# Appendix B - Overview and Results of CNG Emission Testing Programs

## A. Background

Two studies have been conducted to evaluate CNG fuel quality effects on light-duty and heavy-duty vehicle driveability, emissions, and fuel economy. These studies are referred to as the Natural Gas Vehicle Technology and Fuel Performance Evaluation Program (PEP).

The PEP studies were supported by a collaborative group that included the Gas Research Institute (GRI), Pacific Gas & Electric (PG&E), Southern California Gas Company (SoCalGas), Atlanta Gas Light Company (AGL), U.S. Environmental Protection Agency (EPA), Air Resources Board (ARB), and auto manufacturers. The Clean Air Vehicle Technology Center (CAVTC) was contracted to conduct the testing and data evaluation. The results from these studies are documented in a light-duty vehicle test report,[1] completed in 1997, and a heavy-duty data presentation,[2] presented in 2000.

## B. Light Duty Test Program

### 1. Test Protocol

The light-duty testing included emissions tests, fuel economy tests, including highway and acceleration, and driveability tests.[1] The emissions tests used the standard 3-phase Federal Test Procedure (FTP) test cycle and the additional acceleration phase (US06) from the proposed supplemental FTP cycle presented by the United States Environmental Protection Agency (U.S. EPA) in 1994. Each test was run twice for each vehicle/fuel combination to determine test repeatability. The measured emissions included total hydrocarbons (THC), methane (CH4), non-methane organic gases (NMOG), nitrogen oxides (NOx), carbon monoxide (CO), and carbon dioxide ($CO_2$). The vehicles tested included both dedicated NGVs (designed to use only CNG fuel) and bi-fuel vehicles. Some of these NGVs were designed and built by OEMs and others were after-market conversions, as shown in Table B-1 below. The Dodge Dakota vehicle was unique in that it was a bi-fuel prototype designed and built by an OEM. The emissions data for the individual vehicles are provided in Attachment B-1 at the end of this appendix.

**Table B-1: Light-Duty Vehicle Testing - Vehicles**

| Year | Make & Model | Type | OEM | Conversion |
|---|---|---|---|---|
| 1994 | Dodge Caravan | Dedicated | X | |
| 1994 | Dodge Ram Van | Dedicated | X | |
| 1992 | Ford Crown Victoria | Dedicated | X | |
| 1993 | Honda Accord | Dedicated | X | |
| 1994 | GMC Sierra (Cardinal) | Dedicated | | X |
| 1992 | GMC Sierra (PAS) | Dedicated | | X |
| 1995 | Ford F250 (QVM) | Bi-fuel | | X |
| 1994 | Dodge Dakota | Bi-fuel | X | |

The fuels tested, shown in Table B-2, covered Wobbe numbers and methane numbers inclusive of the variation of the gas produced in the South Central Coast and Southern San Joaquin Valley. The current CNG motor vehicle fuel specifications are included in the last column of this table for comparison. Methane numbers of the tested fuels ranged from approximately 63 to 100 and Wobbe numbers from 1425 to 1182. The gas compositions were speciated out to C4+. The C4+ was assumed to be butane for the calculation of the methane number. Only TF-5 had a significant C4+ content. If the C4+ actually included heavier hydrocarbons than butane, the MN of the test fuel would be lower than reported. Methane content for the fuels ranged from 82 percent to 94 percent, ethane content from two percent to eight percent and C3+ from zero percent to 10 percent.

**Table B-2: Light-Duty Vehicle Testing - Fuels**

| Mole % | TF-1 | TF-2 | TF-3 | TF-4 | TF-5 | Current Spec |
|---|---|---|---|---|---|---|
| Methane | 91.44 | 90.04 | 84.89 | 94.97 | 82.38 | 88.0 min |
| **Ethane** | 1.75 | 4.0 | 8.44 | 3.02 | 4.65 | 6.0 max |
| **Propane** | 0.00 | C3+ = 2.0 | 0.00 | 0.14 | 6.00 | C3+ = 3.0 max |
| **C4+** | 0.02 | | 0.00 | 0.06 | 4.07 | |
| **Inerts** | 6.78 | 3.5 | 6.40 | 1.79 | 2.89 | 1.5-4.5 |
| **Oxygen** | 0.01 | 0.5 | 0.27 | 0.02 | 0.02 | 1.0 max |
| **MN*** | 103 | 89 | 88 | 99 | 63 | NA |
| **Wobbe** | 1245 | 1182 | 1284 | 1341 | 1425 | NA |

*ARB staff calculation

2. Test Results

Figure B-1, Figure B-2, and Figure B-3 below show the variation of NOx, CO and NMOG emissions as measured with the FTP cycle for the OEM dedicated light-duty vehicles as a function of fuel methane number. Applicable ARB 50,000 mile ultra low-emissions vehicle (ULEV) standards for the vans and for the passenger cars are shown in these figures for reference. The higher ULEV standards correspond to the two vans, the Caravan and the Ram, while the lower ULEV standards correspond to the two passenger cars, the Accord and Crown Victoria. These standards are only applicable to the FTP test cycle emissions. The emissions from all the OEM dedicated vehicles were below the applicable ULEV standard with each of the tested fuels. Additionally, the NMOG values in Figure B-3 have not been adjusted by the natural gas reactivity adjustment factor of 0.41. Applying this adjustment factor drops these values an additional 60 percent.[1]

**Figure B-1: Measured NOx Emissions from Dedicated Light-Duty Vehicles with the FTP Test Cycle**

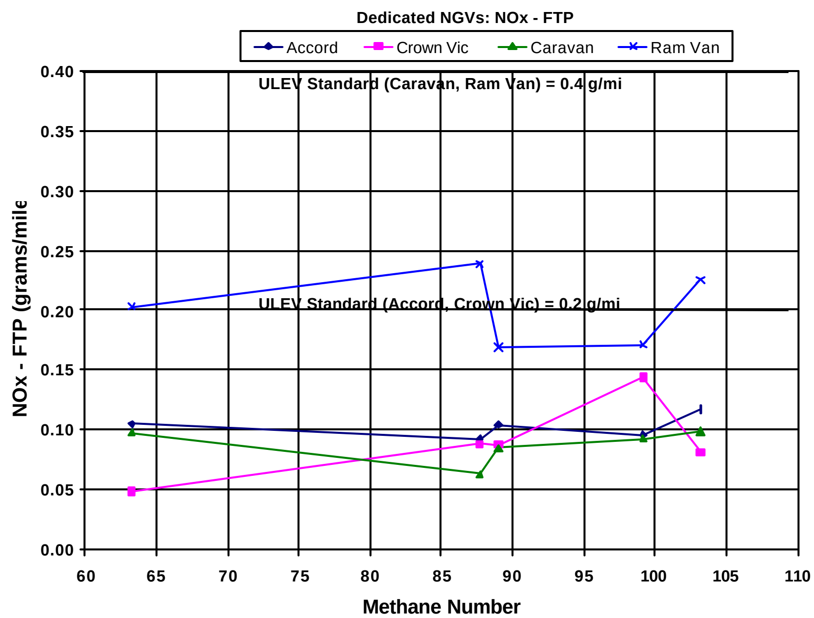


**Figure B-2: Measured CO Emissions from Dedicated Light-Duty Vehicles with the FTP Test Cycle**

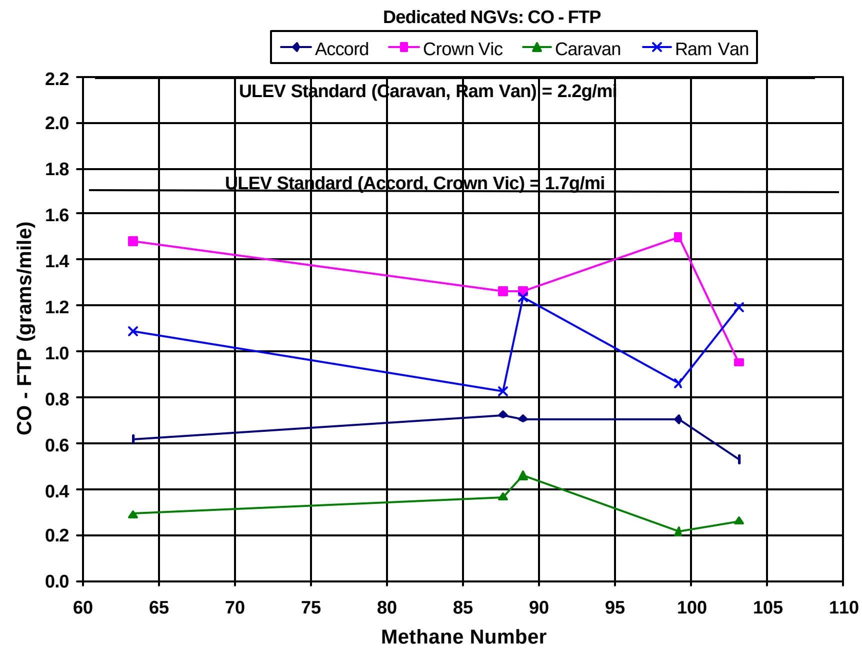



**Figure B-3: Measured NMOG Emissions from Dedicated Light-Duty Vehicles with the FTP Test Cycle**

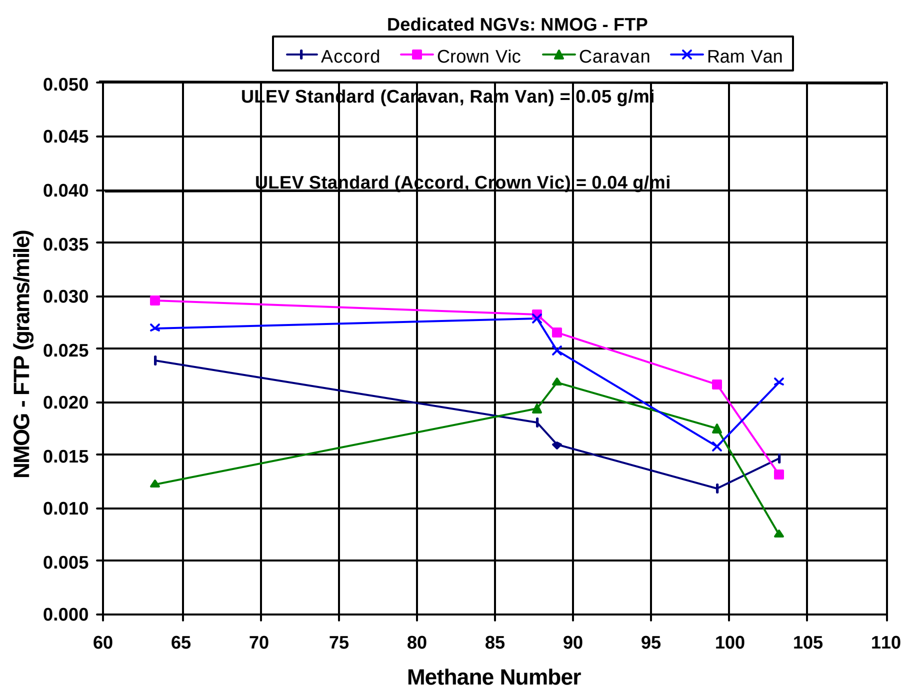


Figure B-4, Figure B-5, and Figure B-6 below show the variation of NOx, CO and NMOG emissions for the after-market conversion dedicated and bi-fuel light-duty vehicles as a function of fuel methane number as measured with the FTP cycle. The OEM prototype bi-fuel Dodge Dakota is included in these figures. The ARB 50,000 mile ultra low-emissions vehicle (ULEV) standard, low emissions vehicle (LEV) standard, and transitional low emission vehicle (TLEV) standard for the this vehicle type (light-duty trucks, 3751-5750 lbs.) are shown in these figures for comparison. Again, these standards are only applicable to the FTP test cycle emissions.

