data with the vehicle operating on gasoline.

TEST RESULTS

GM 1500 bi-fuel CNG Pickup – ECO Fuel systems

Table 1 show the results of the fuel trim monitor testing on the GM 1500 CNG bi-fuel pickup truck.

Tests were run on both CNG and gasoline to compare the results against each other, and against the OBD II malfunction criteria limits. The gasoline fuel trim emissions are higher than baseline, and well within the criteria limits. The CNG emissions for the rich limit are also higher than baseline, and well within the criteria limits. However, when the MIL was set at the lean limit, the emissions were 3.5 times the emissions standard for CO emissions. This is a result of system constraints with the CNG system, resulting in control being compromised, especially at idle and deceleration. This can be corrected in future years.

The oxygen sensor monitor test results are shown in Table 2. The results show emissions thresholds at 1.11 times the emissions standard for CNG and 1.0 times the standard for gasoline. The oxygen sensor thresholds for CNG operation are within the malfunction criteria, and similar to gasoline using gasoline thresholds.

Similar results were obtained with the misfire monitor with the MIL being set by the gasoline strategy at NOx levels of 1.6 times the standard for CNG, and 1.9 times the NMHC standard for gasoline.

For catalyst monitor testing the catalysts were physically damaged by drilling holes to simulate a failed catalyst. With four 3/16” holes in the catalyst, the MIL was set on gasoline at emissions levels of 1.6 times the NOx standard. On CNG, however, no MIL was set with the same four holes in the catalysts, and the emissions remained low at 0.75 times the NOx standard. More work needs to be done on this catalyst to increase emissions with further damage to the catalyst, but this technique is not a good indicator of what the emissions will actually be when the MIL is set by the gasoline thresholds. A better indication of this is provided with the BAF data below, obtained on Ford supplied OBD II threshold catalysts.

Tests with the EGR monitor showed that emissions remained very low even when the EGR flow rate was almost completely shut off. It is believed that in this case, EGR is used as a means of improving fuel economy, and is not emissions related. EPA also suggested that this may be the case.

Ford 500 bi-fuel CNG Pass. Car – ECO Fuel Systems

Table 3 shows the results of a similar set of tests for the baseline and fuel trim monitors conducted on the Ford 500 passenger car. It should be noted that this vehicle is certified to the lower level of Tier 2 Bin 5, compared with the Bin 8 level of the GMC truck. In this case, the baseline CNG emissions are somewhat higher than the gasoline emissions, measured over the FTP cycle.

The CNG emissions and the gasoline emissions at the rich limit are quite satisfactory. The lean limit emissions tests, however, on both fuels showed very high NOx levels on CNG, and on gasoline, ranging from 4 to 6 times the emissions standard. This is probably a function of how the test was conducted, and can be corrected.

The oxygen sensor response rate test results presented in Table 4 show CNG NOx emissions to be 1.04 times the emissions standard, when the MIL was illuminated by the OEM gasoline calibration settings. This is an excellent result. The corresponding gasoline emissions with the MIL illuminated, showed NOx emissions of 1.16 times the emissions standard. It is interesting that when the emissions are similar between CNG and gasoline, and the standards are the same, the gasoline threshold settings for the Ford oxygen sensor monitor, appear adequate. The threshold response is quite similar.

Results from testing the misfire monitor on CNG showed NOx emissions of about 2 times the standard. However, this was at about the minimum level of 1% misfire recognized by CARB as the floor for misfire detection. Therefore, this is the best you can do as an emissions level for detecting the minimum 1% misfire rate. Gasoline misfire testing was not conducted.

Ford Crown Victoria Dedicated CNG Pass Car – BAF Technologies

It should be noted that this is a dedicated CNG Crown Victoria passenger car, certified on CNG to the most stringent level of Tier 2 Bin 2 emissions. The base gasoline vehicle used for conversion to CNG was certified at a much higher level of Tier 2 Bin 5 emissions level, and this is the level for which the OBD II calibration, and threshold levels, would have been set by the OEM.

