Final Report

Characterizing Particulate Emissions from Medium- and Light Heavy-Duty Diesel-Fueled Vehicles

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Executive Summary

Although it is generally agreed that particulate emissions from diesel vehicles account for a significantly disproportionate amount of the mobile source particulate emissions inventory, our knowledge about diesel particulate matter is limited. Most of the emissions testing of light-, medium-, and light heavy-duty diesel vehicles was conducted in the late 1970s and early 1980s and was confined to isolated tests on small numbers of vehicles. The objectives of this study were to augment the current database of tailpipe particulate emissions from medium- and light heavy-duty vehicles, determine their characteristics and percentages in the general population, and evaluate their impact on the particulate emissions inventory.

To estimate the population and determine the characteristics of medium- and light heavy-duty vehicles in the South Coast Basin, data from the Department of Motor Vehicles were disaggregated to provide a profile of manufacturers, models, model years, and vehicle types. Overall, medium- and light heavy-duty vehicles classified in weight classes 2-5 constitute less than 10% of the total population of vehicles and are dominated by class 2 gasoline trucks. Diesel trucks represent less than 1.5% of the total vehicle population, with the fraction of diesel trucks increasing for the higher weight classes. Medium- and light heavy-duty vehicles included a variety of different body styles including pickup trucks, vans, cab and chassis, and others. Pickup trucks and vans are the most prominent body styles for trucks in weight class 2. In weight classes 3, 4, and 5, the most prominent body styles are cab and chassis or variations therein.

Additional analyses were conducted on the South Coast Air Quality Management District's (SCAQMD or District) 1-800-CUT-SMOG database for portions of 1994/1995 and 1997 to determine the contribution of medium- and light heavy-duty vehicles to the population of smoking vehicles. The overall total distribution of trucks in CUT-SMOG is similar to that found in the DMV database. Diesel trucks, however, make a greater contribution to the CUT-SMOG database on a percentage basis than to the total District DMV population. This is not unexpected since the CUT-SMOG database is for identified smoking vehicles.

Fifteen representative medium- and light heavy-duty diesel vehicles were recruited, and their total and size-segregated particulate mass emission rates were measured, as well as their particulate elemental and organic carbon fractions. FTP weighted particulate mass emission rates averaged 264 mg/mi for the test fleet with a range from 58 to 768 mg/mi. Particulate emission rates decreased for progressively newer vehicles, with all but one of the 1994 and newer vehicles having mass emission rates of 100 mg/mi or less. The particulate size distributions were typical

of that expected from diesel vehicles, with over 90% of the total particulate mass below 1.0 μm in aerodynamic diameter. Thermal Optical Reflectance (TOR) analysis showed that elemental carbon is more predominant than organic carbon in diesel particulate, with an average of 64.0±21.6% elemental carbon and 34.0±21.6% organic carbon. For gas-phase emissions, there were no strong and consistent trends of decreasing total hydrocarbon (THC), carbon monoxide (CO), and nitrogen oxide (NO_x) emissions as a function of decreasing vehicle age. In fact, NO_x emissions were relatively high for the 1990 and newer vehicles and the 1995 and newer vehicles were in considerable excess of the emissions standard for this class.

Emissions inventory estimates were developed based on the database results and the results obtained from the emissions tests. These were compared with estimates obtained using EMFAC. Emissions inventory estimates for class 2 and 3 diesel trucks were 0.35 tons/day of PM based on the District DMV population and the emissions tests results for the present study. EMFAC7G estimated 1.54 tons/day of PM for diesel trucks (8,500-14,000 GVW). The estimates based on the results for this study are considerably lower than those from EMFAC7G due to the higher emissions factors used in EMFAC7G and the higher population of vehicles and VMT estimated by EMFAC7G compared with the DMV database. The large discrepancy in the emissions inventory estimates from this study and EMFAC7G indicate that additional research is needed to develop accurate population profiles and improved emissions factors for medium and light heavy-duty diesel trucks.

1.0 Background and Program Objectives

Particulate air pollution has received considerable attention recently in light of studies showing that increases in human mortality and morbidity can be associated with particulate concentrations lower than those previously believed to affect human health (Reichhardt, 1995). In view of the potential risks of exposure to excess levels of ambient particulate, there has been an increased emphasis on understanding which sources make the most significant contribution to the emissions inventory. It is generally agreed that particulate emissions from diesel vehicles account for a significantly disproportionate amount of the mobile-source particulate emissions inventory relative to their total miles traveled. However, our current state of knowledge on diesel particulate is limited, and there is still considerable uncertainty about the contribution of diesel vehicles to the emissions inventory.

Much of the work in quantifying diesel particulate emissions has focused on heavy-duty vehicles and engines (Gautam et al., 1992; Ferguson et al., 1992). To date, emissions testing of light-, medium-, and light heavy-duty diesel vehicles has been limited to isolated tests of small numbers of vehicles (Gabele, 1981; Bouffard, 1981; Cadle et al., 1979; Braddock and Gabele, 1977, Gibbs et al., 1980; Springer and Baines, 1977). Most of this work was conducted in the late 1970s and early 1980s. Few of these studies included medium- or light heavy-duty diesel vehicles (Braddock and Perry, 1986). Although some recent studies have included medium- and light heavy-duty diesel vehicles, these data are still too limited to develop accurate estimates of tailpipe emissions from these vehicles (Norbeck et al., 1996a; Norbeck et al., 1996b; Norbeck et al., 1997). Information about the characteristics and population of medium- and light heavy-duty diesel vehicles is also needed to accurately estimate the contribution of these vehicles to the overall emissions inventory.

The overall objectives of this study were to augment the current database of tailpipe particulate emissions from medium- and light heavy-duty diesel vehicles, and to determine the characteristics and percentages of these vehicles in the general population. To estimate the population and determine the characteristics of medium- and light heavy-duty vehicles in the South Coast Basin, data from the Department of Motor Vehicles (DMV) were disaggregated to provide a profile of manufacturers, models, model years, and vehicle types. Additional analyses were conducted on the District’s 1-800-CUT-SMOG database to determine the contribution of medium- and light heavy-duty vehicles to the population of smoking vehicles. Fifteen representative medium- and light heavy-duty diesel vehicles were recruited, including four from the CUT-SMOG database, and their total and size-segregated particulate mass emission rates were measured. Particulate elemental and organic carbon fractions were also measured for each vehicle. This report discusses the results of this work and provides an evaluation of the impact of these results on the development of particulate emission inventories.

2.0 Experimental Procedures

2.1 Department of Motor Vehicles and CUT-SMOG Databases

The population assessment of the medium- and light heavy-duty vehicles in the South Coast Basin was based on information obtained from a DMV database. This database was generated by the California Department of Motor Vehicles in August 1996. The database contains records of 26 million automobiles, trucks and buses registered throughout California. The database was further subdivided to include only vehicles registered within the District for the analyses presented below. Each record of the database contains a detailed range of vehicle and registered owner information, including vehicle license, vehicle make, model year, vehicle type, weight class (trucks), fuel type, body style, registered owner, and address. The most important fields used for this population assessment were weight class, vehicle make and model year, body style and fuel type.

Additional analyses were conducted on the District's 1-800-CUT-SMOG database. This database is a compilation of records of visibly smoking vehicles identified and reported by the public. Each record contains the location of the sighting and license number of the vehicle. The license information is then forwarded to the DMV to identify the registered owner, the address, and the make and model of the vehicle. For the present work, two versions of CUT-SMOG were used. One version contained approximately 46,000 records, or approximately one-third of the total collected over the period from October 1994 to October 1995. This version was used previously in work to develop a profile of smoking vehicles (Norbeck et al., 1996a). The second version of CUT-SMOG was newer, consisting of 28,000 records for a three-month period in 1997.

