Under Review – Subject to Revision

EMFAC Model Change Technical Memo

SUBJECT: REVISION OF HEAVY HEAVY-DUTY DIESEL TRUCK EMISSION FACTORS AND SPEED CORRECTION FACTORS

LEAD: Lei Zhou

SUMMARY

Staff proposes to revise the running exhaust emission factors, idle emission factors, and speed correction factors (SCF) for heavy heavy-duty diesel trucks (HHDDT) of the Motor Vehicle Emissions Inventory (EMFAC) model. Staff has estimated the impact of the revised emission factors and SCFs on the emissions inventories of hydrocarbon (HC), carbon monoxide (CO), nitrogen oxides (NOx), and particulate matter (PM), as summarized below.

Estimated Impact of Revised Emission Factors and Speed Correction Factors On Statewide HHDDT Emissions Inventories (summer season)

Calendar Year	Percent Changes in Emissions Inventory			
	HC	CO	NOx	PM
2010	146%	65%	23%	96%
2020	135%	7%	64%	18%

NEED FOR REVISION

Since the release of EMFAC2002, there has been significant development in inventory of heavy-duty vehicle (HDV) emissions. One major advance is the Coordinating Research Council (CRC) E55/E59 project, which was sponsored by four governmental agencies and two private organizations and carried out jointly by the CRC, Air Resources Board (ARB), and West Virginia University (WVU). Through the CRC E55/E59 project, chassis dynamometer test data were collected not only from more HDVs of older model years but also from trucks of the late model years. In addition, in the project most trucks were for the first time tested over an ARB developed HHDDT test cycle, generating idle emission data covering a wide span of model years as well as emission data at several different speeds.

As a result, staff decided to use the CRC data to revise the emission factors and develop new SCFs for HHDDTs and update the HHDDT emissions inventory. This document describes the CRC E55/E59 project, presents the revised HHDDT running exhaust emission factors, proposes new idle emission factors and speed correction factors for HHDDTs, and provides estimated impacts of these revisions on the HHDDT emissions inventory.

METHODOLOGY

Sources of Emission Test Data

The emission data used for the revisions of emission factors and SCFs were obtained from a number of sources. The first three sets of data were acquired from the New York State Department of Environmental Conservation and Energy (NYSDEC), WVU, and the Colorado Institute for Fuels and High Altitude Engine Research (CIFER). These data sets (hereafter, the NWC data set) provide emission data collected from 23 HHDDTs, which were tested over the US Environmental Protection Agency's (USEPA) Urban Dynamometer Driving Schedule (UDDS or Test-D)[1] for Heavy-Duty Vehicles (HDV) and were used to develop emission factors for the previous versions of EMFAC (for a detailed description of the three data sets and their analysis, refer to EMFAC technical support document[2]). The NWC data set does not provide idle emission data.

A new set of HHDDT emission data was recently obtained through the CRC E55/E59 project. One primary objective of the E55/E59 project is to quantify emissions from HDVs to support emissions inventory development. The project was designed to test a total of 75 HDVs, including 56 HHDDTs, 15 medium heavy-duty diesel trucks, and 4 medium heavy-duty gasoline trucks. To date, 47 HHDDTs have been tested.

All HHDDTs procured in the E55/E59 project were tested over the UDDS cycle. In addition, all HHDDTs were also tested over the ARB 4-Mode Cycle, which consists of an idle mode, a creep mode, a transient mode, and a cruise mode. Each mode characterizes a unique driving phase in a typical trip of a truck. An additional mode, the High Speed Cruise mode, was also used during testing to obtain emission rates at 50 mph speed. Table 1 lists the parameters of the ARB 4-Mode Cycle as well as those of the High Speed Cruise mode and the UDDS cycle.

Table 1. Parameters of ARB 4-Mode Cycle and UDDS Cycle

Test Cycle / Mode	Average Speed (mph)	Duration (seconds)	Length (miles)
Idle	0	600	N/A
Creep	1.8	253	0.12
Transient	15.4	668	2.85
Cruise	39.9	2,083	23.1
High Speed Cruise	50.2	757	10.5
UDDS	18.8	1063	5.55

1 For a discussion of the UDDS, refer to 40 CFR Part 86 Subpart M.

2 EMFAC Technical Support Document: Sec. 10. Heavy-Duty Truck Emission Factors Development (www.arb.ca.gov/msei/on-road/doctable_test.htm).

The CRC UDDS test data are summarized in Appendix A. It should be pointed out that in the E55/E59 project all tests were carried out using the California clean diesel fuel (CARB diesel). Therefore, all CRC data were corrected back to the pre-clean diesel basis before data merging or analysis.

The CRC data set was merged with the NWC data set for revising the HHDDT running exhaust emission factors. Since the NWC data set does not have idle emission data and only offers emission data at the test speed of the UDDS cycle, the idle emission factors and speed correction factors for HHDDTs were developed from only the CRC data.

HHDDT Running Exhaust Emission Factors

In the EMFAC model, the emission rates of HHDDTs at the zero mile and changes of emission rates with mileage accumulation were evaluated by applying a model developed by the Radian Corporation. The basic assumption of this model is that the emissions from diesel powered trucks remain stable in the absence of tampering and malmaintenance (T&M). The Radian model identifies nineteen specific T&M acts and quantifies their impact on the emissions from trucks using T&M impact rates. For a given pollutant, the T&M impact rate is the percentage increase in emissions over the level that vehicles would have produced if they had all been well maintained and free of tampering. Thus, the Radian model uses the pollutant's average emission for a group of trucks of certain model years and the pollutant's T&M impact rate for the group to calculate a zero-mile rate (ZMR) and a deterioration rate (DR) for that group. For a detailed discussion of the Radian model, see the report by Radian Corporation[3].

Model Year Groups for Calculating Average Emission Rates

To divide the merged CRC-NWC data set into appropriate engine model year groups for applying the Radian model, staff examined subsets of emission data corresponding to various model year groups. In determining boundaries between subsets, staff considered the general emission trends of each pollutant as well as changes in heavy-duty diesel engine emission standard (Appendix B) and emission control technology. Among the more significant of these are the changes of PM standard in 1991, 1994, and 2007 model years; the changes of NOx and HC standards in 2003 and 2007 model years; and the increased use of electronic emission controls starting in 1991 model year. Various subsets of emission data were subjected to a statistical test analysis to determine whether the average emissions of the subsets were statistically different or how significant were the differences. Subsets were then either further divided into smaller sets or merged into larger sets.

Based on such an analysis, staff divided the CRC-NWC data into several model year groups for calculating the average emissions of HC, CO, NOx, and PM, as shown in the first two columns of Table 2. Note that for PM, an additional group (1991-1993) was defined. This reflects the change in PM standard from 0.25 to 0.1 g/bhp-hr in 1994 and an observation that the average PM emission for the 1991-1993 model year group is statistically different from

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[3] Heavy-Duty Diesel Inspection and Maintenance Study, prepared by Radian Corporation for California Air Resources Board, May 16, 1988.

that of the 1994-2002 model year group. For CO_2, no discernable relationship between emissions and engine model year was observed; therefore, the CO_2 data of all the model years were evaluated together as a single group.

Table 2. Summary of HHDDT Model Year and T&M Groups

<table>
<tr><th colspan="2">Engine Model Year Group[a]</th><th rowspan="2">T&M Group[b]</th><th rowspan="2">EMFAC Model Year Group[2]</th><th rowspan="2">Proposed Model Year Group</th></tr>
<tr><th>HC, CO, NOx</th><th>PM</th></tr>
<tr><td rowspan="6">Pre-1991</td><td rowspan="6">Pre-1991</td><td rowspan="5">Pre-1987</td><td>Pre-1975</td><td rowspan="5">Pre-1987</td></tr>
<tr><td>1975-1976</td></tr>
<tr><td>1977-1979</td></tr>
<tr><td>1980-1983</td></tr>
<tr><td>1984-1986</td></tr>
<tr><td>1987-1990</td><td>1987-1990</td><td>1987-1990</td></tr>
<tr><td rowspan="5">1991-2002</td><td>1991-1993</td><td>1991-1993</td><td>1991-1993</td><td>1991-1993</td></tr>
<tr><td rowspan="4">1994-2006</td><td>1994-1997</td><td>1994-1997</td><td>1994-1997</td></tr>
<tr><td rowspan="2">1998-2002</td><td>1998</td><td rowspan="2">1998-2002</td></tr>
<tr><td>1999-2002</td></tr>
<tr><td rowspan="2">2003-2006</td><td rowspan="2">2003-2006</td><td rowspan="2">2003+</td><td>2003</td><td rowspan="2">2003-2006</td></tr>
<tr><td>2004-2006</td></tr>
</table>

a. See text for the basis of grouping.

b. Compiled from Section 10 of the *EMFAC Technical Document* (see Footnote 1).

It should be noted that since the heavy-duty engine emission standards apply to engines rather than vehicles, the above grouping was on the basis of engine model years instead of vehicle model years. However, the activity data of the EMFAC model, such as populations and accrual rates, are vehicle model year specific. A survey of 794 heavy-duty trucks conducted by the ARB shows that for some trucks there is a mismatch between the vehicle and engine model years, typically with the former lagging the latter by one year. For a few vehicle model years, the mismatch can be as high as 20%. Using the survey results, staff made adjustments to the engine model year based emission factors so that they can be used with vehicle model year based activity data in calculating emissions inventories.

<u>Model Year Groups for Estimating Tampering and Malmaintenance Impact Rates</u>

The model year groups used in the analysis of the effect of tampering and malmaintenance on HHDDT emissions are shown in Column 3 of Table 2. This grouping, used in EMFAC2002, is based on the above-mentioned Radian study; a study by Engine, Fuel, and Emissions Engineering (EFEE); and a subsequent analysis by the ARB. Although the CRC E55/E59 project provided extensive emission test data, it only collected limited information on tampering and malmaintenance. As a result, staff decided to adopt the EMFAC2002 T&M groups and use the impact rate of a given group when it is considered appropriate or if there is no data suggesting otherwise and to revise an impact rate when there is updated information and data available. The T&M frequencies and emission impact rates for the model year groups shown in Table 2 can be found in Section 10 of the *EMFAC Technical Document* cited in Footnote 1 above.

However, based on recently available data and observations, staff modified the T&M frequencies for the 1998-2002 and 2003-2006 model year groups, as is discussed below.

In EMFAC2002, the T&M impact rates for the 1998-2002 and 2003-2006 groups were projected mainly from experience with the T&M rates of light-duty vehicles of the same model years. However, staff believes that these rates need to be reexamined and revised to reflect the available information and data. A notable feature revealed by the HHDDT NOx emission data is the elevated emission levels of the 1994-2002 model year trucks. This has been generally attributed to programmed increase in NOx emissions (i.e., the so-called "off-cycle NOx" emissions) and may be treated as a tampering act for the purpose of emission evaluation. Thus, for the frequency of occurrence for the "Electronics Tampered" act, staff decided to use the 10% originally estimated by EFEE for the 1994-1997 group instead of the 5% used currently and to increase the frequency from 5% to 15% for the 1998-2002 group.

Table 3A, which was compiled from the data in Section 10 of the *EMFAC Technical Document*, lists the HHDDT T&M frequencies of EMFAC2002 for three groups covering 1994-2006 model years and proposed revisions for the same groups.

Table 3A. Frequency of Occurrence of T&M Acts for HHDDTs[a,b]

T&M Act	EMFAC2002			Revised		
	1994-97	1998-02	2003-06	1994-97	1998-02	2003-06
Timing Advanced	5%	2%	2%	5%	2%	2%
Timing Retarded	3%	2%	2%	3%	2%	2%
Minor Injector Problem	15%	15%	8%	15%	15%	8%
Moderate Injector Problem	10%	10%	5%	10%	10%	5%
Severe Injector Problem	3%	3%	0%	3%	3%	0%
Puff Limiter Misset	4%	0%	0%	4%	0%	0%
Puff Limiter Disabled	4%	0%	0%	4%	0%	0%
Max Fuel High	3%	0%	0%	3%	0%	0%
Clogged Air Filter	15%	15%	15%	15%	15%	15%
Wrong/Worn Turbo	5%	5%	5%	5%	5%	5%
Intercooler Clogged	5%	5%	5%	5%	5%	5%
Other Air Problem	8%	8%	8%	8%	8%	8%
Engine Mechanical Failure	2%	2%	2%	2%	2%	2%
Excessive Oil Consumption	5%	3%	3%	5%	3%	3%
Electronics Failed	3%	3%	3%	3%	3%	3%
Electronics Tampered	5%	5%	5%	**10%**	**15%**	5%
Catalyst Removed	0%	0%	0%	0%	0%	0%

EGR Stuck Open/Low Flow	0%	0%	0%	0%	0%	**5%**
EGR Disabled	0%	0%	10%	0%	0%	10%

a. Compiled from Tables 10.7-3 and 10.7-4 of the *EMFAC Technical Document* (see Footnote 1).

b. Revised values shown in boldface (see text for discussions).

