Proposed Diesel Vehicle Emissions
National Environment Protection Measure
Preparatory Work

In-Service Emissions Performance - Phase 2: Vehicle Testing - Appendices

NEPC
NATIONAL ENVIRONMENT PROTECTION COUNCIL

November 2000

APPENDIX 1

1. TEST FACILITY

The **Parsons Australia Vehicle Testing Facility** is located at Auburn, 20 km west of Sydney's CBD. It has the following features:

- Located within an industrial zone in the major transport center of Sydney.
- Has ready access for light and heavy vehicles to the M4 Motorway, Ring Road 3 and Parramatta Road.
- Comprises offices, a large fully enclosed workshop area capable of garaging large trucks and buses, and a large external apron with heavy vehicle access to Short Street.
- Incorporates a large, fully enclosed, soundproof test cell, equipped with a heavy-duty chassis dynamometer capable of testing all light and heavy vehicles.
- Incorporates a fully enclosed, air-conditioned laboratory area alongside the test cell, which houses a large variety of specialist exhaust sampling equipment, analytical equipment, instrumentation and data logging equipment.
- Capable of performing chassis tests to any programmed drive cycle.
- Surrounded by straight sections of road to undertake on-road testing.

The operational centerpiece of the facility is the heavy-duty vehicle test cell and instrument laboratory, which were equipped and commissioned during July and August 1999, specifically to carry out preparatory work for the NEPC Diesel NEPM. They provide capability to conduct a full range of tests and analyses of heavy-duty diesel vehicle exhaust emissions.

The test cell and laboratory are shown in schematic plan view in Figure A1-1.

2. DYNAMOMETER

The dynamometer has been Custom-built by Dyno Dynamics, and incorporates special design features to enable transient drive cycle testing. It uses large diameter rollers to reduce the potential for tyres to overheat, a 'drivers aid' to display the appropriate drive cycle trace and a single flywheel to provide a base inertia of 3000lbs (this falls within the IM240 equipment specification). Inertia above 3000lbs is simulated electrically via the eddy current brake and controlled by the drive cycle software.

The dynamometer's main features are:

- Twin-roll Shenck dynamometer with eddy current brake and flywheel.
- Idler rollers to accommodate bogie drive vehicles
- Computersied control system - speed, load and ramp control
- 'Drivers Aid' with 'tram' lines and error count.
- Full electrical inertia simulation during acceleration and cruise conditions.
- Response time of 50 milliseconds.
- Power absorbing capability in excess of 450 kW.
- Permissible axle loading of 14 tonne.
- Pull-down loading on axles to allow high tractive forces.
- Roll diameter (364mm) sufficient to avoid tyre damage.
- Knurled drive roller for traction.
- Temperature compensation.
- Plot to graph, screen or datalogger.
- Parasitic loss and coast down calibration.
- Modem and local technical support.

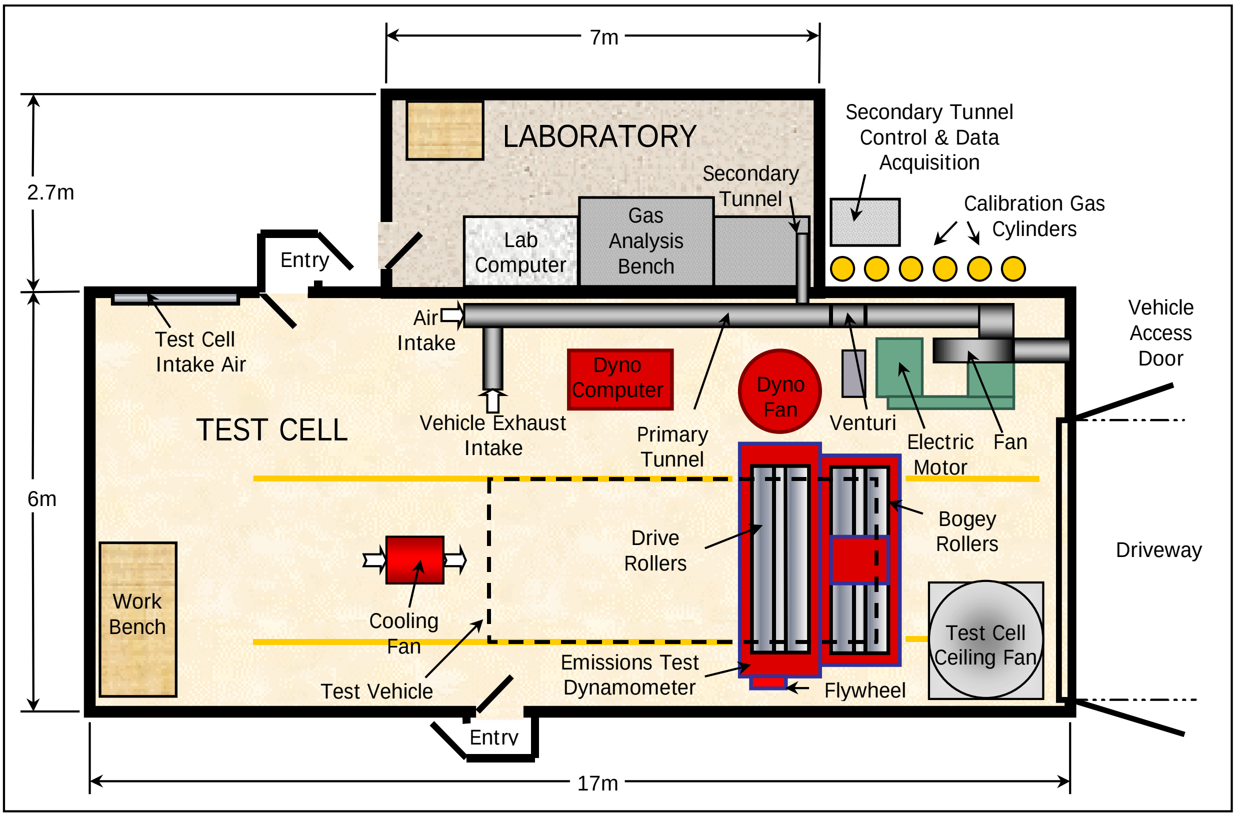


Figure A1 1: Schematic Plan View of Test Cell and Laboratory

Vehicle inertia is simulated electrically via the eddy current brake for conditions of acceleration and cruise. The 3000lb base inertia flywheel provides only limited inertia during deceleration, which reduces the load on the vehicle's braking system during test. This limited inertia during deceleration does not significantly affect emission test results.

The open style dynamometer software allows any drive cycle to be input to the control computer.

The chassis dynamometer was capable of testing the full range of vehicles listed in the project brief. Four wheel drive vehicles were tested by disengaging the front wheel hubs and allowing only the rear wheels to drive. Bogie-axle vehicles were tested by locating the rear wheels on the dynamometer idler rollers, and engaging the power divider so that only the front wheel set drove the rollers. Permanent all-wheel drive vehicles were not tested.

3. SAMPLING AND ANALYTICAL SYSTEMS

The overall sampling system and layout of the instruments, as used in this project, is shown schematically in Figure A1-2. Essentially, the system comprised the following main components –

- the primary and secondary exhaust dilution system,
- the gas analysis system,
- the particle analysis system,
- the data acquisition system.

Each of these components is described below.

3.1 PRIMARY AND SECONDARY EXHAUST DILUTION SYSTEM

The full flow, two-stage exhaust dilution system was designed and constructed by the staff of the Energy and Fuels Research Unit at the University of Auckland (UA), with input and guidance from staff of the exhaust emissions laboratory at West Virginia University in the United States.

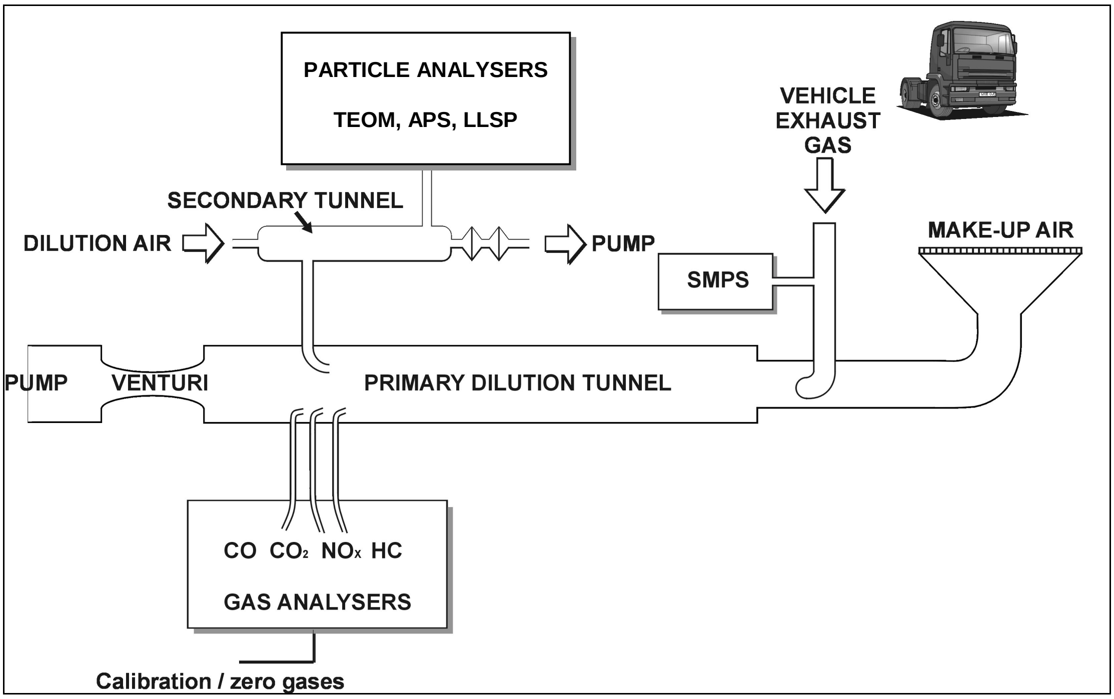
The system utilises the *constant volume flow* (CVS) concept with *electronic flow compensation* (EFC), and was designed –

- To meet the requirements of the US Code of Federal Regulations, Title 40, Subpart B, §86.110-94, applicable to (*inter alia*) 'light duty diesel vehicles' and 'light duty diesel trucks'.
- To enable these technical requirements to be met while testing heavy-diesel vehicles, for which the CFR has no chassis dynamometer test requirements.

The system was installed and initially calibrated by AU staff.

3.1.1 Primary Dilution Tunnel System

The primary dilution tunnel was a stainless steel pipe 3.5 m long and 304.8 mm inside diameter. A Howden Sirocco 77kW radial fan at one end, drew filtered make-up air into the tunnel where it was mixed with the full flow of vehicle exhaust. The gas flow through the tunnel was controlled by a set of three (600, 1,200 and 1,200 cfm) purpose-designed *critical flow venturis*, which were selected to ensure sufficient exhaust dilution such that the maximum temperature in the tunnel was less than 191 ^{o}C. The arrangement of venturies allowed staff to select from 600 to 30,000 cfm in 600 cfm increments to allow optimum flexibility and control. The venturi selection depended on the size (exhaust gas flow) of the vehicle under test. The CO, CO_2, NO_x and hydrocarbon analysers sampled the diluted exhaust stream from the primary tunnel as shown in Figure A1-2.



<u>Figure A1 2: General Layout of Sampling and Analytical Systems.</u>

3.1.2 Secondary Dilution Tunnel System

Attached to the main tunnel was a smaller, secondary dilution tunnel, 1 m long and 75.2 mm inside diameter, also made from stainless steel. This tunnel was for sampling particulate material. Diluted exhaust from the primary tunnel was drawn into the secondary tunnel through an appropriately sized nozzle to ensure that isokinetic sampling conditions were maintained. The size of nozzle used was determined by the flow rate in the primary tunnel. The sample gas was further diluted with a stream of additional make-up air as shown in Figure A1-2.

The total gas flow through the secondary tunnel was controlled by a programmable mass-flow controller, which assured the mass proportionality of sampling from the primary tunnel, and maintained the temperature in the secondary tunnel at less than 51.7 °C. All of the particle analysers except the scanning mobility particle sizer (SMPS) sampled from the secondary tunnel. All remaining gas (i.e. that not used by the particle analysers) passed through primary and backup filters, which were later weighed to determine total particulate emissions. An on / off valve located between the primary and secondary tunnels was used to isolate the secondary tunnel to allow filters to be changed. A remote switch was used to turn the secondary tunnel pump on or off when this valve was operated to ensure accurate capture of particles between the start and finish point of a test.

3.2 GAS ANALYSIS SYSTEM

The general layout of the instrumentation is shown in Figure A1-2. A more detailed schematic, showing the arrangements of pumps, sampling lines, etc is given in Figure A1-3.

3.3 GAS ANALYSIS SYSTEM

The general layout of the instrumentation is shown in Figure A1-2. A more detailed schematic, showing the arrangements of pumps, sampling lines, etc is given in Figure A1-3.

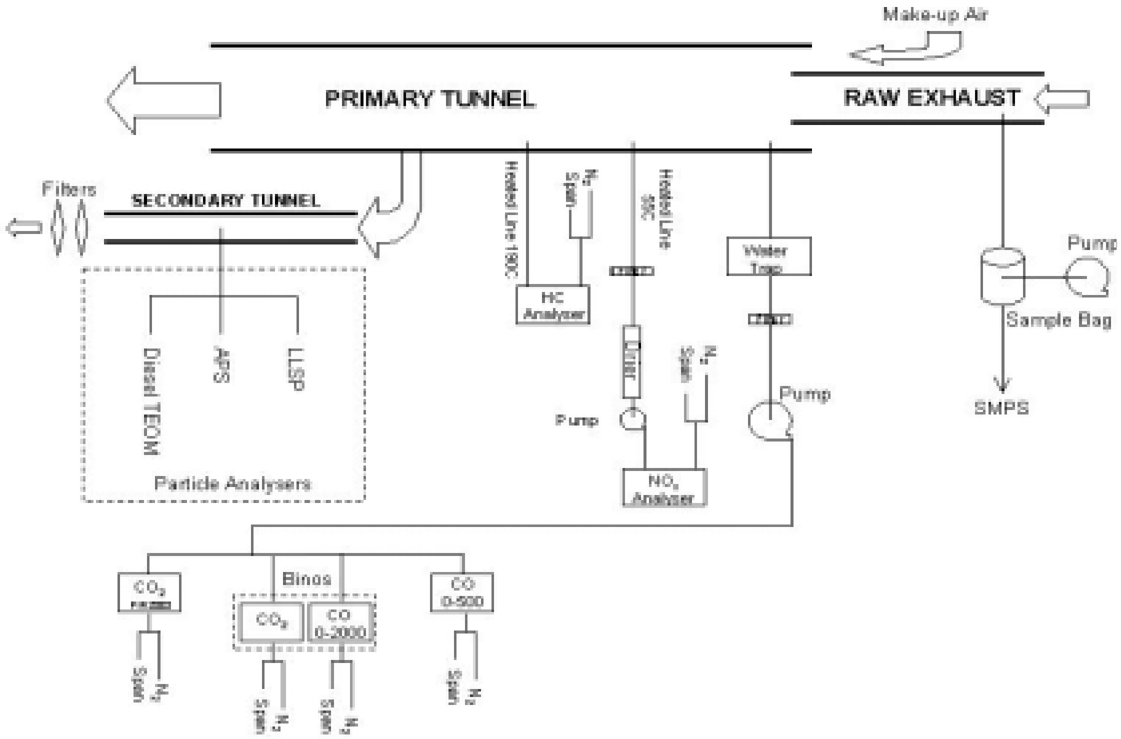


Figure A1 3: Schematic Layout of Gas and Particle Analyses Equipment

The diluted exhaust gas in the primary tunnel was analysed with a range of on-line, continuous analysers for CO_2, CO, NO_x and total hydrocarbons. The analogue output from each instrument was continuously logged by the data acquisition system. The various instruments and their manner of use was generally in conformance with US CFR Title 40, Subpart B, §86.111-90/91. Details of the instruments are given below:

- CO_2 – Two separate instruments were used for the analysis of CO_2; a Binos 100 CO/CO_2 Analyser and a Horiba PIR 2000 General Purpose Gas Analyser.
  (1) Binos 100 – This instrument was a two channel non-dispersive infrared analyser with a measuring range of 0-25 percent CO_2. The second channel measured CO. It was used as a back-up instrument.

  (2) Horiba PIR 2000 - Like the Binos, this instrument was a non-dispersive infrared analyser with a range of 0-5 percent CO_2.
- CO – Two Binos 100 instruments were used to measure CO. One was a single channel unit with a measuring range of 0-500 ppm CO. The other was the second channel of the Binos instrument described above, which was used as a backup instrument and had a range of 0-2000 ppm CO.
- NO_x – A Thermo-Electron Series 44 NO_x analyser was used to measure NO_x. This instrument had multiple ranges but was always operated in the 0-1000 ppm range.
- Hydrocarbons – Total hydrocarbons were measured with a Beckman 402 FID Hydrocarbon Analyser. This instrument was operated in its 0-100 ppm range.

The general layout of the instrumentation is shown in Figure A1-2. A more detailed schematic, showing the arrangements of pumps, sampling lines, etc is given in Figure A1-3.

For the CO_2 and CO analyses, sample gas was pumped into a manifold to a pressure of approximately 35 kPag from where it flowed to each of the instruments (at ambient pressure). A needle valve between each instrument and the manifold maintained the sample flow within the instrument manufacturer's specified limits. Water was removed from the sample gas with a water trap kept at about 0 ^oC in an insulated ice bath (Figure A1-3). Particulates were prevented from entering the system by a 47 mm diameter glass-fibre filter located between the water trap and the sample pump.

A separate sampling system was provided for NO_x analyses as shown in Figure A1-3. Sample gas was pumped to the analyser from the primary tunnel via a Teflon line heated to above 55 ^oC and passed through a 47 mm glass-fibre filter and Nafion drier to remove particulates and moisture.

The hydrocarbon analyser was also installed as a separate system, however, unlike the other instruments, it was fitted with its own pump and 70 mm glass-fibre filter so that ancillary pumps and gas cleaning equipment were not required. Sampling was from the primary tunnel via a Teflon line heated to 190 ^oC.

The exhaust from all analysers was vented to outside the laboratory.

3.3.1 Calibration and Verification of the Gas Analyses System

A six-point calibration of all of the gas analysers was performed by staff from the NSW Department of Mineral Resources, prior to the commencement of the project.

To test the effectiveness of the total sampling-analytical system, several propane and CO recovery tests were performed before commissioning the test facility. These involved injecting a measured volume of either propane or CO into the primary tunnel and measuring the concentration of these species on the appropriate analyser. In all cases the concentration of the propane or CO determined from the analyser was within two percent of the concentration expected due to dilution in the main tunnel.

Two-point calibrations of each gas analyser were carried out before and after every vehicle test using certified calibration gas mixtures. The zero was checked against instrument grade nitrogen (supplied by BOC Gases Pty Ltd) and the span was checked against an appropriate certified calibration mixture. These gases were supplied by either BOC Gases Pty Ltd or the NSW Department of Mineral Resources. A list of the calibration gases used during the measurement program is provided in Table 1. All calibration checks were logged by the data acquisition system.

Table A1 1: Details of Calibration Gases used for routine spanning of Gas Analysis Instruments.

Gas Details	Supplier
527 ppm CO in nitrogen	BOC Gases
573 ppm CO in nitrogen	BOC Gases
2.09 % CO_2 in nitrogen	BOC Gases
1020 ppm NO_x in nitrogen	BOC Gases
252 ppm NO_x in nitrogen	BOC Gases
12.1 % CO_2 in nitrogen	Dept of Min Resources
12.6 % CO_2 in nitrogen	Dept of Min Resources
99.4 ppm propane in nitrogen	Dept of Min Resources
108 ppm propane in nitrogen	Dept of Min Resources
8.3 ppm propane equivalent in nitrogen	BOC Gases

3.4 PARTICLE ANALYSIS SYSTEM

A series of on-line particle analyses instruments were used to provide continuous measurement of the total mass and size distribution of particles within the exhaust. The filters attached to the back of the secondary tunnel, also provided a measure of the total particulate loading. In addition, a scanning mobility particle sizer (SMPS) measured particle size distribution of ‘grab-samples’ taken from the raw exhaust inlet during the D550 short test.

