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MOBILE6 Emission Factors for Natural Gas Vehicles

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1.0 Background

Under the Clean Air Act (CAA)Amendments of 1990, States which have serious, severe, or extreme ozone non-attainment areas, and areas with carbon monoxide design values greater than 16 ppm must establish a Clean Fuel Fleet (CFF) Program. Under the CFF program, a certain percentage of light-duty vehicles, light-duty trucks, and heavy-duty vehicles acquired by certain fleet owners located in areas covered by the CFF will be required to meet clean-fuel emissions standards. Clean Fuel Fleet emissions standards are lower than those set by the CAA. Many states have incorporated compressed (CNGV) or liquidified natural gas vehicles (LNGVs) into their CFF programs, and need to model the emission factors and benefits obtained from the CFF program. The term natural gas is used to represent both compressed and liquidified natural gas, and the term NGV refers to both CNGVs and LNGVs.

2.0 Introduction

The MOBILE6 model allows for the modeling of emissions from vehicles powered by four fuel types. The first two types (gasoline and diesel) are explicitly modeled and emission factors are always calculated. The second two types - natural gas vehicles (NGVs) and zero emitting vehicles (ZEVs) are modeled by specifying the percentage penetration of these vehicles in the fleet. When these percentages are entered as inputs, the MOBILE6 program assumes that NGV or ZEVs proportionately displace both gasoline and diesel fueled vehicles of a given vehicle class. Any MOBILE6 vehicle class (28 vehicle classes are available) will have the capability to be modeled as an NGV.

The model allows for variation in gasoline fuel by permitting a user to specify different Reid vapor pressures, oxygen contents, fuel sulfur levels and the presence of reformulated fuel. MOBILE6 also recognizes vehicles that certify to lower emission standards, such as Low Emitting Vehicles (LEVs), Ultra Low Emitting Vehicles (ULEVs), and Zero Emitting Vehicles (ZEVs). MOBILE6 assumes that all of these vehicles are used and accumulate mileage in the same way as other vehicles of the same age, and that all (except ZEVs) are fueled by gasoline.

The model will not allow the user to model any varying properties of natural gas nor changes in emissions standards of NGVs. The model will also not allow the modeling of hybrid, fuel cell or dual-fuel vehicles (such as those that may have a small supply of gasoline on board for emergency use). Guidance on modeling of such vehicles may be forthcoming from EPA when better information on their design and in-use emissions performance is available.

This document is structured into two primary sections. The first section shows the basic NGV emission factors which were incorporated into MOBILE6, and provides some rationale as to why these values were selected. The second section is Appendix A which describes the data and analysis performed by EPA to develop the preliminary NGV emission factor estimates. In some cases these values were retained in the final model, and in other cases alternative emission factors provided by the natural gas industry based on actual vehicle testing were incorporated into the final model.

3.0 Data and Analysis

See Appendix A for details on the EPA analysis.

4.0 MOBILE6 NGV Emission Factors

4.1 Light-Duty Vehicles

The MOBILE6 model will generally model light-duty NGVs as being equivalent to those of gasoline vehicles certified to the ULEV emission standards. The only exception are the high emitter vehicles which will now be modeled in MOBILE6 using somewhat lower emission factors. This is a change from the original MOBILE6 proposal drafted in April, 1999, and it reflects comments made by the Natural Gas Vehicle Association. (NGVA). In their comments the NGVA provided some limited data on NGV I/M failures which indicate that a failing NGV's emission levels (not the rate of failure) are typically less than a corresponding gasoline fueled vehicles. Engineering rationales based differences in the chemical and physical properties of the two fuels further bolster the view that NGV failures would be less catastrophic (have relatively lower emissions when broken) than gasoline powered vehicles.