Table 5 shows the results of testing this CNG vehicle on all monitors using the gasoline threshold levels set by the OEM. Since the vehicle is being certified to CARB SULEV II as well as Tier 2 Bin 2, the malfunction criteria are 2.5 times the applicable standards. Referring to Table 5, which reflects the CARB SULEV II standards, it is evident that the CNG emissions, when the MIL is illuminated by the gasoline settings, are now all higher than the standard, with the exception of the EGR result. Fuel trim MIL threshold emissions levels are 1.6 to 1.8 times the standard for lean and rich fuel trim limits respectively, presumably because the emission standard is now much lower than that for which the vehicle was originally calibrated. The oxygen sensor response rate, and misfire monitor emissions levels are about 4.5 times the emission standard when the MIL was illuminated at the gasoline setting. Although some threshold levels are high as a result of the low certification standards being sought, compared to gasoline, they can be reset by BAF to a lower threshold level, as a result of the BAF technology employed. The low EGR value is probably a result of the marginal need for EGR. It is believed that Ford uses EGR for fuel economy purposes rather than emission control.

With respect to the catalyst monitor, testing was conducted on a set of Ford threshold catalysts which had been used to test the gasoline catalyst monitor, and set the gasoline thresholds on the OEM gasoline Ford Crown Victoria. This provided an excellent opportunity for a direct comparison of the CNG emissions performance of the catalyst monitor at the OEM gasoline fault thresholds.

Table 5 shows the results. The regulations call for the MIL to be illuminated at 2.5 times the applicable NMHC standard. Recognizing that this is a Bin 5 gasoline calibration, and the CNG variant is being certified to Bin 2, the threshold response on CNG is arguably good. While the NMHC threshold sets the MIL at 90 % of the NMHC useful life standard, (somewhat early), the CO emissions when the light was set are 2.2 times the SULEV II standard. It can be argued, therefore, that the fault needed to be detected on a CO emissions basis, and it would be appropriate to turn on the MIL at that point. This raises the question as to whether NMHC emissions are appropriate for monitoring catalyst faults with a CNG vehicle where NMHC emissions are inherently low even with a damaged catalyst.

DISCUSSION OF RESULTS

The data from both of the ECO Fuel's vehicles, with the exception of a few outliers largely related to methods of testing, is providing a general trend that the gasoline MIL settings for the major monitors are detecting faults at emissions levels which are less than the malfunction criteria set by the regulations, and appropriate for CNG operation. It is important to recognize, however, that this is related to the certification levels being the same on CNG and gasoline for these bi-fuel vehicles.

The BAF vehicle was calibrated to lower emissions levels than gasoline, but was also certified to a lower emissions standard. This resulted in some of the emissions being much greater than the required malfunction criteria before the MIL was illuminated by the gasoline thresholds. These thresholds can be reset by BAF to comply with OBD II regulations.

Although this Tier 2 Bin 5 Crown Victoria was calibrated to pass Bin 2 levels on CNG, it is of interest to calculate what the emissions thresholds would be if the vehicle was certified to the same level as gasoline, (as in a bi-fuel vehicle certification) that is Bin 5 on CNG, using the Bin 5 gasoline OBD II thresholds set by the OEM. How would the CNG emissions now stack up against the Bin 5 certification levels, and what will the emissions be when the MIL is illuminated relative to Bin 5 emissions standards.

Table 6 shows this analysis. The Table now shows the Bin 5 standards, with the CNG emissions performance compared against these standards. With the exception of the EGR results, which are now even lower, of course, because of the higher standards, the results are remarkably similar to the ECO Fuel Systems results. Instead of the MIL being illuminated at 4.5 times the Bin 2 standard for the oxygen sensor monitor, the MIL is now seen to be illuminated at 1.3 times the Bin 5 standard. This is an ideal result for this monitor, and provides further evidence that, for the major monitors, the OEM gasoline MIL settings are adequate, without being reset, provided the same certification level is employed. If the certification level is reduced, then the monitors will have to be reset to comply with the OBD II requirements.