All particle instruments (apart from the SMPS) were connected to the secondary tunnel through isokinetic sampling nozzles for each instrument.

A smoke opacimeter was connected to the exhaust system, at the end of the vehicles’ exhaust pipe.

A description of each instrument and the filter system is provided below.

3.4.1 Opacimeter

The AVL model 439 Opacimeter measured the opacity of the exhaust gases. This instrument operates by drawing a continuous sample of the exhaust through a measuring chamber having a defined length and non-reflecting surfaces. The loss of light intensity between a light source and a receiver (at either end of the chamber) is measured, and opacity calculated according to the Beer-

Lambert law. The instrument includes pressure and temperature sensors that input the data processor, enabling continuous output of temperature and pressure-corrected opacity.

The instrument meets the requirements of relevant current and draft European Union Directives and International Standards Organisation standards.

3.4.2 Filters

Gelman Sciences 'Pallflex' membrane filters, which meet the specifications of the US Code of Federal Regulations, were used throughout the test program. Each test required the use of a 70 mm main and a 47 mm backup filter.

Prior to use the filters were conditioned in CSIRO's North Ryde laboratories balance room for a period of ~3 hours. Each filter was then weighed to the nearest 0.01 mg with a five decimal place analytical balance, and placed in a covered plastic petri dish. The petri dishes were stored in a dessicator until ready for use. Two sets of unexposed filters (each comprising one 70 and one 47 mm filter) were kept in the balance room for use as references. Both sets were weighed with each batch of fresh filters.

The filters were transported to the test site where they were exposed to the particle laden sample stream. Immediately after exposure they were replaced in the petri dishes and returned to the dessicator. At the end of each day's run the filters were transported in the dessicators back to the CSIRO laboratories, where they were reconditioned in the balance room atmosphere and re-weighed. The reference sets were also weighed with each batch of exposed filters.

Figures A3-4 and A3-5 show the variation in the mass of the reference filters over the approximately 5 month duration of the testing program. Note that all the reference filters exhibited constant mass to within ± 0.02mg with the vast majority within ± 0.01mg.

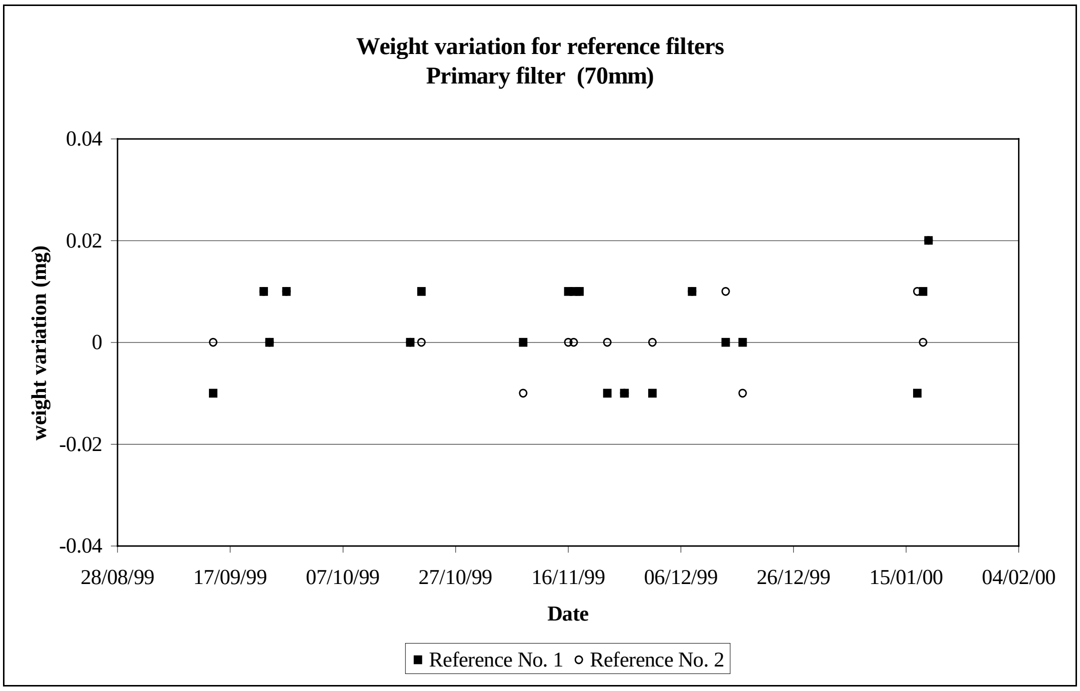


Figure A1 4: Weight Variation for Reference Filters

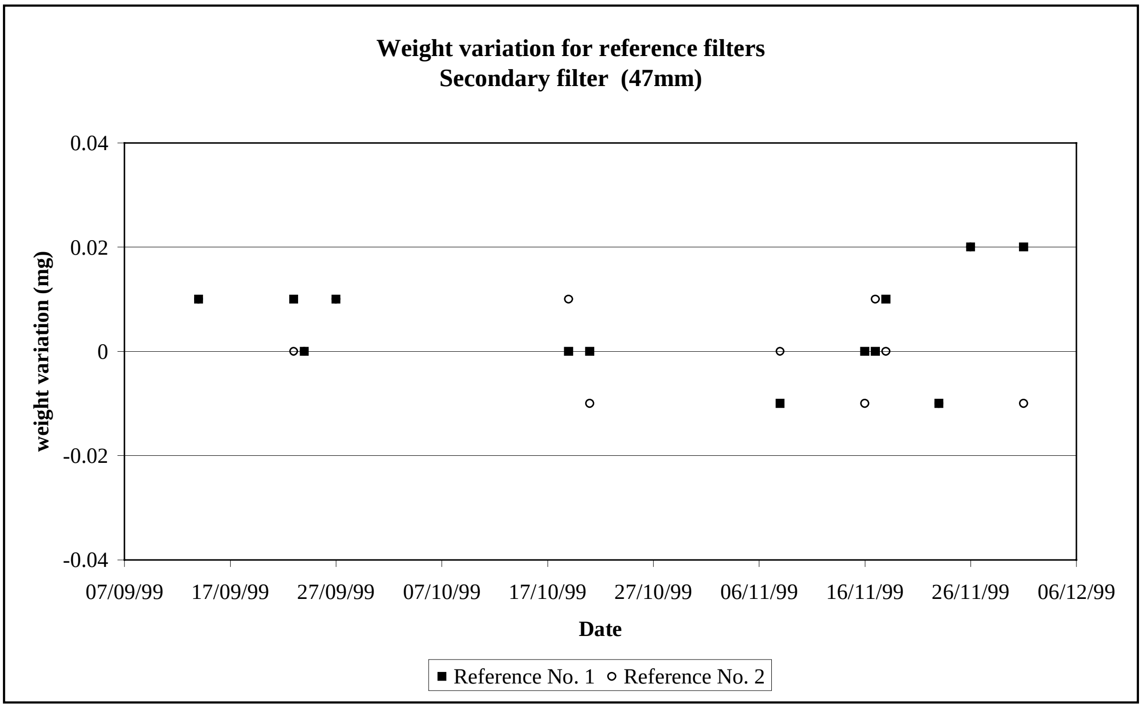


Figure A1 5: Weight Variation for Reference Filters

3.4.3 LLSP

A 'Laser Light Scattering Photometer' was used for on-line measurement of particle mass during vehicle tests. The LLSP uses the laser light-scattering technique for detection of particles. The particular instrument employed in this project was calibrated for diesel exhaust by Queensland University of Technology and was used as a standard instrument during all emissions testing. The data were stored by the LLSP during a run and downloaded at the end of each run. The LLSP was run with a 10 µm cut-off sampler so that it measured PM10. The manufacturer's specification states that the particle size range measured by the LLSP is from 0.1 to 10µm. The LLSP has the fastest response time of any of the particle monitors (~ 2s).

3.4.4 Diesel TEOM

A Rupprecht & Patashnick Co Inc Model 1105 Diesel TEOM instrument was used in the measurement program. The TEOM is a real time particle mass measuring instrument that works on the principle of resonant frequency changes to a tapered oscillating element that collects the fine particles. The instrument was run routinely during drive cycle testing for each vehicle. The TEOM was run with no cut-off sampler so that it measured all particles in the sample gas stream.

3.4.5 Aerodynamic Particle Sizer (APS)

The TSI APS Model 3310 measured the aerodynamic particle radius by a 'time of flight' measurement. A size spectrum was taken every second and saved to disc on the APS computer. At the end of a run the data were processed with software developed by CSIRO and the average particle size distribution for the run determined. The software was designed to deal with the problem of phantom particles being recorded in the larger size ranges when there was an overload of very fine particles, which if properly resolved, overlap and look like larger particles. The total mass corresponding to the size distribution was estimated by assuming a particle density of 1 g cm^{-3}.

APS calibrations were performed during the measurement campaign by generating aerosol at the known sizes of 0.47 and 2.02 µm. On each occasion the particle sizes were accurately recorded by the APS, as shown in figure A1-5. Note that for the 0.47µm, presence of trace impurities in the dispersing solvent can add another 0.1µm to the diameter. (Also occasionally, agglomerated spheres can be detected). The APS measures particles in the size range of ~0.5 to 30µm.

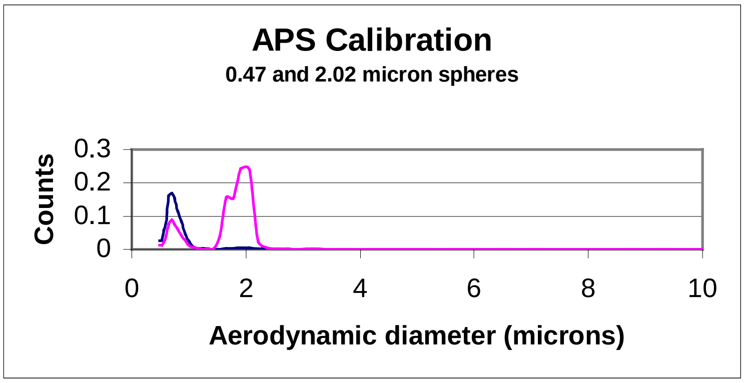


Figure A1 6: APS Calibration

3.4.6 Scanning Mobility Particle Sizer (SMPS)

A TSI Inc Model 3934 SMPS measured particle size distribution within the range 0.04 to 0.5 µm. The SMPS operates on the principle of mobility analysis in an electric field.

The SMPS sampled directly from a raw exhaust 'grab sample' that had been taken from upstream of the primary tunnel during each D550 short test and diluted 1:100 in clean air immediately prior to the SMPS use.

The reason for the dilution was twofold. Firstly, to maintain the sample within the dynamic range of the instrument. Secondly, to provide a set of standard conditions for measurement of particle size. One of the major difficulties in measuring fine particles in diesel exhaust is that the particle size and number distribution are continually changing due to agglomeration and deposition. In diesel exhaust being emitted into normal urban air the final particle size range of the fine particles depends on many factors including the particle size distribution and number concentration of particles in the ambient air, the relative humidity in the exhaust, chemical composition of the particles and exhaust. In this project we have taken the approach of measuring a size distribution and concentration after a standard dilution. This enables the data for each vehicle to be compared with the data from each other vehicle. The number distribution and size range continued to change after the samples were taken and the changing data were recorded for a period up to ~1hr after the initial dilution had taken place.

3.5 DATA ACQUISITION SYSTEM

The analogue data outputs of all instruments except for the LLSP, APS and SMPS were logged on a single central computer. The LLSP, APS and SMPS required dedicated proprietary logging software and did not have analogue outputs. Consequently, data from these instruments were collected on separate computers.

Custom designed Labview software was used to control the logging hardware, display the data in real time and record data to disc. Analogue instrumental inputs were continuously measured using National Instruments AMUX – 64T and PCI-MIO-16E-50 data acquisition cards. Due to the range and resolution of the PCI-MIO-16E-50 data acquisition card (16 bit), range switching of the instrumentation was not required. Channels were logged at one-second intervals with each data recording comprising a mean of 1000 hardware readings with data simultaneously displayed and recorded to disc.

A ‘Datataker’ was utilised as a redundant backup logging device. Streaming digital data from the dynamometer computer, dilution tunnel controller and the ‘DataTaker’ were continuously acquired from the RS-232 serial ports of the logging computer and simultaneously displayed on screen and saved to disk.

The temperature of the dynamometer cell, heated gas sample lines, NO_x analyser catalyst and water traps were measured by an Advantech Adam 4018 thermocouple field point sensor. This device utilises RS-485 communication protocols and the sensor was polled at one-second intervals with the data simultaneously displayed on screen and recorded to disc. The atmospheric pressure, temperature and relative humidity inside the dynamometer cell were also continuously logged.

Data from all of the instruments were transferred to an automated spreadsheet program for processing and plotting.

APPENDIX 2

Table A2 1:

Pre-Test Inspection Form

ITEM	*INSERT ANSWER or SELECT CORRECT OPTION*
Vehicle Details	
Rego Number	
Vehicle Make	
Vehicle Model	
Vehicle Type	*Prime mover / Cab chassis rigid truck / Other rigid truck / Minibus / Route service bus / Other bus / 4WD passenger car derivative*
Engine Make	
Engine Model	
Compliance Plate Date	........../............./...........
VIN	
GVM	................kg
Tare Weight	................kg
Vehicle ADR Category	
Odometer reading	.........................km (or km since last engine rebuild)
Engine displacement	L
No of cylinders	*4 / 6 / 8 / 12*
Turbocharged	*Yes / No*
Intercooler	*Yes / No*
Fuel system	*Direct injection / Indirect Injection*
Air conditioning	*Yes / No*
General Vehicle / Engine Checks	
Engine oil	Level - *ok/low*
Trans. fluid	Level - *ok/low*
Radiator	Water level - *ok/low*
Battery	Water level - *ok/low* Charge - *ok/low*
Tyres	Condition – *Suitable for testing?*

Engine Settings Checks

Idle Speed	Manufacturer's Spec................rpm
Electronic Engine Management System	*Operation & type / NA*
Drive line	Operation & Condition *Safe for test / unsafe*
Brakes	*Safe for test / unsafe*
Exhaust system	Security - *secure/loose* Leakage - *not leaking/leaking*
Safety Issues	Is the vehicle in a satisfactory condition for testing - *yes/no*.

Table A2 2

Vehicle Details

Test No	Vehicle Make	Vehicle Model	Vehicle Type	Year of Manufact'	GVM (kg)	Tare (kg)	ADR Category	Cert'n Standard	Odo' (km)	Air Cond' (Y/N)
1	Toyota	Landcruiser	4WD	1996	2960	1975	MC		46798	Yes
2	Isuzu	900 SVR	Cab chassis rigid truck	1995	16000	7640	NC		159515	Yes
3	Hino	FG	Cab chassis rigid truck	1990	15000	6042	NC		294570	Yes
5	International	3600	Prime mover	1994	38000	14000	NCH		541451	Yes
6	Mitsubishi	Canter	Cab chassis rigid truck	1994	4495	2760	NB		104002	No
7	Toyota	Hilux	Ute	1993	2580	1480	NA		81233	Yes
8	Hino	FGIJ	Cab chassis rigid truck	1999	15000	7060	NC		18260	Yes
9	Nissan	Patrol	4WD	1996	2900	2140	MC		84042	Yes
10	Mack	Value Liner	Prime mover	1989	38000	15140	NCH		366639	No
11	Isuzu	NPR300	Cab chassis rigid truck	1998	6200	3580	NB		48372	Yes
12	Kenworth	Cab Over	Prime mover	1994	38000	14360	NCH		886978	
13	Kenworth	Cab Over K100G	Prime mover	1997	38000	14480	NCH		527593	Yes
14	Hino	FC3J	Cab chassis rigid truck	1997	10000	5140	NB		55388	Yes
15	International	N1650	Cab chassis rigid truck	1989	9500	5360	NB		414258	Yes
16	International	T2670	Prime mover	1985	38000	13800	NCH		183729	No
17	Isuzu	NPR300	Cab chassis rigid truck	1995	6200	3560	NB		150878	No
18	International	Acco 1850D	Cab chassis rigid truck	1987	14340	8680	NC		331063	No
19	Hino	FC3W	Cab chassis rigid truck	1994	9700	4760	NB		148938	No
20	Ford	Econovan Maxi	Light commercial van	1995	2750	1520	NA		167388	Yes
21	Mack	CHR	Prime mover	1995	38000	14400	NCH		502661	Yes
22	Isuzu	NPR	Cab chassis rigid truck	1991	6000	3800	NB		259966	Yes
23	Nissan	PK235	Cab chassis rigid truck	1998	13900	7160	NC		75459	Yes
24	Scania	P113M	Prime mover	1996	38000	13940	NCH		444938	Yes
25	Nissan	Navara	4WD	1995	2740	1800	MC		89674	Yes
26	Toyota	Land Cruiser	4WD	1994	3035	2480	MC		233587	Yes
27	Mitsubishi	Super Frame Turbo	Cab chassis rigid truck	1996	25400	10580	NC		144792	Yes
28	Isuzu	NKR 200	Cab chassis rigid truck	1985	4800	2700	NB		248186	No
29	Mitsubishi	Triton	4WD	1996	2720	1570	MC		60878	Yes
30	Ford	Trader	Cab chassis rigid truck	1990	4495	2760	NB		146116	Yes
31	Toyota	Land Cruiser	4WD	1989	2810	2160	MC		316245	Yes
32	Nissan	Patrol	4WD	1984	2750	2090	MC		217214	Yes
33	Mitsubishi	Canter	Cab chassis rigid truck	1990	4495	2720	NB		187699	Yes
34	Mitsubishi	Pajero	4WD	1991	2400	1800	MC		232729	
35	Volvo	FL618	Cab chassis rigid truck	1995	16900	8140	NC		323301	Yes
38	Mitsubishi	Canter	Cab chassis rigid truck	1996	4495	3720	NB		137623	Yes
39	Mitsubishi	L300 Express	Light commercial	1995	2505	1320	NA		276153	Yes
40	Toyota	Hilux	Light commercial	1995	2730	1750	NA		31942	No
41	Ford	Courier	Light commercial	1993	2495	1450	NA		55555	No
42	Toyota	Landcruiser	4WD	1993	2960	1975	MC		160348	Yes
43	UD/ Nissan	CM160	Cab chassis rigid truck	1994	9500		NB		160260	Yes
44	Mitsubishi	L300 Express	Light commercial	1993	2505	1320	NA		293659	Yes
45	Ford	Transit	Light commercial	1999	3500	1960	NB		7533	Yes
46	Ford	Econovan Maxi	Light commercial	1994	2750	1520	NA		115613	No
47	Mazda	Bravo	4WD	1999	2845	1615	MC		14608	Yes
48	Mitsubishi	Pajero	4WD	1998	2645	2014	MC		46393	Yes
49	Toyota	Dyna	Cab chassis rigid truck	1990	7000	4130	NB		354239	No
50	UD	CWA15	Cab chassis rigid truck	1994	22500	9500	NC		126819	Yes
51	Nissan	Navara	4WD	1994	2740	1635	MC		162074	Yes
61	Toyota	Hiace	Light commercial	1992	2850	1710	NA		143695	No
62	Holden	Rodeo	Light commercial	1987	2350	1440	NA		77256	No
63	Ford	L9000	Prime mover	1996	38000	13100	NCH		782347	Yes
64	Ford	Trader	Cab chassis rigid truck	1990	7055	3390	NB		58901	Yes
65	Hino	GS221	Cab chassis rigid truck	1990	22500	10360	NC		262231	Yes
66	Isuzu	FVR	Cab chassis rigid truck	1992	15000	5350	NC		110310	Yes
68	Mercedes Benz	1517	Cab chassis rigid truck	1993	15000	6550	NC		91511	Yes
70	Mitsubishi	Triton	Light commercial	1997	2830	1800	NA		75888	Yes
71	Isuzu	FVR	Cab chassis rigid truck	1985	13900	5880	NC		20000	No
72	Iveco	9200	Prime mover	1998	38000	14100	NCH		257651	Yes
73	Toyota	Hilux	Light commercial	1989	2580	1275	NA		289900	No