The change in NOx emission standard from 4 to 2 g/bhp-hr in 2003 has lead to the use of EGR systems in heavy-duty diesel trucks. In EMFAC2002, the frequency of the "EGR Disabled" act was estimated to be 10% for the 2003-2006 group, but a 0% value was assumed for the occurrence of EGR malfunctioning. However, based on the data gathered for the HDV OBD regulation (see below), staff concluded that partial functioning of EGR in the form of system stuck open or low flow could occur in certain frequency and hence increased the frequency of the "EGR Stuck Open/Low Flow" act from 0% to 5%.

The original tampering and malmaintenance study by Radian and the subsequent work by EFEE assumed that most HHDD engines would be rebuilt multiple times during their lives and each rebuilding event could completely eliminate the emission increase attributable to malmaintenance. Staff believes that while this may be a reasonable assumption for many older model year trucks, rebuilding may only mitigate a portion of the malmaintenance induced emissions for trucks of newer model years. This is supported by two observations. First, engines on newer model year trucks generally employ advanced designs and emission control technologies. Although rebuilding can bring these engines to the factory specifications with respect to power performance and fuel economy, without enforcement actions the engines' emission performance may not be completely restored. In addition, newer model year trucks are likely to be equipped with some types of emission control devices, and these devices may not be repaired or replaced during engine rebuilding. Second, it had been widely held that engine rebuilds would occur at around 300,000 to 400,000 miles of service based on prevailing information regarding engine rebuild practices. However, investigation by the ARB for the chip reflash regulation reveals that the increased durability of the diesel engine has enabled many engines to run 750,000 to 1,000,000 miles before needing a rebuild. As a result, staff adjusted the 2003-2006 T&M group's T&M impact rates for all pollutants to reflect the likely partial emission mitigation resulting from rebuilding of newer model year engines.

The lowering of the NOx emission standards to 0.2 g/bhp-hr and the introduction of HDV on-board diagnostic (OBD) requirements in 2010 model year led staff to develop a separate T&M group for 2010 and subsequent model year heavy-duty vehicles. Staff analyzed the projected emission controls and configurations for 2010+ model year engines, current inspection programs applicable to light- and heavy-duty vehicles, and the adopted HDV OBD requirements to develop estimated tampering, malmaintenance, and failure rates for various emission control components, the associated emission increase with the failures, and expected repair rates. A description of the frequency of occurrence and emission impact for 2010+ model year HHDD trucks is provided in Appendix C (for further details, see the staff report for the HDV OBD regulation[4]). Table 3B provides a summary of the revisions of T&M and malfunction rates for 2010+ model years.

Table 3B. Frequency of Occurrence of T&M and Malfunction Acts for 2010+ HHDDTs[a]

EMFAC2002		Revised		
T&M Act	2003+	T&M **and Malfunction** Act	2010+	
			No OBD	**w/ OBD**
Timing Advanced	2%	Timing Advanced	2%	**1.33%**
Timing Retarded	2%	Timing Retarded	2%	**1.33%**
Minor Injector Problem	8%	**Injector Problem (Minor/Moderate/Severe)**	13%	**8.67%**
Moderate Injector Problem	5%	**NOx Aftertreatment Sensor #1**	**52.7%**	**40.1%**
Severe Injector Problem	0%	**NOx Aftertreatment Sensor #2**	**1.8%**	**10.8%**
Puff Limiter Misset	0%	**PM Filter Leak**	**13.9%**	**9.75%**
Puff Limiter Disabled	0%	**PM Filter Disabled**	**2%**	**1.33%**
Max Fuel High	0%	**Fuel Pressure High**	0%	0%
Clogged Air Filter	15%	Clogged Air Filter	15%	**10%**
Wrong/Worn Turbo	5%	Wrong/Worn Turbo	5%	**3.33%**
Intercooler Clogged	5%	Intercooler Clogged	5%	**3.33%**
Other Air Problem	8%	Other Air Problem	8%	**5.33%**
Engine Mechanical Failure	2%	Engine Mechanical Failure	2%	**1.33%**
Excessive Oil Consumption	3%	Excessive Oil Consumption	3%	**2%**
Electronics Failed	3%	Electronics Failed	**30%**	**20%**
Electronics Tampered	5%	Electronics Tampered	5%	**3.33%**
Catalyst Removed	0%	**Oxidation Catalyst Malfunction/Removed**	**5%**	3.33%
EGR Stuck Open	5%	**NOx Aftertreatment Malfunction**	**17.1%**	**12%**
EGR Disabled	15%	EGR Disabled**/Low Flow**	**20%**	**13.33%**

a. Revised values shown in boldface (see text for discussions).

Revised emission impact rates of T&M and malfunction

Table 4 lists the T&M impact rates used in EMFAC2002 for different model year groups and the revised impact rates for several T&M groups discussed above.

[4] Staff Report: Malfunction and Diagnostic System Requirements for 2010 and Subsequent Model Year Heavy-Duty Engines (HD OBD), June, 2005 (www.arb.ca.gov/regact/hdobd05/hdobd05.htm).

Table 4. Effect of T&M and Malfunction on Emission Rates of Model Year Groups[a]

Increase in Average Emission at 500,000 miles over Zero-mile Rate (EMFAC2002)								
	Pre1988	1988-90	1991-93	1994-97	1998-02	2003+		
NOx	4.2%	5.7%	10%	7.1%	5.2%	5.3%		
PM	79%	65%	91%	107%	87%	51%		
HC	114%	172%	170%	264%	257%	121%		
Increase in Average Emission at 500,000 miles over Zero-mile Rate (Revised)[b]								
	Pre1988	1988-90	1991-93	1994-97	1998-02	2003-06	2007-09	2010+
NOx	4.2%	5.7%	10%	12%	14%	21%	100%	178%
PM	79%	65%	91%	107%	87%	77%	148%	148%
HC	114%	172%	170%	264%	257%	181%	138%	95%

a. Modified from Table 10.8-1 of the *EMFAC Technical Document* (see Footnote 1).

b. 2007-2009 is the phase-in period for 2007 HDDE standards and 2010-2013 for HDV OBD.

Note that since the EPA 2007 HDDE standards for NOx and HC is to be phased-in in three years, the NOx and HC impact rates for the 2007-2009 T&M group are the averages of those for the 2003-06 and 2010+ groups.

<u>HHDDT Running Exhaust Emission Factors</u>

Based on the above described grouping used for calculating the average emissions and estimating the T&M impact rates, staff proposes a new set of model year groups for calculating HHDDT running exhaust emission factors (i.e., ZMR and DR), as illustrated in the last column of Table 2. For comparison, the model year groups used in EMFAC2002 are also included in the table (Column 4).

Following the methodology used in EMFAC2002, an average emission rate was calculated from the test data for each proposed model year group. With the average emission rates and T&M impact rates, the ZMRs and DRs for HC, CO, NOx, and PM were then calculated for all model year groups using the Radian model:

$$\text{ZMR} = ER_{avg} \div (1+EIR) \quad (1)$$

$$\text{DR} = (ER_{avg} - ZMR) \div MI \quad (2)$$

where ER_{avg} is the average emission rate of a given model year group (in g/mi), *EIR* the T&M emission impact rate for the group (in fraction), and *MI* the mileage at which the group's *EIR* is determined (in unit of 10,000 miles). Since no T&M impact rates are available for CO, the HC impact rates were used in calculating the ZMR and DR for that pollutant. Table 5 shows the EMFAC2002 running exhaust emission factors for HHDDTs and Table 6 the revised HHDDT ZMRs and DRs for the proposed model year groups.

Table 5. EMFAC2002 HHDDT Zero-Mile Rates (ZMR, g/mi) & Deterioration Rate (DR, g/mi/10,000mi)*

Model Year Group	HC		CO		NOx		PM	
	ZMR	DR	ZMR	DR	ZMR	DR	ZMR	DR
Pre 1975	1.60	0.018	8.36	0.095	28.5	0.012	1.98	0.016
1975-76	1.45	0.018	7.81	0.098	27.2	0.013	1.85	0.016
1977-79	1.45	0.019	7.81	0.101	27.2	0.013	1.85	0.017
1980-83	1.45	0.020	7.81	0.108	27.2	0.014	1.85	0.018
1984-86	0.74	0.011	4.87	0.074	20.2	0.011	1.18	0.012
1987-90	0.34	0.009	2.48	0.065	16.8	0.015	0.84	0.008
1991-93	0.28	0.009	1.74	0.056	16.0	0.030	0.51	0.009
1994-97	0.19	0.016	0.84	0.068	19.1	0.042	0.32	0.010
1998	0.18	0.014	0.63	0.049	23.0	0.037	0.26	0.007
1999-02	0.18	0.009	0.63	0.031	13.4	0.013	0.21	0.003
2003	0.14	0.003	1.01	0.023	6.68	0.007	0.26	0.003
2004-06	0.14	0.003	1.01	0.023	6.68	0.007	0.26	0.003
2007-09	0.090	0.003	0.65	0.023	3.67	0.007	0.026	0.003
2010+	0.039	0.003	0.28	0.023	0.67	0.007	0.026	0.003

* The CO_2 emission rate is 2,179 g/mi for all model year groups.

Table 6. Revised HHDDT Zero-Mile Rates (ZMR, g/mi) & Deterioration Rate (DR, g/mi/10,000mi)*

Model Year Group	HC		CO		NOx		PM	
	ZMR	DR	ZMR	DR	ZMR	DR	ZMR	DR
Pre 1987	1.20	0.027	7.71	0.176	23.0	0.019	1.73	0.028
1987-90	0.94	0.032	6.06	0.209	22.7	0.026	1.88	0.025
1991-93	0.62	0.021	2.64	0.090	19.6	0.039	0.78	0.014
1994-97	0.46	0.024	1.95	0.103	19.3	0.046	0.51	0.011
1998-02	0.47	0.024	1.99	0.103	18.9	0.053	0.56	0.010
2003-06	0.30	0.011	0.87	0.031	12.5	0.052	0.35	0.005
2007-09	0.26	0.008	0.74	0.022	6.84	0.047	0.035	0.001
2010+	0.21	0.004	0.61	0.012	1.14	0.041	0.035	0.001
2010+/OBD	0.21	0.003	0.61	0.008	1.14	0.032	0.035	0.0007

* The CO_2 emission rate is 2,237 g/mi for all model year groups.

Because the CO_2 emission data for all model years were evaluated as one group, no ZMR rates and DRs were calculated for individual model year groups for this pollutant; instead the average emission rate of all model years was used for all the model year groups. The revised average CO_2 emission rate is 2,237 g/mi as compared to the EMFAC2002 CO_2 emission rate of 2,179 g/mi.

The ZMRs and DRs for the 2010+ model year groups were estimated from those for the 2003-2006 model year group using the ratio-of-standards method. For the 2007-2009 model year group, the PM emission rate is the same as that of the 2010+ group because of the 100% implementation of EPA 2007 PM standard in 2007. From 2007 to 2009, the EPA 2007 standards for HC and NOx are to be implemented at the 50% level and thus the ZMRs and DRs for the two pollutants were calculated accordingly. It should be noted that although the use of PM traps starting in 2007 could also potentially result in up to 80% reduction in HC emission, staff believes that such a reduction is unlikely to be materialized because the simultaneous lowering of NOx standard would produce increased engine-out HC emissions.