Table 1: Basic emission rates for light-duty NGV vs. EPA proposal for gasoline ULEVS

	ULEV – LDV/ LDT1			ULEV LDT 2			ULEV LDT3/4		
	NOX	NMHC	CO	NOX	NMHC	CO	NOX	NMHC	CO
Zero Mile Level -Normal Emitters	0.133	0.016	0.665	0.265	0.020	0.916	0.398	0.046	1.040
Deterioration Rate (10K miles) - Normal Emitters	0.007	0.0018	0.234	0.015	0.0023	0.280	0.022	0.0053	0.280
NGV High-Emitter	0.74	0.068	5.80	0.99	0.070	5.90	1.23	0.080	5.90
Gasoline High-Emitter	0.960	1.140	38.730	1.280	1.170	39.070	1.600	1.330	39.070

Table 1 shows the NGV emission zero mile and deterioration rates for LDV, LDT1, LDT2 and LDT3/4. The zero mile level units are grams per mile, and the deterioration rates are in grams per mile per 10,000 miles. Both the NGV and Gasoline High Emitter emission levels are in grams per mile units and are constants with respect to mileage. The normal emitter zero mile and deterioration rates are the same as those proposed in the Draft version of this report. The average High emitter emission levels for NGV are now lower than the corresponding gasoline High emitter emission level. This is particularly true for the NMHC and CO emission levels which are considerably lower for the NGV versus the gasoline vehicles.

4.2 Heavy-Duty Vehicles

Table 2 shows the heavy-duty NGV emission factors proposed for use in MOBILE6. Emission factor estimates based on both EPA's original proposal, and EPA's revised proposal are shown. The revised proposal is largely based on data and comments submitted by the Natural Gas Association. The vehicle classes shown in Table 2 are linked to the MOBILE6 vehicle class categories. The Heavy-Heavy category includes MOBILE6 Classes 12, 13, 22, 23, 25, 26 and 27. The Medium-Heavy class includes MOBILE6 Classes 8, 9, 10, 11, 18, 19, 20 and 21. The Light-Heavy Class includes 6, 7, 14, 15, 16 and 17.

EPA's original proposal was based on the assumption that the basic emission rates (BERs) and deterioration rates for heavy-duty NGVs were equivalent to those of diesel engines certified to the 2004 emission standard of 2.5 g/BHP-hr NMHC+NOX. The HC and CO emission factors were also assumed values based on 2004 certification standards and assumed certification compliance margins.

Table 2: BER emission levels for HDNG engines

	Heavy-Heavy			Medium-Heavy			Light-Heavy		
	NOX	CO	NMHC	NOX	CO	NMHC	NOX	CO	NMHC
Initial EPA Proposal (g/BHP-hr)									
Zero Mile Level	1.840	1.070	0.220	1.840	0.850	0.310	1.630	1.190	0.260
Deterioration	0.003	0.004	0.001	0.001	0.009	0.001	0.001	0.003	0.001
Lifetime Average	1.908	1.160	0.243	1.849	0.933	0.319	1.636	1.207	0.266
Final EPA Proposal (g/BHP-hr)									
Zero Mile Level	1.840	0.428	0.440	1.840	0.340	0.620	0.427	1.116	0.049
Deterioration	0.003	0.002	0.002	0.001	0.004	0.002	0.045	0.318	0.005
Lifetime Average	1.908	0.464	0.485	1.849	0.373	0.639	0.673	2.865	0.078

Shaded cells indicate change from Initial EPA proposal

The NOX emission factors for the Heavy-Heavys and the Medium-Heavys were not revised between the original EPA proposal and this current revision. The remaining vehicle classes and pollutants (NMHC and CO) had their emission factors revised based on data from a Colorado School of Mines Study (See NGV Coalition Comments Document).

The NOX emission factors for Heavy-Heavy and Medium-Heavy were not revised based on the data supplied by the industry and shown in Figure 1. This in-use data on natural gas tractor-trailers and comparable vehicles with diesel engines indicates that NOX emissions are relatively the same as the 2004+ standard (1.84 g/bhp-hr), and only minimal deterioration is noted over the 50,000 mile range. Thus, the assumption that the NGV heavy-duties will emit at 2004+ standard levels seems reasonable. The only negative is that there are no high mileage vehicle available for analysis, making a lifetime emission estimate an extrapolation.