Table A2 3

Vehicle Details

Test No	Vehicle Make	Vehicle Model	Vehicle Type	Year of Manufact'	GVM (kg)	Tare (kg)	ADR Category	Cert'n Standard	Odo' (km)	Air Cond' (Y/N)
75	Toyota	Landcruiser	4WD	1997	2960	2050	NA		82974	Yes
76	Volvo	B10BLE	Route Service Bus	1998	16330	11570	ME		10140	Yes
77	MAN	1120 HOCLNL	Route Service Bus	1996	11630	8640	ME		141715	Yes
78	Hino		Route Service Bus	1999	15000	9880	ME		33992	Yes
79	Scania	L113CRL	Route Service Bus	1996	16100	11040	ME		164482	Yes
80	Hino	RG197	Route Service Bus	1997	14200	8930	ME		228359	No
81	Isuzu	LT111P	Route Service Bus	1988	13900	8873	ME		126970	No
82	Mitsubishi	FK617K1	Cab chassis rigid truck	1997	9800	5400	NB		71518	Yes
83	Isuzu	NPR200	Cab chassis rigid truck	1999	4490	2290	NB		5855	Yes
84	Ford	Transit	Light commercial	1998	3300	1960	NA		47137	No
85	Hino	FG1J	Cab chassis rigid truck	1999	15000	7060	NC			Yes
86	Ford	Transit	Light commercial	1998	3300	1960	NA		67482	No
87	Hino	FF1J	Cab chassis rigid truck	1999	14200	6920	NC		50197	No
89	Toyota	Hilux	Light commercial	1998	2730	1640	NA		46005	Yes
90	Nissan	Navara	Light commercial	1986	2570	1400	NA		261538	No
91	Toyota	Hilux	Light commercial	1996	2730	1640	NA		50842	Yes
92	Mercedes Benz		Route Service Bus	1987	16000	9300	ME		432745	No
93	Toyota	Hilux	Light commercial	1988	2580	1480	NA		169756	No
94	Toyota	Landcruiser	4WD	1986	2730	2050	MC		355726	Yes
95	Mitsubishi	L300 Express	Light commercial	1990	2505	1320	NA		251603	No
96	Hino	Ranger 50	Prime mover	1998	38000	14120	NCH		59904	Yes

Table A2 4

Engine Details

Test No	Engine Make	Engine Model	Displ' (L)	No of Cyl's	T/C (Y/N)	I-C (Y/N)	Fuel Injection	Spec Idle (RPM)
1	Toyota	1HZ 80 series	4.2	6	No	No	Direct	625
2	Isuzu	NC 6SAI	8.5	6	No	No	Direct	500
3	Hino			6	No	No	Direct	600
5	Cummins	M11	11.0	6	Yes	Yes	Direct	650
6	Mitsubishi			4	No	No	Direct	650
7	Toyota	LN864-TRYRSQ	2.8	4	No	No	Direct	750
8	Hino	JO8CT	8.0	6	Yes	Yes	Direct	650
9	Nissan	TD42	4.2	6	No	No	Direct	700
10	Mack	E6350	11.0	6	Yes	Yes	Direct	625
11	Isuzu	RLS/4HF1	4.3	4	No	No	Direct	
12	Detroit	60 Series	12.7	6	Yes	Yes	Direct	600
13	Cummins	96N14 4356 1900	14.0	6	Yes	Yes	Direct	650
14	Hino	J07C	5.3	5	No	No	Direct	625
15	International	FE6A	7.3	6	No	No	Direct	650
16	Cummins	NTC 300	10.0	6	Yes	No	Direct	600
17	Isuzu	4HFI	4.3	4	No	No	Direct	625
18	Perkins	180 TI Phaser	6.0	6	Yes	No	Direct	550
19	Hino	WO6E	6.0	6	No	No	Direct	550
20	Mazda	DE04S08	2.2	4	No	No	Direct	550
21	Mack	EA375	11.0	6	Yes	Yes	Direct	650
22	Isuzu	4BD1	3.9	4	No	No	Direct	600
23	Nissan	FE6TA	7.3	6	Yes	Yes	Direct	600
24	Scania	DSC11	11.0	6	Yes	Yes	Direct	550
25	Nissan	TD27	2.7	4	No	No	Direct	600
26	Toyota	1HZ	4.2	6	No	No	Direct	600
27	Mitsubishi	6022-1ATO	11.1	6	Yes	No	Direct	600
28	Isuzu	4BC2	3.3	4	No	No	Direct	650
29	Mitsubishi	4D56	2.5	4	Yes	No	Direct	675
30	Mazda	F code	3.5	4	No	No	Direct	600
31	Toyota	2H	4.2	6	No	No	Direct	625
32	Nissan	S033T	3.3	6	Yes	No	Direct	600
33	Mitsubishi		3.3	4	No	No	Direct	600
34	Mitsubishi	4D56	2.8	4	Yes		Direct	650
35	Volvo	DT61	6.0	6	Yes	Yes	Direct	550
38	Mitsubishi	4D34	3.9	4	No	No	Direct	625
39	Mitsubishi	4D56	2.5	4	No	No	Direct	650
40	Toyota	3L	2.8	4	No	No	Direct	600
41	Ford	R2	2.2	4	No	No	Direct	600
42	Toyota	1HZ	4.2	6	No	No	Direct	650
43	Nissan	FE6A	2.0	6	No	No	Direct	500
44	Mitsubishi	4D56	2.5	4	No	No	Direct	650
45	Ford	H	2.5	4	Yes	No	Direct	750
46	Mazda	DE04S08	2.2	4	No	No	Direct	550
47	Mazda	B6	2.5	4	Yes	No	Direct	750
48	Mitsubishi	4M40	2.8	4	Yes	Yes	Direct	650
49	Toyota	14B	2.6	4	No	No	Direct	600
50	UD	NE6T	7.4	6	Yes	No	Direct	650
51	Nissan	TD27	2.7	4	No	No	Direct	600
61	Toyota	3L	2.8	4	No	No	Direct	650
62	Isuzu	LQ7	2.2	4	No	No	Direct	600
63	Detroit	Series 60	12.0	6	Yes	Yes	Direct	650
64	Ford	K	3.5	4	Yes	No	Direct	700
65	Hino	EM 100	9.5	6	No	No	Direct	600
66	Isuzu	6SAI	8.5	6	No	No	Direct	600
68	Mercedes Benz	OM366LA	5.7	6	Yes	No	Direct	800
70	Mitsubishi	D62	2.8	4	No	No	Direct	650
71	Isuzu	6BD1-T	5.8	6	Yes	No	Direct	650
72	Cummins	N14	14.0	6	Yes	Yes	Direct	600
73	Toyota	2L	2.8	4	No	No	Direct	650

Table A2 5

Engine Details

Test No	Engine Make	Engine Model	Displ' (L)	No of Cyl's	T/C (Y/N)	I-C (Y/N)	Fuel Injection	Spec Idle (RPM)
75	Toyota	1HZ	4.2	6	No	No	Direct	650
76	Volvo	DH10A	9.6	6	Yes	No	Direct	
77				6	Yes		Direct	
78				6	Yes	Yes	Direct	
79	Scania	DSC1124 (Euro 2)	11.0	6	Yes	Yes	Direct	600
80	Hino	H07	6.5	6	Yes	No	Direct	500
81	Isuzu	L29	6.0	6	Yes	No	Direct	600
82	Mitsubishi	6016-2A	7.5	6	No	No	Direct	650
83	Isuzu	FHF1	4.3	4	No	No	Direct	600
84	Ford	H	2.5	4	Yes	No	Direct	750
85	Hino	J08CT	8.0	6	Yes	Yes	Direct	700
86	Ford	H	2.5	4	Yes	No	Direct	750
87	Hino	J08	8.0	6	No	No	Direct	550
89	Toyota	5L	3.0	4	No	No	Direct	650
90	Nissan	SD25	2.5	4	No	No	Direct	550
91	Toyota	3L	2.8	4	No	No	Direct	650
92	Mercedes Benz	OM447H	12.0	6	No	No	Direct	600
93	Toyota	2L	2.4	4	No	No	Direct	650
94	Toyota		3.5	4	Yes	No	Direct	650
95	Mitsubishi	4D56	2.5	4	No	No	Direct	650
96	Hino	K13C	13.0	6	Yes	Yes	Direct	550

Table A2 6

Invalid Tests

Test No	Reason
4	Problems with dynamometer
36	Vehicle unsuitable for test
37	Vehicle unsuitable for test
52	Venturi temperature probe was broken
53	Venturi temperature probe was broken
54	Venturi temperature probe was broken
55	Venturi temperature probe was broken
56	Venturi temperature probe was broken
57	Venturi temperature probe was broken
58	Venturi temperature probe was broken
59	Venturi temperature probe was broken
60	Venturi temperature probe was broken
67	Clutch slipping
69	Vehicle could not be restrained adequately on the dynamometer
74	Vehicle lacked power
88	Vehicle/engine had excessive vibration

APPENDIX 3

1. SIX-POINT INSPECTION

A six-point inspection of each vehicle was carried out prior to testing. This comprised the items shown that were recorded on the Inspection form shown in table A3-1.

Table A3 1: Six-Point Inspection Form

Item to be Checked	Record Response
Air filter condition ?	Clean; moderate; needs replacing
Fuel pump condition Seal intact ? Tampering suspected?	 Yes; no Yes; no
Any missing engine parts ?	Yes; no
Any blue smoke from engine breather & exhaust pipe at idle ?	Yes; no
Turbocharger oil leaks?	Yes; no
Intercooler and compressed air inlet pump hoses condition ?	Intact; leaking

2. ON-ROAD SMOKE ASSESSMENT

On road smoke assessment was carried out on each vehicle according to the requirements of the Project Brief, reproduced below.

10-SECOND SMOKE RULE

The following procedure is to be used in assessing the smoke emissions from on-road use (compliance with the 10-second smoke rule).

Equipment:
Test vehicle plus chase vehicle
Stopwatch
2-way radio
Tape-recorder
Diesel fuel used is to be the same as that used in laboratory testing.

Procedure:
The test vehicle should be loaded to a weight agreed upon with the Project Manager. The test vehicle must be checked for roadworthiness before the test is undertaken. The vehicle must be at proper operating temperature prior to the test.

A minimum of two staff are needed – one in the chase car and one in the test vehicle. If possible, the test vehicle driver should not change throughout the test series. In all cases, the test driver must be suitably qualified and hold the requisite licences.

An observer and / or data logging may be used to log the rpm, speed and gear selection of the test vehicle.

Prior to the test, the engine speed at maximum torque is assessed as per the SAE J1349 or by other methods accepted by the Project Manager.

A bitumen test strip (may be a public road or private test track) is chosen with a grade of greater than 3-5% for at least 0.5 kilometre in length. A flat piece of road with at least an 80 km / hr limit and 3 kilometres in length is also needed for higher speed checking.

Incline Smoke Test

The truck is driven up the sloped test strip at a speed and in a gear that allows the engine to operate between 40% and 80% of the engine speed at maximum power (ESMP), which is approximately equal to the maximum torque output. The driver should ensure that the vehicle is accelerating in the one gear in this engine speed band for more than 10 seconds. Data logging may be used as an additional check.

The observer in the chase vehicle is in two-way contact with the test vehicle and carries out the normal 10 second smoke rule observation whilst the test vehicle is climbing the incline. The chase vehicle driver must be positioned so that they have an uninterrupted view of the end of the test vehicle's exhaust pipe throughout the test. If other vehicles obstruct the test vehicle's path or the exhaust smoke is limited for some reason (eg. traffic congestion) then the test should be abandoned and repeated until a suitable observation is obtained.

The chase vehicle observer notes the following:

- the details of the vehicle (including the make, model, engine size and configuration, type of exhaust (horizontal or vertical), odometer reading, GVM, load carried);
- the location, date and time of the observation;
- the weather conditions (temperature, cloud cover, wind speed);
- the duration of any continuous smoke emitted (seconds) and an estimate of the length and / or height of the plume;
- the distance travelled during the test;
- a description of the intensity of the smoke as per the following:

Category	Intensity	Comments
1	Light	Approx. equiv. to Ringelmann Scale 2 (40% black)
2	Medium	Approx. equiv. to Ringelmann Scale 3 (60% black)
3	Dark	Approx. equiv. to Ringelmann Scale 4 (80% black)
4	Very Dark	Approx. equiv. to Ringelmann Scale 5 (100% black)

Other descriptions or methodologies may be used after discussion and approval by the project team.

The driver/observer in the test vehicle notes the following:

- the details of the vehicle (including the make, model, engine size and configuration, type of exhaust (horizontal or vertical), odometer reading, GVM, load carried);
- the location, date and start and stop time of the test;
- the weather conditions (temperature, cloud cover, wind speed);
- the duration of the test (stop watch);
- the odometer reading at the start and finish of the test;
- the engine speed range (rpm), the speed range (km / hr) and gear engaged during the test.

High Speed Test

The truck is driven along a flat piece of road at approximately 80 km/hr and in a gear that allows the engine to operate at between 40% and 80% of the engine speed at maximum power (ESMP), which is approximately equal to the maximum torque output. The driver should ensure that the vehicle is maintained in the one gear in this engine band for the duration of the test run. Data logging may be used as an additional check.

The observer in the chase vehicle is in two-way contact with the test vehicle and carries out the normal 10 second smoke rule observation whilst the test vehicle is being driven at this higher speed. The chase vehicle driver must be positioned so that they have an uninterrupted view of the end of the test vehicle's exhaust pipe throughout the test. If other vehicles obstruct the test vehicle's path or the exhaust smoke is limited for some reason (eg. traffic congestion) then the test should be abandoned and repeated until a suitable observation is obtained.

The chase vehicle observer notes the following:

- the details of the vehicle (including the make, model, engine size and configuration, type of exhaust (horizontal or vertical), odometer reading, GVM and load carried);
- the location, date and time of the observation;
- the weather conditions (temperature, cloud cover, wind speed);
- the duration of any continuous smoke emitted (seconds) and an estimate of the length and/or height of the plume;
- the distance travelled during the test;
- a description of the intensity of the smoke:

Category	Intensity	Comments
1	Light	Approx. equiv. to Ringelmann Scale 2 (40% black)
2	Medium	Approx. equiv. to Ringelmann Scale 3 (60% black)
3	Dark	Approx. equiv. to Ringelmann Scale 4 (80% black)
4	Very Dark	Approx. equiv. to Ringelmann Scale 5 (100% black)

Other descriptions or methodologies may be used after discussion and approval by the project team.

The driver/observer in the test vehicle notes the following:

- the details of the vehicle (including the make, model, engine size and configuration, type of exhaust (horizontal or vertical), odometer reading, GVM and load carried);
- the location, date and start and stop time of the test;
- the weather conditions (temperature, cloud cover, wind speed);
- the duration of the test (stop watch);
- the odometer reading at the start and finish of the test;
- the engine speed range (rpm), the speed range (km/hr) and gear engaged during the test.

Source: NSW EPA, 13 April 1999

A Report Sheet, shown in figure A3-1, was completed for each vehicle.

ON-ROAD SMOKE TEST

Procedure

- Load vehicle to ½ payload
- Obtain exact weight from weigh bridge
- Drive vehicle up Adderley St (.5km) in a gear that will ensure the vehicle will climb the hill without a gear change at ~80% maxpower.
- Observe from the chase vehicle the colour, weather conditions (wind speed, light) and record the length of time smoke is emitted continuously from the vehicle during the hill climb- record observations on dictaphone and worksheet.
- Drive vehicle to expressway and carryout the same test on a 3 km level stretch of road. Accelerate the vehicle to 80 km/hr, maintain the speed during observations.

Observations

Time: ………………….. **Date:** …………………..

Vehicle………………….. **Rego :** ………………….. **Test No:** ……………

Make: ………………….. **Model:** …………………..

Tare: ………………….. **GVM:** ………………….. **Test Weight:** ………

	Hill Climb	Level Road
Wind speed		
Light cond.		
Colour of smoke		
Time smoking		
Ringleman No.		

Comments:………………………………………………………………………………………
……………………………………………………………………………………………………
……………………………………………………………………………………………………
…………

Figure A3 1: On-Road Smoke Test Report Sheet

3. PREPARATION FOR TEST

3.1 VEHICLE DEFUELLING & REFUELLING

The test vehicle is parked in the dedicated refueling area.

If the vehicle has a dual fuel-tank, one tank is isolated by closng the isolation valve and the primary tank is drained. Where there is no isolation valve, both tanks are drained.

Fuel tanks are drained using an electric pump and hose. While the tank is being drained, the hose is maneuvered around within the fuel tank to ensure as little fuel as possible is left in the tank.

Where anti-theft devices are fitted to the fuel system that prevent insertion of the hose into the tank, the drain plug is removed to permit fuel to be drained. The drain plug is then carefully replaced to ensure a proper seal.

'Waste fuel' is deposited into specially marked 'waste fuel drums'.

The vehicle is then filled with **test fuel** using a hand-operated metered fuel pump (*This pump is only used for test fuel*). If the vehicle has dual tanks that cannot be isolated, then an equal amount of fuel is placed in each tank.

The vehicle is filled with sufficient fuel to ensure all tests can be completed without need to for further addition during the test sequence (typically this requires 40 –70 liters of test fuel, depending on the size of the vehicle). A visual inspection is made after fuel has been added to the tank to ensure there are no leaks.

After refueling, the following information is recorded within the 'fuel log book':

- Date,
- Registration number,
- Quantity of test fuel added (litres).

The vehicle is driven to the test cell in readiness for testing.

On completion of testing 'waste fuel' is used to top up the tank(s) before the vehicle is returned to its owner.

3.2 TEST FUEL

Forty 200-litre drums from a single batch of commercial diesel fuel were supplied for this project by Shell. This was batched at the Melbourne refinery and transported to Parramatta in Sydney for distribution to the test facility as needed.
Principally, the fuel had a sulfur content of 0.17% and a cetane number of 45.5. The 'Certificate of Quality' is reproduced in Attachment A3-1.

3.3 INSTRUMENT LABORATORY PREPARATIONS

The following primary activities are carried out in preparation for testing during the start of each day.

- Gas bottles turned on (NOx air, HC fuel, HC air and zero air).
- Heated hydrocarbon and NOx lines turned on.
- TEOM and associated pump turned on.
- Chillers drained and refilled with ice.
- Line filters changed (HC analyser, heated NOx line, raw gas and dilute gas sample lines).
- Secondary dilution tunnel filters installed for initial calibration.
- Main computer turned on and folders created for calibration and testing in the relevant project directories.
- Data logging turned on.
- LLSP and APS computers turned on and time set to align with main computer.
- Opacity meter turned on, and compressor air connected for sheath air supply.
- Calibrate system (once all analysers and instruments have reached stabilised operating temperatures) and log readings on main computer.

- Once calibration is completed calibration gases turned off (only those gases required for testing are left on).
- Following selection of venturi and setting of gaseous emission baseline, new secondary filters are installed, system temperatures (tunnel, heated lines etc) checked and a clearance to commence testing is given.

3.4 TEST CELL PREPARATION

The vehicle is driven onto the dynamometer so that the drive wheels are centrally located and positioned between the two rollers. The front wheels are chocked and the rear axle tied down to anchor points on the dynamometer bed. (This applies a small downward force to limit tyre slip and to prevent the vehicle from riding up the rollers).

The sample handling pipe is swung into position over the vehicles exhaust pipe.

A high temperature flexible sheath is then secured between the exhaust pipe and sample tube to prevent leaks.

Vehicle details (registration, make, category and test weight) are entered into the dynamometer control software for identification and calculation of the inertia loading applicable for the vehicle. The information is then saved to a dedicated file from which the CUEDC and short tests cycles are referenced to set the correct speeds and loads during testing. Selection of dynamometer configuration, single or dual axle (1,2,3 or 4 rollers in use) is also made to adjust for parasitic losses.

All safety items, connections, data inputs and dynamometer settings are independently verified.

The vehicle is then driven to warm the engine to normal operating temperatures and pressures. During this period the exhaust concentrations are measured. The optimum venturi combination is selected to provide one of five mass flow rates (600,1200,1800,2400,3000 scfm) for optimum tunnel dilution to meet the calibration ranges of the instruments. He vehicle is brought to rest and the engine is switched off.