As shown in the figures below, the after-market conversion vehicles and the OEM prototype bi-fuel vehicle had higher emissions and more variation in emissions with fuel quality than the OEM dedicated fuel vehicles. However, all of these vehicles had NMOG emission levels within the LEV standard and NOx levels that were at or near the TLEV standard. Three of the four vehicles also met the TLEV/LEV CO emissions standard. The GMC (PAS), an after-market conversion dedicated vehicle, had CO emissions that were consistently higher than the standard for all tested fuels.

**Figure B-4: Measured NOx Emissions from After-market Conversion and OEM Prototype Light-Duty Vehicles with the FTP Test Cycle**

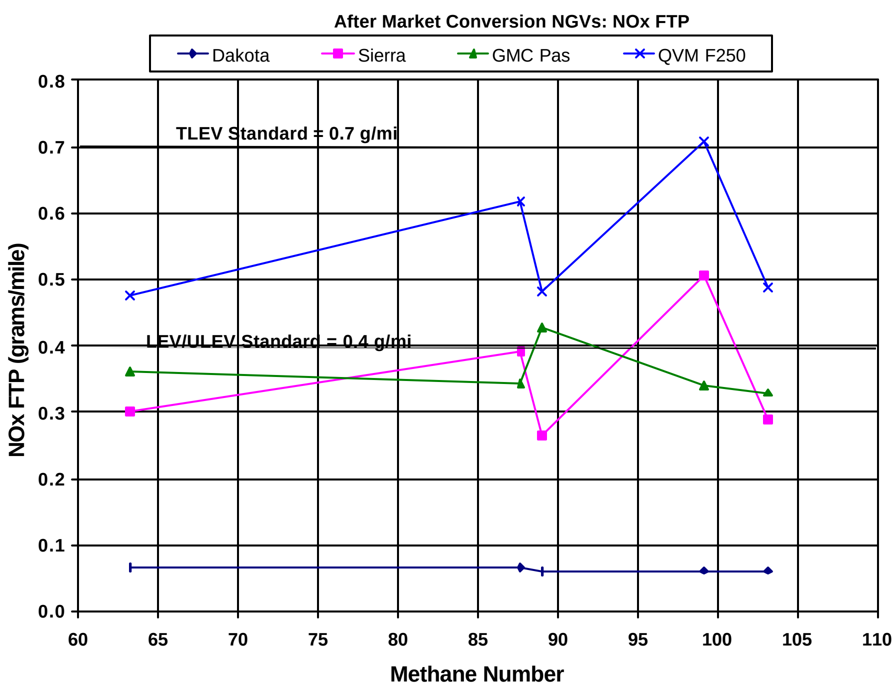


**Figure B-5: Measured CO Emissions from After-market Conversion and OEM Prototype Light-Duty Vehicles with the FTP Test Cycle**

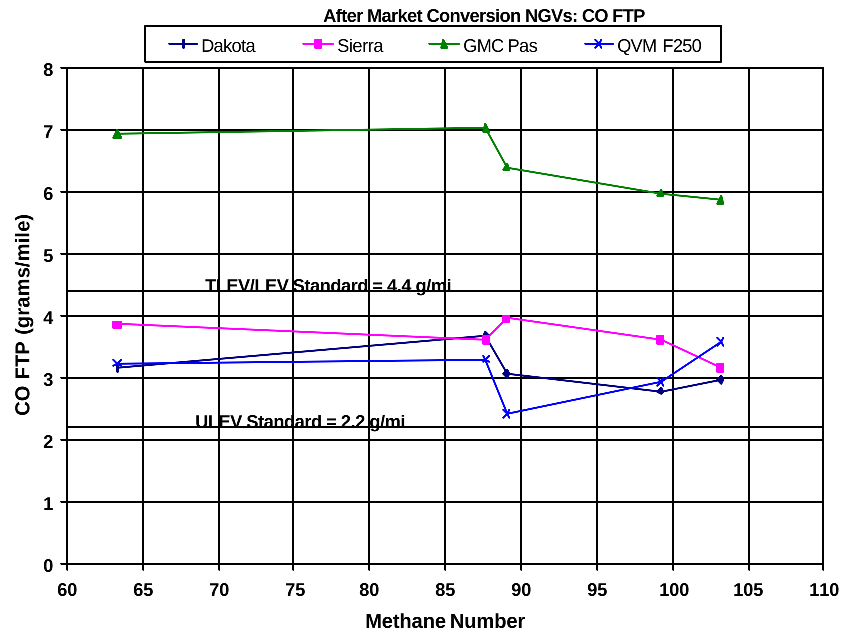



**Figure B-6: Measured NMOG Emissions from After-market Conversion and OEM Prototype Light-Duty Vehicles with the FTP Test Cycle**

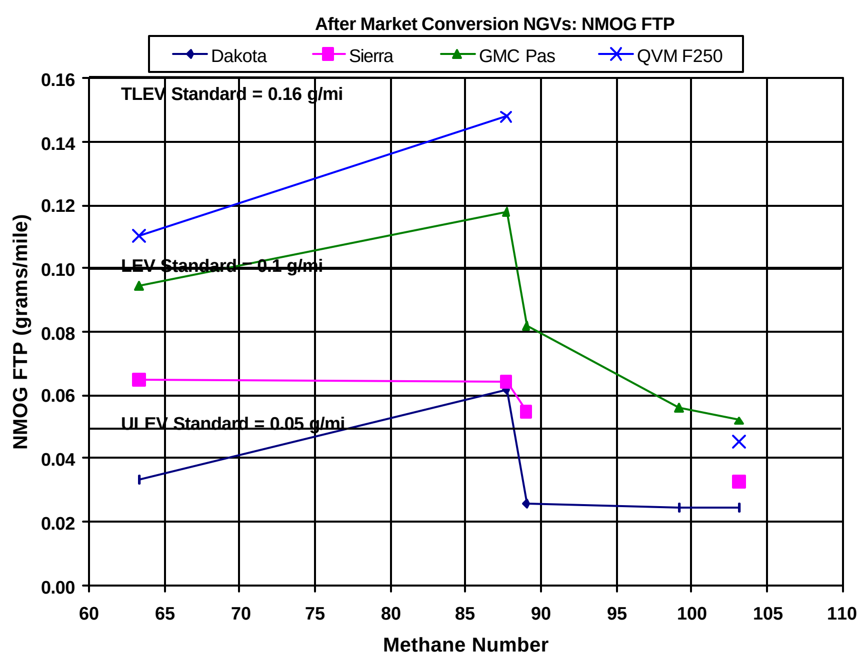
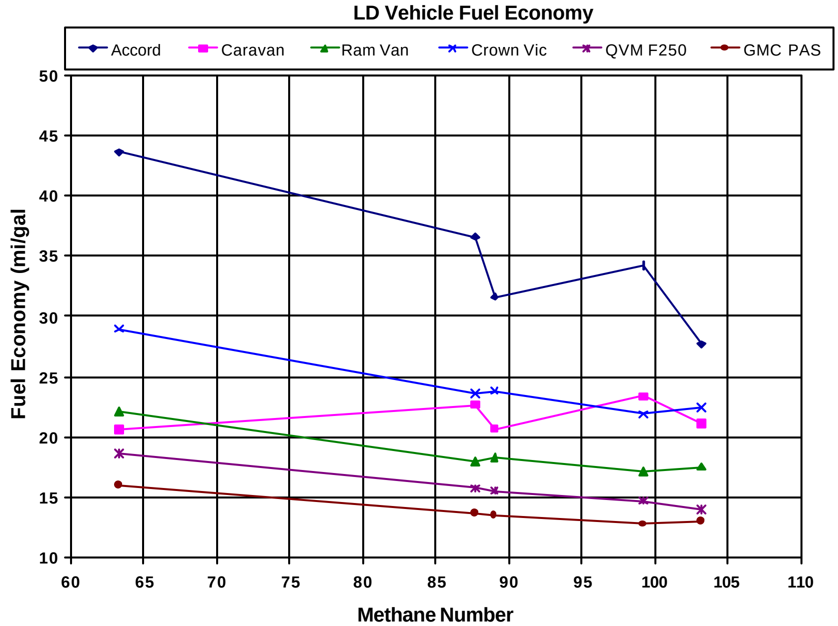



Figure B-7 below shows that fuel economy was either insensitive to fuel quality or increased with the reduced methane number.

**Figure B-7: Measured Fuel Economy with Light Duty Vehicles with the FTP Test Cycle**




C. Heavy Duty Test Program

1. Test Protocol

The heavy-duty vehicle testing evaluated emissions, fuel economy, and performance of seven different HD vehicles with four different fuels.[2] Testing included three different drive cycles with three tests run for each cycle/fuel/vehicle combination. The three drive cycles used were the EPA Heavy-Duty Urban Dynomometer Driving Schedule (UDDS), the Commuter cycle, and the Modified Central Business District (Mod-CBD) cycle. The measured emissions included total hydrocarbons (THC), methane (CH4), non-methane hydrocarbons (NMHC), nitrogen oxides (NOx), carbon monoxide (CO), and carbon dioxide ($CO_2$). The seven vehicles tested included both open loop and closed loop technology engines, as shown in Table B-3 below. The closed loop technology engines are designated as either advanced or first generation in Table B-3. The Cummins closed loop technology engine is considered first generation closed loop technology and is not as adaptable to variable fuel quality as the advanced generation closed loop technology engines such as the John Deere.

**Table B-3: Heavy-Duty Vehicle Testing - Vehicles**

| Year | Make & Model | Duty | Control |
|---|---|---|---|
| 1997 | John Deer 8.1L | School Bus | Closed Loop, Advanced |
| 1999 | Cummins 8.3L | School Bus | Closed Loop, First Generation |
| 1996 | John Deere 6.8L | School Bus | Closed Loop, Advanced |
| 1999 | John Deere 8.1L | Crew Truck | Closed Loop, Advanced |
| 1996 | Detroit Diesel 8.5L Series 50 | Transit Bus | Open Loop |
| 1996 | Cummins 10.0L | Transit Bus | Open Loop |
| 1999/2000 | Detroit Diesel 12.7L Series60G(LNG)* | Tractor | Closed Loop, First Generation |

* Omitted from the data due to inconsistent data trends

The fuel qualities tested, shown in Table B-4, had methane contents ranging from 82 percent to 95 percent, ethane content from 3 percent to 8 percent and C3+ from 0 percent to 5 percent. The Wobbe numbers for the tested fuels ranged from 1310 to 1360 and methane numbers from 73 to 99. The methane number range included the lowest recommended fuel quality for advanced generation closed loop technology heavy-duty engines, methane number 73. The highest methane number fuel, labeled High Quality, meets the current CNG motor vehicle fuel specifications and exceeds the proposed specification of MN 80. The methane number calculated for the high ethane fuel, MN 81, is in the range of the calculated methane number for gas that meets the current specifications, MN ~ 80 – 82, as shown in Table D-1 in Appendix D. Although this high ethane fuel does not meet the current specifications, due to the slightly low methane content and the high ethane content, the emissions data using this fuel can be equated to a fuel that would meet the proposed MN 80 specification.