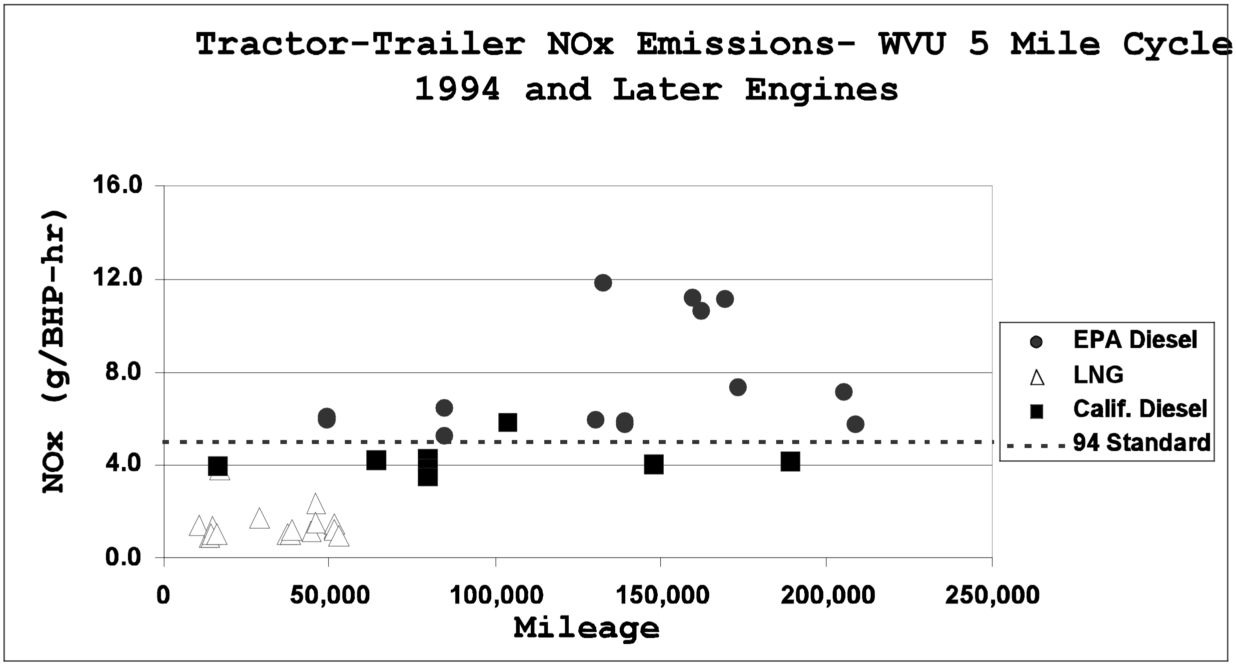
The Light-Heavy duty vehicle NOX emission factors were revised from the original version based on Natural Gas Industry comments. The rationale is as follows: the NGVs included in the light-heavy duty vehicle class use very different engine and emission control technologies than do medium-heavy and heavy-heavy duty vehicles, and as such may have different basic emission factors. For instance, the engines and emission control systems in these vehicles are naturally-aspirated, stoichiometric, port-fuel injected systems with three-way catalytic converters. This technology more closely resembles that used in light-duty gasoline and natural gas trucks than the typical compression engine design of a large diesel engine. Also, most of the light-heavy duty NGVs now in production are certified to California SULEV standards. The recommended BERs in the light-heavy duty column of Table 2 reflect these characteristics.