The appropriate venturi are installed and the mass flow controller set for the venturi size and combination selected. Also, while the engine is off, background checks of the dilution air are carried out to establish the baseline for gaseous emissions measurement.

Once the Instrument Laboratory preparations are complete, the test sequence begins.

4. TESTING

4.1 SCHEDULE OF TESTS

Tests were performed to the schedule shown in Table A3-2.

4.2 VEHICLE POWER AND TRACTIVE EFFORT

A power and tractive effort test is carried out to plot the vehicle's power and tractive effort curves and to determine its rated and intermediate speeds for use during the two speed and lug down short tests. The outline procedure is as follows:

- The 'graph' screen is selected on the dynamometer monitor.

- The vehicle is driven at moderate steady speed and load to re-establish stable engine temperature.
- The highest gear that does not allow the vehicle to reach the speed limiter or 100 km/h under full throttle, is selected.
- The vehicle is driven just above the idle position (>1000 rpm), and then accellerated at full throttle under 'ramp' load control to just past its speed at maximum power and then lugged down to just below its speed at peak torque. The dynamometer load is then removed and the vehicle brought to stop with the engine at idle.
- Maximum power (kW), speed at maximum power (km/h), maximum tractive effort (N) and speed at maximum torque (km/h) are identified from the graph, which is then printed out for record.

Test	Pre-Cond	Sample	Measure
Warm up			
Power/tractive effort plots			
Steady state pre-condition			
D550	90sec	30sec	LLSP, Filter, SMPS Opacity, NOx, THC
Steady state pre-condition			
TWO SPEED -Max power -Max Torque	30sec	30sec 30sec	] LLSP, Opacity, NOx, THC]
SNAP IDLE Vehicle stationary in neutral.	3 x snaps	3 x snaps	LLSP, Opacity, THC, NOx over the 3 snaps
LUG DOWN -max power at rated speed - to 90% rated speed - to 80% rated speed - to 70% rated speed	15 sec	10 sec 10 sec 10 sec 10 sec	LLSP, Opacity, NOx, THC over complete cycle.
Steady state pre-condition			
DT80 - 60 sec idle - three full load accelerations to 80 km/h. First two followed by 10 sec idle. - 60 sec at 80km		]]] Cycle]]	LLSP, Filter, Opacity, NOx, THC, over complete cycle
Steady state pre condition			
AC5080		Sample full cycle	LLSP, Filter, Opacity, NOx, THC
Steady state pr-condition			
CUEDC		Sample for each of the 4 modes	ALL gases, LLSP, filter, APS, TEOM, Opacity

Table A3 2: Schedule of Tests

4.3 SHORT TESTS

The short tests are commenced by selecting the first of the 7 tests (the D550) from the dynamometer control software menu. The vehicle is driven in accordance with instructions on the 'driver's aid' which displays the applicable short test. Each test has a pre-condition followed by a sampling period.

At the finish point of each short test, particulate sample filters and analysis system settings are changed as necessary.

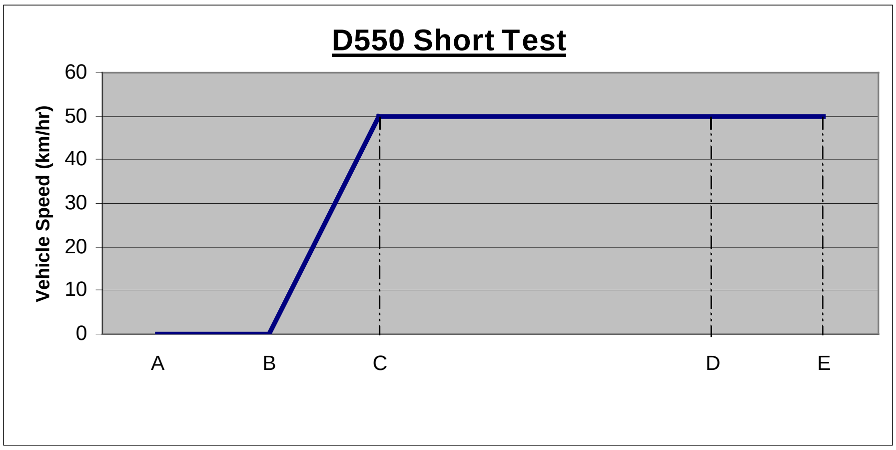
When the last short test in completed, the vehicle is stopped with the engine at idle ready for the CUEDC tests.

The operating sequences for the short tests are shown in figures A3-3 to A3-8. All short tests (except the AC50/80) are described in the Phase 1 report (NSW EPA, 1999).

4.3.1 D550 Short Test

The D550 test is detailed in Anyon P, 1995, *Diesel Inspection and Maintenance. The D550 Short Test*. This paper is included as attachment 3 in the Phase 1 Report.

This Steady-state test is carried out at 50 km/h with application of dynamometer load equivalent to a 5% gradient. This represents a near full-load condition for most vehicles. It is be simple to perform on an inexpensive power dynamometer.

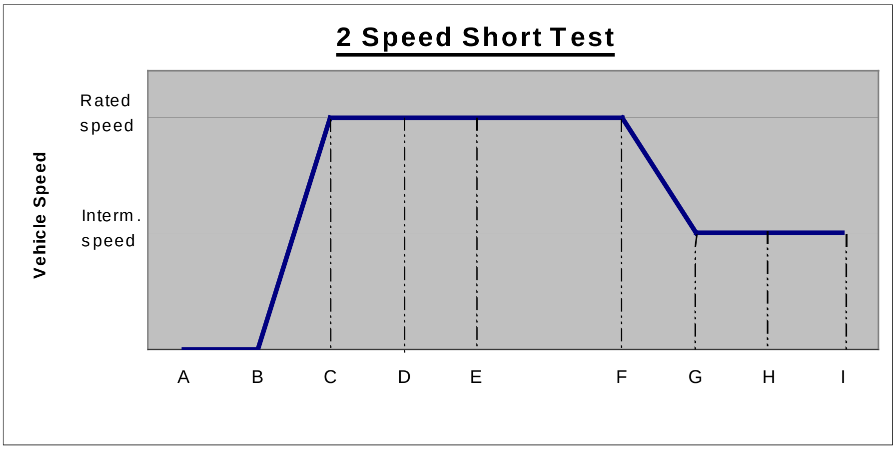


A - B	Idle. Select highest gear to maintain 50 km/h at the specified power (per reference).	
B – C:	Accelerate to 50 km/h	
At C:	Fully depress accelerator as dyno load	
C – D:	Maintain load/speed, stablise engine	90 secs
D - E	Maintain load/speed. **Sample**	30 secs
At E:	**Test complete**. Return vehicle to stop with engine at idle.	

Figure A3 2: D550 Short Test Schematic

4.3.2 Two-Speed Short Test

The Two-Speed Test was suggested in the Phase 1 Report. It is designed for measurement of emissions under steady-state conditions replicating two of the four test points in the engine dynamometer tests carried out for ADR 30 (Diesel Engine Smoke Emissions). The test is carried out under full-load conditions and is relatively simple to perform on an inexpensive power dynamometer.



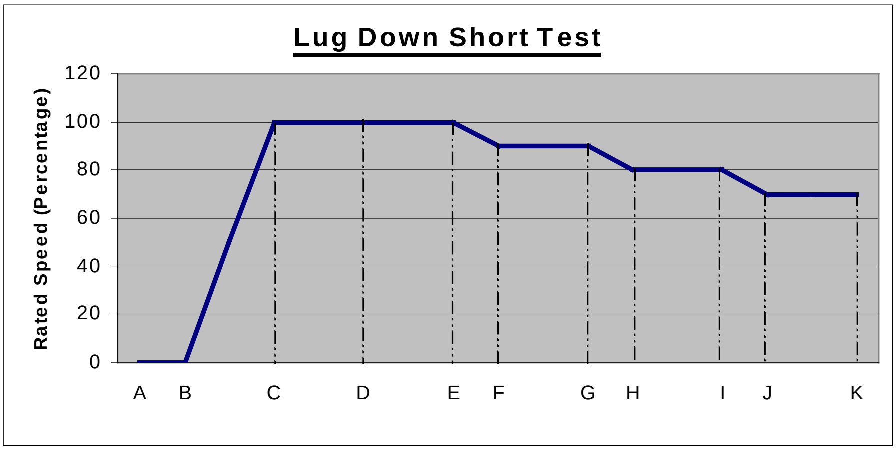
A – B:	Idle. Select gear per power/tractive effort test.	
B – C:	Accelerate to speed at max power.	
At C:	Fully depress accelerator as dyno load applied.	
C – D:	Maintain load/speed, stabilise engine	30 secs
D – E:	Maintain load/speed, **sample.**	30 secs
E - F:	Not applied	
F - G	Decelerate to intermediate speed, ease accelerator as load is reduced.	
G - H	Hold intermediate speed and light load to cool engine.	3 mins
H - I	Hold speed, Increase load and fully depress accelerator until max tractive effort applied. **sample**.	30 secs
At I	**Test complete**. Return vehicle to stop with engine at idle.	

Figure A3 3: Two-Speed Short Test Schematic

4.3.3 Lug-Down Short Test

The lug down test was suggested in the Phase 1 Report. It is based upon similar tests carried out for smoke emissions specified in the *State of Colorado – Regulation 12 'the Reduction of Diesel Vehicle Emissions'*. A copy of this Regulation is included in the Phase 1 Report.

The test is carried out at full load, requiring a relatively inexpensive power dynamometer.



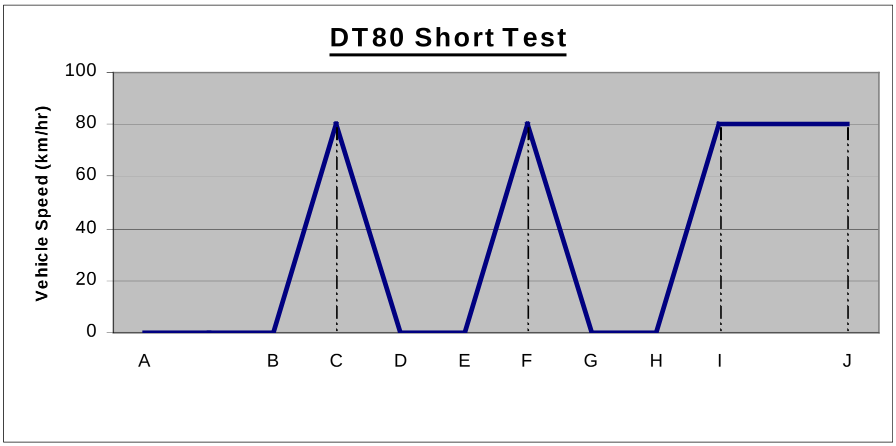
A – B:	Idle. Select gear per power/tractive effort test.	
B – C:	Accelerate to speed at max power.	
At C:	Fully depress accelerator as dyno load applied.	
C – D:	Maintain load/speed, stabilise engine	- 15 secs
D – E:	Maintain load/speed, **sample.**	- 10 secs
E - F:	Maintain full accelerator, increase load lugging to 90% speed at max power,.	
F - G	Maintain load/speed, **sample**	- 10 secs
G - H	Maintain full accelerator, increase load lugging to 80% speed at max power,.	
H - I	Maintain load/speed, **sample**.	- 10 secs
I - J	Maintain full accelerator, increase load lugging to 70% speed at max power,.	
J - K	Maintain load/speed, **sample**.	- 10 secs
At K	**Test complete**. Return vehicle to stop with engine at idle.	

Figure A3 4: Lug-Down Short Test Schematic

4.4 DT80 SHORT TEST

The DT80 Test is a newly proposed test suggested in the Phase 1 Project by Brown S and Mowle M. A description is provided in Attachment 6 to that Report.

It is a relatively aggressive mixed-mode test, having three full-load accelerations, as well as a steady-state 80 km/h cruise. The test requires the use of a dynamometer having inertia simulation.



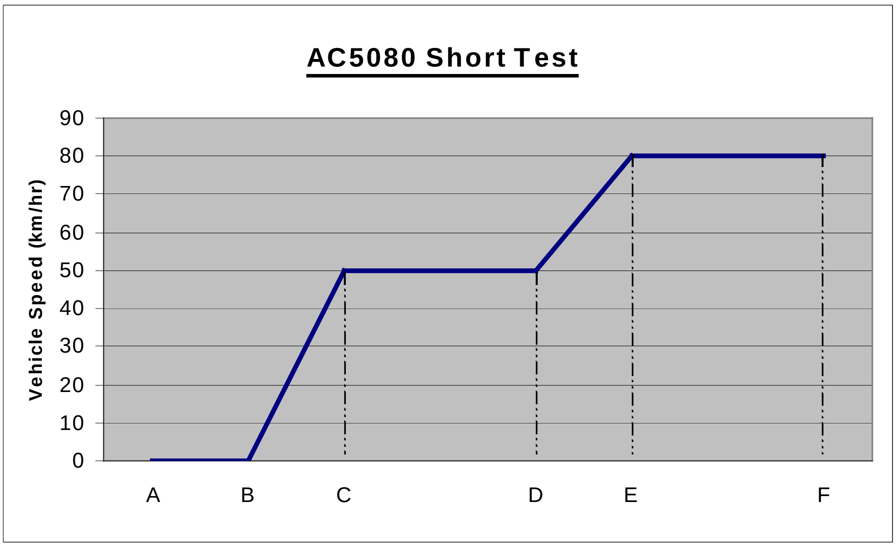
Set dynamometer inertia load to (Tare+GVM)/2 Sample over complete cycle.		
A – B:	Idle. Select low gear.	60 secs
B – C:	Rapidly accelerate through gears to 80	
C – D:	Brake to stop.	
D – E:	Idle, select low gear.	10 secs
E - F:	Rapidly accelerate through gears to 80 km/h.	
F - G	Brake to stop.	
G - H	Idle, select low gear.	10 secs
H - I	Rapidly accelerate through gears to 80	
I - J	Maintain 80 km/h.	60 secs
At J	**Test complete**. Return vehicle to stop with engine at idle.	

Figure A3 5: DT80 Short Test Schematic

4.4.1 AC50/80 Short Test

The AC50/80 is a newly proposed short test, suggested by Parsons for the California Air Resources Board and included as a first trial in this Project after discussion with the NEPC Project Manager.

It is a mixed-mode test having two full-load accelerations and two steady-state cruises. It is less aggressive than the DT80, but may be more representative of on-road driving. It requires the use of an inertia-simulating dynamometer.



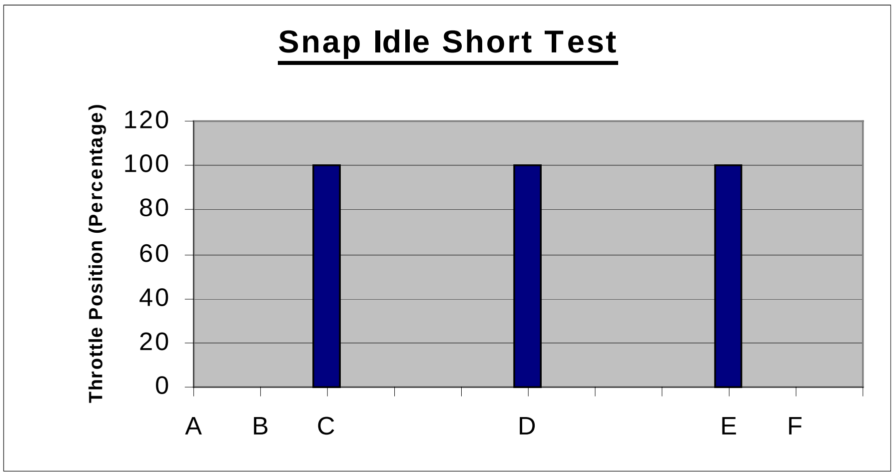
Set dynamometer inertia load to (Tare+GVM)/2 Sample over complete cycle.		
A – B:	Idle. Select low gear.	10 secs
B – C:	Rapidly accelerate through gears to 50	
C – D:	Maintain 50 km/h.	60 secs
D – E:	Rapidly accelerate through gears to 80	
E - F:	Maintain 80 km/h.	80 secs
At F	**Test complete**. Return vehicle to stop with engine at idle.	

Figure A3 6: AC50/80 Short Test Schematic

4.4.2 Snap Idle Short Test

The Snap-Idle (or 'Snap Acceleration' or 'Free Acceleration') test is variously described in Regulations and standards in USA, Europe, Japan and a number of other countries. The most detailed specification for the test is given in Society of Automotive Engineers, 1996, *Surface Vehicle Recommended Practice J1667 Snap Acceleration Smoke Test for Heavy-Duty Diesel Powered Vehicles*.

The test is very simple to perform, and requires no dynamometer.



Neutral gear. Parking brakes applied. Sample over complete cycle.		
A – C:	Idle.	
At C:	Rapidly fully depress accelerator to bring engine to max governed speed. Hold for a 2 or 3 seconds. Release accelerator to bring engine back to idle.	
C – D:	Idle for ~5 seconds.	
D – E:	Repeat at D and E	
At F	**Test complete**.	

Figure A3 7: Snap-Idle Short Test Schematic

4.5 CUEDCs

Test vehicles are run at idle while preparations for the CUEDC are completed. Just prior to the start of the CUEDC, the vehicle is accelerated twice under full throttle to clean any excess soot built up during the idle period. The applicable CUEDC for the vehicle weight category is then selected from the dynamometer control menu, and the driver's load/speed command switch placed in the load position for inertia simulation. The test drive and exhaust sampling is then commenced.

The vehicle is driven according to the 'driver's aid' speed trace displayed on the monitor, so far as is possible keeping the cursor between the 'tram lines'. At the end of each 'traffic flow' sequence the vehicle is at rest. Exhaust sampling is stopped while particulate filters are changed and any necessary adjustments made to the sampling/analytical systems. The vehicle is kept stationary with the engine at idle during this time.

Following completion of the fourth 'traffic flow' sequence (approximately 40 minutes), the engine is stopped and a background dilution air air sample is analysed. Graphs are printed from the dynamometer control computer showing the power absorbed during the test, the target speed trace, the actual speed trace and the driver's error count.

The exhaust sampling system is disconnected from the vehicle's exhaust, and the vehicle dismounted from the dynamometer. The sampling and analytical system is then re-calibrated in readiness for the next vehicle test.

The complete CUEDC cycles are provided in the CD-ROM accompanying the Phase 1 Project. They are shown here in figures A3-8 to A3-13.