**Table B-4: Heavy-Duty Vehicle Testing - Fuels**

| Mole % | High C3+ | High Inerts/C3+ | High Ethane | High Quality* | Current Spec |
|---|---|---|---|---|---|
| Methane | 87.25 | 82.06 | 87.11 | 94.97 | 88.0 min |
| Ethane | 5.84 | 7.11 | 8.25 | 3.02 | 6.0 max |
| Propane | 3.06 | 3.83 | 1.81 | 0.14 | C3+ = 3.0 max |
| Iso-butane | 0.28 | 0.35 | 0.09 | 0.02 | |
| N-butane | 0.55 | 0.17 | 0.17 | 0.02 | |
| Iso-pentane | 0.08 | 0.06 | 0.02 | 0.01 | |
| N-pentane | 0.07 | 0.04 | 0.02 | 0.01 | |
| C6+ | 0.05 | 0.0 | 0.01 | 0.0 | |
| Inerts | 2.82 | 5.92 | 2.52 | 1.81 | 1.5-4.5 |
| Oxygen | 0.0 | 0.0 | 0.0 | 0.03 | 1.0 max |
| MN** | 77 | 73 | 81 | 99 | ~80-82*** |
| Wobbe** | 1363 | 1310 | 1359 | 1338 | |

* Meets current specification
** ARB staff calculation
***No current requirement for MN

Three tests were run for each cycle/fuel/vehicle combination for test repeatability. One exception to this was the 1996 8.5L Detroit Diesel Series 50 open loop technology transit bus tested with the UDDS cycle, where only two tests per fuel were completed. The other exception was the absence of particulate emissions data for 1997 8.1L John Deere closed loop technology school bus with the high ethane fuel. Only one measurement was available for this fuel/vehicle combination for the UDDS cycle. No data was available for this fuel/vehicle combination for the other two test cycles.

2. Test Results

The emissions and fuel economy results shown in the following tables and figures are for the UDDS driving schedule. The UDDS driving schedule generally resulted in the highest emissions levels as well as the highest fuel consumption.[3] Figure B-5 through Table B-7 below summarize the emissions data for each technology group. These tables give the range observed for each pollutant with each fuel quality. Table B-6 does not give a range since the first generation closed loop technology group was represented by a single vehicle. The emissions data for the individual vehicles are provided in Attachment B-1 at the end of this appendix. An average value for each cycle/fuel/vehicle combination is given in the attachment.

**Table B-5: Advanced Generation Closed Loop Technology Engine Emissions and Fuel Economy Comparison of MN99, MN81, and MN73 CNG**

| **Advanced Generation Closed Loop Technology, Vehicles # 1,3,4 only** | | | | | | |
|---|---|---|---|---|---|---|
| **Test Fuel MN** | **99** | | **81** | | **73** | |
| **Tailpipe emissions (grams/mile)** | **Minimum** | **Maximum** | **Minimum** | **Maximum** | **Minimum** | **Maximum** |
| **THC** | 8.0 | 8.6 | 7.5 | 7.9 | 7.5 | 8.2 |
| **CO** | 0.3 | 3.8 | 0.2 | 4.2 | 0.2 | 4.2 |
| **NOx** | 6.0 | 11.4 | 6.9 | 12.8 | 6.1 | 11.0 |
| **$CO_2$** | 910 | 980 | 944 | 1020 | 978 | 1077 |
| **NMHC** | 0.4 | 2.0 | 1.3 | 2.7 | 1.5 | 3.0 |
| **PM** | 0.013 | 0.032 | 0.009 | 0.029 | 0.008 | 0.031 |
| **(Mi/Gal.)** | 6.1 | 7.3 | 7.6 | 7.7 | 8.0 | 8.3 |

**Table B-6: First Generation Closed Loop Technology Engine Emissions and Fuel Economy Comparison of MN99, MN81, and MN73 CNG**

| First Generation Closed Loop Technology, Vehicle # 2 only | | | |
|---|---|---|---|
| **Test Fuel MN** | **99** | **81** | **73** |
| **Tailpipe emissions (grams/mile)** | | | |
| **THC** | 9.6 | 7.2 | 7.3 |
| **CO** | 0.7 | 0.7 | 0.8 |
| **NOx** | 10.3 | 12.4 | 12.4 |
| **$CO_2$** | 1070 | 1098 | 1144 |
| **NMHC** | 1.9 | 1.8 | 1.9 |
| **PM** | 0.066 | 0.043 | 0.039 |
| **(Mi/Gal.)** | 6.1 | 6.7 | 7.0 |

**Table B-7: Open Loop Technology Engine Emissions and Fuel Economy Comparison of MN99, MN81, and MN73 CNG**

| Open Loop Technology, Vehicles # 5 and 6 only | | | | | | |
|---|---|---|---|---|---|---|
| **Test Fuel MN** | **99** | | **81** | | **73** | |
| **Tailpipe emissions (grams/mile)** | **Minimum** | **Maximum** | **Minimum** | **Maximum** | **Minimum** | **Maximum** |
| **THC** | 5.2 | 11.0 | 5.3 | 9.1 | 5.2 | 12.8 |
| **CO** | 0.04 | 4.6 | 0.1 | 5.0 | 0.1 | 5.0 |
| **NOx** | 6.4 | 14.2 | 16.7 | 20.8 | 7.5 | 18.0 |
| **$CO_2$** | 1167 | 1259 | 1290 | 1469 | 1336 | 1478 |
| **NMHC** | 1.0 | 2.4 | 1.3 | 3.0 | 1.3 | 4.7 |
| **PM** | 0.025 | 0.035 | 0.033 | 0.051 | 0.021 | 0.055 |
| **(Mi/Gal.)** | 5.1 | 5.7 | 5.1 | 5.7 | 5.2 | 6.1 |

The closed loop technology 12.7L Detroit Diesel LNG tractor was omitted from the data presented because its CO and PM data trends were inconsistent with the other closed loop technology engine data. The LNG tractor PM emissions were over 10 times higher than those for the other engines, independent of fuel quality. Additionally, the LNG tractor CO emissions varied much more significantly with fuel quality than those from the other closed loop technology engines. However, this data can be found in Attachment B-1.

The PM emissions for the open and closed loop technology engines are shown in Figure B-8 and Figure B-9 versus methane number. Both the closed loop and the open loop technology engine PM emissions were 0.07 grams/mile or less with the majority of the data in the 0.02 to 0.04 gram/mile range. The typical PM variation with fuel quality seen in this data, 0.02 grams/mile, was not significantly different from the test to test variations seen within the data sets.

**Figure B-8: PM Emissions for Open Loop Technology Engines**

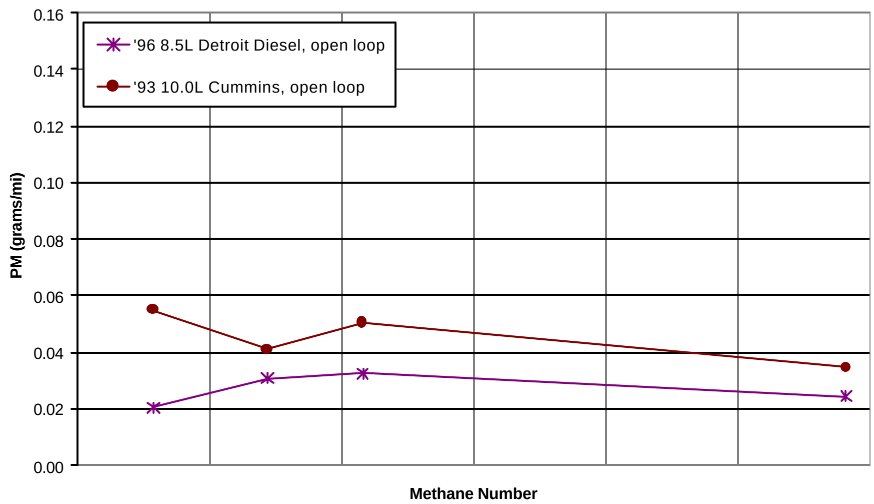
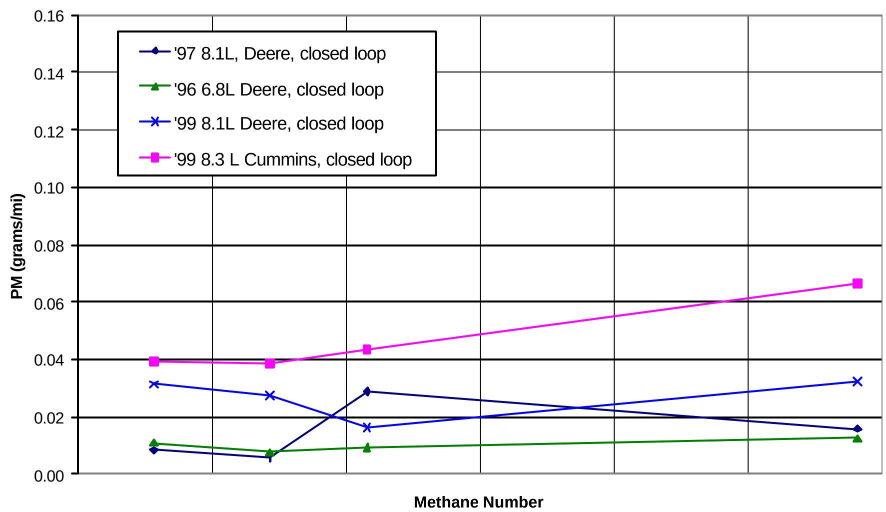



**Figure B-9: PM Emissions for Closed Loop Technology Engines**




NOx emissions for the open loop technology engines, shown in Figure B-10, were higher and had significantly more variation with fuel quality than those measured with the closed loop technology engines, shown in Figure B-11. The NOx emissions with the high quality MN99 fuel were similar in value between the open loop and closed loop technology engines. However, the open loop technology engines indicated an increase in

NOx emissions with reduced methane number that was not evident with the either the first generation or the advanced generation closed loop technology engines.