The same is true of the misfire monitor, the MIL now being illuminated at 1.2 times the Bin 5 standard, compared with 4.1 times the Bin 2 standard.

The fuel trim monitor results at Bin 5 standards are now also similar to the ECO Fuel Systems data, being 0.3 to 0.4 times the Bin 5 standard for rich and lean limits respectively, compared with 1.6 to 1.8 times the standards when the vehicle is certified to Bin 2 levels.

There is therefore a trend emerging, that, the gasoline OBD II calibration set by the OEM may also be adequate for CNG, with out having to reset threshold levels, providing the certification levels are the same as gasoline, as required for bi-fuel vehicles. When the certification level is made more stringent on CNG than on gasoline, then some monitors may need to be reset.

Table 7 shows the results when BAF reset the thresholds to be compliant with the SULEV II certification level. All thresholds are now satisfactory. Table 8 shows the same data compared against the EPA Tier 2 Bin 2 standards. The results are again satisfactory, although the oxygen sensor is now marginally low against the higher CO standards for Bin 2 regulations. However, since only one calibration is desired for both CARB and EPA, this was considered a good compromise.

A further analysis can be carried out assuming that ECO Fuels wanted to take the results from the bi-fuel calibration, and certify it as a dedicated CNG vehicle to a lower certification level. Using the Bin 8 GM vehicle as an example, the analysis assumed the vehicle would now be certified to a Bin 5 level, as a dedicated CNG vehicle. The emissions from the GM vehicle were low enough to support a Bin 5 level on CNG. (but not on gasoline). Table 9 shows this analysis. It is now clear that the emissions for the oxygen sensor monitor now exceed the regulatory requirements, being 3 times the standards when the MIL is illuminated by the gasoline threshold settings. This demonstrates that to achieve more stringent certification levels on CNG compared with gasoline, monitor thresholds will have to be reset.

CONCLUSIONS

- Provided the certification level remains the same as the base gasoline vehicle, the gasoline thresholds may be considered adequate for CNG vehicle conversions and largely meet malfunction criteria when operated on CNG.
- When the certification level on CNG is more stringent than the base gasoline vehicle, then the threshold levels may have to be reset from the gasoline settings.

POINTS FOR DISCUSSION

- When is a false MIL truly a false MIL? Even on a threshold catalyst where the CNG vehicle CO emissions have been compromised to the extent that they are now 2.2 times the applicable standard, the NMHC emissions remain low, below the applicable standard. This is a result of the inherently low NMHC emissions from CNG vehicles, and raises the question as to whether NMHC is an appropriate criterion for detecting catalyst faults.

- Catalyst monitor testing is extremely expensive and difficult to do. In view of the catalyst criterion issue for NGVs, perhaps consideration could be given for converters to carry out a one time catalyst monitor test of their system to demonstrate that very low NMHC emissions exist with a threshold catalyst. In subsequent model years, the gasoline threshold could be used for catalyst monitoring without testing on CNG. Fuel trim and misfire monitor testing would still be tested on CNG which would still catch potential catalyst failures from these malfunctions, but the gasoline monitor is still going to detect catalyst failure on CNG not on the basis of hydrocarbon emissions, but on the basis that low switch ratios will detect a CO failure threshold has been reached, with appropriate illumination of the MIL, as a real fault has occurred. This will considerably reduce the testing costs.

- What is the extent to which carry across, or carry over, of OBD II data may be permitted from one model to another, and how do aftermarket converters find this out.? Carry across provisions can considerably reduce the OBD II testing costs.