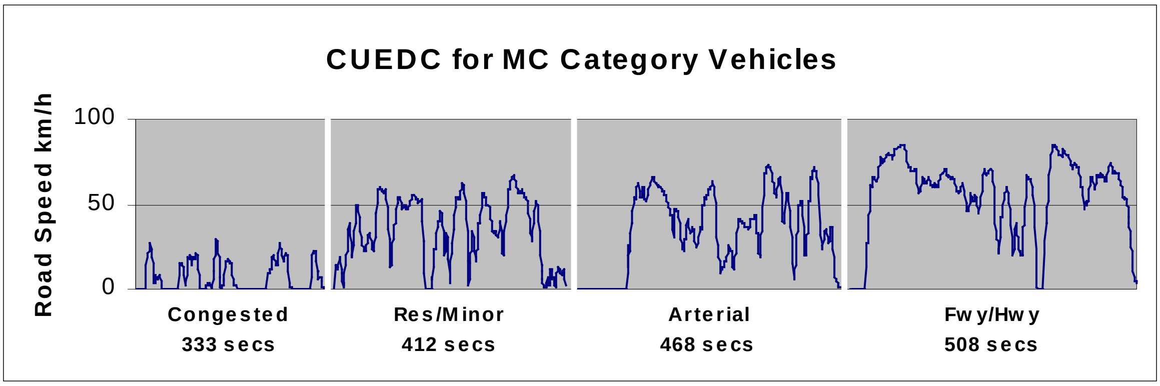


Figure A3 8: CUEDC for MC Category vehicles

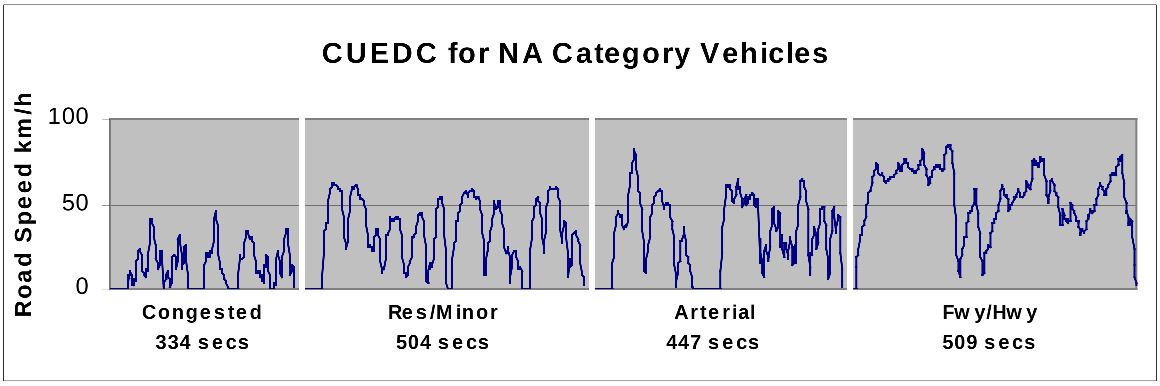


Figure A3 9: CUEDC for NA Category vehicles

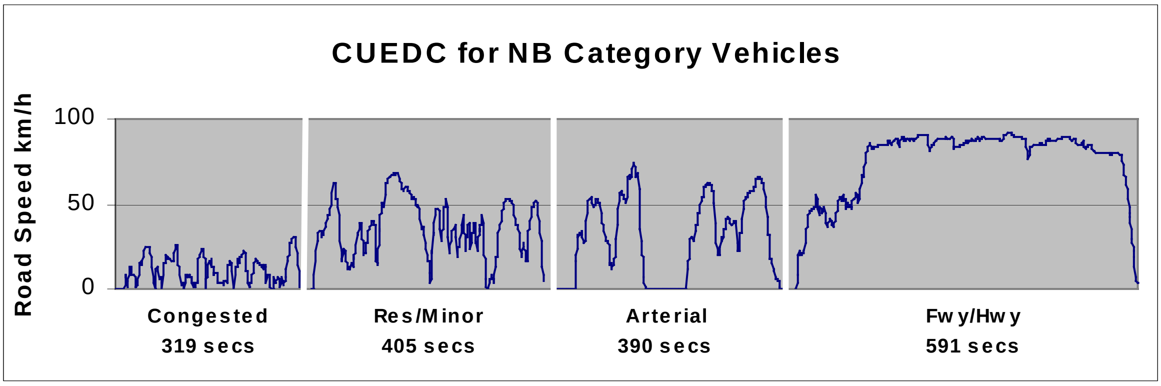


Figure A3 10: CUEDC for NB Category vehicles

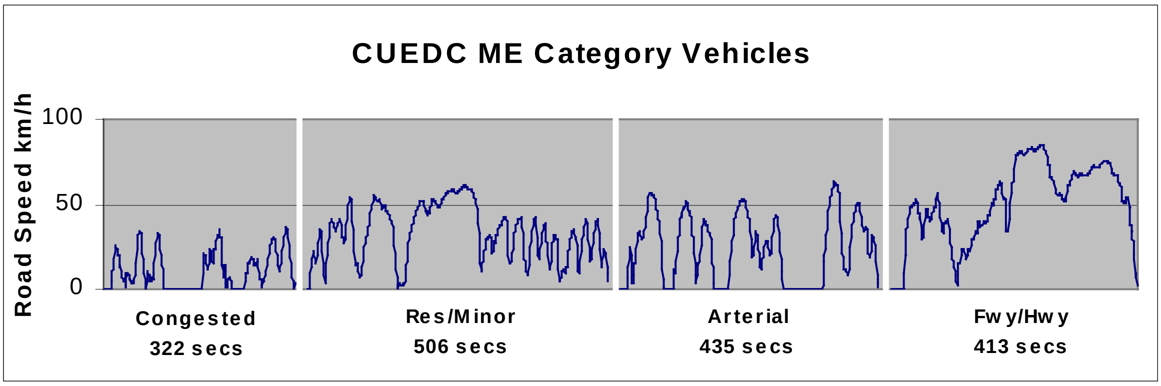


Figure A3 11: CUEDC for ME Category vehicles

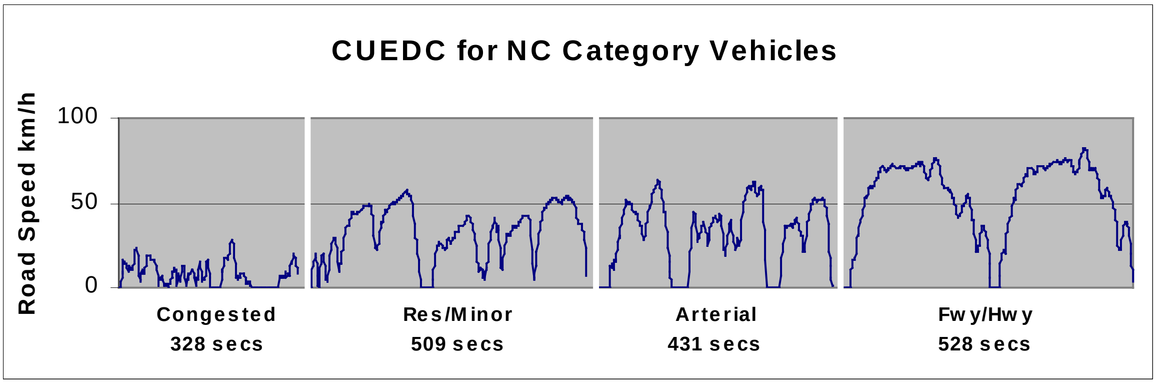


Figure A3 12: CUEDC for NC Category vehicles

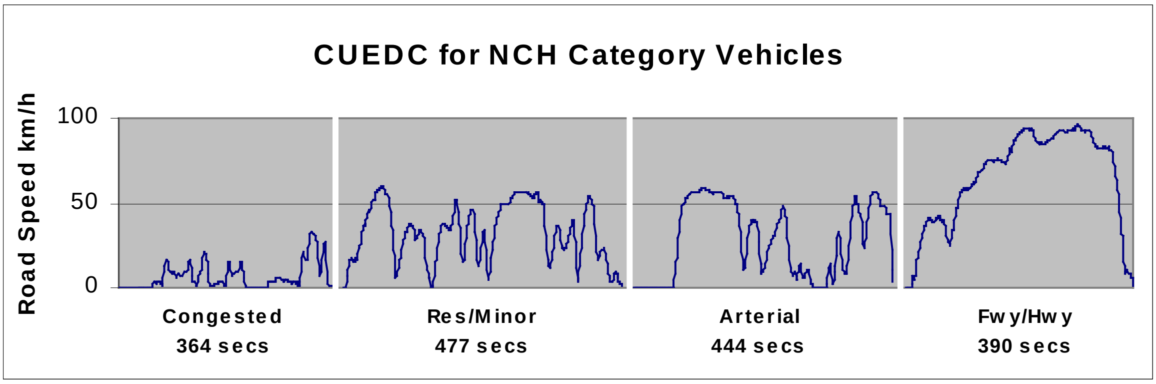


Figure A3 13: CUEDC for NCH Category vehicles

5. SAMPLING AND ANALYSES

5.1 INSTRUMENT LABORATORY WORKSHEET

Task		Initials
1	Date =	
	Vehicle Registration =	
	Vehicle Class =	
	Venturi Setting =	
2	Turn on heated lines for HC and NOx analyser.	
	Turn on fuel and air for HC analyser.	
	Turn on air for NOx analyser.	
	Turn on Opacity meter, APS, SMPS, TEOM, LLSP.	
	Zero Opacity meter.	
	Ignite HC analyser flame.	
	Turn on NOx ozone generator.	
	Turn on air compressor for opacity meter.	
	Start logger, create a new folder with the vehicle licence as an identifier e.g. Vehicle XYZ-123. In the new folder create a folder for calibrations e.g. initial cals , final cals. Also create a data folder i.e. data.	
3	Load ice into water traps.	
4	Carry out zero and span calibrations of all gas instruments. Save in calibration subdirectories.	
	Write zero and span values next to each analyser. Sign off / tick zero and span gas calibrations performed.	

Analyser	Zero	Span
CO (binos 500) – 573 ppm		
CO (binos 2000) – 573 ppm		
CO2 (horiba) – 2.09 %		
CO2 (binos) – 2.09 %		
NOx – 252 ppm		
CO2 – 12.6 %		
O2 – 20.9 %		
HC – 8.25 ppm		
HC – 108 ppm		

Task		Initials
5	Set and check flows on APS and SMPS.	
	Set clock on APS computer and LLSP.	
	Check Venturi setup and isokinetic probe.	
	Set up SMPS. Click on AUTOSAVE under file and place in vehicle ID as filename e.g. XYZ123 *** DO NOT PUT MORE THAN 6 CHARACTERS. Choose file save options as SMPS and DISTFIT files.	
6	Change filters in sample lines and HC analyser.	
7	Turn on sample pumps.	
	Check all valves set to SAMPLE.	
8	Clear LLSP memory and begin logging in LOG 1 mode.	
9	Run background for all instruments incl. APS.	
	Check Opacity meter is measuring.	
10	Load Filters.	
11	Check temps of heated lines, NOx cat, water traps etc (all on logger).	
12	**Short Tests.** (Place a temporary 70 mm filter in primary holder for all short tests that do not require a filter sample to be taken).	
	Monitor TEOM filter pressure (Change before pressure exceeds 15 in.Hg). Check Opacity meter is not in zero mode.	
	Conduct **D550** test (**DT, Filter, SMPS, Opacity, gases**)	
	Change all sample line filters.	
	Monitor TEOM filter pressure (Change before pressure exceeds 15 in.Hg). Check Opacity meter is not in zero mode.	
	Conduct **2-Speed** test (**DT, Opacity, gases**).	
	Change all sample line filters.	
	Monitor TEOM filter pressure (Change before pressure exceeds 15 in.Hg). Check Opacity meter is not in zero mode.	
	Conduct Snap Idle test (DT, Opacity, gases).	
	Change all sample line filters.	
	Monitor TEOM filter pressure (Change before pressure exceeds 15 in.Hg). Check Opacity meter is not in zero mode.	
	Conduct **Lug Down** test (**DT, Opacity, gases**).	

Task		Initials
	Change all sample line filters.	
	Monitor TEOM filter pressure (Change before pressure exceeds 15 in.Hg). Check Opacity meter is not in zero mode.	
	Conduct **DT 80** test (**DT, Filter, Opacity, gases**).	
	Change all sample line filters.	
	Monitor TEOM filter pressure (Change before pressure exceeds 15 in.Hg). Check Opacity meter is not in zero mode.	
	Conduct **AC50/80** test (**DT, Filter, Opacity, gases**).	
	Change all sample line filters.	
	Add ice to water traps as required.	
13	**CUEDC** Testing.	
	Monitor TEOM filter pressure (Change before pressure exceeds 15 in.Hg). Check Opacity meter is not in zero mode.	
	Conduct **Segment 1** of CUEDC test. (**DT, Filter, APS, TEOM, Opacity, all gases**).	
	Transfer APS data and then remove last data files in preparation for next cycle / segment.	
	Change all sample line filters.	
	Monitor TEOM filter pressure (Change before pressure exceeds 15 in.Hg). Check Opacity meter is not in zero mode.	
	Conduct **Segment 2** of CUEDC test. (**DT, Filter, APS, TEOM, Opacity, all gases**).	
	Transfer APS data and then remove last data files in preparation for next cycle / segment.	
	Change all sample line filters.	
	Monitor TEOM filter pressure (Change before pressure exceeds 15 in.Hg). Check Opacity meter is not in zero mode.	
	Conduct **Segment 3** of CUEDC test. (**DT, Filter, APS, TEOM, Opacity, all gases**).	
	Transfer APS data and then remove last data files in preparation for next cycle / segment.	
	Change all sample line filters.	
	Monitor TEOM filter pressure (Change before pressure exceeds 15 in.Hg). Check Opacity meter is not in zero mode.	
	Conduct **Segment 4** of CUEDC test. (**DT, Filter, APS, TEOM, Opacity, all gases**).	
	Transfer APS data and then remove last data files in preparation for next cycle / segment.	

Task				Initials
	Change all sample line filters.			
14	Finish test procedure.			
15	Download LLSP data file, zip and backup all APS files using the controlling software. Having completed that APS zip and backups, run the clear all data option.			
16	Carry out zero and span calibrations of all gas instruments. Save in calibration subdirectories.			
	Analyser	Zero	Span	
	CO (binos 500) – 573 ppm			
	CO (binos 2000) – 573 ppm			
	CO2 (horiba) – 2.09 %			
	CO2 (binos) – 2.09 %			
	NOx –252 ppm			
	CO2 – 12.6 %			
	O2 – 20.9 %			
	HC – 8.25 ppm			
	HC – 108 ppm			
17	At end of day – backup all data to ZIP disks.			
18	Clean Opacity meter lenses and check filter.			
19	Turn off all gases to instruments.			
	Turn off both heated lines.			
	Turn off all sample pumps.			
	Turn off Opacity meter.			
MISCELLANEOUS NOTES				

Tunnel Filter Check List

Prior to sampling.
Tunnel CLOSED, bleed valve open.
Load filters and record details in the log book.
Connect sample pump to back of filter.

Start Sampling.

Check that sample pump connector securely fastened to back of filter.
Open tunnel valve while closing bleed valve.
Check tunnel open.
Check bleed valve in off position.

5.2 TEST DATA ACQUISITION

During the test sequence, all instrument readings, sampling system controls, dynamometer parameters, and test cell environmental conditions were continuously monitored and logged on a second-by-second basis and recorded to disk. At the completion of each test sequence, all data were backed up and copies taken for subsequent data validation and processing.

All particulate filters were stored in petri dishes for transport to the CSIRO laboratories for conditioning and weighing.

Data from all of the instruments, the dilution system, the filter weight results, and vehicle specifications were transferred to an automated spreadsheet program for processing and analyses.