**Figure B-10: NOx Emissions for Open Loop Technology Engines**

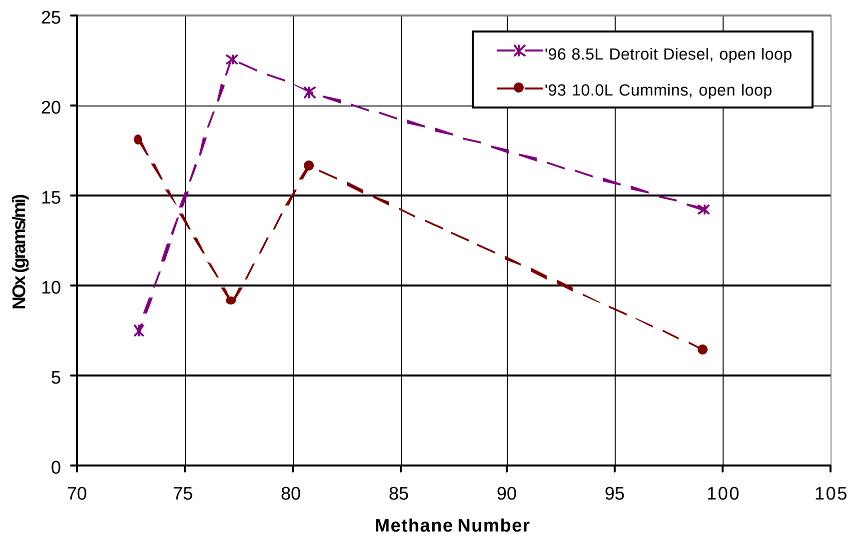
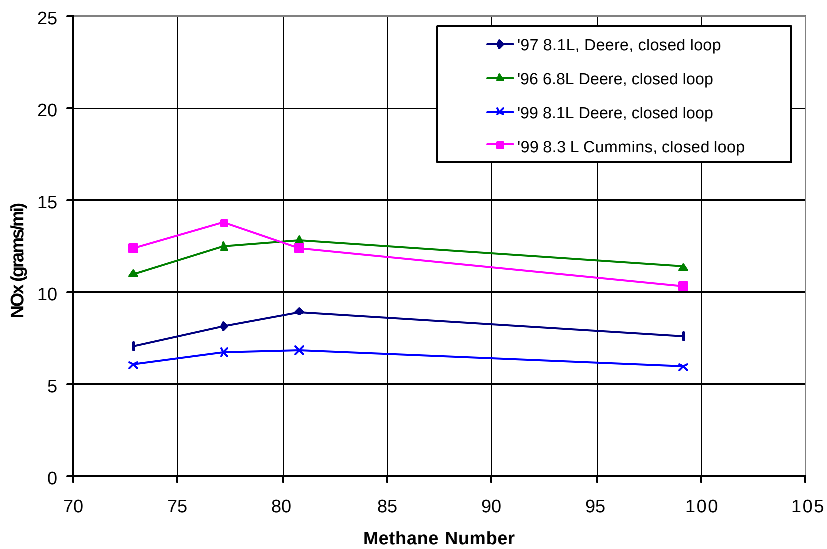



**Figure B-11: NOx Emissions for Closed Loop Technology Engines**



Non-methane hydrocarbon emissions trends with fuel quality, see Figure B-12 and Figure B-13, were similar for the open loop and closed loop technology engines. Both technologies indicated some increases in emissions with decreasing fuel quality. The Detroit Diesel open loop technology engine exhibited a larger increase in NMHC emissions with the MN73 fuel than any of the other engines. The advanced generation technology engines showed the most consistent trends from vehicle to vehicle with approximately a 10 percent increase from MN81 fuel quality to MN73 fuel quality.

**Figure B-12: NMHC Emissions for Open Loop Technology Engines**

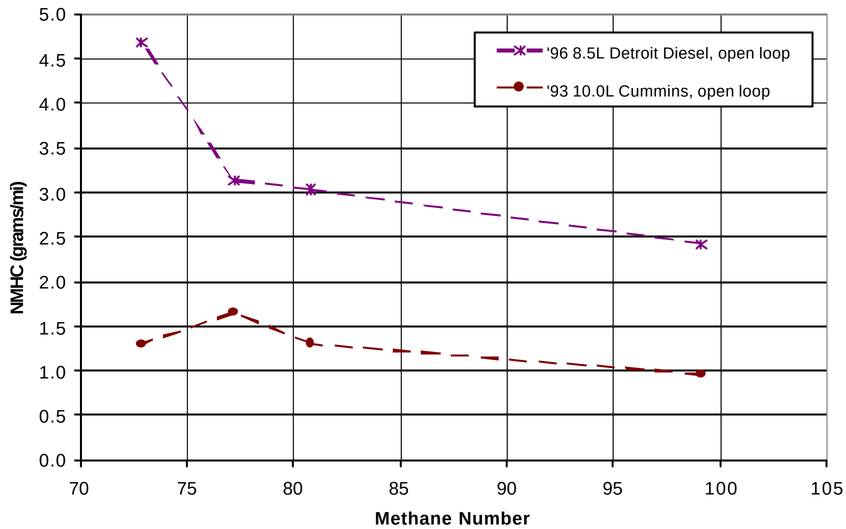
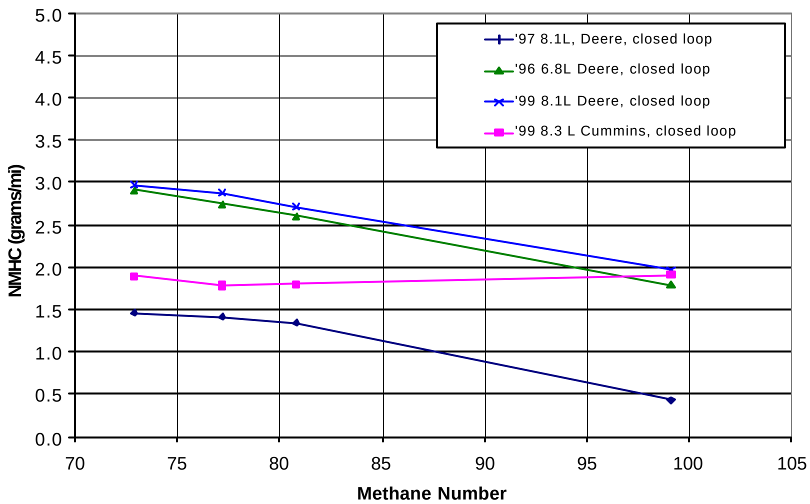


**Figure B-13:  NMHC Emissions for Closed Loop Technology Engines**




THC emissions for both open and closed loop technology engines are shown in Figure B-14 and Figure B-15 below.  With the exception of the Detroit Diesel open loop technology vehicle, there was minimal THC emissions variation with fuel quality.  The Cummins open loop technology engine actually produced lower THC emissions, 5 to 6 grams/mile, than any of the closed loop technology engines.  The THC emissions from all four of the closed loop technology engines were tightly grouped together at approximately 8 grams/mile.

**Figure B-14:  THC Emissions for Open Loop Technology Engines**

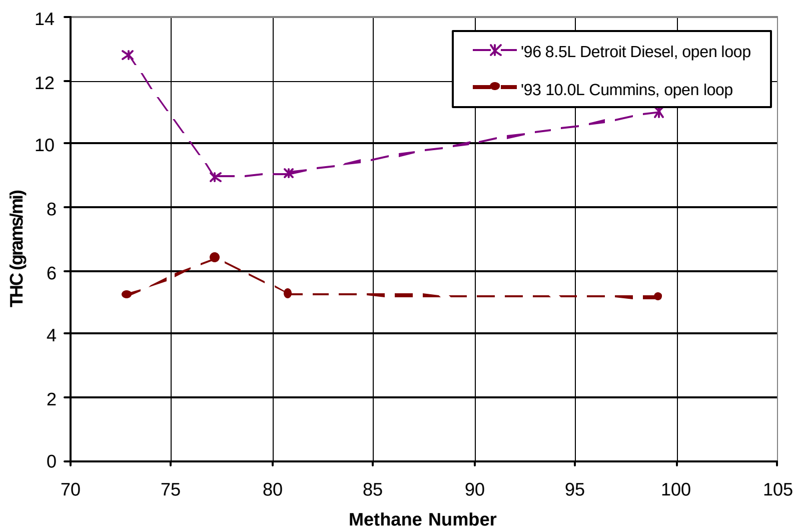
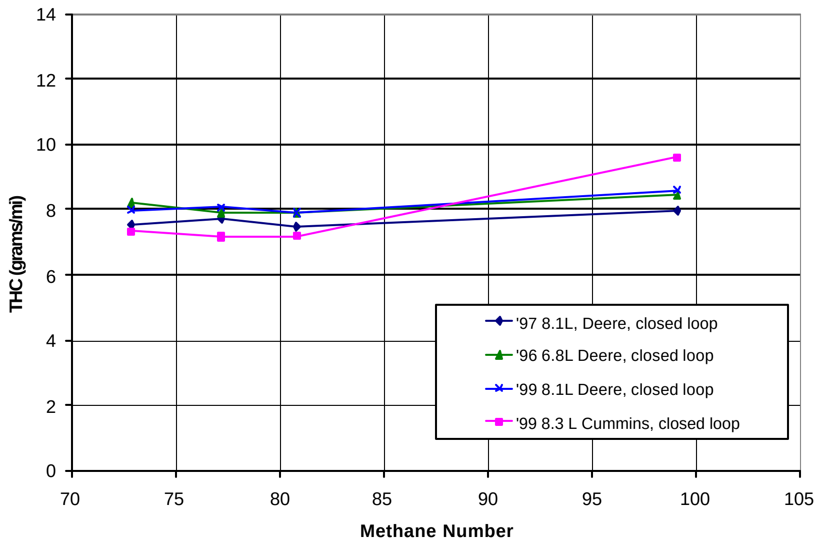


**Figure B-15: THC Emissions for Open Loop Technology Engines**




CO emissions for both open and closed loop technology engines, shown in Figure B-16 and Figure B-17, did not vary significantly with the variation of fuel quality. However, there was a significant difference between the CO emissions for the different engines. Both the first generation closed loop technology Cummins vehicle and the open loop technology Cummins engine as well as one of the advanced technology closed loop technology engines, the 1997 8.1L John Deere school bus, all had measured CO emissions of less than 1 gram/mile. The other two advanced technology closed loop technology engines had CO emissions of approximately 3 to 4 grams/mile. The Detroit Diesel open loop technology engine produced CO emissions of 4 to 5 grams/mile.

**Figure B-16: CO Emissions for Open Loop Technology Engines**

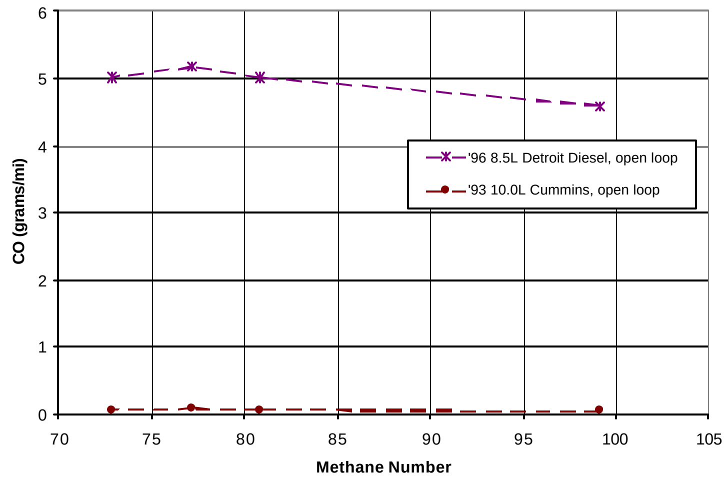
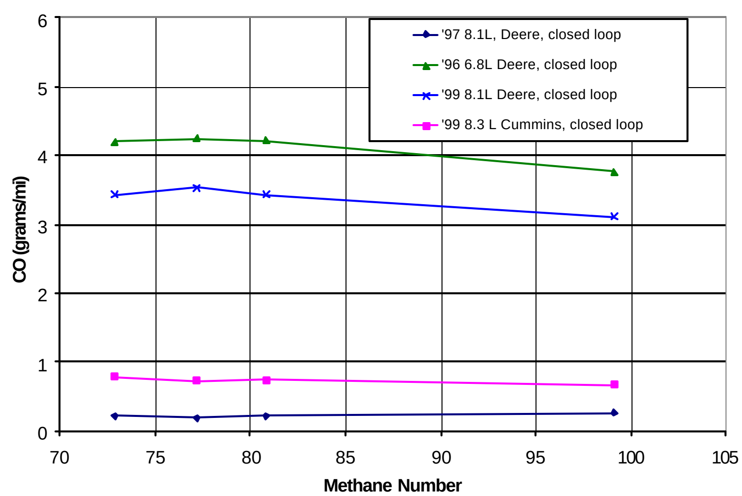



**Figure B-17: CO Emissions for Closed Loop Technology Engines**




$CO_2$ emissions for both open and closed loop technology engines are shown in Figure B-18 and Figure B-19 below. The $CO_2$ emissions for the open loop engines were higher than for the closed loop engines for all fuel qualities. The 1993 Cummins open loop vehicle had significant emissions variation with fuel quality. However the 1996 Detroit Diesel open loop vehicle and all the closed loop vehicles experienced only a six percent increase in emissions from the MN81 to the MN73 fuel quality.