Vehicle classification for the DMV and CUT-SMOG databases was performed based on the vehicle weight and fuel type. Vehicle classifications based on gross vehicle weight code (GVW) are listed in Table 1, along with the classifications used in EMFAC7G and PART5. Since the classification of medium- and light heavy-duty vehicles encompasses weight classes 2 through 5, depending on the definitions used, these weight classes were all included in the following analyses. Additional analyses were conducted for class 1 vehicles, since they comprise a large percentage of the overall truck population. Fuel type classifications were based on the R.L. Polk fuel type field defined in the DMV database for gasoline and diesel vehicles.

Table 1. Weight Classification Information
Manufacturers Gross Vehicle Weight (GVW) Rating Classifications

1. = 6,000 or less	
2. = 6,001 - 10,000	
3. = 10,001 - 14,000	
4. = 14,001 - 16,000	
5. = 16,001 - 19,500	
6. = 19,501 - 26,000	
7. = 26,001 - 33,000	
8. = 33,001 and more	
Model Classifications	
EMFAC7G	PART5
MDT – medium duty gas truck = 6,001 – 8,500 GVW LHD light heavy-duty diesel truck = 8,501 – 14,000 GVW MHD medium heavy-duty diesel truck = 14,001 – 33,000 HDT heavy heavy-duty diesel truck = 33,000+	LDDT – light-duty diesel truck = 6,001-8,500 GVW 2BHDDV – class 2B heavy-duty diesel truck = 8,501-10,000 GVW LHDDV – light heavy-duty diesel vehicle = 10,000 – 19,500 GVW MHDDV – medium heavy-duty diesel vehicle = 19,501 – 33,000 GVW HHDDV – heavy heavy-duty diesel vehicle = 33, 000+

2.2 Vehicle Recruitment

A total of fifteen light heavy-duty diesel vehicles were recruited for vehicle testing, ranging in size from 8,510 to 11,000 lbs. GVW. A listing of the vehicles and their characteristics is presented in Table 2. Vehicles were recruited using a random mailer based on the DMV and 1994/1995 and 1997 CUT-SMOG databases. Of the fifteen vehicles tested, four were recruited from the CUT-SMOG databases. Visual observations were made of the tailpipe smoke levels for the test vehicles. In general, the observed smoke levels were typical of those expected from diesel vehicles in the range of model years tested. Most vehicles emitted smoke either when the engine was started or revved, but were generally smoke-free when idling. Some of the newer vehicles emitted only small plumes of smoke, even when revved near wide-open throttle. Although the 1985 Ford F350 and the 1985 GMC 1500 CUT-SMOG vehicles emitted fair amounts of smoke when revved, these vehicles did not have abnormally high smoke emissions for their respective model years and technologies. The other two CUT-SMOG vehicles emitted relatively low levels of smoke, and were probably reported to CUT-SMOG based on the observation of smoke during normal operation conditions under load.

2.3 Protocol for Vehicle Testing

All vehicles were tested over the Federal Test Procedure to obtain mass emission rates for total particulate, total hydrocarbons (THC), non-methane hydrocarbons (NMHC), carbon monoxide (CO), and nitrogen oxides (NO_x). THC and NMHC measurements were collected using a heated sample line as specified in the Code of Federal Regulations (CFR) for diesel vehicles. Additional particle sampling for collection of samples for size-segregation and chemical analysis was added to the FTP test procedures to meet the program objectives, as discussed below. Each vehicle was tested over a single FTP after an overnight soak at a temperature of 72º±2ºF. To provide a more accurate portrayal of in-use emissions, vehicles were not preconditioned over the UDDS prior to testing. Vehicles were tested with the reformulated diesel fuel in the tank at the time the vehicle was received. All tests were conducted in CE-CERT's Vehicle Emission Research Laboratory (VERL) equipped with a Burke E. Porter 48-inch single-roll electric dynamometer and a 12 inch diameter tunnel for diesel vehicles. A CVS flow rate of 856 SCFM was used for all tests.

Table 2. Vehicle Descriptions for Test Fleet

Model Year	Make	Model	Odometer (miles)	GVW (lbs.)	Engine Size (L)	Catalyst	Fuel Type	CUT-SMOG
1996	Dodge	Ram 2500 PU	9838	8800	5.9	OC	Diesel	
1996	Dodge	Ram 3500 PU	56139	10500	5.9	OC	Diesel	
1995	Dodge	Ram 3500 PU	40103	10500	5.9	OC	Diesel	
1994	Ford	F350 PU	22364	9200	7.3	OC	Diesel	X
1994	Dodge	Ram 2500 PU	59444	8800	5.9	OC	Diesel	
1994	Dodge	Ram 2500 PU	96457	8800	5.9	OC	Diesel	
1992	Dodge	250 LE PU	50405	8510	5.9	None	Diesel	
1989	Ford	F350 PU	58483	11000	7.3	None	Diesel	
1987	Ford	F250 PU	80342	8800	6.9	None	Diesel	
1987	Ford	F250 PU	91564	8800	7.3	None	Diesel	
1986	Ford	F250 PU	57484	8800	7.3	None	Diesel	
1985	Ford	F350 PU	87930	8600	6.9	None	Diesel	X
1985	GMC	1500 PU	32321	N/A	6.2	None	Diesel	X
1984	Ford	F250 PU	84386	8600	6.9	None	Diesel	
1982	GMC	Sierra 3500 PU	66355	10000	6.2	None	Diesel	X

OC = Oxidation Catalyst

2.4 Particulate Sample Collection

The sampling protocol for this project was designed to provide mass emissions rates, size distributions, and samples for analysis for organic and elemental carbon fractions of the particulate. The dilution tunnel used for sampling was fitted with three sampling probes located approximately 130 inches downstream of the exhaust mixing flange. The sampling configuration, filter media, and analyses to be performed are summarized below:

- Probe 1 was fitted with 47 mm, 2.0 µm Gelman Teflon membrane filters using a Pierburg particle sampling system to obtain total mass particulate emission rates for each phase of the FTP. Each filter assembly was fitted with a primary and a backup filter.

- Probe 2 was fitted with prefired Pallflex 2500 QAT-UP quartz fiber filters for organic and elemental carbon analyses. Quartz fiber filters were prefired at 900°C for three hours to reduce background carbon levels. Filters were stored in a refrigerator prior to sampling and after sampling prior to shipment for analysis. Elemental and organic carbon analyses were performed by Chester Labnet using the Thermal Optical Reflectance (TOR) method. Analyses were performed on an approximately 1 cm^2 punch from the filter.

- Probe 3 was fitted with a MOUDI cascade impactor for collection of size segregated samples. This MOUDI includes the following cut-points: >18, 10, 5.6, 3.2, 1.8, 1.0, 0.56, 0.32, 0.18, 0.056, and an after-filter for particles <0.056 µm. The MOUDI was configured using only the inlet for particles greater than 18.0 µm, the 10 µm, 3.2 µm, 1.8 µm, and 1.0 µm impaction stages, and the after-filter for a majority of the tests to provide size distributions for PM_{10}, $PM_{2.5}$, and $PM_{1.0}$. Full MOUDI distributions using all the impaction stages were also obtained for four vehicles. Uncoated aluminum foils were used for impaction substrates together with 47 mm, 2.0 µm pore size Gelman Teflon membrane after-filters.