- EPA has indicated that they have a dilemma to resolve, as a result of the findings of this work. The issue is that the EPA regulations required the MIL to be illuminated at emissions levels greater than 1.5 times the applicable emissions standards. CARB on the other hand requires the MIL to be illuminated at emissions levels less than 1.5 times the standards. EPA will accept CARB OBD II approval, (< 1.5 times) but if a company certifies only with EPA, then they must abide with the EPA regulations (> 1.5 times). The dilemma arises because the data shows that aftermarket conversions will generally set the MIL to illuminate at < 1.5 times using the gasoline monitors. In order to reach the level required for approval, converters will have to “dirty up” the calibration, increasing the NGV emissions, so that the MIL will be illuminated at 1.5 times the applicable standards. However, EPA does not want converters to make their emissions worse, and prefers to have the lower emissions created by the NGV. This dilemma needs to be tracked and resolved with EPA.

TABLE 1

OBD II Monitor Threshold Tests Baseline and Fuel Trim Monitors
ECO GM 1500 Tier 2 Bin 8

Monitor Test Descriptiion	Codes Set	Emission Component	Tier 2 Bin 8 Standards	Malfunction Critera relative to Standard	Target MIL Threshold	4K FTP 75 Emissions at Gasoline Thresholds	EPA Assigned DFs	U/L FTP 75 Emissions at Gasoline Thresholds	MIL Threshold with Gasoline Calibration	
									CNG	Gasoline
Baseline CNG	None	NOx	0.200	1.5 times	0.300	0.017	1.730	0.029	0.15	
No MIL		CO	4.200	1.5 times	6.300	0.614	1.620	0.995	0.24	
9th Feb.		NMHC	0.125	1.75 times	0.218	0.018	1.370	0.025	0.20	
Baseline Gasoline	None	NOx	0.200	1.5 times	0.300	0.068	1.730	0.118		0.59
No MIL		CO	4.200	1.5 times	6.300	1.036	1.620	1.678		0.40
12th Jan.		NMHC	0.125	1.75 times	0.218	0.061	1.370	0.084		0.67
Fuel Trim Max Rich Limit	0171	NOx	0.200	1.5 times	0.300	0.029	1.730	0.050	0.25	
MIL on CNG	0174	CO	4.200	1.5 times	6.300	0.400	1.620	0.648	0.15	
22-Feb		NMHC	0.125	1.75 times	0.218	0.014	1.370	0.019	0.15	
Fuel Trim Max Rich Limit	0171	NOx	0.200	1.5 times	0.300	0.071	1.730	0.123		0.61
MIL on Gasoline	0174	CO	4.200	1.5 times	6.300	0.699	1.620	1.132		0.27
28-Feb		NMHC	0.125	1.75 times	0.218	0.085	1.370	0.116		0.93
Fuel Trim Max Lean Limit	0172	NOx	0.200	1.5 times	0.300	0.008	1.730	0.014	0.07	
MIL on CNG	0175	CO	4.200	1.5 times	6.300	9.111	1.620	14.760	3.51	
23-Feb		NMHC	0.125	1.75 times	0.218	0.040	1.370	0.055	0.44	
Fuel Trim Max Lean Limit	0172	NOx	0.200	1.5 times	0.300	0.090	1.730	0.156		0.78
MIL on Gasoline	0175	CO	4.200	1.5 times	6.300	1.962	1.620	3.178		0.76
24-Feb		NMHC	0.125	1.75 times	0.218	0.094	1.370	0.129		1.03