The emission factors for the 2010+/OBD group were calculated from the ZMRs and DRs for the 2010+ group by applying the expected lower frequencies of occurrence of the T&M acts as a result of the phase-in of the HDV OBD requirement between the years 2010 to 2013 (see Footnote 4 for details).

A comparison between the 500,000-mile composite emission factors based on the current EMFAC and revised running exhaust emission factors are provided in Table 7.

Table 7. Comparison of Composite Emission Factors at 500,000 Miles Calculated Based on Current and Revised ZMR and DR (in g/mi)*

<table>
<tr><th rowspan="2">Model Year Group</th><th colspan="4">Based on EMFAC2002 ZMR & DR</th><th colspan="4">Based on Revised ZMR & DR</th></tr>
<tr><th>HC</th><th>CO</th><th>NOx</th><th>PM</th><th>HC</th><th>CO</th><th>NOx</th><th>PM</th></tr>
<tr><td>Pre 1975</td><td>2.50</td><td>13.1</td><td>29.1</td><td>2.78</td><td rowspan="5">2.56</td><td rowspan="5">16.5</td><td rowspan="5">24.0</td><td rowspan="5">3.11</td></tr>
<tr><td>1975-76</td><td>2.35</td><td>12.7</td><td>27.8</td><td>2.65</td></tr>
<tr><td>1977-79</td><td>2.40</td><td>12.9</td><td>27.8</td><td>2.70</td></tr>
<tr><td>1980-83</td><td>2.45</td><td>13.2</td><td>27.9</td><td>2.75</td></tr>
<tr><td>1984-86</td><td>1.29</td><td>8.57</td><td>20.7</td><td>1.78</td></tr>
<tr><td>1987-90</td><td>0.79</td><td>5.73</td><td>17.5</td><td>1.24</td><td>2.56</td><td>16.5</td><td>24.0</td><td>3.11</td></tr>
<tr><td>1991-93</td><td>0.73</td><td>4.54</td><td>17.5</td><td>0.96</td><td>1.67</td><td>7.12</td><td>21.6</td><td>1.49</td></tr>
<tr><td>1994-97</td><td>0.99</td><td>4.24</td><td>21.2</td><td>0.82</td><td>1.67</td><td>7.12</td><td>21.6</td><td>1.05</td></tr>
<tr><td>1998</td><td>0.88</td><td>3.08</td><td>24.9</td><td>0.61</td><td rowspan="2">1.67</td><td rowspan="2">7.12</td><td rowspan="2">21.6</td><td rowspan="2">1.05</td></tr>
<tr><td>1999-02</td><td>0.63</td><td>2.18</td><td>14.0</td><td>0.36</td></tr>
<tr><td>2003</td><td>0.29</td><td>2.16</td><td>7.03</td><td>0.41</td><td rowspan="2">0.85</td><td rowspan="2">2.44</td><td rowspan="2">15.2</td><td rowspan="2">0.62</td></tr>
<tr><td>2004-06</td><td>0.29</td><td>2.16</td><td>7.03</td><td>0.41</td></tr>
<tr><td>2007-09</td><td>0.24</td><td>1.80</td><td>4.02</td><td>0.18</td><td>0.63</td><td>1.81</td><td>9.17</td><td>0.09</td></tr>
<tr><td>2010+</td><td>0.19</td><td>1.43</td><td>1.02</td><td>0.18</td><td>0.41</td><td>1.19</td><td>3.18</td><td>0.09</td></tr>
<tr><td>2010+/OBD</td><td>n/a</td><td>n/a</td><td>n/a</td><td>n/a</td><td>0.34</td><td>0.99</td><td>2.72</td><td>0.07</td></tr>
</table>

* Values in the unshaded cells are based on test data and those in the shaded cells on projection.

Some observations can be made from Table 7. While in general the emission rates estimated from the revised emission factors are similar to those of EMFAC2002 for the pre-1998 model year groups, the revised rates tend to deviate from the EMFAC2002 rates for the 1998 and later model year groups. In particular, compared to the EMFAC2002 emission rates the revised NOx rates for the 2003 and later model year groups are considerably higher but the revised PM rates for the 2007 and later model year groups are much lower. The emission factors of EMFAC2002 were based on test data from trucks of the 1998 and earlier model years, and hence the emission factors for the post-1998 model year trucks were estimated from the data for the 1998 model year trucks. The CRC project extended emission data to the 2003 model year; in addition, staff also revised the T&M impact rates for the 1998+ model year groups. Thus, one might expect substantial changes in emission factors for the 1998 and later model year groups.

The revised running exhaust emission factors were examined by plotting the ZMRs and DRs of selected model year groups along with the test data of the same model year groups. In Figures 1 and 2, the NOx and PM emission rates of the test vehicles from the 1991 to 2002 model years—which were certified to similar emission standards and make up the major portion of the CRC+NWC HHDDTs tested—are plotted as a function of vehicle mileage. Superimposed on the figures are the revised emission factors (ZMRs and DRs) for the 1994-1997 and 1998-2002 model year groups. As the two figures show, the emission-mileage relationships of these two model year groups appear to be reasonably represented by the revised emission factors.

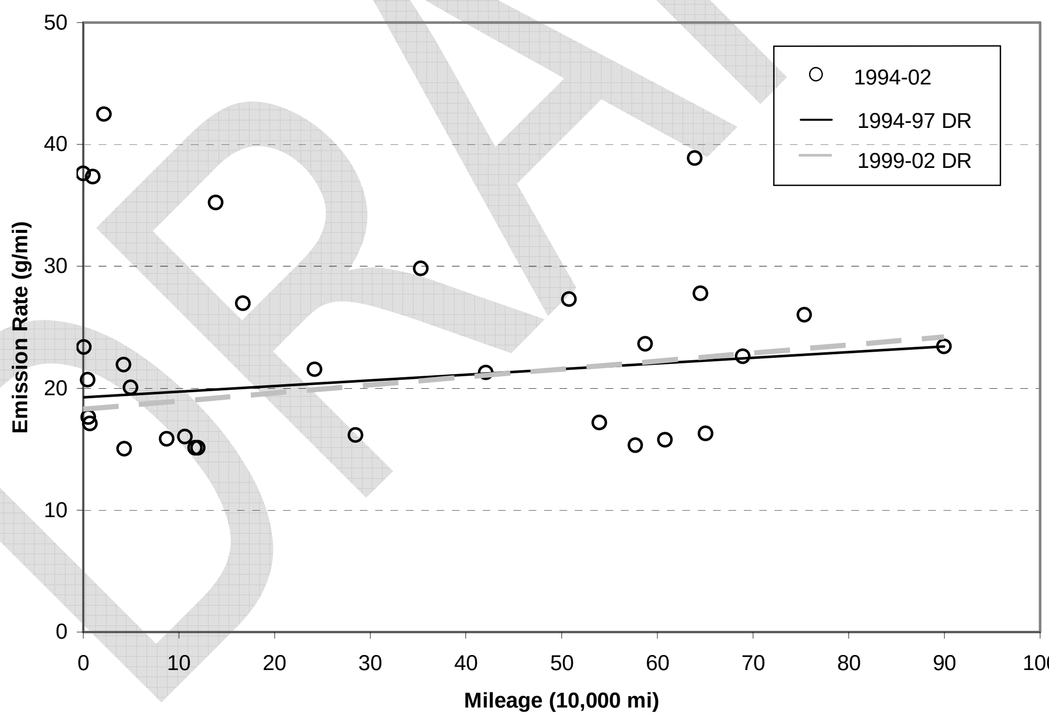


Figure 1. NOx Emission Rate vs. Mileage of Test Vehicles

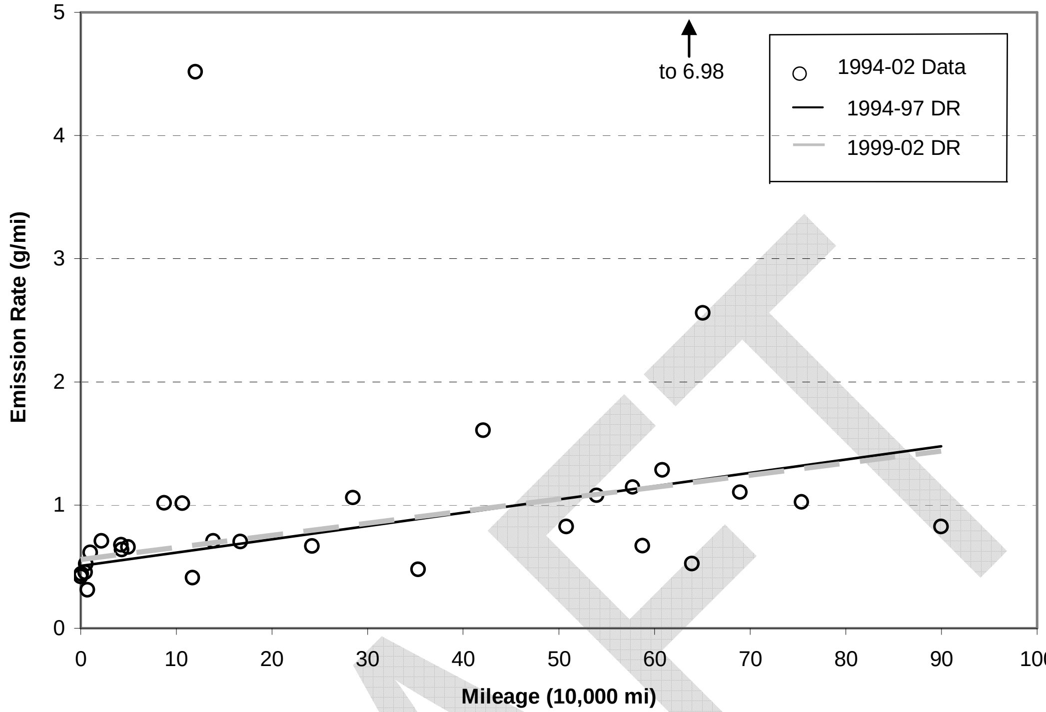


Figure 2. PM Emission Rate vs. Mileage of Test Vehicles

Staff estimated the impact of revised emission factors on the HHDDT running exhaust emissions, and the results are summarized in Table 8.

Table 8. Estimated Impact of Revised Emission Factors on Statewide HHDDT Running Exhaust Emissions (summer season, in tons/day)

Pollutant	Year 2010			Year 2020		
	Current	Revised	Change	Current	Revised	Change
HC	12	28	16	6.9	16	9
CO	62	105	43	44	46	2
NOx	326	394	68	109	178	69
PM	6.1	12	6	3.3	4.1	0.8

HHDDT Idle Emission Factors

In EMFAC2002, the idle emission factors of NOx, HC, CO, and CO_2 for HHDDTs were estimated from the emission data of nine 1996-1998 model year HHDDTs tested by WVU. The average idle emission rates of these trucks were assumed to be applicable to all model years. No PM idle emission data were collected by WVU during the testing, and thus in EMFAC2002 the PM idle emission factors from U.S. EPA's PART5 model were used. Table 9 shows the EMFAC2002 HHDDT idle emission factors.

Table 9. EMFAC2002 HHDDT Idle Emission Factors (in g/hour)*

Model Year Group	HC	CO	NOx	PM	CO_2
Pre-1998	3.48	26.3	80.7	5.37	4,098
1988-1990	3.48	26.3	80.7	3.17	4,098
1991-1993	3.48	26.3	80.7	1.86	4,098
1994+	3.48	26.3	80.7	1.00	4,098

* From PART5 of U.S. EPA.

The CRC E55/E59 project provided staff an opportunity to revise the idle emission factors for HHDDTs. The CRC data include idle emission test results for 47 HHDDTs ranging from 1975 to 2003 engine model years (Appendix D). Using these data, staff calculated idle emission factors for the same model year groups as those for running exhaust emission factors.

Staff first attempted to analyze the idle emission data following the approach used in calculating running exhaust emission factors. Compared to running exhaust emission data, the idle emission data set is smaller (no idle emission data in the NWC data set) and shows much larger scattering in the emission test results of individual vehicles. Thus, for some model year groups the averages of the idle emission rates were dominated by one or two data points. This lead to a large variation in the average idle emission rates of all model year groups that seems to be best attributed to small sample size.