**Figure B-18: $CO_2$ Emissions for Open Loop Technology Engines**

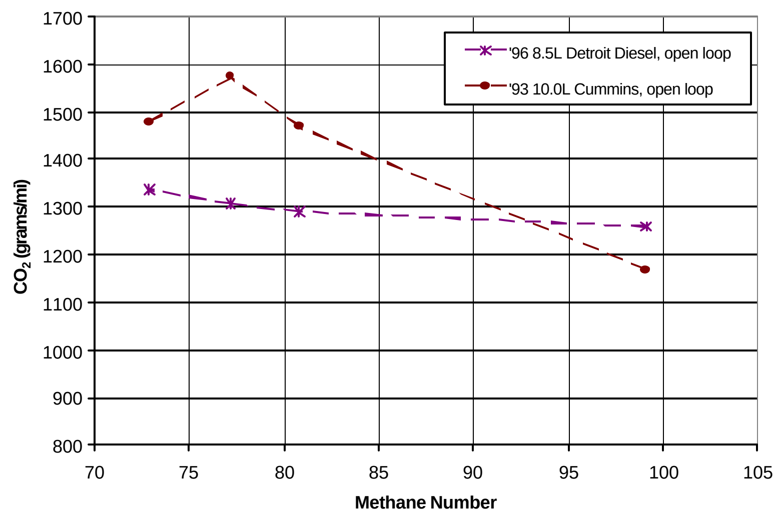



**Figure B-19: $CO_2$ Emissions for Closed Loop Technology Engines**

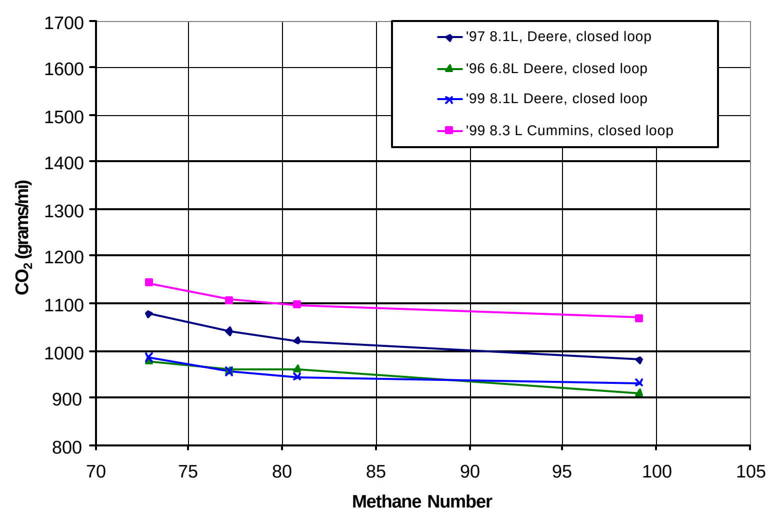



Figure B-20 and Figure B-21, below, show measured fuel economy as a function of fuel grade for the open and closed loop technology engines. The closed loop technology engines produced better fuel economy than the open loop technology engines. All of the closed loop technology engines and one of the open loop technology engines obtained better fuel economy with the lower MN fuels than with the higher MN fuel. The lower MN fuels contain larger fractions of higher molecular weight hydrocarbons, resulting in a higher energy content. The closed loop technology engines were better able to utilize the higher energy content fuels by adjusting the air/fuel ratio accordingly. Consequently, the closed loop technology engines showed a more consistent increase in fuel economy with fuel variations, an average 20 percent increase from MN99 to MN73 fuel quality, than the open loop technology engines. The open loop technology Detroit Diesel engine also showed a 20 percent increase with decreasing fuel MN. However in contrast, the open loop technology Cummins engine showed a 9 percent decrease in fuel economy with decreasing fuel MN.

**Figure B-20: Fuel Economy for Open Loop Technology Engines**

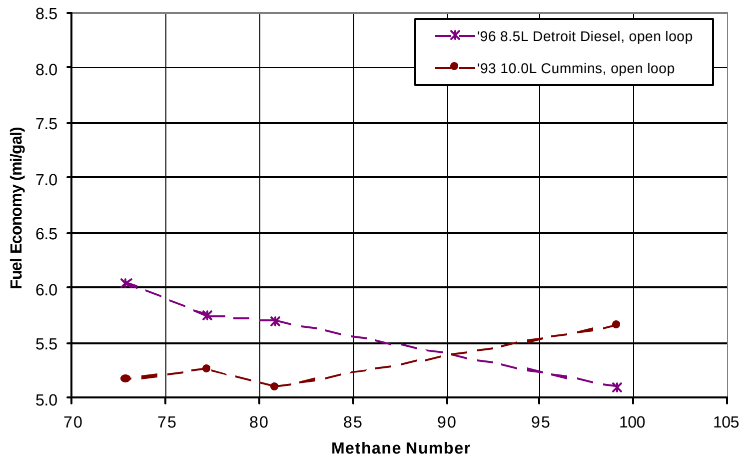
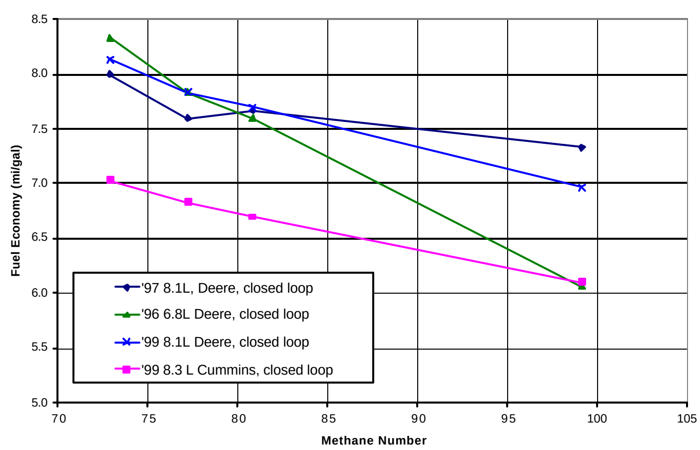



**Figure B-21: Fuel Economy for Closed Loop Technology Engines**




3. Data Analysis

### a) Coefficient of Variance

The coefficient of variance (COV) for the data was maintained at less than 10 percent for the majority of the data, as summarized in Table B-8 for the three technology types.

Table B-8: Coefficient of Variance for Different Technology Groups

| Technology Group | Average Coefficient of Variance (%) | | | | | | |
|---|---|---|---|---|---|---|---|
| | THC | CO | NOx | $CO_2$ | NMHC | Partic | Fuel Econ |
| Advanced Generation Closed Loop | 2.8% | 5.5% | 3.5% | 1.1% | 3.3% | 26.2% | 3.7% |
| First Generation Closed Loop | 2.6% | 4.0% | 2.7% | 0.5% | 3.0% | 16.9% | 0.6% |
| Open Loop | 1.6% | 15.2% | 4.5% | 0.9% | 2.5% | 43.1% | 1.0% |

The COV for the CO emissions exceeded 10 percent for three of the seven vehicles, the 1997 8.1L John Deere advanced generation closed loop technology school bus, the 1993 10.0L Cummins open loop technology transit bus, and the 1999/2000 12.7L Detroit Diesel Series 60G (LNG) closed loop technology tractor. The Detroit Diesel Series 60G (LNG) tractor was excluded from the summary due to inconsistent data trends. The high COVs for the John Deere and the Cummins vehicles were due to the low absolute value of the emissions. The standard deviations of the data were similar to that for the other test vehicles, but the measured CO emissions for these two vehicles were significantly lower, so the standard deviations were a higher percentage of the measured values.

The COVs for the PM emissions were also high due to low emission level. The COV for the PM emissions significantly exceeded 10 percent for at least two of the four fuels for every single vehicle, as evidenced in Table B-8. However, these high COVs were primarily due to the low measured PM emissions values. The PM test to test variations were small relative to more typical diesel PM measurements. However, again, these variations were a large percentage of the measured values for these vehicles. Consequently, while there appears to be a large degree of scatter in the PM emissions measurements, this variation is primarily due to the difficulty of measuring theses low values.

### b) Statistical Analysis

A statistical analysis of the NOx and PM emissions data showed minimal statistically significant differences between the different vehicle technology groups and fuels for the UDDS cycle data shown in the preceding figures. The PM emissions data analysis indicated that only the first generation vehicle with the high quality fuel, which appears anomalously high, was statistically different, at a 95 percent confidence level, than any of the other vehicle/fuel combinations. The NOx emissions data analysis indicated that within individual vehicle technology groups, there were no statistically differences from fuel to fuel. However, the NOx emission response of the advanced generation closed loop technology engines showed less variation than either the first generation closed loop technology engine or the open loop technology engines, as shown in Figure B-22. The results of the statistical analysis are summarized in Table B-9 and Table B-10 for PM and NOx respectively.