TABLE 2

OBD II Monitor Threshold Tests O2, Misfire, and Catalyst Monitors

ECO GM 1500 Tier 2 Bin 8

Monitor Test Descriptiion	Codes Set	Emission Component	Tier 2 Bin 8 Standards	Malfunction Critera relative to Standard	Target MIL Threshold	4K FTP 75 Emissions at Gasoline Thresholds	EPA Assigned DFs	U/L FTP 75 Emissions at Gasoline Thresholds	MIL Threshold with Gasoline Calibration	
									CNG	Gasoline
O2 Sensor Response Rat	0133	NOx	0.200	1.5 times	0.300	0.128	1.730	0.221	1.11	
MIL set CNG	0153	CO	4.200	1.5 times	6.300	0.602	1.620	0.975	0.23	
1st March		NMHC	0.125	1.75 times	0.218	0.016	1.370	0.022	0.18	
O2 Sensor Response Rat	0133	NOx	0.200	1.5 times	0.300	0.116	1.730	0.201		1.00
MIL set Gasoline	0153	CO	4.200	1.5 times	6.300	1.281	1.620	2.075		0.49
2nd March		NMHC	0.125	1.75 times	0.218	0.072	1.370	0.099		0.79
Misfire CNG	0300	NOx	0.200	1.5 times	0.300	0.188	1.730	0.325	1.63	
		CO	4.200	1.5 times	6.300	0.284	1.620	0.460	0.11	
		NMHC	0.125	1.75 times	0.218	0.038	1.370	0.052	0.42	
Misfire Gasoline	0300	NOx	0.200	1.5 times	0.300	0.067	1.730	0.116		0.58
		CO	4.200	1.5 times	6.300	1.486	1.620	2.407		0.57
		NMHC	0.125	1.75 times	0.218	0.178	1.370	0.244		1.95
CAT Monitor CNG	no MIL	NOx	0.200	1.5 times	0.300	0.090	1.730	0.156	0.78	
		CO	4.200	1.5 times	6.300	0.914	1.620	1.481	0.35	
		NMHC	0.125	1.75 times	0.218	0.017	1.370	0.023	0.19	
CAT Monitor Gasoline	0420	NOx	0.200	1.5 times	0.300	0.188	1.730	0.325		1.63
		CO	4.200	1.5 times	6.300	1.426	1.620	2.310		0.55
		NMHC	0.125	1.75 times	0.218	0.108	1.370	0.148		1.18

TABLE 3
OBD II Monitor Threshold Tests Baseline and Fuel Trim Monitors
ECO Ford 500 Tier 2 Bin 5

Monitor Test Descriptiion	Codes Set	Emission Component	Tier 2 Bin 5 Standards	Malfunction Critera relative to Standard	Target MIL Threshold	4K FTP 75 Emissions at Gasoline Thresholds	EPA Assigned DFs	U/L FTP 75 Emissions at Gasoline Thresholds	MIL Threshold with Gasoline Calibration	
									CNG	Gasoline
Baseline CNG	None	NOx	0.070	1.5 times	0.105	0.029	1.730	0.050	0.72	
No MIL		CO	4.200	1.5 times	6.300	0.425	1.620	0.689	0.16	
		NMHC	0.090	1.75 times	0.158	0.009	1.370	0.012	0.14	
Baseline Gasoline	None	NOx	0.070	1.5 times	0.105	0.016	1.730	0.028		0.40
No MIL		CO	4.200	1.5 times	6.300	0.232	1.620	0.376		0.09
		NMHC	0.090	1.75 times	0.158	0.027	1.370	0.037		0.41
Fuel Trim Max Rich Limit	0171	NOx	0.070	1.5 times	0.105	0.021	1.730	0.036	0.52	
MIL pending on CNG	0174	CO	4.200	1.5 times	6.300	0.303	1.620	0.491	0.12	
3rd March		NMHC	0.090	1.75 times	0.158	0.006	1.370	0.008	0.09	
Fuel Trim Max Rich Limit	0171	NOx	0.070	1.5 times	0.105	0.044	1.730	0.076		1.09
MIL set on Gasoline	0174	CO	4.200	1.5 times	6.300	0.373	1.620	0.604		0.14
28-Feb		NMHC	0.090	1.75 times	0.158	0.056	1.370	0.077		0.85
Fuel Trim Max Lean Limit	0172	NOx	0.070	1.5 times	0.105	0.255	1.730	0.441	6.30	
MIL illuminated on CNG	0175	CO	4.200	1.5 times	6.300	0.363	1.620	0.588	0.14	
2nd March		NMHC	0.090	1.75 times	0.158	0.020	1.370	0.027	0.30	
Fuel Trim Max Lean Limit	0172	NOx	0.070	1.5 times	0.105	0.172	1.730	0.298		4.25
MIL on Gasoline	0175	CO	4.200	1.5 times	6.300	0.738	1.620	1.196		0.28
1st March		NMHC	0.090	1.75 times	0.158	0.043	1.370	0.059		0.65