Staff subsequently decided to estimate the average idle emission rates for all model year groups based on the overall trend of the idle emission data. Regression analysis of the idle emission rates of individual trucks was performed to determine the best fit equations that represent the general relationship between emissions and model years. Emission rate values were calculated from the equations for individual model years and then averaged for the same model year groups as those used in calculating running exhaust emission factors. The average idle emission rates for all model year groups are given in Table 10. Because the CRC data were collected at "curb" idle (idling at engine speed $\leq$ 800 rpm) with no accessory loading, the values shown in the table are low idle emission rates.

Table 10. Proposed HHDDT Low Idle Emission Rates (g/hour)*

Model Years	HC	CO	NOx	PM	CO_2
Pre-1987	25.9	28.4	45.7	4.76	4,640
1987-90	15.2	23.4	70.2	2.38	4,640
1991-93	12.1	21.5	78.4	1.78	4,640
1994-97	9.68	19.8	85.3	1.33	4,640

1998-02	7.26	17.8	92.1	0.92	4,640
2003-06	5.97	16.6	95.5	0.72	4,640
2007-09	5.97	16.6	95.5	0.072	4,640
2010+	5.97	16.6	95.5	0.072	4,640
2010+/OBD	5.97	16.6	95.5	0.072	4,640

* Calculated from the idle emission test data of the CRC E55/E59 project.

Several studies have shown that idle emissions from trucks are highly dependent on ambient conditions, accessory usage, and engine speed. During extended idling (hours to overnight), often a truck's air conditioner or heater is on in addition to the use of other accessories. For extended idling, truck operators usually set the engine speed at a high rpm (>800 rpm) to increase power output and reduce engine wear. A recent multi-agency study, which included the U.S. EPA and Oak Ridge National Laboratories among others, examined high-rpm idle emissions from trucks under simulated summer (90°F) and winter (0°F) conditions. From the data obtained in this study, staff derived high idle correction factors for estimating high idle emission rates; i.e., idle emission rates at high rpm and with accessory loading[5]. By applying the high idle correction factors to the low idle emission rates in Table 10, high idle emission rates for HHDDTs were calculated for summer months (March through September) and winter months (October through February), as shown in Tables 11 and 12.

Table 11. HHDDT High Idle Emission Rates for Summer (Mar-Sep, in g/hour)*

Model Years	HC	CO	NOx	PM	CO_2
Pre-1987	44.0	87.9	96.0	11.9	10,670
1987-90	25.8	72.5	147	5.94	10,670
1991-93	20.6	66.7	165	4.44	10,670
1994-97	16.4	61.4	179	3.33	10,670
1998-02	12.3	55.2	193	2.31	10,670
2003-06	10.1	51.3	201	1.79	10,670
2007-09	10.1	51.3	201	0.18	10,670
2010+	10.1	51.3	201	0.18	10,670
2010+/OBD	10.1	51.3	201	0.18	10,670

* Calculated by multiplying the low idle emission rates in Table 10 by the high idle correction factors for the summer season.

5 ARB internal document: *Development of Idle Emission Factors*.

Table 12. HHDDT High Idle Emission Rates for Winter (Oct-Feb, in g/hour)*

Model Years	HC	CO	NOx	PM	CO_2
Pre-1987	57.0	207	82.2	20.5	8,350
1987-90	33.4	171	126	10.2	8,350
1991-93	26.6	157	141	7.64	8,350
1994-97	21.3	145	153	5.73	8,350
1998-02	16.0	130	172	3.96	8,350
2003-06	13.1	121	172	3.07	8,350
2007-09	13.1	121	172	0.31	8,350
2010+	13.1	121	172	0.31	8,350
2010+/OBD	13.1	121	172	0.31	8,350

* Calculated by multiplying the low idle emission rates in Table 10 by the high idle correction factors for the winter season

To calculate the HHDDT idle emission factors for a given month, the low and high idle emission rates are weighted by the fractions of time that trucks operate at the low idle and high idle conditions. Based on a recent study by the University of California at Davis, Staff concluded that on average the percentages of low and high idles for HHDDTs are approximately 61% and 39%, respectively (see Footnote 5 for more details).

Staff estimated the impact of the proposed idle emission rates on the statewide HHDDT idle emissions, and the results are given in Table 13.

Table 13. Estimated Impact of Proposed Idle Emission Factors on Statewide HHDDT Idle Emissions (summer season, in tons/day)

Pollutant	Year 2010			Year 2020		
	Current	Revised	Change	Current	Revised	Change
HC	1.3	4.7	3.4	1.5	3.7	2.2
CO	9.8	13	3	12	14	2
NOx	30	45	15	36	60	24
PM	0.6	0.8	0.2	0.5	0.3	-0.2

HHDDT Speed Correction Factors

The HHDDT SCFs for HC, CO, and NOx in EMFAC2002 were inherited from the U.S. EPA's MOBILE4 model. Since the MOBILE4 model did not have SCFs for PM and CO_2, the SCFs for HC were assumed to apply to PM and the SCFs for CO_2 were set to 1. The CRC E55/E59 project provides emission data at several different speeds, offering an opportunity for staff to develop new HHDDT SCFs for all five pollutants.

In the E55/E59 project, emission rates were collected at the average speeds of the UDDS, the Creep mode, the Transient mode, the Cruise mode, and the High Speed Cruise mode, respectively. Emission rates at 65 mph speed were estimated from the high-speed portion of the High Speed Cruise mode's second-by-second data.

An examination of the CRC data suggests that the speed-specific emission data should be evaluated as two subsets corresponding to two broad model year groups. Plotting of all truck's speed-specific emission rates on an emission rate-speed chart indicated that the curves of individual trucks tended to cluster into one of the two groups: a group including pre-1991 and 2003+ (2003 and later) model years and a group of 1991-2002 model years. The 1991-2002 model year group is apparently different from the pre-1991&2003+ model year group for all pollutants except for CO_2. Thus, for HC, CO, NOx, and PM two sets of SCFs were developed for the pre-1991/2003+ model year group and 1991-2002 model year group, respectively. The CO_2 data were analyzed as one group and only one set of SCFs was developed for this pollutant.

For each group, emission rates of a pollutant were first normalized to its UDDS emission rate and the normalized emission rate multiples were then plotted as a function of speed. Regression curves were then fit to find the equations best representing the normalized data. The SCF for a given pollutant and speed can be calculated using the following equation:

$$SCF = A + B\times(\text{Speed}) + C\times(\text{Speed})^2 \quad (3)$$

where *A*, *B*, and *C* are coefficients. Table 14 lists the coefficients of the best fit equations for calculating the SCFs of all five pollutants. A series of graphs comparing the proposed SCFs and the current EMFAC SCFs are given in Appendix E.

Table 14. Coefficients for Proposed HHDDT Speed Correction Factors*

	Model Year Group	Speed (mph)	A	B	C
HC	Pre-1991&2003+	5-18.8	7.3204	-0.5058	9.021×10^{-3}
		18.8-65	1.6379	-4.139×10^{-2}	3.679×10^{-4}
	1991-2002	5-18.8	11.614	-0.9929	2.278×10^{-2}
		18.8-65	2.3019	-8.712×10^{-2}	9.773×10^{-4}
CO	Pre-1991&2003+	5-65	1.7340	-4.754×10^{-2}	4.494×10^{-4}
	1991-2002	5-18.8	3.0388	-0.1511	2.267×10^{-3}
		18.8-65	1.8753	-5.664×10^{-2}	5.141×10^{-4}
NOx	Pre-1991&2003+	5-18.8	2.4014	-0.1487	3.943×10^{-3}
		18.8-65	1.4039	-2.654×10^{-2}	2.537×10^{-4}
	1991-2002	5-18.8	3.7668	-0.2862	7.394×10^{-3}
		18.8-65	1.0771	-5.981×10^{-3}	9.271×10^{-5}
PM	Pre-1991&2003+	5-18.8	2.5492	-0.1202	2.009×10^{-3}

		18.8-65	1.8044	-5.622×10^{-2}	7.145×10^{-4}
	1991-2002	5-18.8	5.7807	-0.4032	7.918×10^{-3}
		18.8-65	2.2766	-8.661×10^{-2}	9.948×10^{-4}
CO_2	All Model Years	5-18.8	2.0722	-7.559×10^{-2}	9.873×10^{-4}
		18.8-65	1.3256	-2.142×10^{-2}	1.969×10^{-4}

* Based on analysis of the emission test data of the CRC E55/E59 project.

Note that with the exception of the Pre-1991&2003+ group CO, it was found that for both model year groups the data were better fit when different equations were used for the two specified speed domains.

The estimated impact of the proposed SCFs on the statewide HHDDT running exhaust emissions is shown in Table 15.

Table 15. Estimated Impact on Statewide HHDDT Running Exhaust Emissions from Proposed Speed Correction Factors (summer season, in tpd)

Pollutant	Year 2010			Year 2020		
	Current	Revised	Change	Current	Revised	Change
HC	12	12	0	6.9	7.3	0.4
CO	62	58	-4	44	43	-1
NOx	330	260	-70	110	82	-28
PM	6.1	7.8	1.7	3.3	4.4	1.1

Total Impact on Statewide Emissions Inventories

Staff estimated the total impact of the revised running emission factors and proposed idle emission factors and SCFs on the statewide emissions inventories, and the results are given in Table 16.

Table 16. Estimated Impact of Revised Emission Factors and Proposed SCFs on Statewide Emissions Inventories (summer season, in tons/day)

Pollutant	Year 2010			Year 2020		
	Current	Revised	Change	Current	Revised	Change
HC	13	32	19	8.4	20	12
CO	72	119	47	56	60	4
NOx	356	438	82	145	238	93
PM	6.7	13	6.3	3.8	4.5	0.7

Emission Factors and SCFs for Federal Trucks

Staff also proposes revisions of the emission factors for the federal HHDDTs, which account for 25% of the HHDDTs operating in California. The emission factors for the federal trucks were derived by adjusting the emission factors for California trucks by comparing the California and federal heavy-duty diesel engine emission standards (Appendices B and F). The proposed HC, CO, NOx, PM, and CO_2 running and idle emission factors for federal HHDDTs are given in Appendix G.

The proposed SCFs, which were developed based on test data from California trucks, are assumed to apply to federal HHDDTs.

AFFECTED SOURCE CODE

The following source code files of the EMFAC model are affected by the proposed revisions of emission factors and SCFs.

- BER_Data.for
- SCF_Data.for
- TEFxAssign.for

Methodology for Source Code Revision

The running exhaust emission zero mile rates and deterioration rates for heavy heavy-duty diesel trucks will be modified according to Table 6 for California certified trucks and Table F-1 for federally certified trucks. The idle emission rates will be modified according to Tables 10, F-3 and F-6, for California and Federal trucks, respectively. Table 17 provides the model year and tech group bins for running exhaust and idle emission factors.

Table 17. Heavy Heavy-Heavy Duty Diesel Model Year and Tech Group Bins for Exhaust and Idle Emission Factors

California Certified Trucks		Federally Certified Trucks	
Model Year	Technology Group	Model Year	Technology Group
Pre-1987	Tech Groups 150-154	Pre 1988	Tech Groups 200-203
1987-90	Tech Group 155	1988-90	Tech Group 204
1991-93	Tech Group 156	1991-93	Tech Group 205
1994-97	Tech Group 157	1994-97	Tech Group 206
1998-02	Tech Groups 158-159	1998-02	Tech Groups 207-208
2003-06	Tech Group 160	2003-06	Tech Group 209
2007-09[a]	Tech Group 161	2007-09[a]	Tech Group 210
2010+[b]	Tech Group 162	2010+[e]	Tech Group 211
2010+/OBD[c]	Tech Group 163[d]		

a. Modification of the group's definition (EPA 2007 rule HHDV/LHV diesel vehicles phase-in).
b. New technology group (EPA 2007+ rule HHDV/LHV diesel vehicles).
c. New technology group (ARB 2010+ HHDV/LHV diesel vehicles OBD).
d. Tech Group 163 has the same idle emission factors as Tech Group 162.
e. Modification of the group's definition (EPA 2007+ rule HHDV/LHV diesel vehicles).

For model years 2007 to 2013, the **TEFxAssign.for** file will be modified to reflect the phase-in schedules for the US EPA 2007 standards and the ARB 2010 HDV OBD regulation according to Table 18.