The Light-Heavy duty emission factors in Table 2 were calculated from emissions estimated for ULEV natural gas LDT-4 vehicles. This was done by converting the estimated LDT4 valued in grams per mile to the values shown in g/BHP-hr by multiplying the value by 1.17 to get the equivalent emissions from a CARB medium-duty vehicle (MDV) in the 8,500 to 10,000 pound GVWR range. The CARB is similar to the Light-Heavy category used by EPA. 1.17 is the ratio of CARB MDV emission standards for the two groups. This value in g/mile was converted to g/bhp-hr units by multiplying it by EPA's estimated conversion factor of 1.09 BHP-hr/mile. This process produces NOX emission values which are significantly lower than the original estimates.

The industry data was also used to compute revised estimates for NMHC and CO emission factors for Heavy-Heavy and Medium-Heavy NGVs. In general, the new NHHC estimates are higher (approximately double those originally estimated by EPA) and the CO estimates are lower than the original EPA estimates which were based on the certification standard. These estimates are based on the assumption that some form of oxidation catalyst will be required in the next few years on NGVs. The same rationale was used to estimate Light-Heavy NMHC and CO emissions as was used to estimate Light-Heavy NOx emissions. The relatively low ULEV NMHC standards helped produce considerably lower NMHC emission factors, but slightly higher CO emission factors.

Figure 1

In-use NOX emissions for diesel and LNG trucks equipped with 1994 and later model engines. Source: EF&EE analysis of NREL database



5.0 Other NGV Emission Effects

5.1 Heavy-Duty Off-Cycle Effects (Alleged Defeat Device)

The alledged Heavy-Duty vehicle defeat device (or heavy-duty off-cycle emissions) are calculated for heavy-duty vehicle classes with model years 1988 through 2000. These devices were never employed in the heavy-duty natural gas engines. Thus, natural gas emission factors are never adjusted for these off-cycle effects.

5.2 Temperature Effects

MOBILE6 contains temperature correction factors used to adjust emissions for temperatures other than 75 degrees F. For gasoline and diesel vehicles there is typically an inverse relationship between temperature and emissions. For NGVs, this relationship is relatively unknown. In their comments the NGV coalition argued that temperature effects for light-duty NGVs should not be modeled as equivalent to those of gasoline vehicles. They cite data from an EF&EE study (see NGV industry comments document) that show that NMHC and CO emissions from NGVs under low-temperature conditions (20 degrees F) are nearly identical to those measured at 75F, whereas as NMHC and CO from gasoline vehicles are increase more than tenfold.

For MOBILE6, it was decided that the temperature correction factor for NGV vehicles would be unity (a multiplicative factor equal to one and having no effect on emissions). This is based on the industry comments, the general lack of data to develop a meaningful relationship, and the fact that the NGV fuel is in a gaseous state even at low temperatures, and thus avoids all of the vaporizing and mixing issues associated with gasoline vehicle cold start. However, if in the future, NGVs gain greater market share, and test data become more available, this assumption may be revised, as necessary.

5.3 Evaporative Emissions from NGVs

EPA's original proposal was to model dedicated NGVs as having zero evaporative emissions. The final MOBILE6 proposal will also model evaporative emissions as zero in MOBILE6. The rationale for this assumption rests on three points. First, some very limited evaporative test data from NREL on taxicabs indicates that evaporative emissions are quite low. For instance, the old 1-hour evaporative test procedure showed total emissions around 0.3 g/test which are well below the 2.0 g/test standard, and may represent non-fuel evaporative emissions. Second, from an engineering perspective, a sealed system containing a gaseous product should in theory emit no hydrocarbons if it is functioning properly (older systems frequently develop leaks, though). Third, any evaporative losses would be of a more minor consequence for air pollution, since natural gas is more than 90% methane, and most of the remainder is ethane, and neither of which is a precursor to ozone formation.

5.4 Operating characteristics

EPA proposes to model NGVs as operating and accumulating mileage in the same manner as heavy or light duty diesel and gasoline cars and trucks. The reason for this assumption is that no data or in-use vehicle usage study has been undertaken that could produce a different result. In addition, the market penetration for NGVs is currently quite small, and slightly different usage patterns would have only a limited effect on overall fleet inventories.