TABLE 4

OBD II Monitor Threshold Tests O2 and Misfire Monitors

ECO Ford 500 Tier 2 Bin 5

Monitor Test Descriptiion	Codes Set	Emission Component	Tier 2 Bin 5 Standards	Malfunction Critera relative to Standard	Target MIL Threshold	4K FTP 75 Emissions at Gasoline Thresholds	EPA Assigned DFs	U/L FTP 75 Emissions at Gasoline Thresholds	MIL Threshold with Gasoline Calibration	
									CNG	Gasoline
O2 Sensor Response Rate	0133	NOx	0.070	1.5 times	0.105	0.042	1.730	0.073	1.04	
MIL set CNG	0153	CO	4.200	1.5 times	6.300	0.913	1.620	1.479	0.35	
24th Feb.		NMHC	0.090	1.75 times	0.158	0.006	1.370	0.008	0.09	
O2 Sensor Response Rate	0133	NOx	0.070	1.5 times	0.105	0.047	1.730	0.081		1.16
MIL set Gasoline	0153	CO	4.200	1.5 times	6.300	0.813	1.620	1.317		0.31
		NMHC	0.090	1.75 times	0.158	0.040	1.370	0.055		0.61
Misfire CNG		NOx	0.070	1.5 times	0.105	0.084	1.730	0.145	2.08	
		CO	4.200	1.5 times	6.300	0.552	1.620	0.894	0.21	
		NMHC	0.090	1.75 times	0.158	0.005	1.370	0.007	0.08	
Misfire Gasoline		NOx	0.070	1.5 times	0.105	0.000	1.730	0.000		0.00
(Not completed)		CO	4.200	1.5 times	6.300	0.000	1.620	0.000		0.00
		NMHC	0.090	1.75 times	0.158	0.000	1.370	0.000		0.00

TABLE 5
OBD II Monitor Threshold Tests at Gasoline Thresholds
BAF 2006 CNG Crown Victoria

Monitor Test Description	Emission Component	Applicable Emission Standard SULEV II	Target MIL Threshold 2.5 times Standard	CNG FTP 75 Emission Results at gasoline monitor Thresholds	CNG MIL Threshold with gasoline calibration
Fuel Trim Max Lean Limit-25%	NOx	0.020	0.050	0.032	1.6
MIL illuminated	CO	1.000	2.500	0.140	
	NMHC	0.010	0.025	0.005	
Fuel Trim Max Rich Limit +25%	NOx	0.020	0.050	0.022	
MIL not illuminated, Ford sets	CO	1.000	2.500	1.786	1.786
MIL to illuminate at +26%	NMHC	0.010	0.025	0.043	
EGR flow rate restricted 60%	NOx	0.020	0.050	0.017	0.85
until MIL is illuminated	CO	1.000	2.500	0.127	
	NMHC	0.010	0.025	0.001	
Oxygen sensor response rate:	NOx	0.020	0.050	0.091	4.55
MIL set at 10% normal frequency	CO	1.000	2.500	0.130	
of 1.52 Hz	NMHC	0.010	0.025	0.003	
Misfire Monitor	NOx	0.020	0.050	0.085	4.25
MIL set at 1.2% misfire	CO	1.000	2.500	0.270	
	NMHC	0.010	0.025	0.041	4.1
Catalyst Monitor	NOx	0.020	0.050	0.017	0.85
Tests on Ford Threshold Cats	CO	1.000	2.500	2.234	2.234
MIL illuminated	NMHC	0.010	0.025	0.009	0.9

TABLE 6

OBD II Monitor Threshold Tests at Gasoline Thresholds
BAF Dedicated CNG Crown Vic. if certified to Tier 2 Bin 5 Levels