Table 18. Modifications to TEFxAssign.for

California Certified HHDDT Trucks					Federally Certified HHDD Trucks				
Model Year	Tech Group	Weight	Tech Group	Weight	Model Year	Tech Group	Weight	Tech Group	Weight
2007	160	0%	161	100%	2007	209	0%	210	100%
2008	160	0%	161	100%	2008	209	0%	210	100%
2009	160	0%	161	100%	2009	209	0%	210	100%
2010	162	95%	163	5%	2010+	210	0%	211	100%
2011	162	95%	163	5%					
2012	162	95%	163	5%					
2013+	162	0%	163	100%					

High Idle emission rates will be established for both winter and summer for California and federally certified HHDD trucks. California high idle rates for summer and winter are given in

Tables 8 and 9; Federal high idle rates for summer and winter are given in Tables F-4 and F-5. It is suggested that these new rates be accommodated by populating an unused process in the **BER_Data.for** file.

The gram per hour idle emission rates will be calculated according to the following equation:

$$ER_{idle} = (\textit{Low Idle})\times(\textit{Weighting Factor}) + (\textit{High Idle})_{Season}\times(1-\textit{Weighting Factor}) \qquad (4)$$

where *Low Idle* is the low idle emission rate, *High Idle* the high idle emission rate (which is a function of month or episode), and the *Weighting Factor* a variable representing the low idle portion of all idle operation.

Two sets of speed correction factors will be established for California and federally certified trucks: one for pre-1991 and 2003+ model years and the other for 1991-2002 model years. The parameters of the SCF equation are given in Table 14, and the affected technology groups are listed in Table 19.

Table 19. Speed Correction Factor Technology Groups

Pre-1991&2003+	Tech Groups: 150-155, 160-163, 200-204, 209-211
1991-2002	Tech Groups: 156-159, 205-208

File Location:

x:\EMFAC QA QC 2007\Heavy Duty Emissions

Appendix A. CRC E55/E59 HHDDT UDDS Test Data

Test ID	Make	Engine Model	Engine MY	Odometer Reading	Vehicle MY	Test Cycle	CO	NOx	HC	PM	CO2
							(g/mile)	(g/mile)	(g/mile)	(g/mile)	(g/mile)
E55CRC-1	Detroit	Diesel Series 60	1994	639,105	1994	UDDS	14.2	36.2	0.24	0.39	1,996
E55CRC-2	Caterpillar	3406B	1995	241,843	1995	UDDS	4.20	20.1	0.84	0.50	2,502
E55CRC-3	Cummins	NTCC-300	1985	501,586	1985	UDDS	13.2	12.4	2.74	1.76	2,203
E55CRC-4	Caterpillar	C-10	2000	42,362	2000	UDDS	9.61	20.4	0.28	0.51	2,523
E55CRC-5	Cummins	N14-435E1	2000	166,980	2000	UDDS	5.35	25.1	1.42	0.53	2,752
E55CRC-6	Cummins	M11-370	1995	689,536	1995	UDDS	9.36	21.0	0.87	0.83	1,954
E55CRC-7	Detroit	Diesel Series 60	1990	399,224	1990	UDDS	6.57	21.5	0.24	0.75	1,991
E55CRC-8	Cummins	M11-300	1996	507,855	1996	UDDS	5.16	25.4	0.83	0.62	2,210
E55CRC-9	Caterpillar	C12	1998	607,968	1998	UDDS	6.98	14.7	0.91	0.97	2,206
E55CRC-10	Detroit	series 60	1998	21,631	1998	UDDS	8.76	39.5	0.22	0.53	2,139
E55CRC-11	Cummins	ISM	2000	117,048	2000	UDDS	2.45	14.1	0.73	0.31	1,942
E55CRC-12	Cummins	300	1986	533,377	1986	UDDS	30.0	18.6	4.42	3.89	2,212
E55CRC-13	Cummins	Cummins 350	1978	570,546	1978	UDDS	18.9	28.1	1.57	1.48	2,302
E55CRC-14	Cummins	LTA10	1985	565,927	1986	UDDS	11.9	18.6	1.13	1.47	2,077
E55CRC-15	Cummins	NTC-350	1986	340,486	1973	UDDS	11.4	27.1	6.98	3.25	2,772
E55CRC-16	Caterpillar	3208	1979	200,000	1979	UDDS	72.7	14.8	1.74	12.1	2,230
E55CRC-17	Cummins	L-10	1993	733,868	1993	UDDS	9.55	17.5	0.92	1.02	2,154
E55CRC-18	Cummins	L-10	1991	440,456	1991	UDDS	5.21	17.5	1.82	0.89	2,102
E55CRC-19	Cummins	L-10	1987	465,061	1987	UDDS	17.0	15.7	4.47	2.01	2,055
E55CRC-20	Detroit	Diesel Series 60	1992	514,188	1992	UDDS	16.6	20.7	0.26	1.12	2,045
E55CRC-21	Caterpillar	3406B	1990	937,438	1990	UDDS	20.5	24.2	0.43	2.97	2,384
E55CRC-22	Cummins	L10-280	1993	232,829	1993	UDDS	4.70	19.0	4.70	0.95	1,980
E55CRC-23	Cummins			320,885	1983	UDDS	33.2	29.5	2.10	2.38	2,393
E55CRC-24	Cummins	NTCC-350	1975	773,487	1975	UDDS	9.88	30.4	2.58	1.19	2,204
E55CRC-25	Cummins		1983	806,068	1983	UDDS	12.4	27.3	2.15	1.33	1,976
E55CRC-26	Caterpillar	C-10	1998	539,553	1999	UDDS	15.0	16.0	0.37	0.81	2,493
E55CRC-27	Detroit	Diesel Series 60	1999	420,927	2000	UDDS	9.44	19.8	0.32	1.21	2,889
E55CRC-28	Detroit	Diesel Series 60	1998	645,034	1999	UDDS	57.5	25.8	0.92	5.24	2,497
E55CRC-29	Cummins	1SX475ST2	1999	120,000	2000	UDDS	8.10	14.1	3.30	3.39	2,395
E55CRC-30	Detroit	Diesel Series 60	1998	138,625	1999	UDDS	10.0	32.8	0.43	0.53	2,155
E55CRC-31	Cummins	N14-460E+	1997	587,389	1998	UDDS	3.15	22.0	2.04	0.50	2,414
E55CRC-32	Caterpillar	3406B	1991	596,082	1992	UDDS	4.53	14.4	0.90	0.81	2,119
E55CRC-33	Caterpillar	3406	1984	988,726	1985	UDDS	12.0	45.1	2.03	2.00	2,268
E55CRC-34	Detroit	Diesel Series 60	2003	19,094	2004	UDDS	6.63	12.8	0.41	1.26	2,446
E55CRC-35	Detroit	Diesel Series 60	2000	106,377	2001	UDDS	6.87	14.9	0.56	0.76	2,017
E55CRC-36	Caterpillar	C-15	2001	284,553	2001	UDDS	6.84	15.0	0.71	0.80	2,409
E55CRC-38	Cummins	ISX	2003	2,829	2004	UDDS	1.04	14.8	0.76	0.17	2,641
E55CRC-39	Cummins	ISX	2003	45	2004	UDDS	1.29	13.0	0.82	0.31	2,582
E55CRC-40	Detroit	Diesel Series 60	2003	8,916	2004	UDDS	0.79	15.8	0.44	0.13	2,148
E55CRC-42	Caterpillar	3406	1999	576,998	2000	UDDS	2.19	14.3	1.00	0.86	2,627
E55CRC-43	Detroit	Diesel Series 60	1994	899,582	1995	UDDS	1.82	21.8	0.32	0.62	1,946
E55CRC-44	Caterpillar	3406	1989	811,202	1989	UDDS	7.88	17.3	0.94	0.84	1,948
E55CRC-45	Cummins	L10-280	1993	685,168	1993	UDDS	3.47	12.2	15.80	3.04	2,029
E55CRC-46	Caterpillar	3176	1989	935,582	1989	UDDS	7.60	16.2	0.35	1.43	2,067
E55CRC-47	Detroit	6V92	1986	760,810	1986	UDDS	7.59	13.3	1.24	2.82	2,272
E55CRC-48	Cummins	N1 Plus	1998	753,792	1998	UDDS	2.11	24.2	1.42	0.77	2,407
E55CRC-49	Caterpillar		1993	650,557	1994	UDDS	12.9	15.2	0.40	1.92	2,085

Appendix B. California Heavy-Duty Diesel Engine Emission Standards (in g/bhp-hr)

Model Year	HC[a]	CO	NOx	PM	HC+NOx
1975-1976	---	30.0	---	---	10.0
1977-1979	1.0	25.0	7.5	---	---
1980-1983	1.0	25.0	---	---	6.0
1984-1986	1.3	15.5	5.1	---	---
1987-1990	1.3	15.5	6.0	0.60	---
1991-1993	1.3	15.5	5.0	0.25	---
1994-1997	1.3	15.5	5.0	0.10	---
1998-2002	1.3	15.5	4.0	0.10	---
2003-2006	0.2	15.5	2.2[b]	0.10	---
2007-2009[c]	---	15.5	---	0.01	---
2010+	0.14	15.5	0.2	0.01	---

a. The HC standards are for total hydrocarbons except those for 2003 and subsequent model years, which are for NMHC.

b. Nominal NOx value of 2.2 g/bhp-hr based on 2.4 g/bhp-hr NOx+NMHC standards effective October 2002.

c. EPA 2007 standards for HC and NOx are to be phased in between 2007-2010.

Appendix C. Frequency of Occurrence of T&M and Malfunction and Resulting Emission Impact for 2010+ Model Year HHDD Trucks

Tampering and malmaintenance (T&M) and malfunction rates were developed for the model year group of 2010 and subsequent model year heavy-duty vehicles. This appendix provides a description of the frequency of occurrence of T&M and malfunction categories and the resulting emission impact for 2010+ model year HHDD trucks (further detail can be found in the staff report for the HDV OBD regulation; see Footnote 4 of this memo).

Frequency of Occurrence Rates

The table below shows the revisions to the frequency of occurrence of T&M and malfunction categories for 2010+ model year group.

Table C. Frequency of Occurrence of T&M and Malfunction Acts for 2010+ HHDDTs[a]

EMFAC2002		Revised		
T&M Act	2003+	T&M **and Malfunction** Act	2010+	
			No OBD	**w/ OBD**
Timing Advanced	2%	Timing Advanced	2%	**1.33%**
Timing Retarded	2%	Timing Retarded	2%	**1.33%**
Minor Injector Problem	8%	**Injector Problem (Minor/Moderate/Severe)**	13%	**8.67%**
Moderate Injector Problem	5%	**NOx Aftertreatment Sensor #1**	**52.7%**	**40.1%**
Severe Injector Problem	0%	**NOx Aftertreatment Sensor #2**	**1.8%**	**10.8%**
Puff Limiter Misset	0%	**PM Filter Leak**	**13.9%**	**9.75%**
Puff Limiter Disabled	0%	**PM Filter Disabled**	**2%**	**1.33%**
Max Fuel High	0%	**Fuel Pressure High**	0%	0%
Clogged Air Filter	15%	Clogged Air Filter	15%	**10%**
Wrong/Worn Turbo	5%	Wrong/Worn Turbo	5%	**3.33%**
Intercooler Clogged	5%	Intercooler Clogged	5%	**3.33%**
Other Air Problem	8%	Other Air Problem	8%	**5.33%**
Engine Mechanical Failure	2%	Engine Mechanical Failure	2%	**1.33%**
Excessive Oil Consumption	3%	Excessive Oil Consumption	3%	**2%**
Electronics Failed	3%	Electronics Failed	**30%**	**20%**
Electronics Tampered	5%	Electronics Tampered	5%	**3.33%**
Catalyst Removed	0%	**Oxidation Catalyst Malfunction/Removed**	**5%**	**3.33%**
EGR Struck Open	5%	**NOx Aftertreatment Malfunction**	**17.1%**	**12%**
EGR Disabled	15%	EGR Disabled**/Low Flow**	**20%**	**13.33%**

a. Revised values shown in boldface (see text for discussions).