APPENDIX 4

Figure A4-1

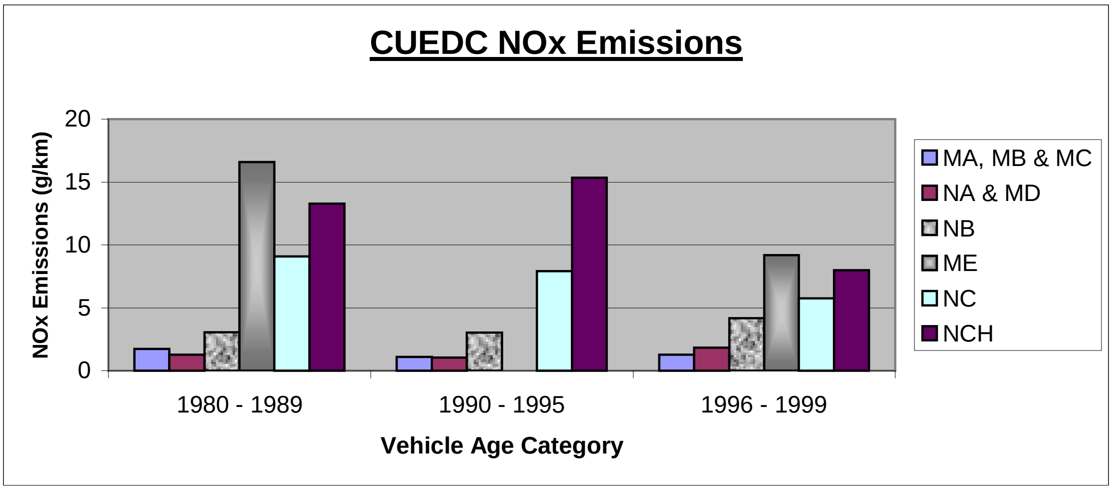


Figure A4-2

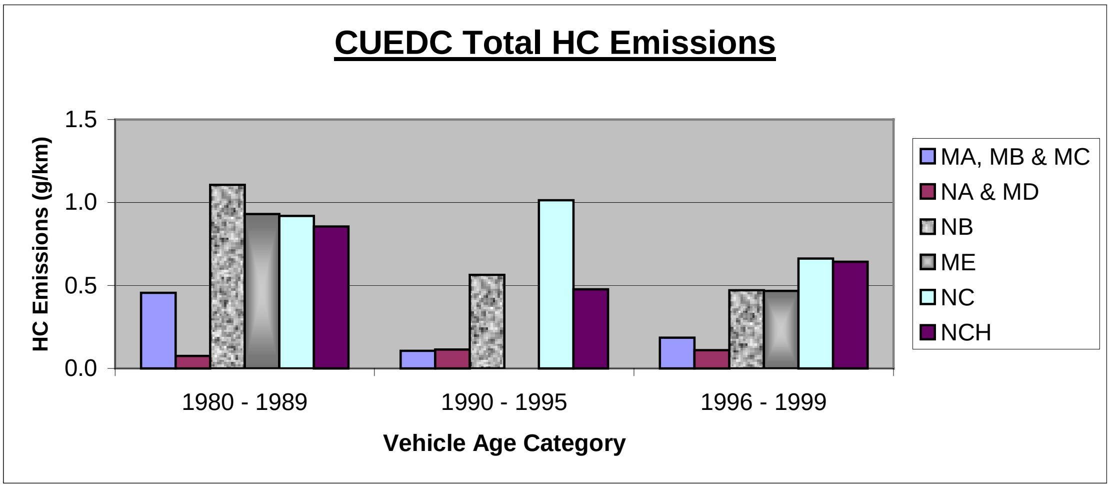


Figure A4-3

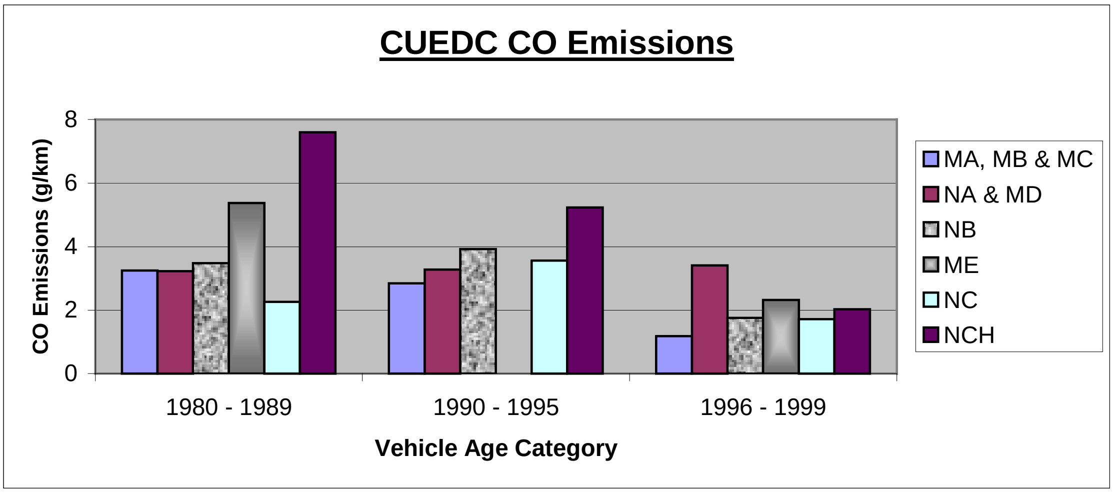


Figure A4-4

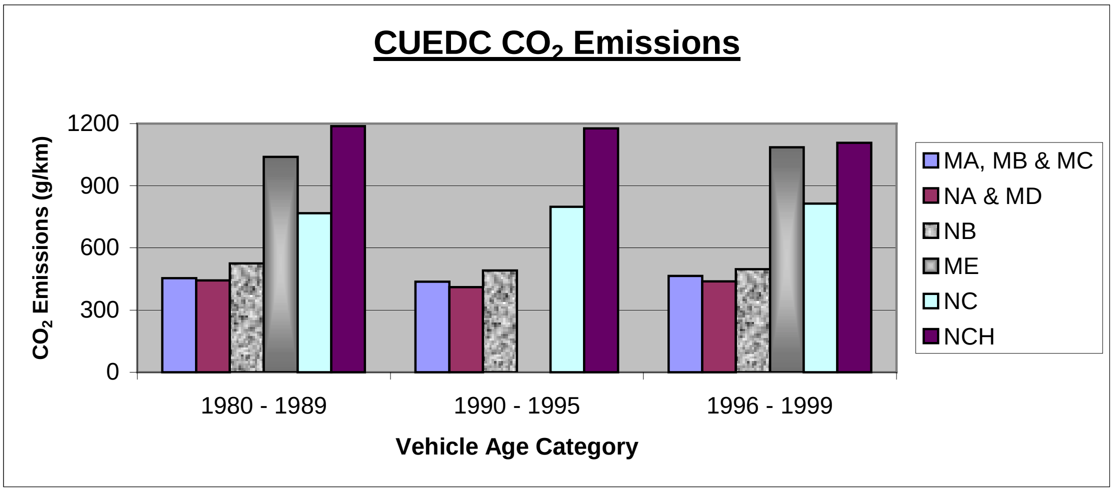


Figure A4-5

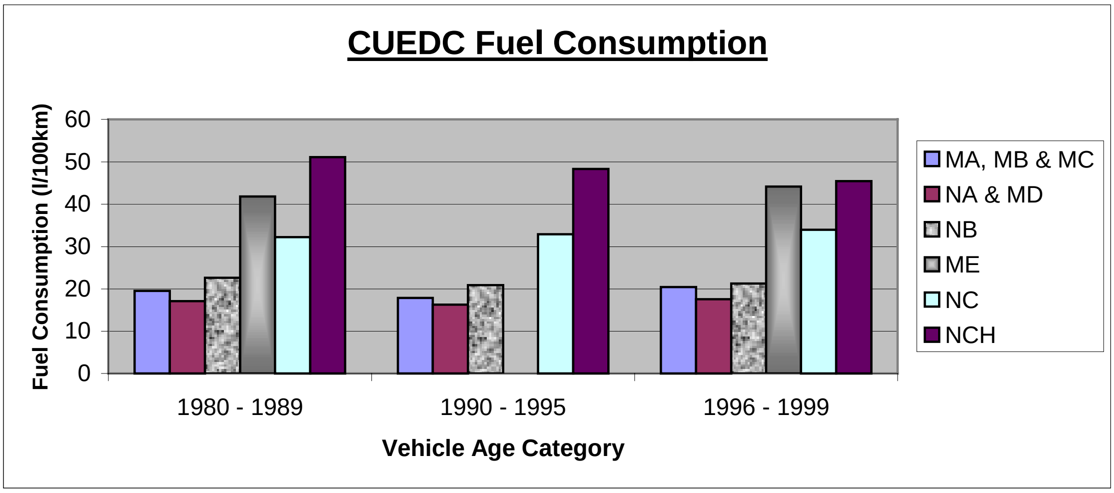


Figure A4-6

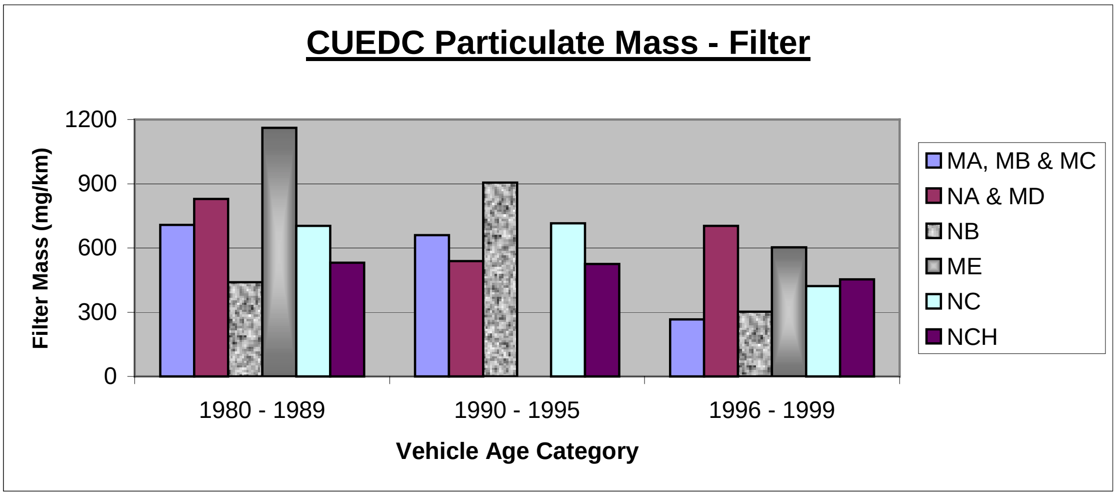


Figure A4-7

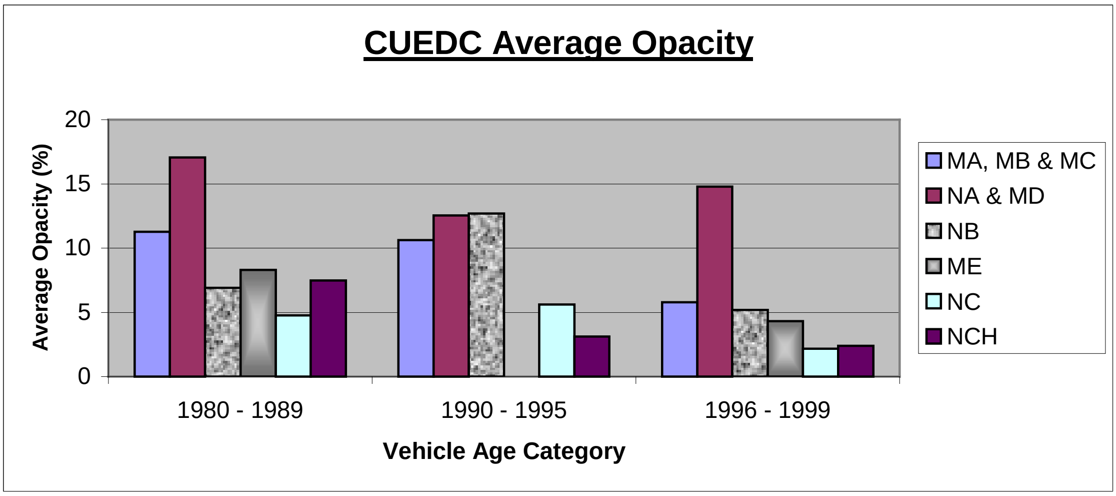


Figure A4-8

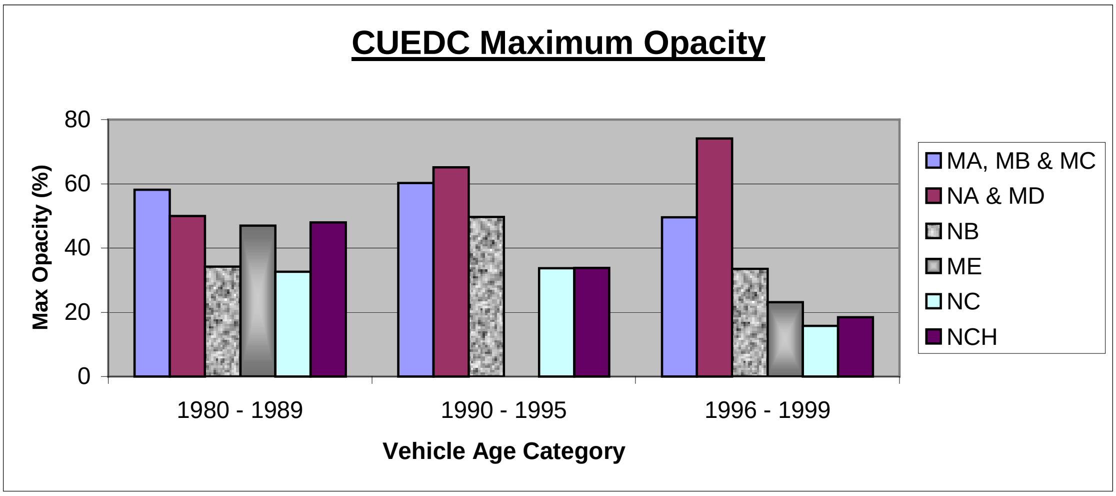


Figure A4-9

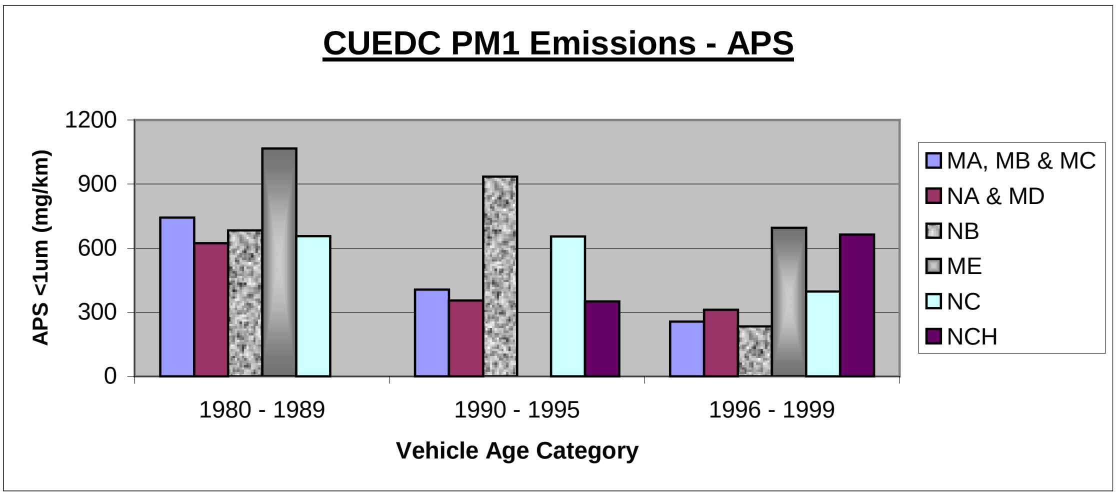


Figure A4-10

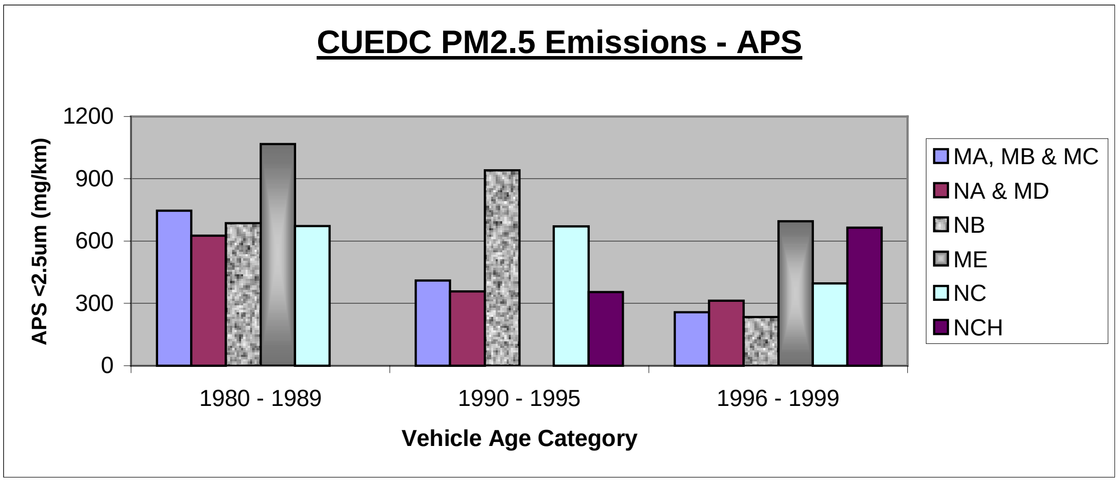


Figure A4-11

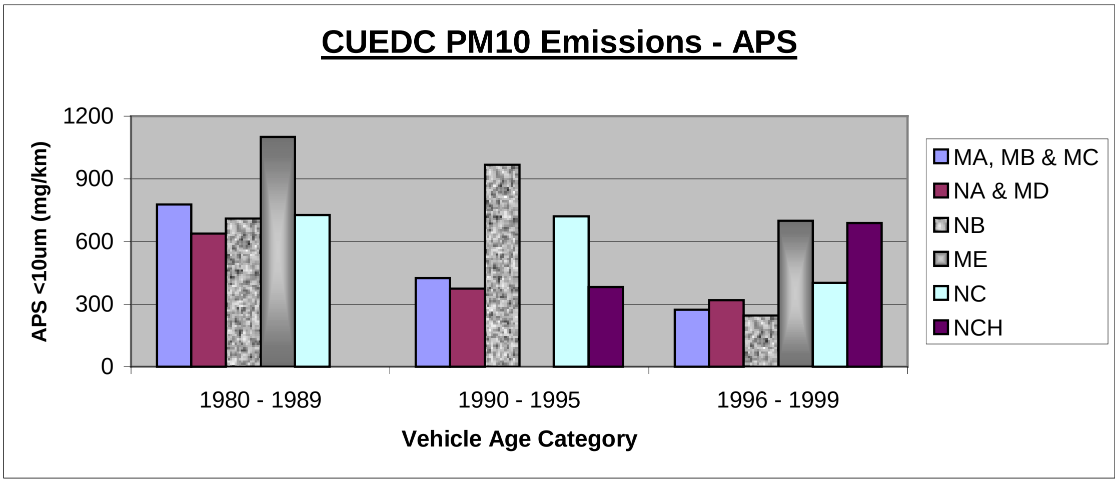


Figure A4-12

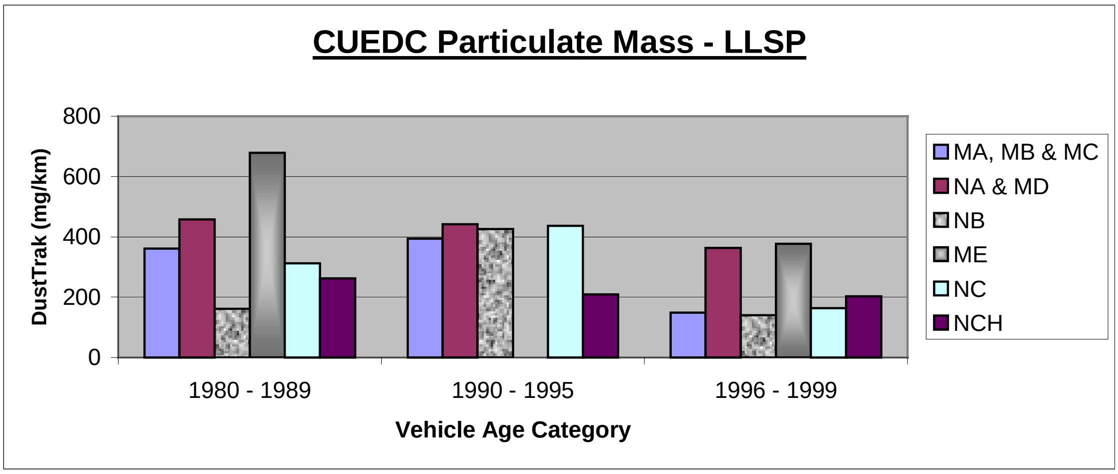


Figure A4-13

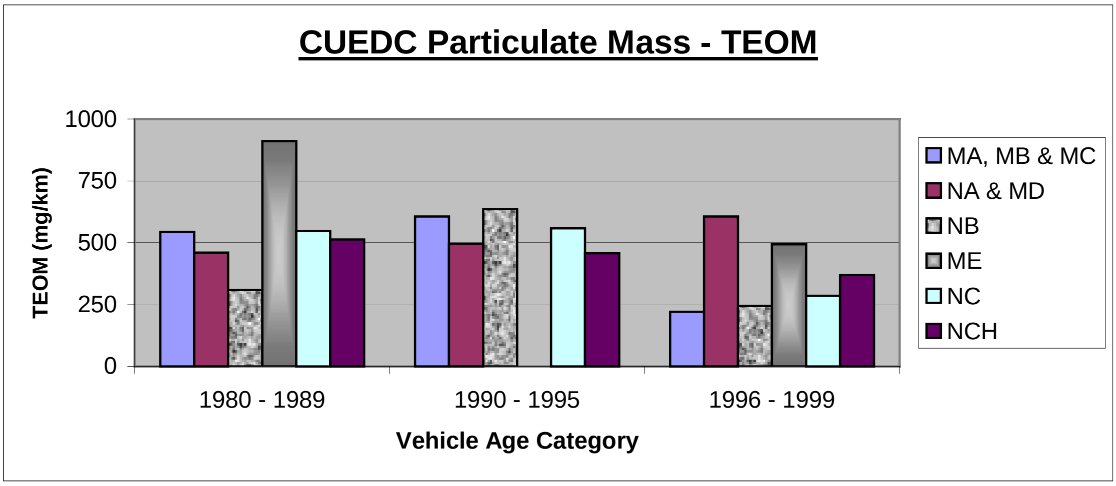