Malfunction Criteria	Emission Component	Tier 2 Bin 5 Standards	Target MIL Threshold	U/L FTP 75 Emissions at Gasoline Thresholds	MIL Threshold with Gasoline Calibration CNG
Fuel Trim Max Rich Limit	NOx	0.070	0.105 (1.5X)	0.022	0.31
MIL illuminated CNG	CO	4.200	6.30 (1.5X)	1.786	0.43
	NMHC	0.090	0.158 (1.75X)	0.043	0.48
Fuel Trim Max Lean Limit	NOx	0.070	0.105 (1.5X)	0.032	0.46
MIL illuminated CNG	CO	4.200	6.30 (1.5X)	0.140	0.03
	NMHC	0.090	0.158 (1.75X)	0.005	0.06
Oxygen sensor response rate:	NOx	0.070	0.105 (1.5X)	0.091	1.30
MIL set CNG, 0133, 0153	CO	4.200	6.30 (1.5X)	0.130	0.03
	NMHC	0.090	0.158 (1.75X)	0.003	0.03
EGR Flow rate restricted 60%	NOx	0.070	0.105 (1.5X)	0.017	0.24
MIL illuminated CNG	CO	4.200	6.30 (1.5X)	0.127	0.03
	NMHC	0.090	0.158 (1.75X)	0.001	0.01
Misfire Monitor	NOx	0.070	0.105 (1.5X)	0.085	1.21
MIL set at 1.2% misfire	CO	4.200	6.30 (1.5X)	0.270	0.06
	NMHC	0.090	0.158 (1.75X)	0.041	0.46
Catalyst Monitor	NOx	0.070	0.050	0.017	0.24
Tests on Ford Threshold Cats	CO	4.200	2.500	2.234	0.53
MIL illuminated	NMHC	0.090	0.025	0.009	0.10

TABLE 7

OBD II Monitor Threshold Tests with Thresholds reset for CNG Operation
BAF 2006 CNG Crown Victoria certified to CARB SULEV II Standards

Monitor Test Description	Codes Set	Emission Component	Applicable Emission Standard SULEV II	Target MIL Threshold 2.5 times Standard	CNG FTP 75 Emmissions 120K	MIL Threshold with BAF CNG calibration
Fuel Trim Max Lean Limit -40%	0171, 0174	NOx	0.020	0.050	0.018	0.9
MIL illuminated at -32%		CO	1.000	2.500	0.560	0.56
		NMHC	0.010	0.025	0.002	0.2
Fuel Trim Max Rich Limit +40%	0172, 0175	NOx	0.020	0.050	0.021	1.05
MIL illuminated at +32%		CO	1.000	2.500	0.569	0.569
		NMHC	0.010	0.025	0.003	0.3
EGR flow rate restricted 100%	0401,	NOx	0.020	0.050	0.031	1.55
MIL set to illuminate at this point		CO	1.000	2.500	0.869	0.869
		NMHC	0.010	0.025	0.007	0.7
Oxygen sensor response rate:	0133, 0153	NOx	0.020	0.050	0.019	0.95
MIL illuminated		CO	1.000	2.500	1.328	1.328
		NMHC	0.010	0.025	0.002	0.2
Misfire Monitor	0300,	NOx	0.020	0.050	0.053	2.65
MIL set at 1.0% misfire		CO	1.000	2.500	2.700	2.7
		NMHC	0.010	0.025	0.007	0.7
Catalyst Monitor	0420, 0430	NOx	0.020	0.050	0.017	0.85
MIL illuminated		CO	1.000	2.500	2.234	2.234
		NMHC	0.010	0.025	0.009	0.9

TABLE 8

OBD II Monitor Threshold Tests with Thresholds Reset for CNG Operation
BAF 2006 CNG Crown Victoria Certified to EPA Tier 2 Bin 2 Standards