For the frequency of occurrence rates in Table C, staff modified several of the existing components to better reflect the technology that is expected to be used on 2010 and subsequent engines as well as to account for malfunction of components in addition to tampering or malmaintenance. Specifically, staff added categories for PM filter leaks, missing/tampered PM filters, NOx aftertreatment system malfunctions, and NOx aftertreatment control sensor malfunctions. Staff eliminated the categories deemed to be not applicable to 2010+ model years, such as puff limiter misset, puff limiter disabled, and EGR stuck open. Staff also merged minor, moderate, and severe injector problems into a single injector problem category, expanded EGR disabled to include EGR low flow/performance malfunctions, and modified the category for catalyst removed to oxidation catalyst malfunction/removed. The frequency of occurrence in Table C represents an overall average failure rate over the life of the 2010+ model year vehicles.

For the baseline "without OBD" values in EMFAC, staff estimated various failure rates for the categories. For the existing categories in the table (except for the electronics failed category), staff did not modify the estimated failure rates. However, for the added and modified categories staff estimated failure rates based on information from manufacturers, suppliers, and, where appropriate, experience with similar components in light-duty. In all cases, staff assumed any failures occurring during the warranty period would be fixed immediately, and thus a failure rate of 0% was assumed during the warranty period.

For EGR, staff increased the failure rate from 10% to 20% to account for nearly every engine using EGR in the 2010 timeframe and for the increased sensitivity and reliance to proper EGR performance on those engines. For the oxidation catalysts, staff increased the failure rate from 1% to 5% to account for nearly every engine being equipped with a catalyst, to account for combining oxidation catalyst performance malfunctions with oxidation catalyst tampered/removed into a single category, and to account for the increased sensitivity and reliance on proper oxidation catalyst performance to achieve PM filter regeneration.

For the electronics failed category, staff increased the frequency of occurrence from 3% to 30% to account for the significant increase in complexity of the 2010+ emission control systems. For these engines, a substantial number of sensors (e.g., temperature, mass air flow, pressure) and actuators (e.g., intake or exhaust throttles) are being added and other components have become more complex (e.g., high pressure common rail fuel injection system components, variable geometry turbos). In addition to actual sensor or actuator failures, each sensor and actuator has additional circuits and wiring that increase the chance for a failure in-use.

For the added category of PM filter leak, staff estimated a failure rate that increased over time starting with an approximately 6% failure rate at the end of useful life (~450,000 miles) and ramping up to a failure rate of 37% at 1,000,000 miles. In setting this failure rate, staff largely discounted the high failure rates currently being observed in the heavy-duty fleet (both OEM-equipped and retrofit) and estimated much more conservative failure rates. For the category of PM filter disabled (largely due to tampering), staff assumed a rate of only 2%.

At present, two competing NOx aftertreatment technologies are still being considered for 2010 model year applications. Accordingly, staff analyzed both systems and their associated components and assumed a blend of the two would exist in the fleet with some using a selective catalytic reduction (SCR) system with a single NOx control sensor and reductant delivery (e.g., urea) and some using a NOx adsorber system with upstream and downstream air-fuel (A/F) control sensors. For the category in Table C of NOx aftertreatment, staff grouped together the SCR catalyst and the components associated with reductant storage and delivery to the exhaust or, in the case of an adsorber system, included failures of the adsorber itself. For these failures, staff again estimated a failure rate that increased over time. The failure rate for this category was ramped in starting with a 10% failure rate at 500,000 miles (50,000 miles beyond useful life) to a 50% failure rate by 1,000,000 miles. While failures of an SCR catalyst itself may be fairly limited, the associated hardware includes urea tank, tank heaters, in-exhaust injector, compressed air delivery to the injector, and urea supply pump and control system are all components subject to malfunction and can have the same emission impact as an SCR catalyst failure. In assuming that only half of the trucks left on the road at 1,000,000 miles will have experienced a failure of any one of these components at some point in its 1,000,000-mile life, staff believes the estimate is fairly conservative. For an adsorber system, the adsorber itself will likely have a significant failure rate in a 1,000,000-mile timeframe given the sensitivity to thermal damage and the need for periodic desulfation that must be conducted at temperatures extremely close to the thermal damage point. Further, each desulfation event will likely slightly deteriorate the performance of the adsorber leading to an eventual fail on some share of the engines. In some cases, adsorber systems may also rely on in-exhaust injectors, fuel supply lines, control, and metering systems that are subject to malfunction and can have a similar emission impact.

For the two NOx aftertreatment control sensor (e.g., NOx sensor, A/F sensor) categories, a two-part failure rate was estimated and modeled as two separate categories. For SCR systems using a single NOx control sensor, the model assumes the sensor has an initial fail, some portion of those sensors are replaced, and a second fail occurs later in the life of the new sensor. For NOx adsorber systems with two A/F sensors, the model assumes one of the two sensors has an initial fail, some portion of those sensors are replaced, and a second fail occurs later in the life of the engine which could be either a failure of the replaced sensor or a an initial failure of the other A/F sensor on the vehicle.

For the initial failure in both systems, a single failure of a control sensor was estimated to ramp in starting with a 35% failure by 250,000 miles and peaking at a 90% failure rate after a subsequent 200,000 miles (i.e., by 450,000 miles). Staff based these failure rates on discussions with engine manufacturers expressing concern that they had not been convinced that NOx sensor durability was sufficient to last 100,000 miles, much less the useful life period of 450,000 miles. Discussions with sensor suppliers show significant potential for further improvement in durability over the next few years, and accordingly staff assumed essentially a 0% failure rate for double the current expected life of the sensor before ramping the failure up to near complete failure at 4.5 times the current expected sensor life. Further, A/F sensors are commonplace in light- and medium-duty vehicles and Inspection and Maintenance (I/M) program data indicates these sensors are failing in I/M on approximately 2.5% of the fleet at 100,000 miles. Assuming this failure rate were to grow linearly at a failure rate of 2.5% per 100,000 miles, that would represent a cumulative failure rate of 7.5% at 250,000 miles. Additionally, this 2.5% failure rate only includes the subset of vehicles with a malfunctioning A/F sensor vehicles that ignore an illuminated warning light and actually fail the I/M test. Data from non-I/M areas would support that the actual in-use failure rate is higher than that and is a result of a portion of the people fixing the vehicle prior to the I/M test. When adjusting that number to reflect the more realistic situation that the failure rate increases non-linearly over time, that the actual in-use failure rate in light-duty is actually higher than the 2.5% that show up in I/M, and that each engine with a NOx adsorber system is projected to use two A/F sensors, a 35% failure rate at 250,000 miles is reasonable. To further assume that 90% of the sensors will have failed once by 450,000 miles is consistent with a continued increase of the failure rate and engine manufacturers' expressed opinions that the sensors will not last through the useful life. This failure of the first control sensor is represented in the category for NOx aftertreatment control sensor #1.

The second part of the failure rate for the NOx aftertreatment control sensor categories estimates the percentage of the fleet that will repair/replace the first failed sensor and then experience a subsequent failure of the repair/replaced sensor while still within the first 1,000,000 miles of the engine life. For this failure rate, staff assumed the same sensor durability and failure rate (i.e., failure rate ramps in at 35% beginning 250,0000 miles after the previous sensor repair/replacement and peaks at 90% after an additional 200,000 miles) but only applied it to the fraction of vehicles which were estimated to already have a failed sensor and a subsequent repair. This second part of the failure rate of the control sensor is represented in the category for NOx aftertreatment control sensor #2.

<u>OBD Repair Rate</u>

While the frequency of occurrence rates shown in Table C are a single number that represents the average failure rate, or probability of occurrence, the model actually assumes that there are constantly some additional failures and repairs that are occurring in the fleet. For the baseline (without OBD) scenario described above, these numbers represent the failures that are above and beyond what is being routinely repaired in the field.

To account for the adopted HD OBD program (phased in from 2010-2013), staff then estimated a repair rate for all the categories in Table C. Staff estimated a 33% reduction in the frequency of occurrence across all categories to simulate an additional 33% of the malfunctions that are repaired due to the presence of the OBD system. Staff's rationale for the 33% repair rate was that all the malfunctions estimated in the categories would likely result in MIL illumination. It is expected that some fraction of vehicle owners or operators would take repair action simply because they were alerted to the presence of a malfunction by the MIL. Additionally, California has two inspection programs that are applicable to heavy-duty vehicles. First, the heavy-duty vehicle inspection program (HDVIP) conducts roadside testing and issues citations or notice-of-violations for trucks that fail either a snap-idle opacity test or a visual inspection. This inspection program currently tests about 6% of the heavy-duty fleet in California. Secondly, California has a fleet annual self-inspection program whereby all fleets (defined as anybody with two or more trucks) are required to perform self-inspections for snap-idle opacity on an annual basis, repair any vehicles that fail the inspection, and retain records of the inspection for review by ARB inspectors. Currently, about 75% of the California fleet is subject to this fleet self-inspection. While both programs are currently focused on smoke emissions and visual tamper inspections, it is expected that they will both be updated to also include an inspection of the OBD system and to fail vehicles that have an illuminated MIL. When combining these three factors together (voluntary response to an illuminated MIL, HDVIP inspections, and fleet self-inspections), staff believes it is fairly conservative to expect that 30% of the illuminated MILs will be repaired.

Staff also considered that some malfunctions could also cause degraded drivability, performance, or fuel economy and those impacts would also influence the repair rate. However, as stated above, these failure rates already assume that additional failures and repairs are currently occurring in the fleet and will continue to. Furthermore, in analyzing the categories created by staff, the failures with the largest emission impacts (e.g., PM filter malfunctions and NOx aftertreatment related categories) are not expected to have an adverse impact on drivability or performance and may actually result in an improvement to fuel economy, thus negating any additional incentive to repair the detected malfunction.

<u>Malfunction Emission Rates</u>

Staff also modified the associated emission rates for each of the categories of Table C to better reflect the best estimates available at this time based on the expected 2010 and subsequent emission control systems. For the existing categories that result in an increase in PM emissions, staff reduced the estimates for the PM emission increases by a factor of 0.95 based on the expectation that all 2010 engines will be equipped with a PM filter which will trap 95% of any engine out increases in PM. For the added categories of PM filter leaks and PM filter missing/tampered, staff estimated PM increases of 600% and 1,000%, respectively. For the PM filter leaks, this represents an emission level of 0.07 g/bhp-hr which is above the adopted OBD threshold of 0.05 g/bhp-hr but reflects industry's contention that most PM filter leaks will rapidly grow beyond a small leak. For the category of PM filter missing/tampered, staff estimated the emissions would approach that of an engine without a PM filter for an increase of 1000% (to 0.10 g/bhp-hr).

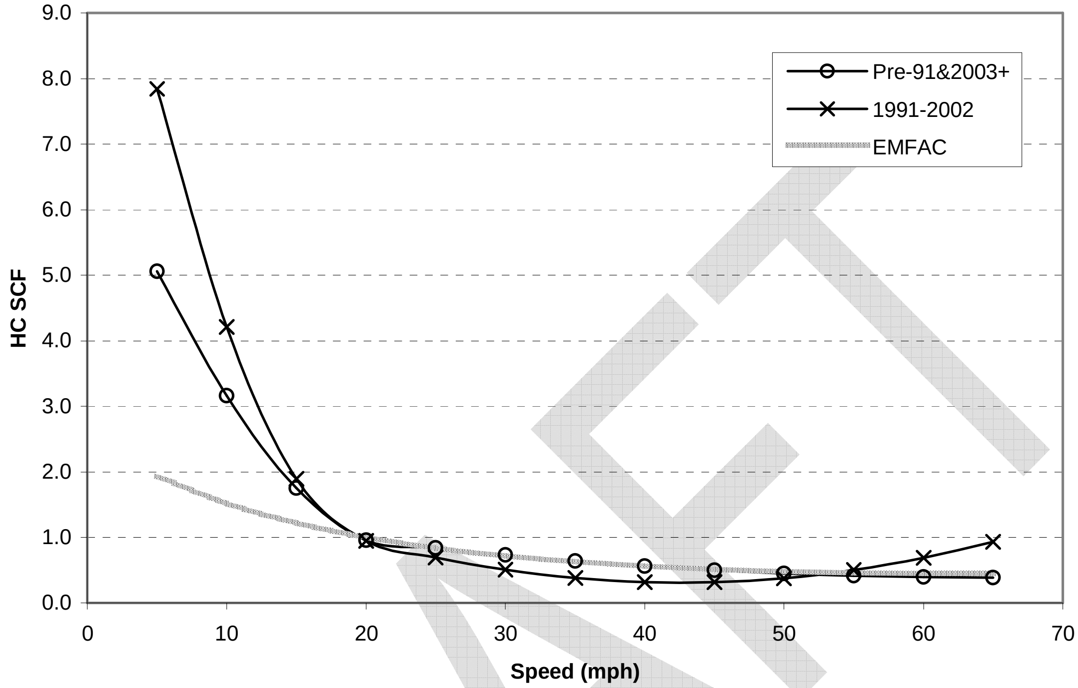
For HC emission rates for the existing categories, staff estimated the presence of larger oxidation catalysts to achieve sufficient exotherms for PM filter regeneration would convert 50% of any increases in engine out HC rates and thus reduced the HC emission increases by a factor of 0.5. For the added categories related to PM filters and malfunctions associated with NOx aftertreatment or the aftertreatment control sensors, staff assumed a small HC increase due to reduced conversion of HCs within the PM trap itself or improper reductant malfunctions (e.g., overdosing fuel in a NOx adsorber system). For a malfunction of the oxidation catalyst itself, staff assumed a 50% increase in HC emissions.