Figure A4-14

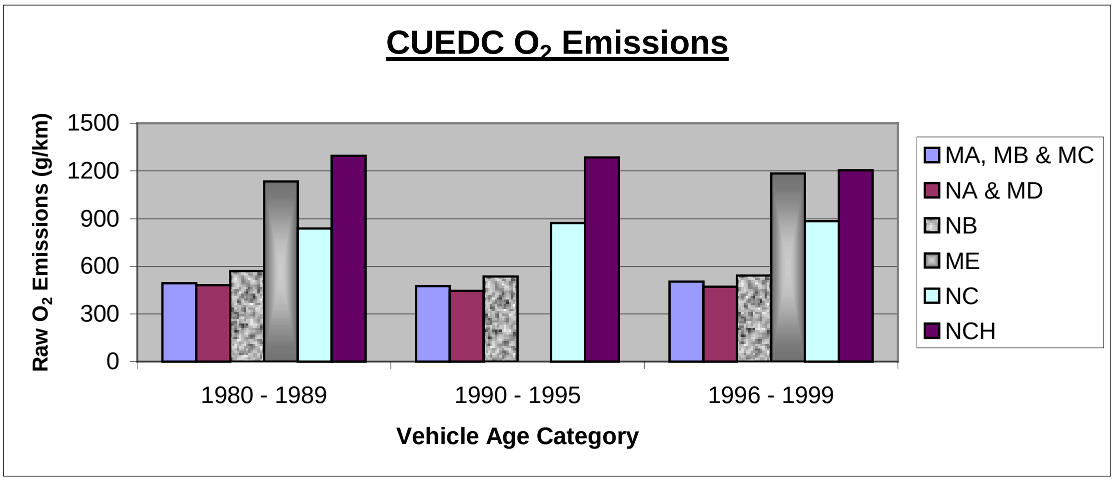


Figure A4-15

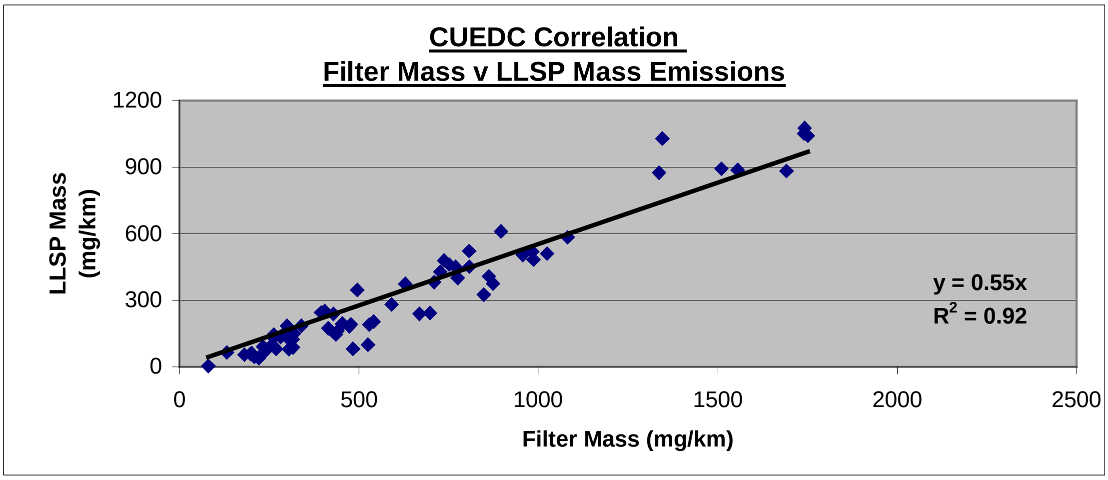


Figure A4-16

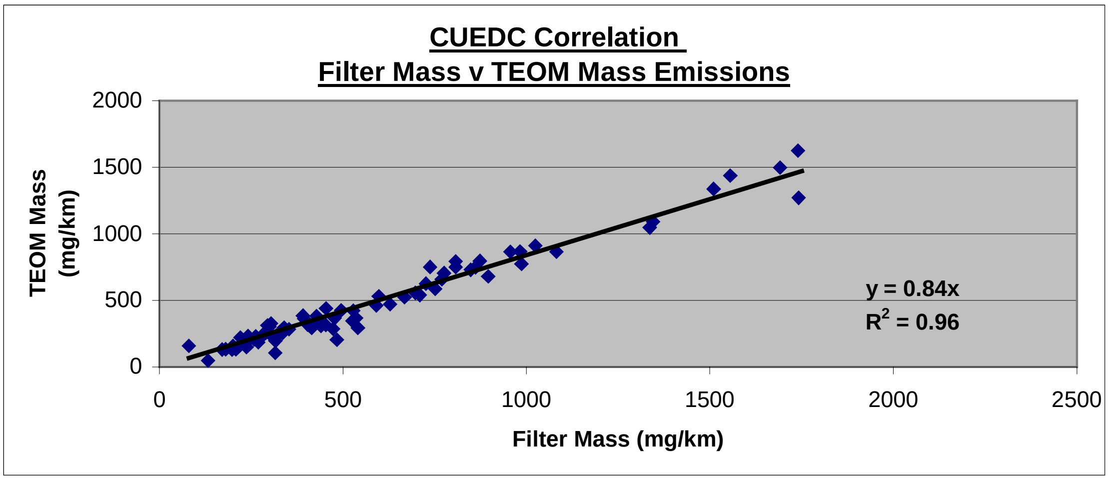


Figure A4-17

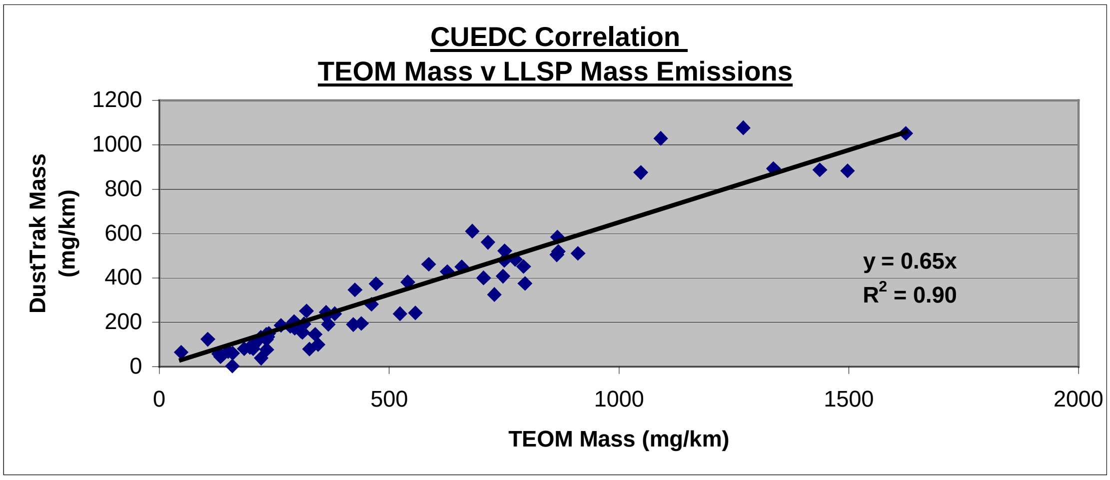


Figure A4-18

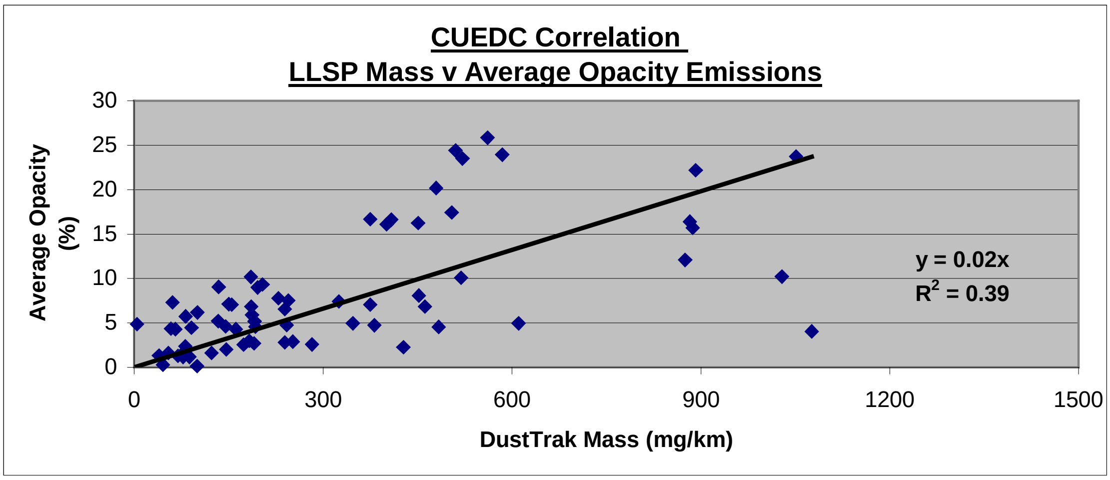


Figure A4-19

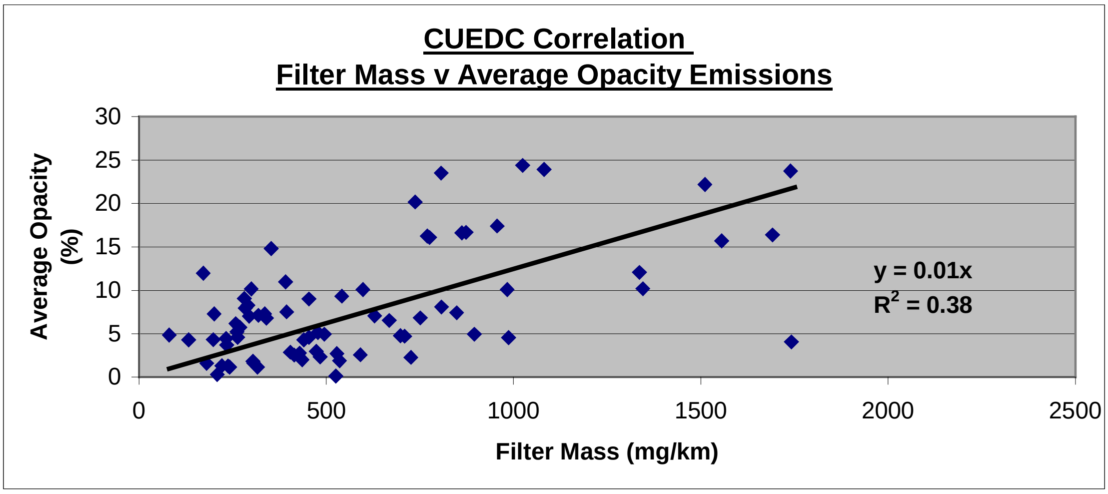


Figure A4-20

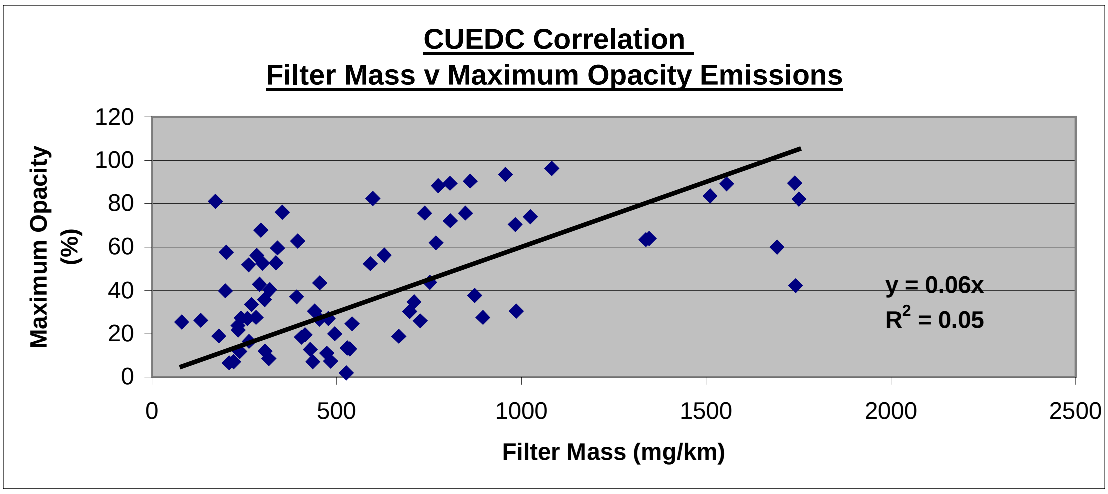


Figure A4-21

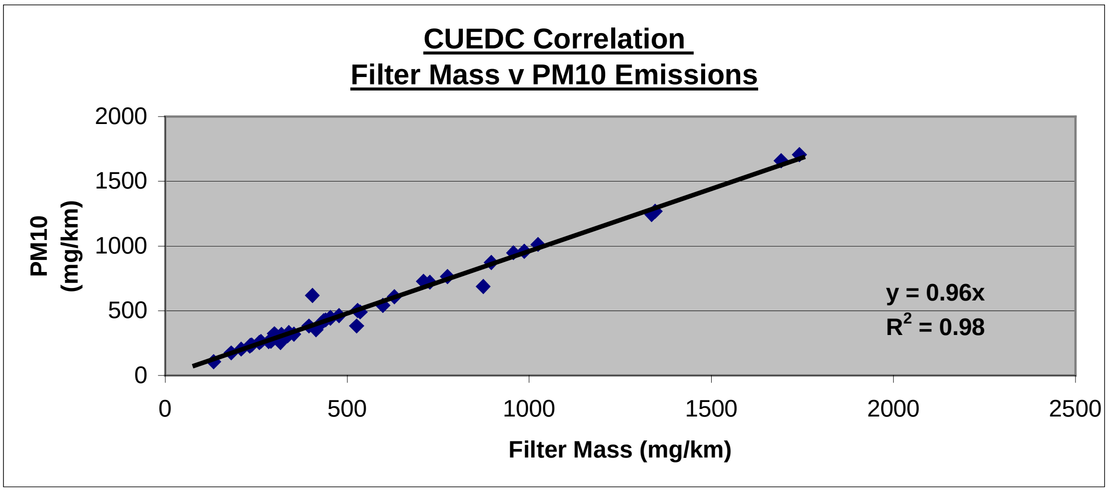


Figure A4-22

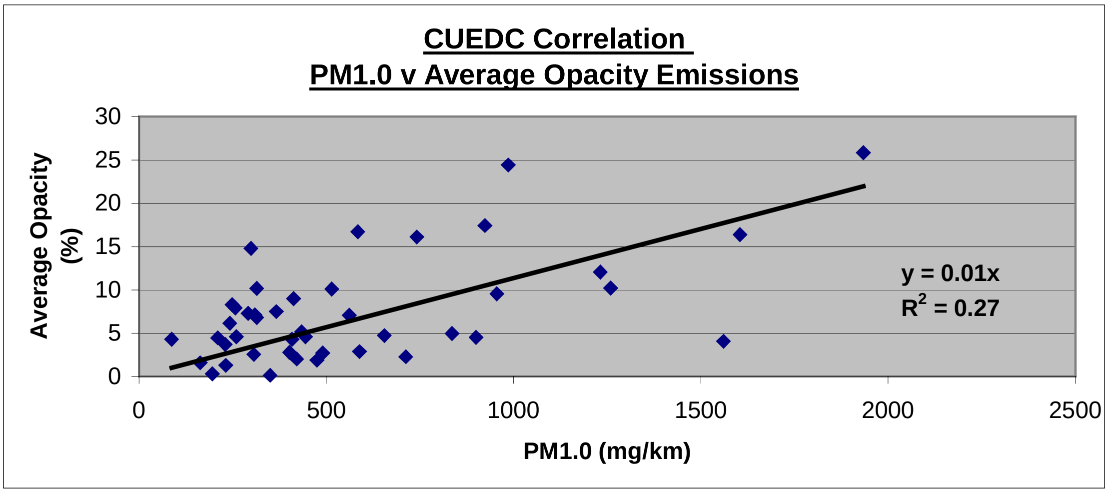


Figure A4-23

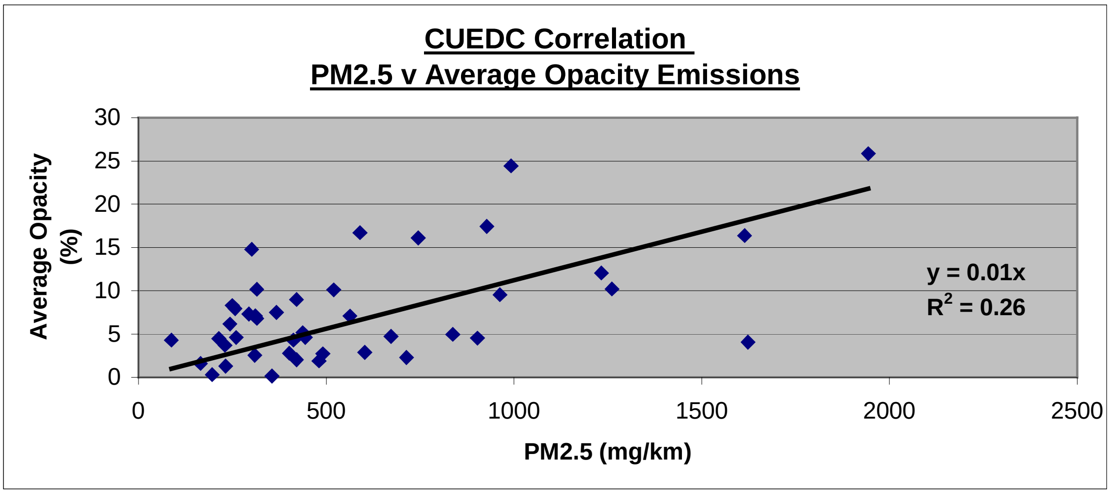


Figure A4-24

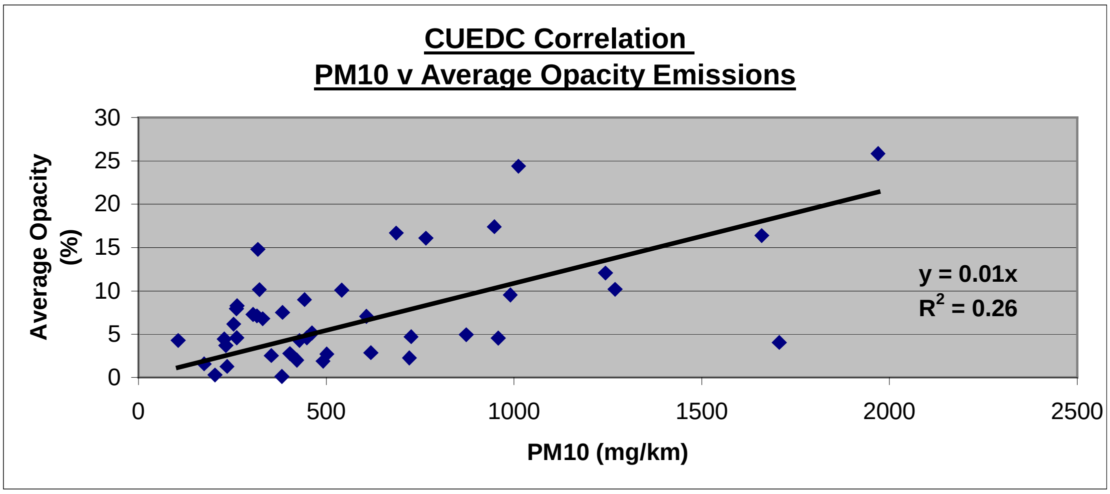


Figure A4-25

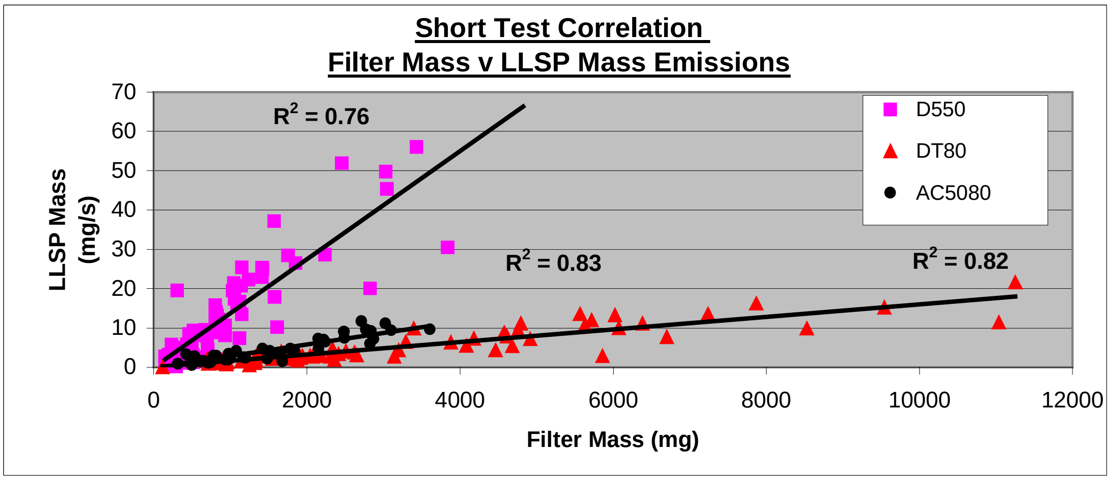
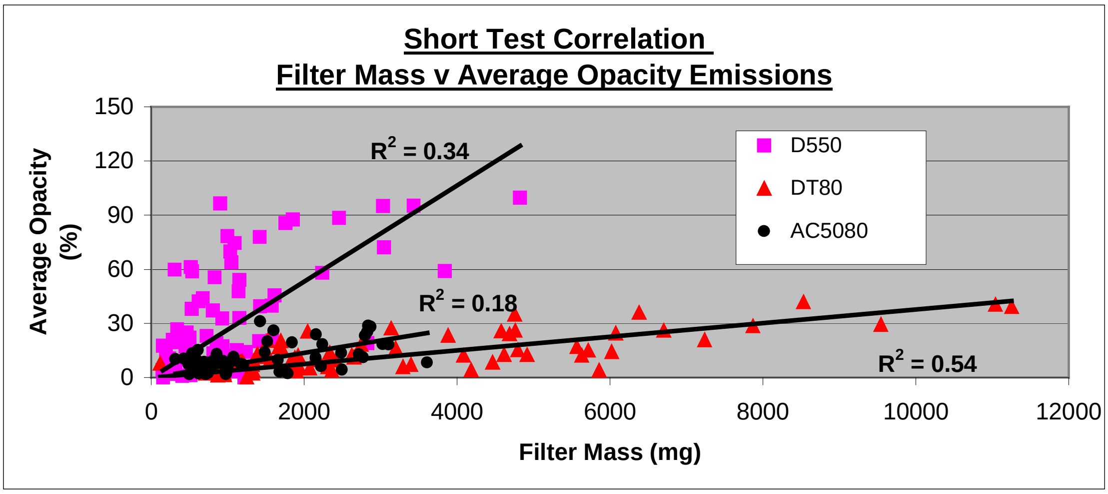