5.5 Hydrocarbon Speciation

EPA's original document did not address the issue of hydrocarbon speciation. However, since the MOBILE6 model reports emission estimates in terms of Total Hydrocarbon (THC), Total Organic Gases (TOG), Non Methane Hydrocarbon (NMHC), Volatile Organic Compounds (VOC), and Non Methane Organic Gases (NMOG), the NGV HC emission factors also required factors to split the HC into these various classifications.

The following factors were obtained from the EF&EE study of emissions from light-duty NGVs. All are based on the NMOG basic emission factor.

Light-Duty Hydrocarbon Speciation

THC = 11.5 * NMOG

NMHC = 0.93 * NMOG

VOC = 0.45 * NMOG

TOG = NMOG + Methane

Heavy-duty Hydrocarbon Speciation

Emissions speciation data for HDNG vehicles have recently become available from the Colorado School of Mines (CSM) (See NGV Coalition Comments). Using fuels with 4.8 to 5.0% ethane (similar to CARB certification natural gas), CSM measured THC, methane, aldehydes, and ethane emissions for three catalyst-equipped NGVs in two different driving cycles. On average, THC emissions were 9.4 times NMHC emissions, while NMOG emissions were 1.06 times NMHC; and VOC emissions were only 27% of NMOG emissions or 29% of NMHC.

THC = 9.40 * NMHC

NMOG = 1.06 * NMHC

VOC = 0.29 * NMHC

TOG = NMOG + Methane

5.6 Other Correction Factors

Several correction factors are applied to vehicle emissions in MOBILE6. These include off-cycle corrections, air conditioning corrections, fuel corrections, Inspection / Maintenance effects, OBD effects, Speed Effects and Tampering Assumptions. Virtually, no data are available to create new factors for NGVs. Thus, the same off-cycle and air conditioning correction factors that are applied to gasoline ULEVs will be applied to all NGVs. No fuel corrections will be applied to NGVs. The same I/M, OBD, Speed and Tampering Assumptions will also be applied to NGV as well as gasoline and diesel vehicles.

A start and running emissions split was also required for light-duty NGVs to be consistent in MOBILE6. A limited analysis of NGV data was done to estimate start and running emissions separately. However, this analysis produced inconsistent results, and was not used. Instead, it was assumed that NGV vehicles have the same start and running emission ratio as the corresponding gasoline vehicles.

5.7 Alternate NGV Inputs into MOBILE6

The MOBILE6 program will give the user the option to enter in alternative NGV emission factors and NGV fleet penetration fractions. The NGV fleet penetration fraction is actually a required input to get an NGV emission factor because the default MOBILE6 penetration of NGVs in the fleet is zero. The MOBILE6 program will give the user the ability to enter an NGV fleet penetration that ranges from 0.0% to 100%. The 100% may be useful if the user desires to model a pure NGV fleet.

Alternative NGV emission factors may be important since the NGV emission factors shown in this report will be used for ALL current(1994 and later) and future model years regardless of future Federal or California Certification Standards. Thus, in the future, the default NGV emission factors may be higher than the prevailing gasoline tailpipe standards. If such is the case, and if it is believed to be incorrect, the user will have to enter alternative NGV basic emission factors into MOBILE6 to override the built-in NGV emission factors.

In their comments, the NGV industry coalition suggested that NGV usage patterns (mileage accumulation, VMT distributions, vehicle registration distributions, etc.) be a user controlled input. Unfortunately, this feature could not be programmed into MOBILE6. However, the user may be able to model such changes by setting the NGV fleet fraction to 100% and altering the usage patterns as needed. This would produce a pure NGV emission factor which could be weighted outside the model with a pure non-NGV emission factor to produce an average.