For each test, mass emission rates were determined for each phase of the FTP. Samples for chemical analysis on quartz-fiber filters were collected cumulatively over the entire FTP. MOUDI samples were collected over only phase 2 of the FTP since the MOUDI has a tendency to become overloaded with high particulate emitting vehicles. All samples were collected at 20 lpm with the exception of the MOUDI, which was operated at 30 lpm. All flows were measured and controlled using mass flow controllers, and all sampling is performed under isokinetic conditions using removable probe tips.

Teflon membrane filters and aluminum MOUDI substrates were weighted before and after sampling to determine the collected mass using an ATI Orion ultra-microbalance. The microbalance is located in an environmental weighing chamber maintained at a temperature of 25±0.5°C and a relative humidity of 40±5%. Before and at the completion of sample collection, substrates were preconditioned for at least 24 hours in the environmental chamber before weighing. Tunnel blanks for mass emission measurements were collected weekly with an average value of 0.1±0.1 mg/mi and a range from 0.0 to 0.3 mg/mi. Mass emission rates are corrected based on the average tunnel blank value.

3.0 Results from DMV and CUT-SMOG Database

Table 3 presents the distribution of trucks in the DMV database by weight class and fuel type for the SCAQMD. These data are presented as percentage of the total SCAQMD population in Table 4. These data show that class 1 and 2 gasoline trucks are the largest component of the truck population, with diesel trucks representing only a small portion of the overall population of vehicles and trucks. Overall, diesel trucks amount to less than 1.5% of the total fleet population. As expected, the fraction of diesel trucks increases for the higher weight classes. It should be noted that although diesel trucks compose only a small portion of the total population, their contribution to the overall particulate emissions inventory can still be comparable to that of light-duty vehicles, given their elevated emissions rates, as discussed below.

Table 3. Distribution of Trucks by Weight Class and Fuel Type

Weight Class	1	2	3	4	5	6	7	8	All Classes	% of Total
Gasoline	1,242,699	657,595	20,591	8,274	5,298	24,737	5,229	562	1,964,985	93.1%
Diesel	10,026	29,153	11,113	5,857	2,330	14,755	28,259	43,850	145,343	6.9%
Total	1,252,725	686,748	31,704	14,131	7,628	39,492	33,488	44,412	2,110,328	
% by Weight Class	59.4%	32.5%	1.5%	0.7%	0.4%	1.9%	1.6%	2.1%		

*Total population in District is 10,555,714 based on DMV database

Table 4. Percentage of Trucks by Weight Class and Fuel Type Compared with District DMV Population

Weight Class	1	2	3	4	5	6	7	8	All Classes
Gasoline	11.77%	6.23%	0.20%	0.08%	0.05%	0.23%	0.05%	0.01%	18.62%
Diesel	0.09%	0.28%	0.11%	0.06%	0.02%	0.14%	0.27%	0.42%	1.38%

Medium- and light heavy-duty vehicles, which are the focus of the present work, are classified into weight classes ranging from 2 to 5. These trucks compose less than 10% of the total population of vehicles, on vehicle number basis, and are dominated by class 2 gasoline trucks. The distribution of body styles found in each of these weight categories is presented in Table 5. Body style data for class 1 also are included for comparison. These data show that a variety of different body styles are included in these weight categories, including pickup trucks, vans, cab and chassis and others. Pickup trucks and vans are the most prominent body styles for trucks in weight classes 1 and 2. In weight classes 3, 4, and 5, the most prominent body styles are cab and chassis or variations therein. Motorhomes are another body style found in classes 3 and 4.

Table 5. Body Style Distributions

	Class 1	Class 2	Class 3	Class 4	Class 5
Bus		1,191	69	86	149
Cab and Chassis	18,426	38,891	12,567	7,582	2,402
Conventional Cab			20	452	2,167
Cargo Cutaway		3,018	3,711	31	
Cutaway		1,943	207		
Flatbed		4,518		2	
Flatbed Platform			61		
Forward Cab	112	4,786			
Forward Control			837	1,012	704
Incomplete Chassis	4,061	27,911	175	115	39
Motorhome	1	159	1,331	2,060	68
Motorized Home Cutaway	1	6,774	4,986	33	220
Other Commercial	2,207	2,221			
Panel	303	45			
Parcel Delivery	51	42	138		
Pickup	1,067,992	420,877	2,329		
Sport Van	6,355	6,812			
Stake		50			
Station Wagon	12,671	1,331			
Step Van	498	5,691	312		
Utility	20,690	1,247			
Van	115,716	157,757	2		
Vannette(GMC Handy Van)	5				
Stepvan				504	
Stakebed				32	
Tiltcab			4,973	2,220	1,886
Cutaway				7	
Unknown	4,829	2,299			
Total	1,253,918	687,563	31,718	14,136	7,635

Model year distributions for trucks in weight classes 1-5 are presented in Table 6. The model year distributions for class 1 trucks peak in the mid- to late-1980s, while the model year distribution for class 2 is relatively evenly distributed from the late 1970s to the present. For classes 3 and 4, the vehicles are predominantly manufactured from the early to mid-1980s through the present, with some pre-1973 class 4 gasoline trucks. The population of class 5 trucks, on the hand, includes a larger percentage of older trucks with model years older than 1980. The diesel vehicles in all categories are predominantly model years from the early to mid-1980s to the present. There are very few class 1 diesel trucks, however, with model years newer than 1985. It is important to emphasize that although significant numbers of older vehicles are found in some weight classes, their contribution to the emissions inventory is still less than that for newer vehicles due to lower estimated annual average vehicle miles traveled (VMT). Manufacturer distributions for trucks in weight classes 1-5 are also presented in Table 7. These distributions show that for each of the weight classes, the most prominent manufacturers are also major manufacturers of light-duty vehicles.

The 1994/1995 and 1997 CUT-SMOG databases were also disaggregated to determine the relative contribution of medium- and light heavy-duty vehicles. The distribution of trucks in the 1994/1995 and 1997 versions of CUT-SMOG as a function of weight class and fuel type is given in Table 8. These data are also included as a percentage by weight class and percentage compared with the percentage of the vehicles as a whole in the DMV population. Overall, the total percentage of trucks identified in each of the weight class categories is very similar for the two CUT-SMOG databases and comparable to that found in the DMV registered database. The largest discrepancy between CUT-SMOG and the DMV database is for class 7 trucks which represent 1.49% and 1.26% of the 1994/1995 and 1997 CUT-SMOG databases, but only 0.32% of the DMV population. CUT-SMOG also includes a disproportionately larger contribution of diesel trucks compared with the DMV population. In particular, diesel trucks comprise approximately 6.13 and 4.98%, respectively, of the 1994/1995 and 1997 CUT-SMOG databases but only 1.38% of the total DMV population. It should be noted that the overrepresentation of diesel trucks in CUT-SMOG is found for nearly all truck weight classes. This is not unexpected since the CUT-SMOG database is for identified smoking vehicles.