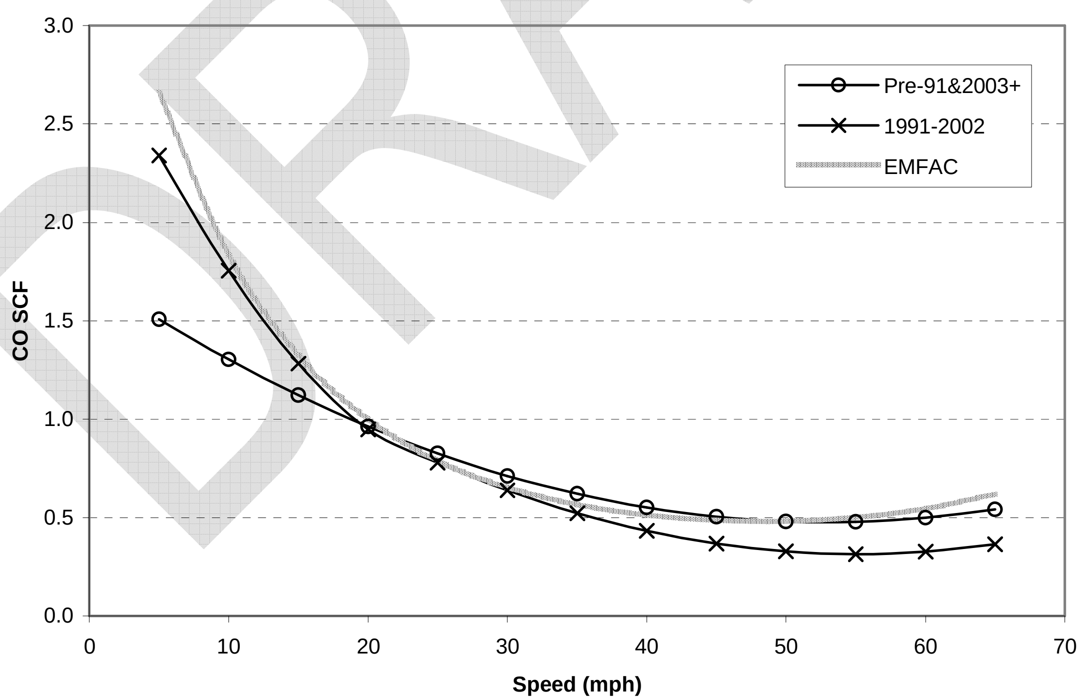
For NOx emission rates for the existing categories, staff estimated that engine out NOx increases would be reduced by the presence of NOx aftertreatment to varying degrees. For smaller engine out NOx increases, the aftertreatment was estimated to convert 75% of the excess NOx (thus reducing the emission rate by multiplying by a factor of 0.25). For larger engine out NOx increases, a slightly reduced aftertreatment conversion efficiency (65%) was used to reflect a reduced ability in the system to handle large feed gas concentration increases. For the added categories of NOx aftertreatment control sensors, an emission increase of 200% (to a tailpipe emission level of 0.6 g/bhp-hr NOx) was assigned based on the assumption that a loss of feedback control (either a NOx sensor for SCR or an A/F sensor for an adsorber) would result in significantly lower NOx conversion rates because a manufacturer would likely shut off reductant delivery or go to a very conservative open loop control system that injected minimal reductant to minimize the risk for overdosing or inefficient use of reductant. For the added category of NOx aftertreatment, a failure was calculated to have a 300% increase to reflect a tailpipe emission level of 0.8 g/bhp-hr NOx). This represents an intermediate level between a MIL on failure (at 0.5 g/bhp-hr) and a complete loss of NOx aftertreatment (at 1.2 g/bhp-hr). Considering that this category includes failures of the SCR catalyst or adsorber itself as well as failures of the reductant delivery system (in exhaust injectors, reductant tank, reductant delivery lines, reductant metering, reductant heaters, and compressed air delivery system), many of which would likely result in the manufacturer shutting off reductant delivery or defaulting to open loop operation, the emission increase of 300% is appropriate. Staff also adjusted the emission rates and frequency of occurrence rates for both the NOx aftertreatment system category and the NOx aftertreatment control sensor categories to properly account for the combined emission impact (e.g., an engine with a failure in both categories will get a 300% NOx increase, not a combined 200% NOx increase from the aftertreament control sensor failure and an additional 300% NOx increase from the aftertreatment failure). Lastly, while EMFAC already included a category for EGR malfunctions, the NOx emission increase associated with an EGR failure was set to a 0.0% increase previously. This was modified to a NOx emission increase of 150% to a tailpipe level of 0.5 g/bhp-hr NOx. This emission rate was calculated by assuming a complete loss of EGR would cause engine out NOx to go from 1.2 to 2.4 g/bhp-hr for an increase of 1.2 g/bhp-hr and then assuming that the NOx aftertreatment would convert 60% of that increase leaving a tailpipe increase of 0.48 g/bhp-hr. Thus, EGR failures were estimated to range from the OBD MIL on point of 0.3 g/bhp-hr to a complete loss of EGR at 0.68 g/bhp-hr with a nominal middle failure point of 0.5 g/bhp-hr.

Appendix D. CRC E55/E59 HHDDT Idle Emission Test Data

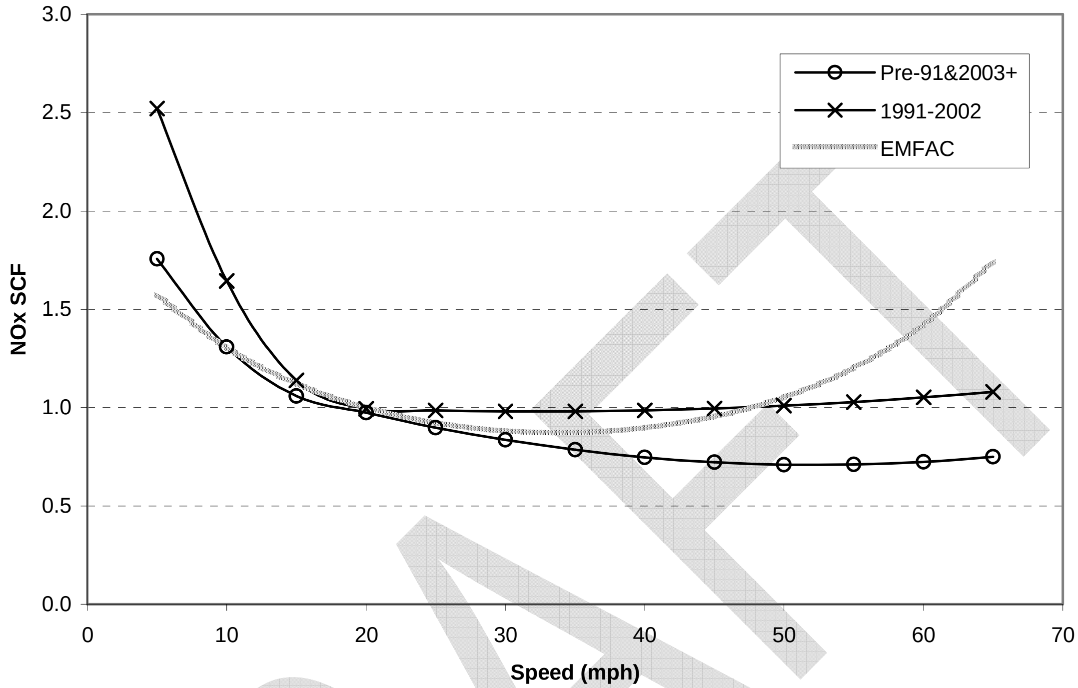
Test ID	Make	Engine Model	Engine MY	Odometer Reading	Vehicle MY	Test Cycle	CO	NOx	HC	PM	CO2
							g/min	g/min	g/min	g/min	g/min
E55CRC-1	Detroit	Diesel Series 60	1994	639,105	1994	Idle32	0.230	1.33	0.070	0.010	73.2
E55CRC-2	Caterpillar	3406B	1995	241,843	1995	Idle32	0.340	1.79	0.150	0.060	88.6
E55CRC-3	Cummins	NTCC-300	1985	501,586	1985	Idle32	1.33	0.36	0.320	0.140	75.2
E55CRC-4	Caterpillar	C-10	2000	42,362	2000	Idle32	1.58	1.66	0.050	0.010	114
E55CRC-5	Cummins	N14-435E1	2000	166,980	2000	Idle32	0.230	1.60	0.180	0.020	84.9
E55CRC-6	Cummins	M11-370	1995	689,536	1995	Idle32	0.180	1.56	0.110	0.030	69.7
E55CRC-7	Detroit	Diesel Series 60	1990	399,224	1990	Idle32	0.130	1.33	0.050	0.000	60.0
E55CRC-8	Cummins	M11-300	1996	507,855	1996	Idle32	0.270	1.32	0.140	0.030	84.0
E55CRC-9	Caterpillar	C12	1998	607,968	1998	Idle32	0.340	1.02	0.080	0.020	63.6
E55CRC-10	Detroit	series 60	1998	21,631	1998	Idle32	0.470	1.33	0.090	0.010	70.0
E55CRC-11	Cummins	ISM	2000	117,048	2000	Idle32	0.230	0.89	0.110	0.010	59.6
E55CRC-12	Cummins	300	1986	533,377	1986	Idle32	0.560	0.41	0.700	0.100	76.1
E55CRC-13	Cummins	Cummins 350	1978	570,546	1978	Idle32	0.530	0.64	0.150	0.050	83.8
E55CRC-14	Cummins	LTA10	1985	565,927	1986	Idle32	0.320	0.22	0.140	0.080	57.6
E55CRC-15	Cummins	NTC-350	1986	340,486	1973	Idle32	0.680	0.23	0.840	0.190	83.9
E55CRC-16	Caterpillar	3208	1979	200,000	1979	Idle32	0.640	1.11	0.110	0.010	62.5
E55CRC-17	Cummins	L-10	1993	733,868	1993	Idle32	0.080	0.97	0.060	0.030	64.1
E55CRC-18	Cummins	L-10	1991	440,456	1991	Idle32	0.720	1.19	0.480	0.090	67.6
E55CRC-19	Cummins	L-10	1987	465,061	1987	Idle32	0.580	0.37	0.450	0.100	65.2
E55CRC-20	Detroit	Diesel Series 60	1992	514,188	1992	Idle32	0.260	1.35	0.070	0.010	68.3
E55CRC-21	Caterpillar	3406B	1990	937,438	1990	Idle32	0.720	1.46	0.100	0.020	66.5
E55CRC-22	Cummins	L10-280	1993	232,829	1993	Idle32	0.470	1.07	0.990	0.070	67.2
E55CRC-23	Cummins			320,885	1983	Idle32	0.630	0.555	0.560	0.060	79.3
E55CRC-24	Cummins	NTCC-350	1975	773,487	1975	Idle32	0.310	0.595	0.330	0.030	67.8
E55CRC-25	Cummins		1983	806,068	1983	Idle32	0.350	0.560	0.390	0.050	69.4
E55CRC-26	Caterpillar	C-10	1998	539,553	1999	Idle32	0.293	1.03	0.066	0.004	70.7
E55CRC-27	Detroit	Diesel Series 60	1999	420,927	2000	Idle32	0.462	2.50	0.048	0.010	90.8
E55CRC-28	Detroit	Diesel Series 60	1998	645,034	1999	Idle32	0.591	1.29	0.040	0.010	58.7
E55CRC-29	Cummins	1SX475ST2	1999	120,000	2000	Idle32	0.375	0.749	0.229	0.110	95.9
E55CRC-30	Detroit	Diesel Series 60	1998	138,625	1999	Idle32	0.543	1.70	0.050	0.010	70.5
E55CRC-31	Cummins	N14-460E+	1997	587,389	1998	Idle32	0.269	1.84	0.300	0.018	82.1
E55CRC-32	Caterpillar	3406B	1991	596,082	1992	Idle32	0.436	0.807	0.178	0.022	83.4
E55CRC-33	Caterpillar	3406	1984	988,726	1985	Idle32	0.448	1.85	0.236	0.044	74.7
E55CRC-34	Detroit	Diesel Series 60	2003	19,094	2004	Idle32	0.373	1.86	0.035	0.001	91.5
E55CRC-35	Detroit	Diesel Series 60	2000	106,377	2001	Idle32	0.408	1.33	0.110	0.016	76.4
E55CRC-36	Caterpillar	C-15	2001	284,553	2001	Idle32	0.299	1.33	0.098	0.004	99.7
E55CRC-38	Cummins	ISX	2003	2,829	2004	Idle32	0.168	1.06	0.108	0.010	82.8
E55CRC-39	Cummins	ISX	2003	45	2004	Idle32	0.128	1.17	0.115	0.006	86.7
E55CRC-40	Detroit	Diesel Series 60	2003	8,916	2004	Idle32	0.142	1.29	0.071	0.003	66.5
E55CRC-42	Caterpillar	3406	1999	576,998	2000	Idle32	0.184	1.16	0.077	0.022	97.9
E55CRC-43	Detroit	Diesel Series 60	1994	899,582	1995	Idle32	0.596	1.08	0.094	0.008	74.7
E55CRC-44	Caterpillar	3406	1989	811,202	1989	Idle32	0.274	1.75	0.154	0.012	77.3
E55CRC-45	Cummins	L10-280	1993	685,168	1993	Idle32	0.998	0.731	4.20	0.505	70.7
E55CRC-46	Caterpillar	3176	1989	935,582	1989	Idle32	0.141	1.65	0.018	0.010	76.0
E55CRC-47	Detroit	6V92	1986	760,810	1986	Idle32	0.202	1.09	0.485	0.025	84.2
E55CRC-48	Cummins	N1 Plus	1998	753,792	1998	Idle32	0.231	3.30	0.011	0.040	119
E55CRC-49	Caterpillar		1993	650,557	1994	Idle32	0.203	1.04	0.040	0.008	85.9