Appendix A

Initial EPA NGV Proposal and Data Analysis

The data used in this analysis were provided in a report entitled 'Comparison of Off-Cycle and Cold-Start Emissions from Dedicated NGVs and Gasoline Vehicles' by Engine, Fuel, and Emissions Engineering, Incorporated (EF&EE).[1] EF&EE was contracted by the Gas Research Institute (GRI) to conduct an automotive emission testing program that would compare emissions from CNGVs to emissions from their gasoline fueled counterparts. The study consisted of twelve vehicles, six CNGVs and six gasoline counterparts. For each fuel type there were two light-duty vehicles, two light-duty truck class 1 (LDT1, up to 6000 lb GVW) , and two light-duty truck class 2 (LDT2, 6001-8500 lb GVW). Exhaust emissions were measured using several different procedures, but this analysis considered only the data obtained through testing using the Federal Test Procedure (FTP).

Many CNGVs can be certified to the ULEV emissions standards set by the Environmental Protection Agency (EPA). Manufacturers have tested CNG vehicles that have had emission rates lower than the ULEV standard. In order to insure that CNG vehicles are credited with the correct modeling benefit, EPA performed a comparison between the CNGV emission data and the ULEV emission factors proposed for use in MOBILE6. The CNG vehicles in the data set were relatively new and had low mileage accumulation, therefore they were compared with the emission factors for normal emitting ULEV vehicles at the same mileage. This comparison was performed for both the light-duty vehicles (LDV) and light-duty trucks (LDT) in the data sample. Table A1 contains the estimated emission values for M6 ULEVs, average measured emissions data from CNGVs, and the percent change between the two vehicle types. The standard deviation for CNGV emissions is also given for the readers information. Due to the limited sample size, p-values were not calculated.

[1] A copy of this report can be obtained by contacting Gas Research Institute, 8600 West Bryn Mawr Avenue, Chicago, Illinois 60631-3562

Table A1: Emission Values and Percent Change for Predicted M6 ULEVs and Measured CNGVs

Vehicle Type and Pollutant	Estimated M6 ULEV Emissions	Average Emissions from CNGVs	Percent Change	Standard Deviation for CNGV Emissions
LDV - NMHC	.026	.025	3.9% decrease	.008
- CO	.544	.62	13.9% increase	.444
-NOX	.156	.058	62.8% decrease	.055
LDT1 - NMHC	.026	.03	15.4% increase	.007
- CO	.544	.23	57.7% decrease	.046
- NOX	.156	.122	21.8% decrease	.107
LDT2 - NMHC	.03	.03	N/A	.018
- CO	.781	1.09	39.5% increase	.548
- NOX	.265	.473	78.5% increase	.228

The average emissions at an average mileage for light-duty vehicles in the data set were compared to predicted MOBILE6 ULEV emission factors at the same mileage. Figure A1 shows the graphical comparison. Figure A1 shows a slight decrease in NGV non-methane hydrocarbons (NMHC) and a decrease in oxides of Nitrogen (NOX). An increase in carbon monoxide (CO) emissions for NGV vehicles, relative to gasoline vehicles, was observed using this comparison.

The data set used contained two weight classes of light-duty trucks, Light-Duty Truck 1 (LDT1) and Light-Duty Truck 2 (LDT2). The average emissions for each pollutant from each truck class were compared to the estimated MOBILE6 ULEV emission factors for that truck class at the same milage. Figures A2 and A3 show the comparison.

Figure A2 shows a decrease in NGV NMHC, CO, and NOX emissions. Figure A3 shows no change in CNG NMHC, while there is a noticeable increase in CO and NOX emissions. It is hard to justify the inconsistencies seen in these comparisons. It may be due to the small sample size (only two CNG vehicles of each vehicle type), or a problem with the vehicles themselves.