Table 6. Model Year Distributions

Class 1 GVW less than 6,000 lbs

MYR	*	Diesel	Gas	Total	%
66	1		6,121	6,122	0.5%
67			6,157	6,157	0.5%
68			7,712	7,712	0.6%
69			10,926	10,926	0.9%
70		32	10,613	10,645	0.8%
71		12	12,425	12,437	1.0%
72		1	18,834	18,835	1.5%
73			23,559	23,559	1.9%
74			23,933	23,933	1.9%
75			14,221	14,221	1.1%
76			17,967	17,967	1.4%
77			18,500	18,500	1.5%
78	2	502	23,383	23,887	1.9%
79	21	859	28,334	29,214	2.3%
80	706	714	26,115	27,535	2.2%
81	55	1,881	30,704	32,640	2.6%
82	42	2,845	37,059	39,946	3.2%
83	70	1,397	37,718	39,185	3.1%
84	117	1,033	68,287	69,437	5.5%
85	61	571	83,311	83,943	6.7%
86	14	61	118,917	118,992	9.5%
87	7	115	96,776	96,898	7.7%
88	30		87,120	87,150	7.0%
89	9		82,964	82,973	6.6%
90	4	3	59,348	59,355	4.7%
91	2		57,248	57,250	4.6%
92	6		45,086	45,092	3.6%
93	2		53,473	53,475	4.3%
94	12		58,024	58,036	4.6%
95	31		48,399	48,430	3.9%
96			25,606	25,606	2.0%
97	1		3,859	3,860	0.3%
Total	1,193	10,026	1,242,699	1,253,918	

Class 2 GVW 6,001-10,000 lbs

MYR	*	Diesel	Gas	Total	%
66	202		3,109	3,311	0.5%
67		13	4,400	4,413	0.6%
68		10	6,095	6,105	0.9%
69		3	8,672	8,675	1.3%
70			9,461	9,461	1.4%
71		2	9,275	9,277	1.3%
72			13,404	13,404	1.9%
73			16,909	16,909	2.5%
74			12,136	12,136	1.8%
75			15,849	15,849	2.3%
76			22,377	22,377	3.3%
77		6	38,353	38,359	5.6%
78	11	31	36,868	36,910	5.4%
79	48	11	39,112	39,171	5.7%
80	6	22	18,355	18,383	2.7%
81	32	296	15,614	15,942	2.3%
82	43	2,161	14,817	17,021	2.5%
83	36	2,173	15,394	17,603	2.6%
84	46	2,738	23,871	26,655	3.9%
85	21	2,603	27,978	30,602	4.5%
86	5	2,730	27,262	29,997	4.4%
87	4	1,519	20,546	22,069	3.2%
88	10	1,152	25,932	27,094	3.9%
89	14	1,793	33,247	35,054	5.1%
90	6	1,655	27,944	29,605	4.3%
91	1	1,242	22,310	23,553	3.4%
92	77	1,121	22,304	23,502	3.4%
93	27	1,444	23,643	25,114	3.7%
94	38	1,670	34,943	36,651	5.3%
95	127	3,107	40,375	43,609	6.3%
96	61	1,651	26,971	28,683	4.2%
97			69	69	0.0%
Total	815	29,153	657,595	687,563	

Class 3 GVW 10,001-14,000 lbs

MYR	*	Diesel	Gas	Total	%
66		1	3	4	0.0%
67		2	1	3	0.0%
68			20	20	0.1%
69			14	14	0.0%
70			32	32	0.1%
71			5	5	0.0%
72			46	46	0.1%
73		6	72	78	0.2%
74		12	73	85	0.3%
75		4	35	39	0.1%
76		2	32	34	0.1%
77		2	268	270	0.9%
78			87	87	0.3%
79			326	326	1.0%
80			22	22	0.1%
81	1	1	356	358	1.1%
82	1	20	313	334	1.1%
83	1	80	326	407	1.3%
84	1	293	858	1,152	3.6%
85	1	337	1,598	1,936	6.1%
86	1	1,191	1,898	3,090	9.7%
87		929	1,810	2,739	8.6%
88	6	947	1,534	2,487	7.8%
89		1,303	1,701	3,004	9.5%
90		1,365	1,637	3,002	9.5%
91	1	855	1,114	1,970	6.2%
92		847	809	1,656	5.2%
93		891	1,167	2,058	6.5%
94	1	769	1,691	2,461	7.8%
95		710	1,866	2,576	8.1%
96		546	877	1,423	4.5%
97				0	0.0%
Total	14	11,113	20,591	31,718	

Class 4 GVW 14,001-16,000 lbs

MYR	*	Diesel	Gas	Total	%
66			69	69	0.5%
67		3	109	112	0.8%
68		1	165	166	1.2%
69		4	163	167	1.2%
70		1	194	195	1.4%
71		2	152	154	1.1%
72		1	255	256	1.8%
73			43	43	0.3%
74			47	47	0.3%
75			25	25	0.2%
76			15	15	0.1%
77			17	17	0.1%
78			7	7	0.0%
79			15	15	0.1%
80			3	3	0.0%
81		1	43	44	0.3%
82			61	61	0.4%
83			117	117	0.8%
84		71	211	282	2.0%
85		66	341	407	2.9%
86		83	226	309	2.2%
87		43	235	278	2.0%
88	1	373	623	997	7.1%
89		607	985	1,592	11.3%
90	2	717	848	1,567	11.1%
91		323	654	977	6.9%
92		562	455	1,017	7.2%
93	1	482	573	1,056	7.5%
94		591	494	1,085	7.7%
95	1	1,444	839	2,284	16.2%
96		482	290	772	5.5%
97				0	0.0%
Total	5	5,857	8,274	14,136	

Class 5 GVW 16,001-19,500 lbs

MYR	*	Diesel	Gas	Total	%
66	6	1	197	204	2.7%
67		5	303	308	4.0%
68		2	362	364	4.8%
69		4	491	495	6.5%
70			453	453	5.9%
71			292	292	3.8%
72			234	234	3.1%
73		21	420	441	5.8%
74			264	264	3.5%
75		11	232	243	3.2%
76		1	192	193	2.5%
77			117	117	1.5%
78			73	73	1.0%
79			126	126	1.7%
80			50	50	0.7%
81	1	10	153	164	2.1%
82		13	124	137	1.8%
83		4	99	103	1.3%
84		10	170	180	2.4%
85		26	199	225	2.9%
86		17	105	122	1.6%
87		278	71	349	4.6%
88		181	78	259	3.4%
89		238	58	296	3.9%
90		231	43	274	3.6%
91		123	28	151	2.0%
92		276	29	305	4.0%
93		258	10	268	3.5%
94		224	122	346	4.5%
95		285	152	437	5.7%
96		107	51	158	2.1%
97		4		4	0.1%
Total	7	2,330	5,298	7,635	