**Figure B-22: NOx Emission Response of the Different Engine Technologies**

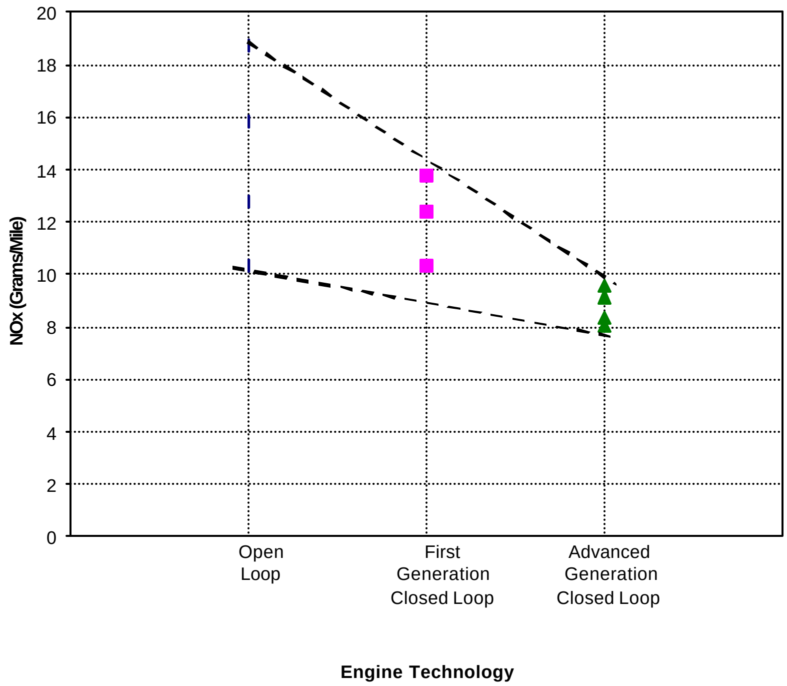



**Table B-9: Statistical Mean and Standard Error of the PM Emissions for the Three Technology Groups and Four Fuel Qualities**

| UDDS Cycle Technology Group | Pollutant | Fuel MN | Mean | Standard Error | Group* |
|---|---|---|---|---|---|
| **Closed Loop Advanced** | PM | 73 | 0.017 | 0.007 | A |
| **Closed Loop Advanced** | PM | 77 | 0.014 | 0.007 | A |
| **Closed Loop Advanced** | PM | 81 | 0.014 | 0.007 | A |
| **Closed Loop Advanced** | PM | 99 | 0.020 | 0.007 | A |
| **First Generation Closed Loop** | PM | 73 | 0.039 | 0.012 | A |
| **First Generation Closed Loop** | PM | 77 | 0.039 | 0.012 | A |
| **First Generation Closed Loop** | PM | 81 | 0.043 | 0.012 | A |
| **First Generation Closed Loop** | PM | 99 | 0.066 | 0.012 | B |
| **Open Loop** | PM | 73 | 0.039 | 0.009 | A B |
| **Open Loop** | PM | 77 | 0.035 | 0.009 | A B |
| **Open Loop** | PM | 81 | 0.042 | 0.009 | A B |
| **Open Loop** | PM | 99 | 0.029 | 0.009 | A |

*** Means that share the same letter are not statistically different**

**Table B-10: Statistical Mean and Standard Error of the NOx Emissions for the Three Technology Groups and Four Fuel Qualities**

| UDDS Cycle<br>Technology Group | Pollutant | Fuel MN | Mean | Standard Error | Group* |
|---|---|---|---|---|---|
| **Closed Loop Advanced** | NOx | 73 | 8.1 | 2.6 | C |
| **Closed Loop Advanced** | NOx | 77 | 9.1 | 2.6 | C |
| **Closed Loop Advanced** | NOx | 81 | 9.6 | 2.6 | C |
| **Closed Loop Advanced** | NOx | 99 | 8.3 | 2.6 | C |
| **First Generation Closed Loop** | NOx | 73 | 12.4 | 4.6 | C D |
| **First Generation Closed Loop** | NOx | 77 | 13.8 | 4.6 | C D |
| **First Generation Closed Loop** | NOx | 81 | 12.4 | 4.6 | C D |
| **First Generation Closed Loop** | NOx | 99 | 10.3 | 4.6 | C D |
| **Open Loop** | NOx | 73 | 12.8 | 3.2 | C D |
| **Open Loop** | NOx | 77 | 15.9 | 3.2 | C D |
| **Open Loop** | NOx | 81 | 18.7 | 3.2 | D |
| **Open Loop** | NOx | 99 | 10.3 | 3.2 | C D |

*** Means that share the same letter are not statistically different**

D. Estimated Effect on Individual Vehicle Emissions

From the test data presented in the preceding sections, staff concluded that for the advanced generation closed loop technology engines the data show no discernable emissions impact for NOx, PM, THC and CO. However, the data indicate increases of approximately six and 10 percent in $CO_2$ and NMHC respectively from MN81 to MN73 CNG. For first generation closed loop technology the data show similar emissions trends. However, for open loop technology the data indicate significant increases in NMHC of up to approximately 50 percent.

# Attachment B-1: Data Tables

## Table A: Measured Emissions From Light-Duty Dedicated Fuel OEM Vehicles[1]

Vehicle Emissions (grams/mile) - Dedicated OEMs

**NOx - FTP**

| Fuel | Wobbe | Accord | Crown Vic | Caravan | Ram Van | MN* |
|---|---|---|---|---|---|---|
| TF-1 | 1245 | 0.1175 | 0.0815 | 0.0988 | 0.2255 | 103 |
| TF-2 | 1182 | 0.1045 | 0.0880 | 0.0850 | 0.1695 | 89 |
| TF-3 | 1284 | 0.0930 | 0.0885 | 0.0630 | 0.2387 | 88 |
| TF-4 | 1341 | 0.0963 | 0.1442 | 0.0930 | 0.1715 | 99 |
| TF-5 | 1425 | 0.1050 | 0.0490 | 0.0980 | 0.2030 | 63 |

**NOx - US06**

| Fuel | Wobbe | Accord | Crown Vic | Caravan | Ram Van | MN* |
|---|---|---|---|---|---|---|
| TF-1 | 1245 | 0.3840 | 0.3625 | 0.1645 | 0.2987 | 103 |
| TF-2 | 1182 | 0.1570 | 0.2705 | 0.1340 | 0.2345 | 89 |
| TF-3 | 1284 | 0.1865 | 0.1970 | 0.1040 | 0.2700 | 88 |
| TF-4 | 1341 | 0.1203 | 0.3534 | 0.1680 | 0.2210 | 99 |
| TF-5 | 1425 | 0.1360 | 0.0935 | 0.1503 | 0.2700 | 63 |

**NMOG - FTP**

| Fuel | Wobbe | Accord | Crown Vic | Caravan | Ram Van | MN* |
|---|---|---|---|---|---|---|
| TF-1 | 1245 | 0.0146 | 0.0132 | 0.0076 | 0.0219 | 103 |
| TF-2 | 1182 | 0.0159 | 0.0266 | 0.0219 | 0.0249 | 89 |
| TF-3 | 1284 | 0.0181 | 0.0282 | 0.0194 | 0.0279 | 88 |
| TF-4 | 1341 | 0.0119 | 0.0216 | 0.0175 | 0.0158 | 99 |
| TF-5 | 1425 | 0.0239 | 0.0296 | 0.0123 | 0.0270 | 63 |

**NMOG - US06**

| Fuel | Wobbe | Accord | Crown Vic | Caravan | Ram Van | MN* |
|---|---|---|---|---|---|---|
| TF-1 | 1245 | 0.0040 | 0.0038 | 0.0037 | 0.0040 | 103 |
| TF-2 | 1182 | 0.0056 | 0.0049 | 0.0045 | 0.0021 | 89 |
| TF-3 | 1284 | 0.0037 | 0.0042 | 0.0049 | 0.0044 | 88 |
| TF-4 | 1341 | 0.0017 | 0.0055 | 0.0029 | 0.0035 | 99 |
| TF-5 | 1425 | 0.0040 | 0.0041 | 0.0023 | 0.0046 | 63 |

**CO - FTP**

| Fuel | Wobbe | Accord | Crown Vic | Caravan | Ram Van | MN* |
|---|---|---|---|---|---|---|
| TF-1 | 1245 | 0.5315 | 0.9525 | 0.2623 | 1.1925 | 103 |
| TF-2 | 1182 | 0.7080 | 1.2640 | 0.4605 | 1.2365 | 89 |
| TF-3 | 1284 | 0.7260 | 1.2615 | 0.3665 | 0.8283 | 88 |
| TF-4 | 1341 | 0.7063 | 1.4974 | 0.2145 | 0.8590 | 99 |
| TF-5 | 1425 | 0.6187 | 1.4815 | 0.2907 | 1.0870 | 63 |

**CO - US06**

| Fuel | Wobbe | Accord | Crown Vic | Caravan | Ram Van | MN* |
|---|---|---|---|---|---|---|
| TF-1 | 1245 | 0.5970 | 1.1550 | 0.4813 | 1.6343 | 103 |
| TF-2 | 1182 | 0.7545 | 1.4770 | 0.6545 | 1.2610 | 89 |
| TF-3 | 1284 | 0.7010 | 1.3395 | 0.6110 | 0.9615 | 88 |
| TF-4 | 1341 | 0.7527 | 1.8116 | 0.2435 | 1.0160 | 99 |
| TF-5 | 1425.00 | 0.6760 | 1.6680 | 0.3423 | 1.1090 | 63 |

* ARB Staff Calculation

## Table B: Measured Emissions From Light-Duty Bi-fuel and After-Market Conversion Vehicles[1]

Vehicle Emissions (grams/mile) - Bi-Fuel After Market Conversions and Prototype

NOx - FTP

| Fuel | Wobbe | Dakota | Sierra | GMC Pas | QVM F250 | MN* |
|---|---|---|---|---|---|---|
| TF-1 | 1245 | 0.0613 | 0.2893 | 0.3295 | 0.4890 | 103 |
| TF-2 | 1182 | 0.0600 | 0.2650 | 0.4275 | 0.4820 | 89 |
| TF-3 | 1284 | 0.0673 | 0.3910 | 0.3420 | 0.6170 | 88 |
| TF-4 | 1341 | 0.0615 | 0.5070 | 0.3405 | 0.7075 | 99 |
| TF-5 | 1425 | 0.0670 | 0.3015 | 0.3610 | 0.4765 | 63 |

NOx - US06

| Fuel | Wobbe | Dakota | Sierra | GMC Pas | QVM F250 | MN* |
|---|---|---|---|---|---|---|
| TF-1 | 1245 | 0.2280 | 0.4877 | 0.7375 | 0.6285 | 103 |
| TF-2 | 1182 | 0.2940 | 0.4235 | 0.8120 | 0.6740 | 89 |
| TF-3 | 1284 | 0.2935 | 0.5805 | 0.7325 | 0.7315 | 88 |
| TF-4 | 1341 | 0.2370 | 0.7130 | 0.7700 | 0.7300 | 99 |
| TF-5 | 1425 | 0.3170 | 0.5175 | 0.8080 | 0.5745 | 63 |

NMOG - FTP

| Fuel | Wobbe | Dakota | Sierra | GMC Pas | QVM F250 | MN* |
|---|---|---|---|---|---|---|
| TF-1 | 1245 | 0.0246 | 0.0327 | 0.0520 | 0.0452 | 103 |
| TF-2 | 1182 | 0.0256 | 0.0550 | 0.0820 | n/a | 89 |
| TF-3 | 1284 | 0.0616 | 0.0645 | 0.1179 | 0.1479 | 88 |
| TF-4 | 1341 | 0.0245 | n/a | 0.0562 | n/a | 99 |
| TF-5 | 1425 | 0.0334 | 0.0648 | 0.0946 | 0.1105 | 63 |

NMOG - US06

| Fuel | Wobbe | Dakota | Sierra | GMC Pas | QVM F250 | MN* |
|---|---|---|---|---|---|---|
| TF-1 | 1245 | 0.0023 | 0.0068 | 0.0262 | 0.0213 | 103 |
| TF-2 | 1182 | 0.0033 | 0.0184 | 0.0717 | n/a | 89 |
| TF-3 | 1284 | 0.0044 | 0.0135 | 0.0764 | 0.0488 | 88 |
| TF-4 | 1341 | 0.0034 | n/a | 0.0427 | n/a | 99 |
| TF-5 | 1425 | 0.0041 | 0.0154 | 0.0771 | 0.0418 | 63 |