Monitor Test Description	Codes Set	Emission Component	Applicable Emission Standard Tier 2 Bin 2	Target MIL Threshold 2.5 times Standard	CNG FTP 75 Emissions 120K	MIL Threshold with BAF CNG calibration
Fuel Trim Max Lean Limit -40% MIL illuminated at -32%	0171, 0174	NOx CO NMHC	0.020 2.100 0.010	0.050 5.250 0.025	0.018 0.560 0.002	0.90 0.27 0.20
Fuel Trim Max Rich Limit +40% MIL illuminated at +32%	0172, 0175	NOx CO NMHC	0.020 2.100 0.010	0.050 5.250 0.025	0.021 0.569 0.003	1.05 0.27 0.30
EGR flow rate restricted 100% MIL set to illuminate at this point	0401,	NOx CO NMHC	0.020 2.100 0.010	0.050 5.250 0.025	0.031 0.869 0.007	1.55 0.41 0.70
Oxygen sensor response rate: MIL illuminated	0133, 0153	NOx CO NMHC	0.020 2.100 0.010	0.050 5.250 0.025	0.019 1.328 0.002	0.95 0.63 0.20
Misfire Monitor MIL set at 1.0% misfire	0300,	NOx CO NMHC	0.020 2.100 0.010	0.050 5.250 0.025	0.053 2.700 0.007	2.65 1.29 0.70
Catalyst Monitor MIL illuminated	0420, 0430	NOx CO NMHC	0.020 2.100 0.010	0.050 5.250 0.025	0.017 2.234 0.009	0.85 1.06 0.90

TABLE 9

OBD II Monitor Threshold Tests Baseline and Fuel Trim Monitors

ECO GM 1500 Tier 2 Bin 5 Certification Level

Monitor Test Description	Codes Set	Emission Component	Tier 2 Bin 5 Standards	Malfunction Criteria relative to Standard	Target MIL Threshold	4K FTP 75 Emissions at Gasoline Thresholds	EPA Assigned DFs	U/L FTP 75 Emissions at Gasoline Thresholds	MIL Threshold with Gasoline Calibration	
									CNG	Gasoline
O2 Sensor Response Rate	0133	NOx	0.070	1.5 times	0.300	0.128	1.730	0.221	3.16	
MIL set CNG	0153	CO	4.200	1.5 times	6.300	0.602	1.620	0.975	0.23	
1st March		NMHC	0.090	1.75 times	0.218	0.016	1.370	0.022	0.24	
O2 Sensor Response Rate	0133	NOx	0.070	1.5 times	0.300	0.116	1.730	0.201		2.87
MIL set Gasoline	0153	CO	4.200	1.5 times	6.300	1.281	1.620	2.075		0.49
2nd March		NMHC	0.090	1.75 times	0.218	0.072	1.370	0.099		1.10
Fuel Trim Max Rich Limit	0171	NOx	0.070	1.5 times	0.300	0.029	1.730	0.050	0.72	
MIL on CNG	0174	CO	4.200	1.5 times	6.300	0.400	1.620	0.648	0.15	
22-Feb		NMHC	0.090	1.75 times	0.218	0.014	1.370	0.019	0.21	
Fuel Trim Max Rich Limit	0171	NOx	0.070	1.5 times	0.300	0.071	1.730	0.123		1.75
MIL on Gasoline	0174	CO	4.200	1.5 times	6.300	0.699	1.620	1.132		0.27
28-Feb		NMHC	0.090	1.75 times	0.218	0.085	1.370	0.116		1.29
Fuel Trim Max Lean Limit	0172	NOx	0.070	1.5 times	0.300	0.008	1.730	0.014	0.20	
MIL on CNG	0175	CO	4.200	1.5 times	6.300	9.111	1.620	14.760	3.51	
23-Feb		NMHC	0.090	1.75 times	0.218	0.040	1.370	0.055	0.61	
Fuel Trim Max Lean Limit	0172	NOx	0.070	1.5 times	0.300	0.090	1.730	0.156		2.22
MIL on Gasoline	0175	CO	4.200	1.5 times	6.300	1.962	1.620	3.178		0.76
24-Feb		NMHC	0.090	1.75 times	0.218	0.094	1.370	0.129		1.43