* Other

Table 7. Manufacturer Distributions

	Class 1 GVW less than 6,000 lbs					Class 2 GVW 6,001-10,000 lbs					Class 3 GVW 10,001-14,000 lbs					Class 4 GVW 14,001-16,000 lbs					Class 5 GVW 16,001-19500 lbs				
	**	*Diesel*	*Gas*	*Total*	*%*	**	*Diesel*	*Gas*	*Total*	*%*	**	*Diesel*	*Gas*	*Total*	*%*	**	*Diesel*	*Gas*	*Total*	*%*	**	*Diesel*	*Gas*	*Total*	*%*
Amer. Motors		14	19,327	19,341	1.5			1,311	1,311	0.2				0	0.0				0	0.0				0	0.0
Chevrolet	183	2,298	238,326	240,807	19.2	278	5,849	229,185	235,312	34.2	3	425	4,115	4,543	14.3		375	3,192	3,567	25.2	7	78	1,899	1,984	26.0
Chrysler			19	19	0.0				0	0.0				0	0.0				0	0.0				0	0.0
Daihatsu			2	2	0.0				0	0.0				0	0.0				0	0.0				0	0.0
Datsun		1,296	41,973	43,269	3.5				0	0.0				0	0.0				0	0.0		39		39	0.5
Dodge	74	231	83,705	84,010	6.7	364	4,214	108,139	112,717	16.4		2,035	1,650	3,685	11.6			199	199	1.4		1	261	262	3.4
Ford	158	143	257,160	257,461	20.5	150	16,332	248,914	265,396	38.6	8	3,268	12,009	15,285	48.2	2	2,754	3,519	6,275	44.4		75	2,489	2,564	33.6
Freightliner				0	0.0				0	0.0				0	0.0		21		21	0.1		29	2	31	0.4
Geo			13	13	0.0				0	0.0				0	0.0				0	0.0				0	0.0
GMC	28	614	39,188	39,830	3.2	23	2,580	59,154	61,757	9.0	1	903	1,997	2,901	9.1	2	491	1,212	1,705	12.1		253	632	885	11.6
Hino				0	0.0				0	0.0		85		85	0.3		84		84	0.6		546		546	7.2
Honda			10	10	0.0				0	0.0				0	0.0				0	0.0				0	0.0
International	1	45	756	802	0.1		34	1,421	1,455	0.2		3	107	110	0.3		47	149	196	1.4		237	4	241	3.2
Isuzu	24	2,131	9,991	12,146	1.0				0	0.0		3,174	704	3,878	12.2	1	1,509		1,510	10.7		557		557	7.3
Iveco				0	0.0		112		112	0.0		514		514	1.6		284		284	2.0		50		50	0.7
Jeep Eagle			3,364	3,364	0.3			745	745	0.1				0	0.0				0	0.0		223		223	2.9
Kia			3	3	0.0				0	0.0				0	0.0				0	0.0				0	0.0
Mazda		329	57,007	57,336	4.6				0	0.0				0	0.0				0	0.0				0	0.0
Mercedes Benz				0	0.0				0	0.0		26		26	0.1				0	0.0				0	0.0
Mercury			24	24	0.0				0	0.0				0	0.0				0	0.0				0	0.0
Mitsubishi	9	408	26,142	26,559	2.1				0	0.0		465		465	1.5		48		48	0.3				0	0.0
NDMC				0	0.0				0	0.0		50		50	0.2		8		8	0.1				0	0.0
Nissan		37	125,813	125,850	10.0				0	0.0		45		45	0.1		38		38	0.3		85		85	1.1
Oldsmobile			375	375	0.0				0	0.0				0	0.0				0	0.0				0	0.0
Oshkosh				0	0.0		28		28	0.0		36	5	41	0.1		39	3	42	0.3		27	11	38	0.5
Plymouth	13		2,251	2,264	0.2			156	156	0.0				0	0.0				0	0.0				0	0.0
Pontiac			15	15	0.0				0	0.0				0	0.0				0	0.0				0	0.0
Range Rover			3	3	0.0			16	16	0.0				0	0.0				0	0.0				0	0.0
Subaru			456	456	0.0				0	0.0				0	0.0				0	0.0				0	0.0
Suzuki			125	125	0.0				0	0.0				0	0.0				0	0.0				0	0.0
Toyota		986	334,830	335,816	26.8			8,547	8,547	1.2				0	0.0				0	0.0				0	0.0
UD				0	0.0				0	0.0		83		83	0.3		129		129	0.9		130		130	1.7
Volkswagen	704	1,473	840	3,017	0.2				0	0.0				0	0.0				0	0.0				0	0.0
Winnebago		1		1	0.0		4	7	11	0.0		1		1	0.0				0	0.0				0	0.0
Other		20	981	1,001	0.1				0	0.0	2		4	6	0.0		30		30	0.2				0	0.0
Total	1,194	10,026	1,242,699	1,253,919		815	29,153	657,595	687,563		14	11,113	20,591	31,718		5	5,827	8,274	14,136		7	2,330	5,298	7,635	

* Other

Table 8. Distribution of Vehicles in CUT-SMOG Database by Weight Class

Vehicle Type	1994/1995 CUT-SMOG						1997 CUT-SMOG						District Population		
	Gasoline Trucks		Diesel Trucks		Total		Gasoline Trucks		Diesel Trucks		Total		Gasoline	Diesel	Total
Trucks															
Class 1	2,616	9.14%	298	1.04%	2,936	10.26%	831	8.65%	68	0.71%	904	9.41%	11.77%	0.09%	11.86%
Class 2	1,470	5.14%	428	1.50%	1,899	6.64%	425	4.42%	125	1.30%	553	5.75%	6.23%	0.28%	6.51%
Class 3	23	0.08%	160	0.56%	183	0.64%	9	0.09%	45	0.47%	54	0.56%	0.20%	0.11%	0.33%
Class 4	6	0.02%	63	0.22%	69	0.24%	3	0.03%	26	0.27%	29	0.30%	0.08%	0.06%	0.14%
Class 5	7	0.02%	23	0.08%	30	0.10%	2	0.02%	8	0.08%	10	0.10%	0.05%	0.02%	0.07%
Class 6	59	0.21%	215	0.75%	274	0.96%	13	0.14%	42	0.44%	55	0.57%	0.23%	0.14%	0.37%
Class 7	6	0.02%	421	1.47%	427	1.49%	-	-	121	1.26%	121	1.26%	0.05%	0.27%	0.32%
Class 8	1	0.00%	147	0.51%	150	0.52%	-	-	44	0.46%	44	0.46%	0.01%	0.42%	0.43%
Autos					22,644	79.14%					7,841	81.58%			80.0%
Total	4,188	14.64%	1,755	6.13%	28,612		1,283	13.35%	479	4.98%	9,611		18.62%	1.38%	

*includes only CUT-SMOG records which could be identified by cross reference with the DMV database

*Totals for CUT-SMOG include a small number vehicles which could not be identified as gasoline or diesel

4.0 Vehicle Emissions Test Results

4.1 Mass Emission Results

Table 9 presents the FTP weighted particulate and gaseous mass emission rates for each of the 15 test vehicles. Complete FTP data for each vehicle are presented in Appendix A. FTP weighted total particulate mass emission rates averaged 264 mg/mi for the test fleet with a range from 58 to 768 mg/mi. These emission rates are similar to those reported previously for diesel vehicles (Norbeck et al., 1996b, 1997, and 1998). The data show a trend of decreasing particulate emission rates for progressively newer vehicles, as expected. In particular, all but one of the catalyst-equipped 1994 or newer vehicles had mass emission rates of 100 mg/mi or less. The mass emission rates for even the newer light heavy-duty pickup trucks, however, are still substantially higher than those for properly maintained modern light-duty gasoline automobiles and trucks, which are generally 5 mg/mi or less (Norbeck et al., 1998). It should also be noted that the vehicles recruited from CUT-SMOG had particulate emissions comparable to those of other vehicles in the test fleet.