Figure A1: Emissions for LDV ULEVs M6 vs NGV Data

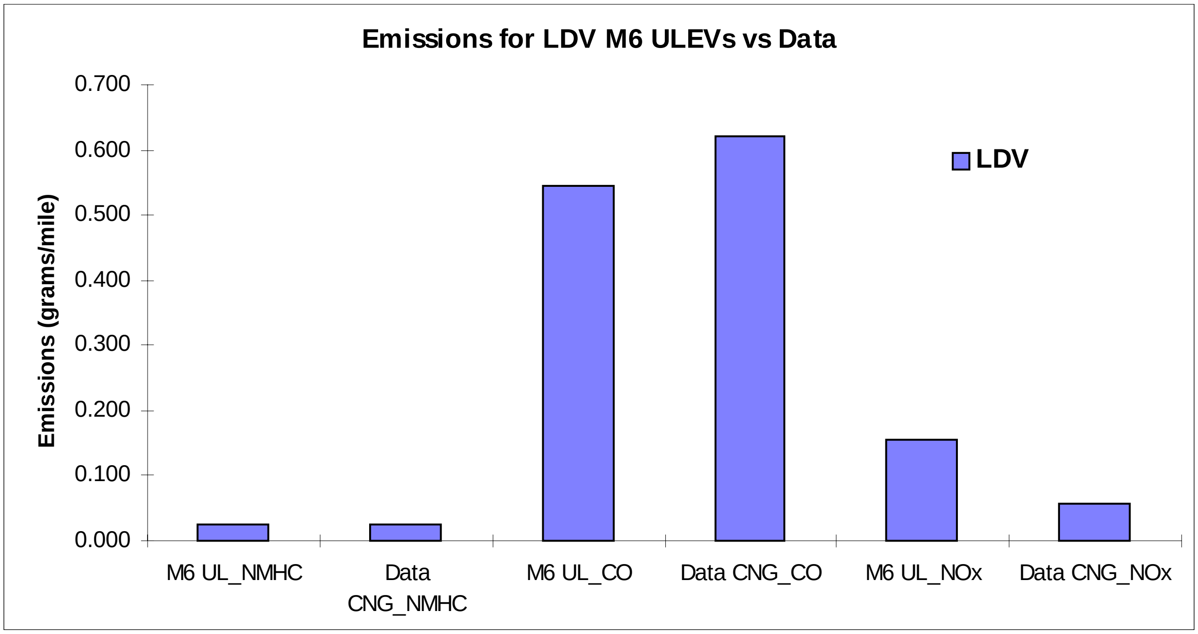
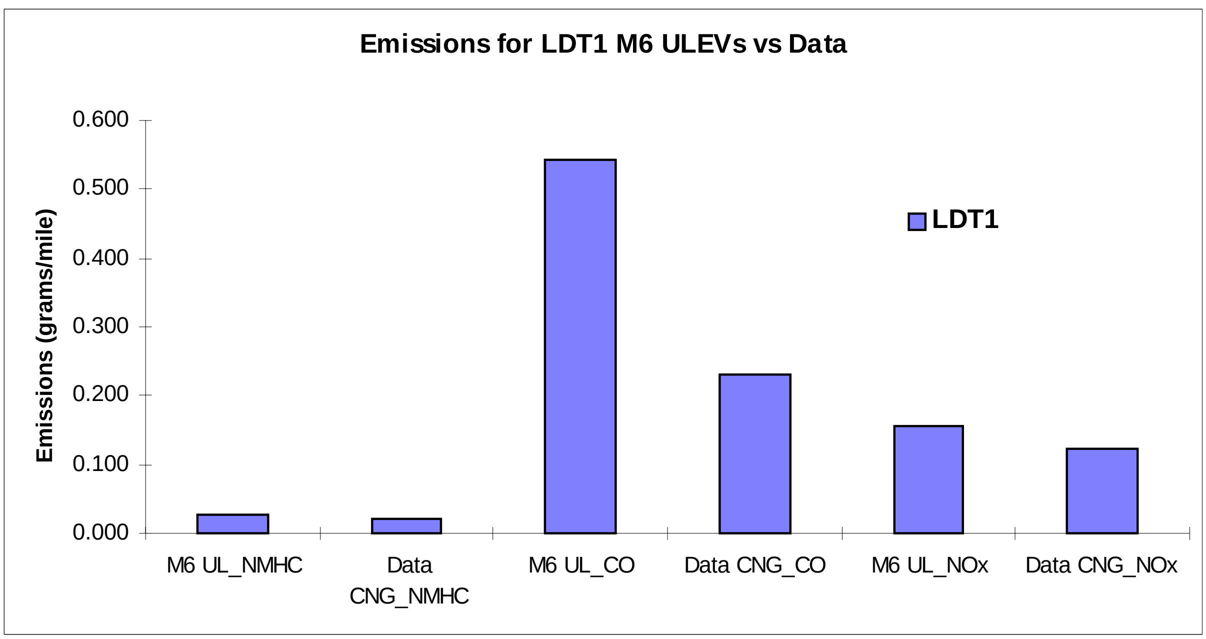