CO - FTP

| Fuel | Wobbe | Dakota | Sierra | GMC Pas | QVM F250 | MN* |
|---|---|---|---|---|---|---|
| TF-1 | 1245 | 2.9727 | 3.1593 | 5.8705 | 3.5800 | 103 |
| TF-2 | 1182 | 3.0585 | 3.9595 | 6.4060 | 2.4220 | 89 |
| TF-3 | 1284 | 3.6863 | 3.6100 | 7.0400 | 3.3060 | 88 |
| TF-4 | 1341 | 2.7850 | 3.6160 | 5.9830 | 2.9340 | 99 |
| TF-5 | 1425 | 3.1605 | 3.8565 | 6.9345 | 3.2380 | 63 |

CO - US06

| Fuel | Wobbe | Dakota | Sierra | GMC Pas | QVM F250 | MN* |
|---|---|---|---|---|---|---|
| TF-1 | 1245 | 3.6005 | 3.4223 | 7.3355 | 4.7420 | 103 |
| TF-2 | 1182 | 3.9195 | 4.6905 | 7.8355 | 3.6990 | 89 |
| TF-3 | 1284 | 4.3705 | 4.1320 | 8.2180 | 4.4495 | 88 |
| TF-4 | 1341 | 3.9160 | 3.9233 | 7.5235 | 4.3950 | 99 |
| TF-5 | 1425 | 4.1515 | 4.2080 | 8.2880 | 4.5340 | 63 |

* ARB Staff Calculation

## Table C: Light-Duty Dedicated OEM Vehicle Fuel Economy Data[1]

**Dedicated NGVs (OEMs)**

**Average Fuel Economy (mpg)**

| Fuel | Wobbe | CH4/THC Vol. % | Lower Heating Value (LHV) | Specific Gravity X LHV | Accord | Caravan | MN* |
|---|---|---|---|---|---|---|---|
| TF-1 | 1245 | 0.981 | 864 | 512 | 27.69 | 21.15 | 103 |
| TF-2 | 1182 | 0.938 | 839 | 519 | 31.66 | 20.67 | 89 |
| TF-3 | 1284 | 0.910 | 913 | 566 | 36.62 | 22.68 | 88 |
| TF-4 | 1341 | 0.967 | 922 | 536 | 34.22 | 23.38 | 99 |
| TF-5 | 1425 | 0.848 | 1101 | 799 | 43.65 | 20.64 | 63 |

| Fuel | Wobbe | CH4/THC Vol. % | Lower Heating Value (LHV) | Specific Gravity X LHV | Ram Van | Crown Vic | MN* |
|---|---|---|---|---|---|---|---|
| TF-1 | 1245 | 0.981 | 864 | 512 | 17.54 | 22.47 | 103 |
| TF-2 | 1182 | 0.938 | 839 | 519 | 18.31 | 23.82 | 89 |
| TF-3 | 1284 | 0.910 | 913 | 566 | 17.93 | 23.62 | 88 |
| TF-4 | 1341 | 0.967 | 922 | 536 | 17.16 | 21.88 | 99 |
| TF-5 | 1425 | 0.848 | 1101 | 799 | 22.08 | 28.97 | 63 |

* ARB Staff Calculation

## Table D: Light-Duty Bifuel and After-Market Conversion Vehicles Fuel Economy Data[1]

**Bi-Fuel After Market Conversion and Prototype**

**Average Fuel Economy (mpg)**

| Fuel I | Wobbe | CH4/THC Vol. % | Lower Heating Value (LHV) | Specific Gravity X LHV | QVM F250 | GMC PAS | MN* |
|---|---|---|---|---|---|---|---|
| TF-1 | 1245 | 0.981 | 864 | 512 | 13.94 | 12.95 | 103 |
| TF-2 | 1182 | 0.938 | 839 | 519 | 15.52 | 13.47 | 89 |
| TF-3 | 1284 | 0.910 | 913 | 566 | 15.74 | 13.62 | 88 |
| TF-4 | 1341 | 0.967 | 922 | 536 | 14.70 | 12.74 | 99 |
| TF-5 | 1425 | 0.848 | 1101 | 799 | 18.65 | 15.97 | 63 |

* ARB Staff Calculation

# Table E: Summarized HD Data for UDDS Cycle[2]

TEST CYCLE: UDDS

| '97 8.1L, Deere, closed loop | | | | | | | |
|---|---|---|---|---|---|---|---|
| #1 | Tailpipe Emissions (GRAMS/MI.) | | | | | | Fuel Econ |
| MN* | THC | CO | NOx | CO2 | NMHC | Partic | (Mi/Gal.) |
| 99.1 | 7.97 | 0.26 | 7.62 | 980.1 | 0.43 | 0.016 | 7.33 |
| 80.8 | 7.47 | 0.22 | 8.98 | 1020.3 | 1.34 | 0.029 | 7.67 |
| 77.2 | 7.71 | 0.19 | 8.16 | 1040.7 | 1.41 | 0.006 | 7.60 |
| 72.9 | 7.52 | 0.22 | 7.10 | 1077.1 | 1.466 | 0.008 | 8.00 |

| '99 8.3 L Cummins, closed loop | | | | | | | |
|---|---|---|---|---|---|---|---|
| #2 | Tailpipe Emissions (GRAMS/MI.) | | | | | | Fuel Econ |
| MN* | THC | CO | NOx | CO2 | NMHC | Partic | (Mi/Gal.) |
| 99.1 | 9.59 | 0.68 | 10.34 | 1069.9 | 1.90 | 0.07 | 6.10 |
| 80.8 | 7.18 | 0.75 | 12.40 | 1097.7 | 1.80 | 0.043 | 6.70 |
| 77.2 | 7.16 | 0.72 | 13.79 | 1106.2 | 1.78 | 0.039 | 6.83 |
| 72.9 | 7.33 | 0.78 | 12.42 | 1143.7 | 1.89 | 0.039 | 7.03 |

| '96 6.8L Deere, closed loop | | | | | | | |
|---|---|---|---|---|---|---|---|
| #3 | Tailpipe Emissions (GRAMS/MI.) | | | | | | Fuel Econ |
| MN* | THC | CO | NOx | CO2 | NMHC | Partic | (Mi/Gal.) |
| 99.1 | 8.43 | 3.77 | 11.39 | 910.3 | 1.79 | 0.013 | 6.07 |
| 80.8 | 7.90 | 4.22 | 12.84 | 961.2 | 2.60 | 0.009 | 7.60 |
| 77.2 | 7.90 | 4.24 | 12.51 | 959.2 | 2.74 | 0.008 | 7.83 |
| 72.9 | 8.22 | 4.20 | 11.03 | 978.1 | 2.91 | 0.011 | 8.33 |

| '99 8.1L Deere, closed loop | | | | | | | |
|---|---|---|---|---|---|---|---|
| #4 | Tailpipe Emissions (GRAMS/MI.) | | | | | | Fuel Econ |
| MN* | THC | CO | NOx | CO2 | NMHC | Partic | (Mi/Gal.) |
| 99.1 | 8.59 | 3.12 | 5.96 | 931.6 | 1.97 | 0.032 | 6.97 |
| 80.8 | 7.91 | 3.43 | 6.86 | 944.1 | 2.71 | 0.016 | 7.70 |
| 77.2 | 8.06 | 3.54 | 6.76 | 956.2 | 2.87 | 0.027 | 7.83 |
| 72.9 | 7.99 | 3.44 | 6.07 | 985.3 | 2.97 | 0.031 | 8.13 |

| '96 8.5L Detroit Diesel, open loop | | | | | | | |
|---|---|---|---|---|---|---|---|
| #5 | Tailpipe Emissions (GRAMS/MI.) | | | | | | Fuel Econ |
| MN* | THC | CO | NOx | CO2 | NMHC | Partic | (Mi/Gal.) |
| 99.1 | 11.01 | 4.59 | 14.24 | 1258.9 | 2.42 | 0.02 | 5.10 |
| 80.8 | 9.07 | 5.01 | 20.76 | 1290.1 | 3.03 | 0.033 | 5.70 |
| 77.2 | 8.96 | 5.18 | 22.57 | 1306.7 | 3.14 | 0.031 | 5.75 |
| 72.9 | 12.79 | 5.02 | 7.52 | 1336.3 | 4.67 | 0.021 | 6.05 |

| '93 10.0L Cummins, open loop | | | | | | | |
|---|---|---|---|---|---|---|---|
| #6 | Tailpipe Emissions (GRAMS/MI.) | | | | | | Fuel Econ |
| MN* | THC | CO | NOx | CO2 | NMHC | Partic | (Mi/Gal.) |
| 99.1 | 5.16 | 0.04 | 6.39 | 1167.1 | 0.96 | 0.03 | 5.66 |
| 80.8 | 5.25 | 0.06 | 16.66 | 1468.7 | 1.30 | 0.051 | 5.10 |
| 77.2 | 6.40 | 0.08 | 9.15 | 1573.2 | 1.65 | 0.041 | 5.27 |
| 72.9 | 5.22 | 0.06 | 18.04 | 1478.5 | 1.30 | 0.055 | 5.17 |

| '99/'00 12.7L DD (LNG), closed loop | | | | | | | |
|---|---|---|---|---|---|---|---|
| #7 | Tailpipe Emissions (GRAMS/MI.) | | | | | | Fuel Econ |
| MN* | THC | CO | NOx | CO2 | NMHC | Partic | (Mi/Gal.) |
| 99.1 | 15.00 | 6.45 | 4.53 | 1101.1 | 0.85 | 0.52 | 8.80 |
| 80.8 | 13.53 | 10.88 | 6.10 | 1084.3 | 2.71 | 0.482 | 8.90 |
| 77.2 | 14.64 | 13.48 | 6.46 | 1083.8 | 3.24 | 0.512 | 8.83 |
| 72.9 | 14.19 | 7.53 | 4.47 | 1139.8 | 3.34 | 0.500 | 8.50 |