Table 9. FTP Weighted Emissions Results

Model Year	Make	Model	THC g/mi	NMHC g/mi	CO g/mi	NO_x g/mi	Particles mg/mi	CUT-SMOG
1996	Dodge	Ram 2500 PU	0.440	0.453	1.431	8.029	76.6	
1996	Dodge	Ram 3500 PU	0.383	0.391	1.489	6.334	58.4	
1995	Dodge	Ram 3500 PU	0.539	0.553	1.923	6.583	63.9	
1994	Ford	F350 PU	0.394	0.406	1.317	3.926	160.9	X
1994	Dodge	Ram 2500 PU	0.453	0.466	1.305	6.744	57.9	
1994	Dodge	Ram 2500 PU	0.418	0.422	1.385	6.745	75.1	
1992	Dodge	Ram 250 PU	0.505	0.506	1.321	7.356	163.8	
1989	Ford	F350 Stakebed	0.226	0.254	1.208	4.370	214.5	
1987	Ford	F250 PU	0.510	0.521	1.447	4.205	687.8	
1987	Ford	F250 PU	0.809	0.812	2.581	2.740	218.5	
1986	Ford	F250 PU	0.492	0.501	1.836	3.155	767.7	
1985	Ford	F350 PU	0.230	0.242	1.202	4.163	288.1	X
1985	GMC	1500 PU	0.898	0.907	2.017	2.552	412.3	X
1984	Ford	F250 PU	0.425	0.438	1.627	4.193	550.9	
1982	GMC	Sierra 3500 PU	0.331	0.344	1.485	3.994	162.3	X
		ave.	0.470	0.481	1.572	5.006	263.9	

For THC, NMHC, CO, and NO_x emissions, in contrast to the particulate emissions, there were no strong and consistent trends of decreasing emissions as a function of decreasing vehicle age or for vehicles equipped with oxidation catalysts. NO_x emissions were relatively high for the 1990 and newer vehicles, and generally exceeded the NO_x emissions levels for the pre-1990 vehicles. All three of the 1995 and newer vehicles had NO_x emissions which were considerably in excess of the California 50,000 miles NO_x standard of 1.3 g/mi for vehicles with GVWs from 8,501 to 10,000 lbs. or 2.0 g/mi for vehicles with GVWs from 10,001 to 14,000 lbs. It should be noted that NO_x emissions are not expected to be substantially reduced using only an oxidation catalyst. THC, NMHC, and CO emissions were relatively constant over the model years tested and were not substantially lower for the vehicles equipped with oxidation catalyst. These emissions are typically lower for diesel vehicles due to their lean operation.

4.2 Particulate Size Distributions

The percentage of particulate mass <10 µm, <2.5 µm, and <1.0 µm is presented in Table 10. Although there is no specific impaction substrate for the collection of 2.5 µm particulate matter, the mass of particulate below 2.5 µm is obtained by assuming that half of the mass collected on the 1.8 µm impaction stage is below 2.5 µm in aerodynamic diameter. The results show that greater than 90% of the mass is below 1 µm in diameter. These results are consistent with previous studies showing that a large majority of the particulate mass from diesel vehicles is below 1 µm in aerodynamic diameter (Hildemann et al., 1991; Verrant and Kittelson, 1977; Norbeck et al., 1996b, 1997, 1998). Full MOUDI distributions were obtained for four vehicles, as denoted in Table 10. A composite distribution for these four vehicles is presented in Figure 1, showing a single maximum in the size range 0.10-0.18 µm.

4.3 Chemical Analysis Results

Thermal Optical Reflectance measurements were performed on total particulate samples from each FTP test. These results are presented in Table 11 and Figure 2, with the breakdown of elemental and organic carbon in the sample in terms of percent of total particulate carbon. Note that these data are presented as percent of total carbon, as opposed to percent of total mass, since the total mass identified through chemical analysis was typically less than that determined by gravimetric measurements (given that the inorganic contribution to the particulate is assumed to be small). This result has been observed by other researchers (Hildemann et al., 1991; Watson et al., 1994; and Sagebiel et al., 1997 on more heavily loaded samples), and could be attributed, in part, to the fact that not all of species that contribute to the particulate composition are measured, or possibly to the impact of filter inhomogenities. The breakdowns show that elemental carbon is more predominant than organic carbon, with an average of 64.0±21.6% elemental carbon and 34.0±21.6% organic carbon. This is similar to the results obtained in previous studies of light-duty diesel vehicles (Norbeck et al., 1998). The carbon fraction varied significantly from vehicle-to-vehicle, however, with a slight trend toward greater organic carbon percentages for higher particulate emitting vehicles.

Table 10. Percentage of Particulate Mass below 10.0, 2.5, and 1.0 μm

Model Year	Make	Model	Particles Mg/mi	<10.0 μm	<2.5 μm	<1.0 μm	Full MOUDI
1996	Dodge	Ram 2500 PU	76.6	96.0%	94.1%	90.6%	
1996	Dodge	Ram 3500 PU	58.4	100.0%	95.7%	93.9%	
1995	Dodge	Ram 3500 PU	63.9	99.7%	95.7%	92.6%	
1994	Ford	F350 PU	160.9	97.6%	96.2%	93.4%	X
1994	Dodge	Ram 2500 PU	57.9	96.1%	93.3%	90.9%	
1994	Dodge	Ram 2500 PU	75.1	95.4%	92.0%	84.4%	
1992	Dodge	Ram 250 PU	163.8	100.0%	97.8%	94.1%	
1989	Ford	F350 Stakebed	214.5	99.5%	98.7%	96.9%	
1987	Ford	F250 PU	687.8	100.0%	98.9%	94.7%	
1987	Ford	F250 PU	218.5	99.2%	98.3%	96.7%	
1986	Ford	F250 PU	767.7	100.0%	99.7%	97.6%	
1985	Ford	F350 PU	288.1	99.2%	98.1%	95.4%	X
1985	GMC	1500 PU	412.3	99.7%	99.2%	95.7%	X
1984	Ford	F250 PU	550.9	99.8%	98.2%	89.8%	
1982	GMC	Sierra 3500 PU	162.3	98.3%	97.5%	94.2%	X
		Ave.	263.9	98.7%	96.9%	93.5%	

Figure 1. MOUDI Size Distributions

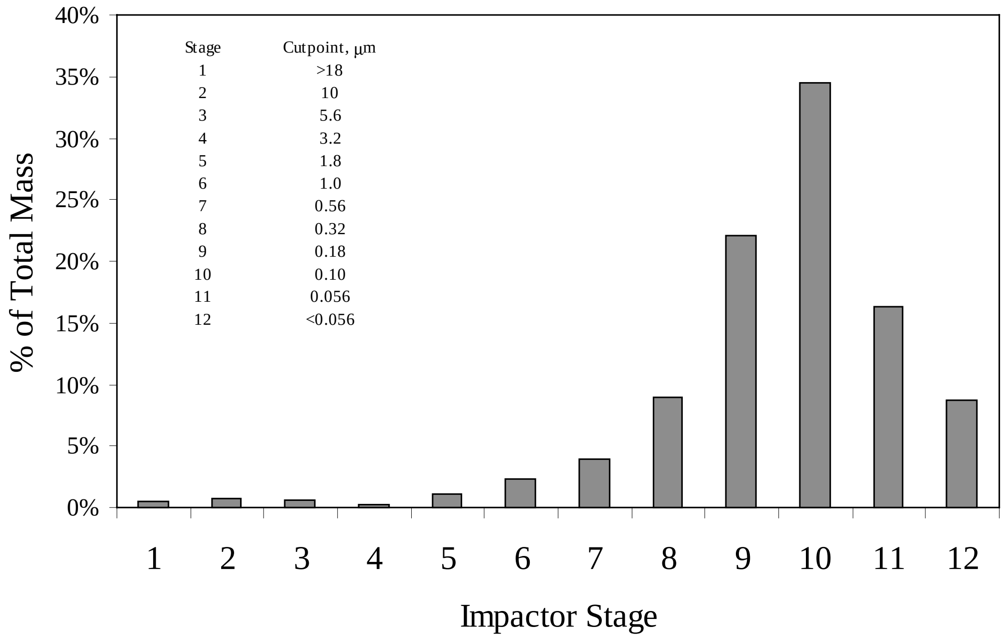
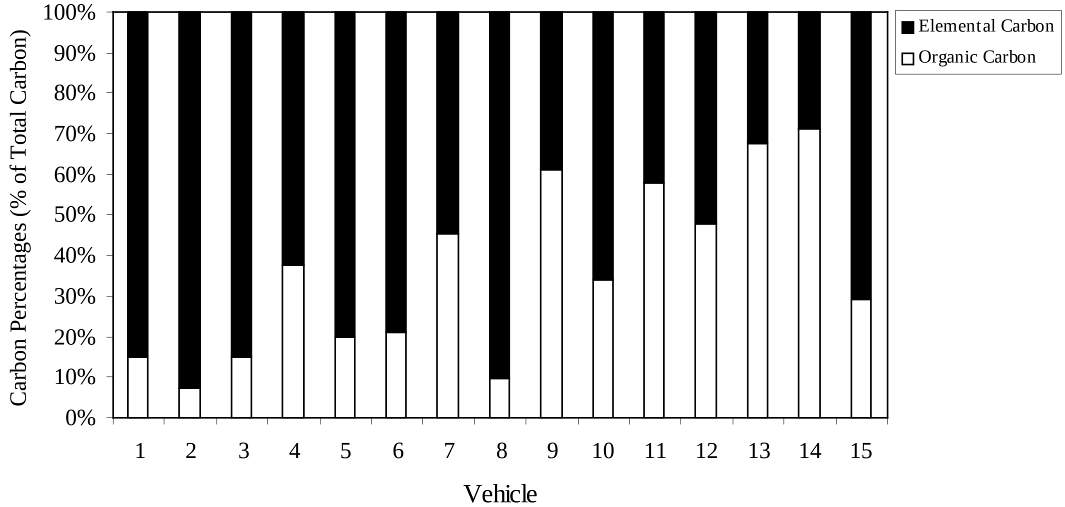