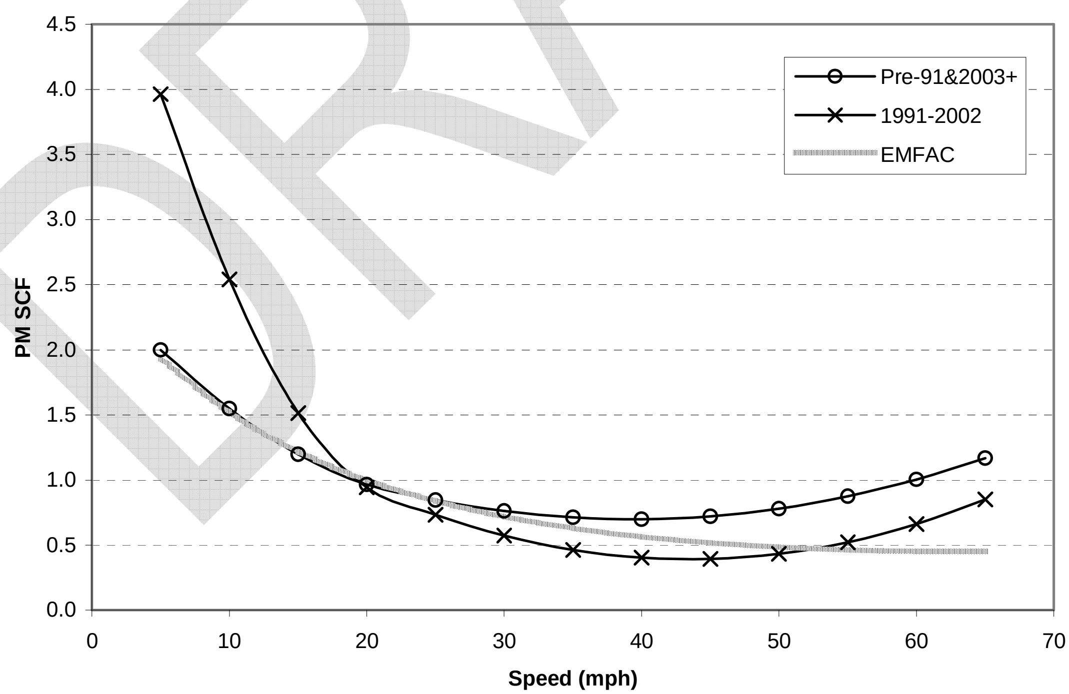
Appendix E. Proposed HHDT SCFs as Compared with SCFs in EMFAC



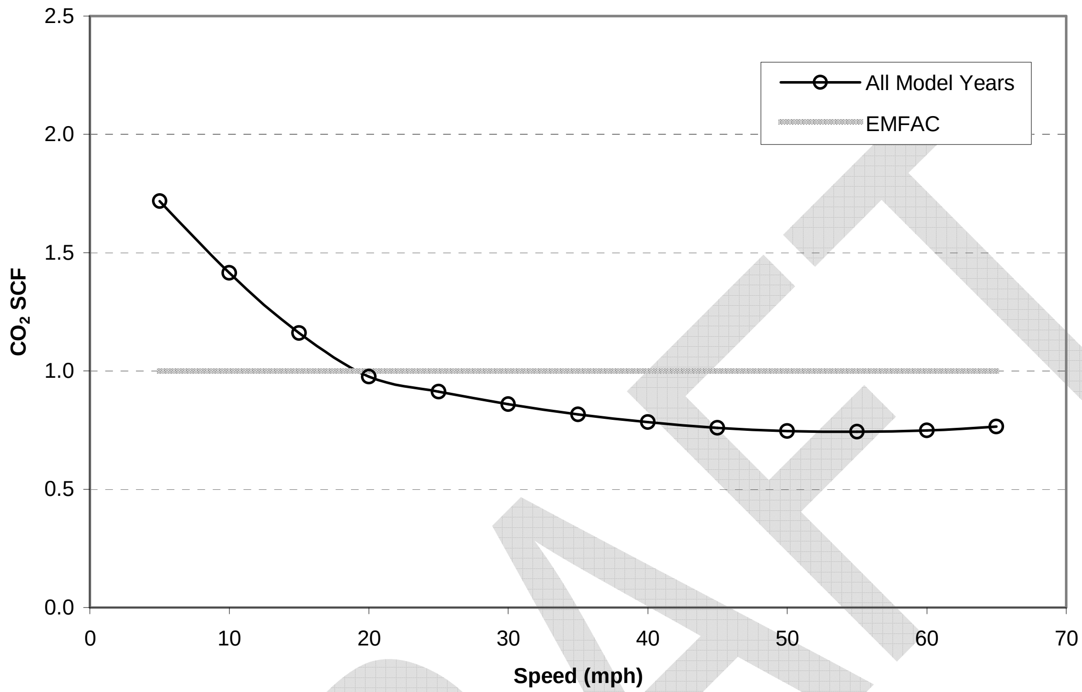


Appendix E (continued)





Appendix E (continued)



Appendix F. Federal Heavy-Duty Diesel Engine Emission Standards (in g/bhp-hr)

Model Year	HC[a]	CO	NOx	PM	HC+NOx
1974-1978	---	40.0	---	---	16.0
1979-1983	1.5	25.0	---	---	10.0
1984-1987	1.3	15.5	10.7	---	---
1988-1989	1.3	15.5	10.7	0.60	---
1990	1.3	15.5	6.0	0.60	---
1991-1993	1.3	15.5	5.0	0.25	---
1994-1997	1.3	15.5	5.0	0.10	---
1998-2002	1.3	15.5	4.0	0.10	---
2003-2006	0.2	15.5	2.2[b]	0.10	---
2007-2009[c]	---	15.5	---	0.01	---
2010+	0.14	15.5	0.2	0.01	---

a. The HC standards are for total hydrocarbons except those for 2003 and subsequent model years, which are for NMHC.

b. Nominal NOx value of 2.2 g/bhp-hr based on 2.4 g/bhp-hr NOx+NMHC standards effective October 2002.

c. EPA 2007 standards for HC and NOx are to be phased in between 2007-2010.

Appendix G. Emission Factors for Federal HHDDTs

Table G-1. Revised Zero-Mile Rates (ZMR, g/mi) & Deterioration Rate (DR, g/mi/10,000mi) for Federal HHDDTs*

Model Year Group	HC		CO		NOx		PM	
	ZMR	DR	ZMR	DR	ZMR	DR	ZMR	DR
Pre 1988	1.20	0.027	7.71	0.176	23.0	0.019	1.73	0.028
1988-90	0.94	0.032	6.06	0.209	22.9	0.022	1.88	0.025
1991-93	0.62	0.021	2.64	0.090	19.6	0.039	0.78	0.014
1994-97	0.46	0.024	1.95	0.103	19.3	0.046	0.51	0.011
1998-02	0.47	0.024	1.99	0.103	18.9	0.053	0.56	0.010
2003-06	0.30	0.011	0.87	0.031	12.5	0.052	0.35	0.005
2007-09	0.26	0.008	0.74	0.022	6.84	0.047	0.035	0.001
2010+	0.21	0.004	0.61	0.012	1.14	0.041	0.035	0.001

* The CO_2 emission rate is 2,237 g/mi for all model year groups.

Table G-2. Proposed Federal HHDDT Low Idle Emission Rates (g/hour)

Model Years	HC	CO	NOx	PM	CO_2
Pre-1988	25.9	28.4	45.7	4.76	4,640
1988-90	15.2	23.4	53.8	2.38	4,640
1991-93	12.1	21.5	78.4	1.78	4,640
1994-97	9.68	19.8	85.3	1.33	4,640
1998-02	7.26	17.8	92.1	0.92	4,640
2003-06	5.97	16.6	95.5	0.72	4,640
2007-09	5.97	16.6	95.5	0.072	4,640
2010+	5.97	16.6	95.5	0.072	4,640

Appendix G (continued)

Table G-3. Proposed Federal HHDDT High Idle Emission Rates for Summer (g/hour)

Model Years	HC	CO	NOx	PM	CO_2
Pre-1988	44.0	87.9	96.0	11.9	10,670
1988-90	25.8	72.5	113	5.94	10,670
1991-93	20.6	66.7	165	4.44	10,670
1994-97	16.4	61.4	179	3.33	10,670
1998-02	12.3	55.2	193	2.31	10,670
2003-06	10.1	51.3	201	1.79	10,670
2007-09	10.1	51.3	201	0.18	10,670
2010+	10.1	51.3	201	0.18	10,670

Table G-4. Proposed Federal HHDDT High Idle Emission Rates for Winter (g/hour)

Model Years	HC	CO	NOx	PM	CO_2
Pre-1988	57.0	207	82.2	20.5	8,350
1988-90	33.4	171	96.8	10.2	8,350
1991-93	26.6	157	141	7.64	8,350
1994-97	21.3	145	153	5.73	8,350
1998-02	16.0	130	172	3.96	8,350
2003-06	13.1	121	172	3.07	8,350
2007-09	13.1	121	172	0.31	8,350
2010+	13.1	121	172	0.31	8,350