Figure A2: Emissions for LDT1 M6 ULEVs vs NGV Data



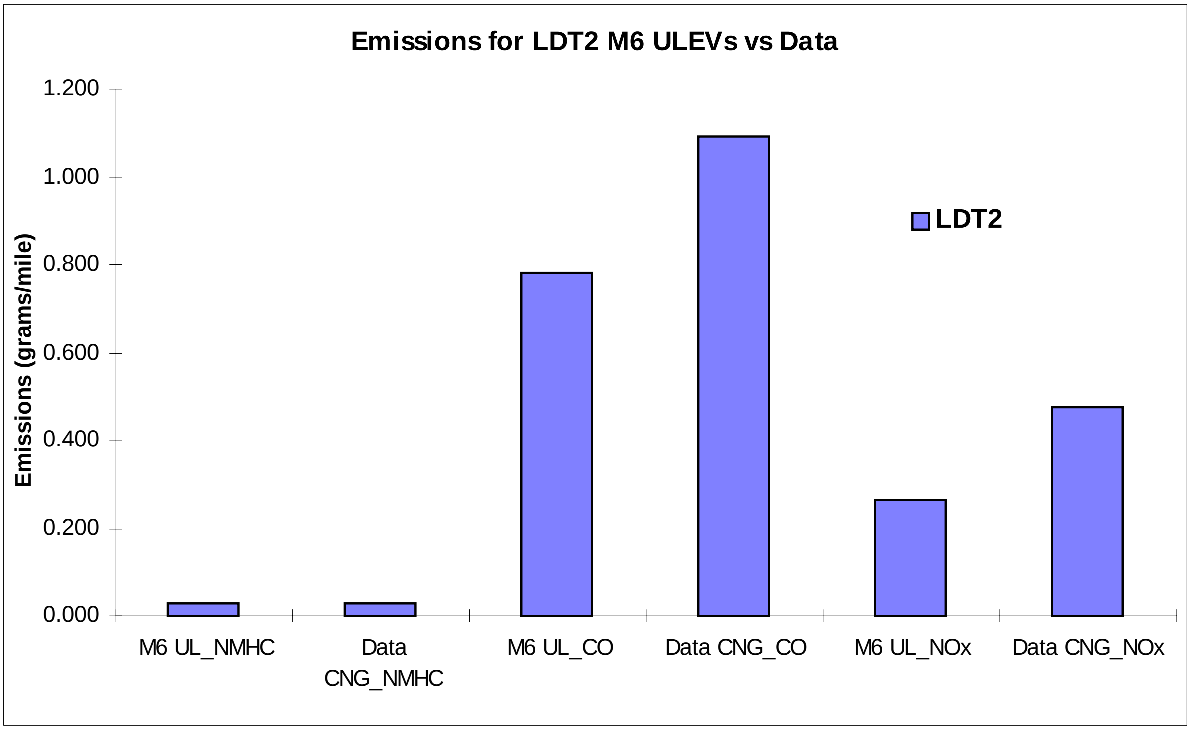


Figure A3: Emissions for LDT2 M6 ULEVs vs NGV Data