Table 11. Elemental and Organic Particulate Carbon Fractions (% of Total Carbon)

Model Year	Make	Model	FTP Particles mg/mi	Organic Carbon	Elemental Carbon
1996	Dodge	Ram 2500 PU	76.6	15.0%	85.0%
1996	Dodge	Ram 3500 PU	58.4	7.4%	92.6%
1995	Dodge	Ram 3500 PU	63.9	14.9%	85.1%
1994	Ford	F350 PU	160.9	37.5%	62.5%
1994	Dodge	Ram 2500 PU	57.9	19.9%	80.1%
1994	Dodge	Ram 2500 PU	75.1	21.1%	78.9%
1992	Dodge	Ram 250 PU	163.8	45.2%	54.8%
1989	Ford	F350 Stakebed	214.5	9.5%	90.5%
1987	Ford	F250 PU	687.8	61.1%	38.9%
1987	Ford	F250 PU	218.5	34.0%	66.0%
1986	Ford	F250 PU	767.7	57.9%	42.1%
1985	Ford	F350 PU	288.1	47.7%	52.3%
1985	GMC	1500 PU	412.3	67.6%	32.4%
1984	Ford	F250 PU	550.9	71.2%	28.8%
1982	GMC	Sierra 3500 PU	162.3	29.1%	70.9%
		Ave.	263.9	36.0±21.6%	64.0±21.6%

Figure 2. Carbon Percentage Fractions



5.0 Emissions Inventory Estimates and Model Comparisons

It is important to compare the results of this work with results obtained from EMFAC7G. EMFAC7G uses a set of default particulate emission factors for different vehicle classes according to model year. For diesel trucks, EMFAC7G includes values for light-heavy-duty diesel trucks, but not for medium-duty diesel trucks. A comparison of the averages emissions rates obtained in this study with the EMFAC7G emissions factors is presented in Table 12. Overall, the emissions rates measured in this work are lower than those presently used in the EMFAC7G. It should be noted that the diesel trucks tested in this study had GVW ranging from only 8,500 to 11,000 lbs., whereas the light heavy-duty diesel trucks under the EMFAC7G definition range from 8,500 to 14,000 lbs. This difference should not have a significant impact on the emission factors, however.

Table 12. Comparison of Emissions Factors for EMFAC7G vs. Test Results

	EMFAC *	CE-CERT
Pre-1982	877	N.A.
1982-1986	825	436.4 (5)
1987-1990	822	373.7 (3)
1991-1993	431	163.9 (1)
1994-1997	152	82.2 (6)

* For light heavy-duty diesel vehicles
Note: Number of vehicles testing in category is in ()

The emission factors and population distributions obtained from this study also can be used to make emission inventory estimates and compared to those obtained from EMFAC7G. Emissions inventories were calculated based on the model year population distributions from the District DMV database and the emissions factors derived from testing as shown in Table 12. Since no pre-1982 vehicles were tested, the default emission factor from EMFAC7G was used for these model years. Annual mileage accrual rates for light heavy-duty diesel vehicles were obtained from EMFAC7G. Calculations were made for 1996 since this is last year for which DMV data are available. The resulting emission inventory estimates for classes 2 and 3 are presented in Table 13. Based on the population estimates and emissions test results, a total PM emissions inventory of 0.35 tons/day for 40,266 in-use vehicles in classes 2 and 3 for the calendar year 1996 was obtained.

Table 13. Light Heavy-Duty Diesel Vehicle Emissions Inventory Estimates

Based on CE-CERT Population Distributions and Emission Test Results

	Class 2 6,000-10,000 GVW	Class 3 10,001-14,000 GVW	Total
Total PM Emissions (Tons/day)	0.25	0.10	0.35
# of vehicles	29,153	11,113	40,266
Daily VMT (x1000)	859	358	1,217

* includes only diesel vehicles

For comparison, emission inventories also were derived using EMFAC7G and the default emissions factors and population distributions therein. The emission inventory estimates were run for the calendar year 1996 for the South Coast Air Basin for comparison. These results are presented in Table 14 for light heavy-duty diesel trucks ranging from 8,500 to 14,000 GVW. It should be noted that the contribution from diesel trucks from 6,000 to 8,500 GVW is assumed to be zero in EMFAC7G. The EMFAC7G results indicate a much higher contribution for class 2 and 3 diesel trucks compared with the results obtained from this study. This can be attributed to the higher emission factors used in EMFAC7G, as shown in Table 12, as well as the higher population of vehicles and total VMT estimated by EMFAC7G compared to our population estimates.

Table 14. EMFAC7G Emissions Inventory Estimates

EMFAC7G Estimates for Calendar Year 1996

	Light Heavy-duty Diesel Trucks 8,500 – 14,000 GVW
Total PM Emissions (Tons/day)	1.54
# of vehicles	69,048
Daily VMT (x1000)	2,830

To evaluate the effect of the higher emission factors used in EMFAC7G, additional calculations were performed using the CE-CERT population distributions along with the EMFAC7G emissions factors. These results are presented in Table 15. These emissions inventory results provided better agreement with the EMFAC model, but were still considerably below the model estimates.

Table 15. CE-CERT Light Heavy-Duty Diesel Vehicle Emissions Inventory Estimates using EMFAC7G Emissions Factors

Based on CE-CERT population distributions and EMFAC7G Emission Factors

	Class 2 6,000-10,000 GVW	Class 3 10,001-14,000 GVW	Total
Total PM Emissions (Tons/day)	0.50	0.22	0.72

* includes only diesel vehicles

Overall, these results indicate that additional research should be conducted to provide better estimates of particulate emissions inventories for medium and light heavy-duty diesel vehicles. Although these vehicles compose a relatively small component of the total vehicle population, their particulate emissions impact is comparable to that of all light-duty gasoline and diesel automobiles in the South Coast Basin, which is estimated to be 2.15 tons/day for 1996. Additional work should include emissions testing for larger numbers of vehicles and vehicles with higher GWV capacity (11,000 – 14,000 lbs.) to develop improved emissions factors for medium and light heavy-duty vehicles. More detailed population distributions are also needed along with good mileage estimates to provide more accurate emissions inventories for these vehicles.