*ARB staff calculation

## Table F: Summarized HD Data for Mod-CBD Cycle[2]

**TEST CYCLE: MCBD**

| '97 8.1L, Deere, closed loop | | | | | | | |
|---|---|---|---|---|---|---|---|
| #1 | Tailpipe Emissions (GRAMS/MI.) | | | | | | Fuel Econ |
| MN* | THC | CO | NOx | CO2 | NMHC | Partic | (Mi/Gal.) |
| 99.1 | 5.06 | 0.16 | 3.88 | 767.1 | 0.329 | 0.008 | 9.43 |
| 80.8 | 4.64 | 0.14 | 4.56 | 788.2 | 0.78 | n.a. | 9.97 |
| 77.2 | 4.90 | 0.18 | 4.60 | 811.1 | 0.86 | 0.004 | 9.80 |
| 72.9 | 4.53 | 0.14 | 4.09 | 825.2 | 0.82 | 0.008 | 10.47 |

| '99 8.3 L Cummins, closed loop | | | | | | | |
|---|---|---|---|---|---|---|---|
| #2 | Tailpipe Emissions (GRAMS/MI.) | | | | | | Fuel Econ |
| MN* | THC | CO | NOx | CO2 | NMHC | Partic | (Mi/Gal.) |
| 99.1 | 5.01 | 0.53 | 7.28 | 831.9 | 1.01 | 0.028 | 7.87 |
| 80.8 | 3.87 | 0.57 | 9.28 | 853.0 | 0.95 | 0.03 | 8.67 |
| 77.2 | 3.82 | 0.59 | 9.04 | 845.7 | 0.93 | 0.026 | 9.00 |
| 72.9 | 3.91 | 0.59 | 8.59 | 872.6 | 0.99 | 0.028 | 9.30 |

| '96 6.8L Deere, closed loop | | | | | | | |
|---|---|---|---|---|---|---|---|
| #3 | Tailpipe Emissions (GRAMS/MI.) | | | | | | Fuel Econ |
| MN* | THC | CO | NOx | CO2 | NMHC | Partic | (Mi/Gal.) |
| 99.1 | 6.29 | 3.38 | 8.38 | 766.4 | 1.40 | 0.006 | 8.43 |
| 80.8 | 5.81 | 3.89 | 9.12 | 805.1 | 1.97 | 0.004 | 9.10 |
| 77.2 | 5.87 | 4.01 | 10.70 | 822.0 | 2.06 | 0.006 | 9.17 |
| 72.9 | 6.36 | 3.90 | 7.02 | 838.4 | 2.24 | 0.006 | 9.73 |

| '99 8.1L Deere, closed loop | | | | | | | |
|---|---|---|---|---|---|---|---|
| #4 | Tailpipe Emissions (GRAMS/MI.) | | | | | | Fuel Econ |
| MN* | THC | CO | NOx | CO2 | NMHC | Partic | (Mi/Gal.) |
| 99.1 | 5.50 | 2.58 | 3.82 | 759.6 | 1.29 | 0.033 | 8.57 |
| 80.8 | 4.78 | 2.94 | 4.32 | 755.1 | 1.65 | 0.019 | 9.67 |
| 77.2 | 5.14 | 2.99 | 4.15 | 781.2 | 1.87 | 0.019 | 9.60 |
| 72.9 | 5.31 | 2.97 | 3.79 | 813.4 | 2.00 | 0.025 | 9.87 |

| '96 8.5L Detroit Diesel, open loop | | | | | | | |
|---|---|---|---|---|---|---|---|
| #5 | Tailpipe Emissions (GRAMS/MI.) | | | | | | Fuel Econ |
| MN* | THC | CO | NOx | CO2 | NMHC | Partic | (Mi/Gal.) |
| 99.1 | 7.69 | 3.49 | 8.04 | 1013.5 | 1.68 | 0.025 | 6.40 |
| 80.8 | 6.70 | 3.78 | 11.15 | 1039.8 | 2.25 | 0.04 | 7.07 |
| 77.2 | 6.48 | 3.97 | 12.32 | 1039.1 | 2.25 | 0.022 | 7.23 |
| 72.9 | 8.43 | 3.91 | 4.44 | 1099.8 | 2.98 | 0.021 | 7.43 |

| '93 10.0L Cummins, open loop | | | | | | | |
|---|---|---|---|---|---|---|---|
| #6 | Tailpipe Emissions (GRAMS/MI.) | | | | | | Fuel Econ |
| MN* | THC | CO | NOx | CO2 | NMHC | Partic | (Mi/Gal.) |
| 99.1 | 6.90 | 0.07 | 9.96 | 1454.0 | 1.26 | 0.090 | 4.50 |
| 80.8 | 4.14 | 0.04 | 9.70 | 1193.1 | 1.02 | 0.03 | 6.23 |
| 77.2 | 4.96 | 0.05 | 4.36 | 1242.0 | 1.30 | 0.030 | 6.67 |
| 72.9 | 3.87 | 0.06 | 11.24 | 1180.2 | 0.94 | 0.037 | 6.47 |

| '99/'00 12.7L DD (LNG), closed loop | | | | | | | |
|---|---|---|---|---|---|---|---|
| #7 | Tailpipe Emissions (GRAMS/MI.) | | | | | | Fuel Econ |
| MN* | THC | CO | NOx | CO2 | NMHC | Partic | (Mi/Gal.) |
| 99.1 | 10.08 | 5.33 | 2.26 | 1051.7 | 0.82 | 0.175 | 9.33 |
| 80.8 | 8.50 | 7.43 | 2.95 | 1034.9 | 1.97 | 0.18 | 9.47 |
| 77.2 | 8.43 | 7.70 | 3.13 | 1050.6 | 2.14 | 0.177 | 9.33 |
| 72.9 | 10.35 | 6.19 | 2.20 | 1126.4 | 2.70 | 0.196 | 8.70 |

*ARB staff calculation

# Table G: Summarized HD Data for Commuter Cycle[2]

TEST CYCLE: Commuter

| '97 8.1L, Deere, closed loop | | | | | | | |
|---|---|---|---|---|---|---|---|
| #1 | Tailpipe Emissions (GRAMS/MI.) | | | | | | Fuel Econ |
| MN* | THC | CO | NOx | CO2 | NMHC | Partic | (Mi/Gal.) |
| 99.1 | 4.69 | 0.08 | 3.58 | 674.9 | 0.208 | 0.005 | 10.67 |
| 80.8 | 4.17 | 0.03 | 4.59 | 718.5 | 0.60 | n.a. | 10.97 |
| 77.2 | 3.97 | 0.08 | 4.33 | 690.1 | 0.62 | 0.007 | 11.57 |
| 72.9 | 3.77 | 0.04 | 4.47 | 711.3 | 0.57 | 0.009 | 12.13 |

| '99 8.3 L Cummins, closed loop | | | | | | | |
|---|---|---|---|---|---|---|---|
| #2 | Tailpipe Emissions (GRAMS/MI.) | | | | | | Fuel Econ |
| MN* | THC | CO | NOx | CO2 | NMHC | Partic | (Mi/Gal.) |
| 99.1 | 4.69 | 0.30 | 3.99 | 723.8 | 0.96 | 0.075 | 9.07 |
| 80.8 | 3.47 | 0.34 | 5.46 | 712.4 | 0.81 | 0.02 | 10.33 |
| 77.2 | 3.58 | 0.35 | 5.05 | 715.7 | 0.83 | 0.035 | 10.63 |
| 72.9 | 3.53 | 0.34 | 4.92 | 737.4 | 0.85 | 0.031 | 10.97 |

| '96 6.8L Deere, closed loop | | | | | | | |
|---|---|---|---|---|---|---|---|
| #3 | Tailpipe Emissions (GRAMS/MI.) | | | | | | Fuel Econ |
| MN* | THC | CO | NOx | CO2 | NMHC | Partic | (Mi/Gal.) |
| 99.1 | 4.66 | 2.64 | 10.22 | 627.1 | 0.99 | 0.009 | 10.30 |
| 80.8 | 4.35 | 2.90 | 11.63 | 662.0 | 1.46 | 0.006 | 11.10 |
| 77.2 | 4.52 | 3.01 | 11.49 | 676.9 | 1.58 | 0.021 | 11.13 |
| 72.9 | 4.47 | 2.93 | 9.80 | 681.7 | 1.55 | 0.004 | 12.00 |

| '99 8.1L Deere, closed loop | | | | | | | |
|---|---|---|---|---|---|---|---|
| #4 | Tailpipe Emissions (GRAMS/MI.) | | | | | | Fuel Econ |
| MN* | THC | CO | NOx | CO2 | NMHC | Partic | (Mi/Gal.) |
| 99.1 | 4.55 | 1.95 | 4.40 | 614.2 | 0.99 | 0.033 | 10.60 |
| 80.8 | 5.08 | 2.40 | 4.56 | 714.3 | 1.74 | 0.030 | 10.20 |
| 77.2 | 5.14 | 2.45 | 4.32 | 717.4 | 1.83 | 0.027 | 10.47 |
| 72.9 | 5.17 | 2.45 | 4.20 | 740.8 | 1.92 | 0.013 | 10.83 |

| '96 8.5L Detroit Diesel, open loop | | | | | | | |
|---|---|---|---|---|---|---|---|
| #5 | Tailpipe Emissions (GRAMS/MI.) | | | | | | Fuel Econ |
| MN* | THC | CO | NOx | CO2 | NMHC | Partic | (Mi/Gal.) |
| 99.1 | 5.27 | 3.05 | 7.81 | 894.7 | 1.24 | 0.020 | 7.27 |
| 80.8 | 4.32 | 3.43 | 10.65 | 926.4 | 1.43 | 0.03 | 8.00 |
| 77.2 | 4.02 | 3.53 | 11.91 | 914.5 | 1.39 | 0.018 | 8.27 |
| 72.9 | 5.95 | 3.45 | 4.20 | 983.9 | 2.19 | 0.024 | 8.37 |

| '93 10.0L Cummins, open loop | | | | | | | |
|---|---|---|---|---|---|---|---|
| #6 | Tailpipe Emissions (GRAMS/MI.) | | | | | | Fuel Econ |
| MN* | THC | CO | NOx | CO2 | NMHC | Partic | (Mi/Gal.) |
| 99.1 | 4.08 | 0.04 | 8.32 | 1070.5 | 0.70 | 0.029 | 6.13 |
| 80.8 | 2.80 | 0.02 | 12.91 | 1075.0 | 0.61 | 0.02 | 6.97 |
| 77.2 | 2.44 | 0.02 | 16.34 | 1068.2 | 0.53 | 0.044 | 7.17 |
| 72.9 | 3.54 | 0.03 | 6.36 | 1137.5 | 0.82 | 0.020 | 7.30 |

| '99/'00 12.7L DD (LNG), closed loop | | | | | | | |
|---|---|---|---|---|---|---|---|
| #7 | Tailpipe Emissions (GRAMS/MI.) | | | | | | Fuel Econ |
| MN* | THC | CO | NOx | CO2 | NMHC | Partic | (Mi/Gal.) |
| 99.1 | 5.02 | 2.54 | 3.02 | 660.8 | 0.31 | 0.116 | 14.93 |
| 80.8 | 4.15 | 3.22 | 5.39 | 657.4 | 0.89 | 0.10 | 15.07 |
| 77.2 | 4.33 | 3.83 | 4.33 | 667.2 | 1.00 | 0.113 | 14.80 |
| 72.9 | 4.77 | 3.13 | 3.26 | 706.8 | 1.15 | 0.117 | 14.03 |

*ARB staff calculation

[1] Bevilacqua, Oreste M., Ph.D. “Natural Gas Vehicle Technology and Fuel Performance Evaluation Program”, Clean Air Vehicle Technology Center, File No. Z-19-2-013-96, April 1, 1997.

[2] Bevilacqua, Oreste M., Ph.D., “Impacts of Natural Gas Fuel Composition on Tailpipe Emissions and Fuel Economy”, ARB Public Workshop on the Alternative Fuels Regulations, Sacramento, CA, June 21, 2000.

[3] Bevilacqua, Oreste M., “Natural Gas Vehicle Technology and Fuel Performance Evaluation Program (PEP), Phase II: Medium- and Heavy-Duty Vehicle Testing, Technical Proposal”, Clean Air Vehicle Technology Center, December 18, 1998.