6.0 Summary and Conclusions

The objectives of this study were to augment the current database of tailpipe particulate emissions from medium- and light heavy-duty vehicles, determine the characteristics and percentages of these vehicles in the general population, and determine the impact of these vehicles on the particulate emissions inventory. A summary of the major conclusions and accomplishments of this project are:

- Overall, diesel trucks represent less than 1.5% of the total vehicle population, with the fraction of diesel trucks increasing for the higher weight classes.
- Medium- and light heavy-duty vehicles classified in weight classes 2-5, compose less than 10% of the total population of vehicles and are dominated by class 2 gasoline trucks.
- Medium- and light heavy-duty vehicles included a variety of different body styles including pickup trucks, vans, cab and chassis and others. Pickup trucks and vans are the most prominent body styles for trucks in weight class 2. In weight classes 3, 4, and 5, the most prominent body styles are cab and chassis or variations therein.
- The overall total distribution of trucks in CUT-SMOG is similar to that found in the DMV database. Diesel trucks, however, make greater contribution to the CUT-SMOG database on a percentage basis than to the total District DMV population. This is not unexpected since the CUT-SMOG database is for identified smoking vehicles.
- FTP weighted particulate mass emission rates averaged 264 mg/mi for the test fleet with a range from 58 to 768 mg/mi. Particulate emission rates decreased for progressively newer vehicles, with all but one of the 1994 and newer vehicles having mass emission rates of 100 mg/mi or less.
- Over 90% of the total particulate mass was below 1.0 μm in aerodynamic diameter.
- Carbon analysis using Thermal Optical Reflectance (TOR) showed that elemental carbon is more predominant than organic carbon in diesel particulate, with an average of 64.0% elemental carbon and 34.0% organic carbon.
- There were no strong and consistent trends of decreasing THC, CO, and NO_x emissions as a function of decreasing vehicle age. In fact, NO_x emissions were relatively high for the 1990 and newer vehicles, and the 1995 and newer vehicles were considerably in excess of the

emissions standard for this class. The 1990 and newer vehicles also generally exceeded the NO_x emissions levels for the pre-1990 vehicles. THC and CO emissions were relatively consistent as a function of model year.

- Emission factors developed from the emissions testing results were lower than the default values used in EMFAC7G for light heavy-duty diesels (8,500 to 14,000 lbs.). This could be due in part to the fact that vehicles with GWV above 11,000 lbs. were not included in the present test matrix, although this should not have a significant impact on the emissions factors.

- Emissions inventory estimates for class 2 and 3 diesel trucks were 0.35 tons/day of PM. These estimates were based on the District DMV population and the emissions tests results for the present study. The estimate increased to 0.72 tons/day of PM using the default emissions factors used in EMFAC7G.

- Emissions inventory estimates based on EMFAC7G were 1.54 tons/day of PM for diesel trucks (8,500 to 14,000 lbs.). This estimate was considerably higher than the results of this study due to the higher emissions factors used in EMFAC7G, and the higher population of vehicles and VMT estimated by EMFAC7G compared with the DMV database.

- The large discrepancy in the emissions inventory estimates from this study and EMFAC7G indicate that additional research is needed to develop accurate population profiles and improved emissions factors for medium and light heavy-duty diesel trucks. This should include emissions testing of larger number of vehicles and vehicles with higher GVWs (11,000 – 14,000 lbs.).

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Appendix A. FTP Emissions Results

Model	Make	Model	Phase 1					Phase 2					Phase 3					Weighted				
Year			THC	NMHC	CO	$N0_x$	Parts.	THC	NMHC	CO	$N0_x$	Parts.	THC	NMHC	CO	$N0_x$	Parts.	THC	NMHC	CO	NO_x	Parts.
			g/mi	g/mi	g/mi	g/mi	mg/mi	g/mi	g/mi	g/mi	g/mi	mg/mi	g/mi	g/mi	g/mi	g/mi	mg/mi	g/mi	g/mi	g/mi	g/mi	mg/mi
1996	Dodge	Ram 2500 PU	0.564	0.576	1.969	6.934	116.2	0.471	0.491	1.494	9.260	65.4	0.288	0.288	0.904	6.526	67.9	0.440	0.453	1.431	8.029	76.6
1996	Dodge	Ram 3500 PU	0.363	0.363	2.044	5.873	66.0	0.436	0.453	1.570	7.047	53.1	0.297	0.295	0.918	5.331	62.8	0.383	0.391	1.489	6.334	58.4
1995	Dodge	Ram 3500 PU	0.621	0.625	2.929	6.168	82.8	0.595	0.619	1.865	7.330	57.4	0.372	0.375	1.274	5.475	62.0	0.539	0.553	1.923	6.583	63.9
1994	Ford	F350 PU	0.309	0.313	1.432	5.018	174.6	0.485	0.504	1.448	3.815	164.9	0.285	0.290	0.981	3.318	142.9	0.394	0.406	1.317	3.926	160.9
1994	Dodge	Ram 2500 PU	0.495	0.497	1.790	6.408	76.6	0.512	0.533	1.358	7.379	52.7	0.308	0.315	0.836	5.790	53.5	0.453	0.466	1.305	6.744	57.9
1994	Dodge	Ram 2500 PU	0.398	0.386	1.900	6.111	115.1	0.470	0.480	1.428	7.487	61.9	0.334	0.339	0.905	5.825	69.3	0.418	0.422	1.385	6.745	75.1
1992	Dodge	250 LE PU	0.521	0.526	1.608	9.294	209.1	0.578	0.581	1.404	7.677	144.9	0.353	0.347	0.948	5.289	165.4	0.505	0.506	1.321	7.356	163.8
1989	Ford	F350 PU	0.260	0.281	1.054	4.290	510.0	0.213	0.256	1.293	4.820	121.7	0.226	0.230	1.162	3.579	166.7	0.226	0.254	1.208	4.370	214.5
1987	Ford	F250 PU	0.569	0.576	1.668	4.283	917.5	0.497	0.517	1.344	4.335	517.8	0.492	0.487	1.473	3.901	836.0	0.510	0.521	1.447	4.205	687.8
1987	Ford	F250 PU	0.785	0.786	2.551	2.859	228.3	0.934	0.940	2.981	2.871	218.3	0.590	0.588	1.839	2.401	211.5	0.809	0.812	2.581	2.740	218.5
1986	Ford	F250 PU	0.686	0.688	2.137	2.766	1159.8	0.334	0.353	1.655	3.584	540.5	0.645	0.641	1.951	2.633	903.1	0.492	0.501	1.836	3.155	767.7
1985	Ford	F350 PU	0.326	0.331	1.759	3.830	459.7	0.158	0.183	0.878	4.631	214.2	0.294	0.286	1.393	3.530	298.3	0.230	0.242	1.202	4.163	288.1
1985	GMC	1500 PU	1.460	1.451	2.704	2.265	896.0	0.815	0.839	1.980	2.833	256.9	0.633	0.626	1.571	2.236	343.3	0.898	0.907	2.017	2.552	412.3
1984	Ford	F250 PU	0.350	0.359	1.639	4.132	639.8	0.483	0.508	1.786	4.424	501.9	0.370	0.365	1.317	3.800	576.9	0.425	0.438	1.627	4.193	550.9
1982	GMC	Sierra 3500 PU	0.557	0.569	1.761	4.610	258.9	0.266	0.283	1.368	4.086	111.5	0.285	0.291	1.500	3.356	185.7	0.331	0.344	1.485	3.994	162.3