Figure A4-26



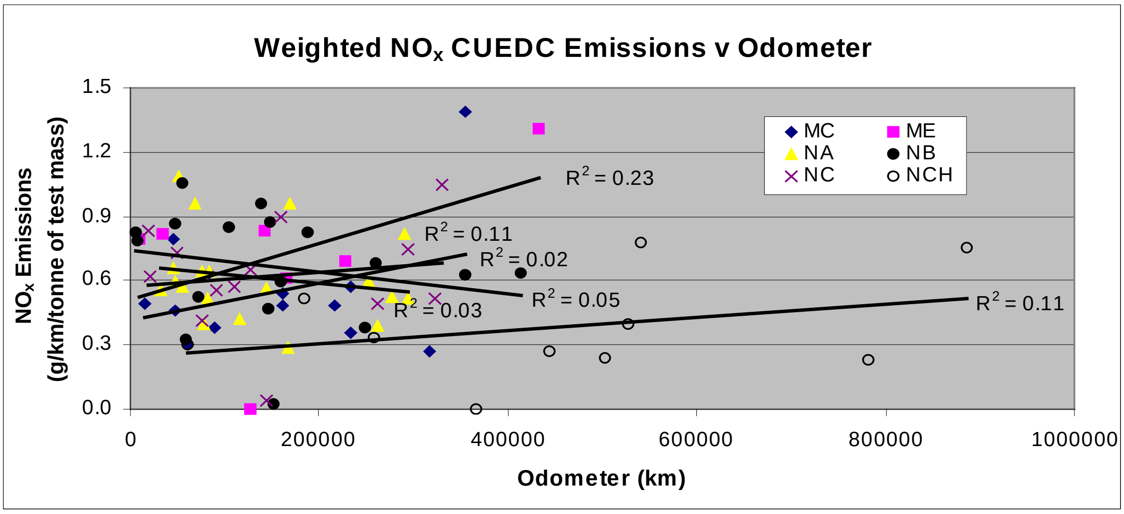


Figure A4-27

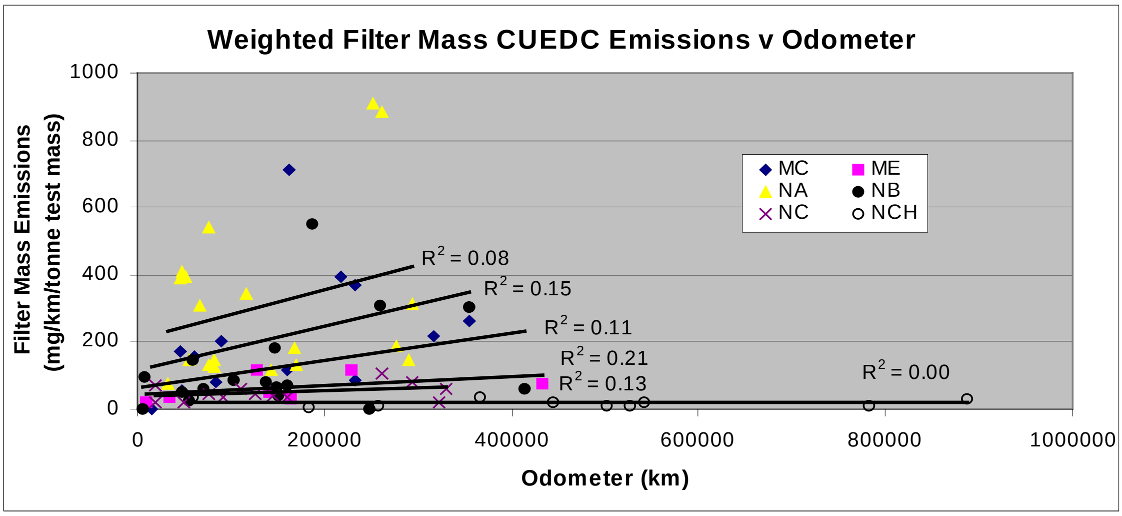


Figure A4-28

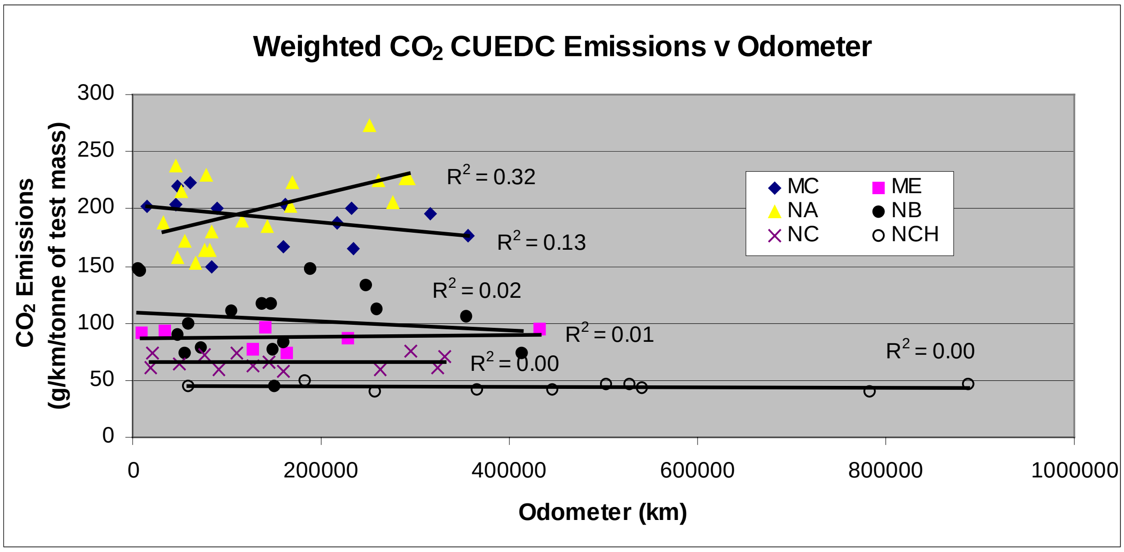


Figure A4-29

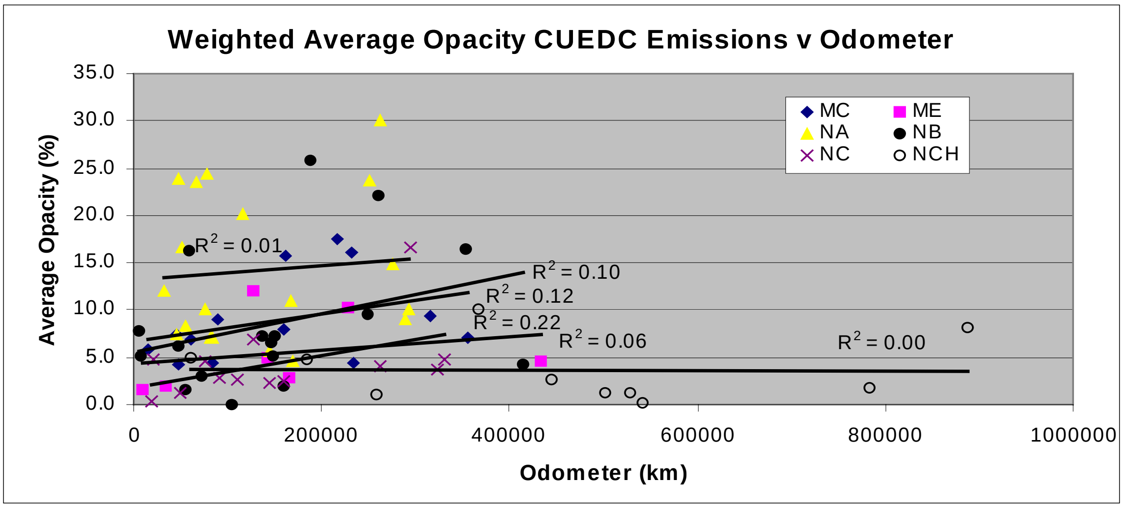


Figure A4-30

Table A4-1

MC Vehicles (1980-89)	No of Results	Average CUEDC Emissions (g/km)				
		Congested	Minor	Arterial	Highway	Weighted Total
NOx (g/km)	3	2.74	1.77	1.72	1.59	1.72
CO (g/km)	3	5.65	3.51	3.30	2.85	3.25
CO_2 (g/km)	3	714.62	475.58	451.10	419.67	454.10
O_2 (g/km)	3	778.32	517.77	491.13	456.79	494.36
THC (g/km)	3	1.22	0.62	0.45	0.30	0.46
Opacity - Average (%)	3	5.39	12.05	11.57	16.04	11.26
Opacity - Maximum (%)	3	46.56	59.53	59.88	66.63	58.15
Cumulative Power (kWh)	3	0.20	1.37	1.46	2.52	1.39
Cumulative Power (kWh/ tonne of test mass)	3	0.08	0.56	0.60	1.04	0.57
Fuel Consumption (l/100km)	3	27.07	17.97	17.03	15.82	19.47
Fuel Consumption (l/100km/ tonne of test mass)	3	11.11	7.39	7.00	6.50	8.00
Fuel Consumption (l/kWh)	3	0.99	0.53	0.52	0.49	0.52
Filter Mass (g/km)	3	1209.45	735.00	725.94	637.85	708.87
LLSP Mass (g/km)	3	430.27	394.67	368.61	332.35	360.93
APS - PM1.0 (g/km)	2	800.13	780.40	793.72	688.00	742.54
APS - PM1.0 (g/kg fuel)	2	3893.98	5325.11	5585.38	5229.93	5256.61
APS - PM1.0 (g/kWh)	2	2980.80	2308.27	2436.61	2131.38	2286.44
APS - PM2.5 (g/km)	2	801.82	783.52	796.98	691.06	745.61
APS - PM2.5 (g/kg fuel)	2	3902.25	5346.40	5608.09	5252.64	5278.10
APS - PM2.5 (g/kWh)	2	2987.17	2317.54	2446.78	2141.02	2296.01
APS - PM10 (g/km)	2	818.23	821.08	832.19	719.23	777.31
APS - PM10 (g/kg fuel)	2	3979.94	5603.16	5861.77	5476.72	5508.56
APS - PM10 (g/kWh)	2	3045.53	2423.80	2551.01	2225.85	2390.26
TEOM - Total (g/km)	3	473.04	592.83	578.48	504.48	543.52

Table A4-2

MC Vehicles (1990-95)	No of Results	Average CUEDC Emissions (g/km)				
		Congested	Minor	Arterial	Highway	Weighted Total
NOx (g/km)	5	2.14	1.21	1.08	0.93	1.09
CO (g/km)	5	1.77	3.03	3.05	2.73	2.84
CO_2 (g/km)	5	593.58	459.15	448.71	403.75	436.88
O_2 (g/km)	5	645.08	499.34	487.86	438.96	475.01
THC (g/km)	5	0.23	0.13	0.12	0.07	0.11
Opacity - Average (%)	5	3.63	11.25	10.58	17.07	10.63
Opacity - Maximum (%)	5	44.05	62.91	65.20	68.61	60.19
Cumulative Power (kWh)	5	0.18	1.29	1.40	2.47	1.33
Cumulative Power (kWh/ tonne of test mass)	5	0.08	0.55	0.60	1.05	0.57
Fuel Consumption (l/100km)	5	22.22	17.28	16.89	15.19	17.89
Fuel Consumption (l/100km/ tonne of test mass)	5	9.50	7.39	7.22	6.52	7.66
Fuel Consumption (l/kWh)	5	0.92	0.53	0.53	0.47	0.52
Filter Mass (g/km)	5	500.35	682.29	671.07	657.92	660.28
LLSP Mass (g/km)	4	234.73	418.78	402.42	390.62	393.59
APS - PM1.0 (g/km)	4	439.02	416.22	393.04	403.69	405.48
APS - PM1.0 (g/kg fuel)	4	2324.25	2898.37	2852.23	3147.83	2959.33
APS - PM1.0 (g/kWh)	4	1844.00	1280.51	1247.44	1250.03	1277.35
APS - PM2.5 (g/km)	4	441.68	419.75	398.43	406.94	409.33
APS - PM2.5 (g/kg fuel)	4	2338.27	2922.48	2889.61	3172.00	2986.54
APS - PM2.5 (g/kWh)	4	1855.30	1291.39	1263.91	1259.76	1289.18
APS - PM10 (g/km)	4	451.83	432.29	415.33	422.78	424.43
APS - PM10 (g/kg fuel)	4	2391.57	3008.34	3009.00	3292.23	3094.62
APS - PM10 (g/kWh)	4	1897.32	1329.70	1316.48	1308.00	1336.06
TEOM - Total (g/km)	5	386.11	605.80	614.37	622.65	606.17

Table A4-3

MC Vehicles (1996-99)	No of Results	Average CUEDC Emissions (g/km)				
		Congested	Minor	Arterial	Highway	Weighted Total
NOx (g/km)	5	2.35	1.35	1.18	1.16	1.27
CO (g/km)	5	2.90	1.27	1.27	0.91	1.18
CO_2 (g/km)	5	820.96	479.90	466.46	420.31	464.77
O_2 (g/km)	5	891.60	520.94	506.26	456.12	504.46
THC (g/km)	5	0.51	0.18	0.19	0.15	0.19
Opacity - Average (%)	5	3.92	6.29	6.21	6.64	5.76
Opacity - Maximum (%)	5	32.40	50.75	58.74	56.54	49.61
Cumulative Power (kWh)	5	0.21	1.18	1.23	2.09	1.18
Cumulative Power (kWh/ tonne of test mass)	5	0.09	0.51	0.53	0.91	0.51
Fuel Consumption (l/100km)	5	30.78	17.95	17.45	15.71	20.47
Fuel Consumption (l/100km/ tonne of test mass)	5	13.12	7.72	7.50	6.76	8.78
Fuel Consumption (l/kWh)	5	1.55	0.72	0.71	0.70	0.74
Filter Mass (g/km)	5	558.72	291.59	299.84	222.84	266.29
LLSP Mass (g/km)	5	246.63	165.01	170.45	117.07	148.10
APS - PM1.0 (g/km)	5	560.97	288.33	268.37	200.04	255.94
APS - PM1.0 (g/kg fuel)	3	2321.14	1813.18	1865.72	1511.98	1671.06
APS - PM1.0 (g/kWh)	3	2529.34	984.49	909.27	723.06	930.53
APS - PM2.5 (g/km)	5	562.00	288.97	269.25	200.68	256.66
APS - PM2.5 (g/kg fuel)	3	2325.11	1817.11	1871.80	1516.87	1675.53
APS - PM2.5 (g/kWh)	3	2534.76	987.43	912.87	726.21	934.14
APS - PM10 (g/km)	5	586.64	305.08	286.19	212.17	273.31
APS - PM10 (g/kg fuel)	3	2407.49	1917.40	1987.26	1600.67	1780.89
APS - PM10 (g/kWh)	3	2675.48	1058.03	980.85	780.65	1012.80
TEOM - Total (g/km)	5	348.19	237.22	246.94	183.63	220.25

Table A4-4

NA Vehicles (1980-89)	No of Results	Average CUEDC Emissions (g/km)				
		Congested	Minor	Arterial	Highway	Weighted Total
NOx (g/km)	4	1.66	1.30	1.27	1.16	1.26
CO (g/km)	4	2.65	2.87	2.91	3.72	3.23
CO_2 (g/km)	4	511.28	441.29	435.03	434.98	442.48
O_2 (g/km)	4	555.97	480.08	473.32	473.25	481.38
THC (g/km)	4	0.24	0.08	0.11	0.06	0.08
Opacity - Average (%)	4	6.94	16.04	15.46	29.67	17.03
Opacity - Maximum (%)	4	38.79	52.19	51.38	57.67	50.01
Cumulative Power (kWh)	4	0.37	1.43	1.19	2.37	1.34
Cumulative Power (kWh/ tonne of test mass)	4	0.19	0.73	0.61	1.21	0.68
Fuel Consumption (l/100km)	4	19.20	16.59	16.37	16.41	17.14
Fuel Consumption (l/100km/ tonne of test mass)	4	9.80	8.47	8.37	8.37	8.75
Fuel Consumption (l/kWh)	4	0.68	0.53	0.54	0.52	0.54
Filter Mass (g/km)	4	455.13	679.19	681.96	1065.38	829.87
LLSP Mass (g/km)	4	211.37	356.05	347.91	620.59	457.67
APS - PM1.0 (g/km)	2	396.06	590.21	683.48	652.24	623.07
APS - PM1.0 (g/kg fuel)	2	2546.48	4205.77	4788.93	4764.97	4430.95
APS - PM1.0 (g/kWh)	2	1383.56	1834.77	2099.87	1961.13	1921.75
APS - PM2.5 (g/km)	2	397.52	592.11	687.79	655.80	626.19
APS - PM2.5 (g/kg fuel)	2	2556.07	4219.63	4818.91	4790.91	4453.31
APS - PM2.5 (g/kWh)	2	1388.61	1840.69	2112.97	1971.77	1931.34
APS - PM10 (g/km)	2	405.05	602.16	706.02	664.25	637.18
APS - PM10 (g/kg fuel)	2	2605.08	4292.53	4946.09	4852.50	4531.68
APS - PM10 (g/kWh)	2	1414.87	1872.00	2168.58	1997.08	1965.09
TEOM - Total (g/km)	3	360.46	573.39	604.79	485.61	459.93

Table A4-5

NA Vehicles (1990-95)	No of Results	Average CUEDC Emissions (g/km)				
		Congested	Minor	Arterial	Highway	Weighted Total
NOx (g/km)	9	1.44	1.12	0.99	0.94	1.04
CO (g/km)	9	2.79	3.10	3.76	3.22	3.28
CO_2 (g/km)	9	502.77	422.41	422.04	380.71	410.17
O_2 (g/km)	9	546.63	459.62	459.50	414.43	446.42
THC (g/km)	9	0.20	0.12	0.15	0.08	0.11
Opacity - Average (%)	9	6.06	12.16	13.00	18.91	12.53
Opacity - Maximum (%)	9	54.07	67.43	67.24	71.74	65.12
Cumulative Power (kWh)	9	0.36	1.37	1.20	2.27	1.30
Cumulative Power (kWh/ tonne of test mass)	9	0.17	0.67	0.58	1.10	0.63
Fuel Consumption (l/100km)	9	18.90	15.91	15.94	14.36	16.28
Fuel Consumption (l/100km/ tonne of test mass)	9	9.19	7.77	7.78	7.02	7.94
Fuel Consumption (l/kWh)	9	0.70	0.54	0.52	0.48	0.52
Filter Mass (g/km)	9	475.10	505.10	623.16	525.97	538.39
LLSP Mass (g/km)	4	318.42	395.09	507.50	458.19	441.72
APS - PM1.0 (g/km)	4	318.39	368.93	331.16	292.89	354.13
APS - PM1.0 (g/kg fuel)	3	2211.86	2831.41	2556.12	2439.45	2808.87
APS - PM1.0 (g/kWh)	3	1225.37	1261.83	1122.65	981.90	1215.98
APS - PM2.5 (g/km)	4	319.86	372.62	333.54	295.39	356.93
APS - PM2.5 (g/kg fuel)	3	2222.16	2858.75	2573.54	2459.90	2830.32
APS - PM2.5 (g/kWh)	3	1231.05	1274.30	1130.52	990.19	1225.44
APS - PM10 (g/km)	4	325.36	393.14	349.17	312.53	373.92
APS - PM10 (g/kg fuel)	3	2260.39	3017.58	2692.08	2604.02	2966.16
APS - PM10 (g/kWh)	3	1252.22	1344.57	1182.52	1047.77	1283.87
TEOM - Total (g/km)	9	380.94	453.82	557.37	510.41	495.88

Table A4-6

NA Vehicles (1996-99)	No of Results	Average CUEDC Emissions (g/km)				
		Congested	Minor	Arterial	Highway	Weighted Total
NOx (g/km)	6	2.45	1.88	1.87	1.69	1.84
CO (g/km)	6	4.57	3.30	4.07	2.94	3.41
CO_2 (g/km)	6	539.68	473.43	463.59	386.84	438.49
O_2 (g/km)	6	576.82	507.06	496.32	416.90	470.64
THC (g/km)	6	0.21	0.12	0.13	0.07	0.11
Opacity - Average (%)	6	9.43	14.47	15.70	19.55	14.79
Opacity - Maximum (%)	6	70.15	76.60	74.16	75.58	74.12
Cumulative Power (kWh)	6	0.40	1.49	1.32	2.38	1.40
Cumulative Power (kWh/ tonne of test mass)	6	0.17	0.62	0.55	0.99	0.58
Fuel Consumption (l/100km)	6	20.37	17.82	17.50	14.58	17.57
Fuel Consumption (l/100km/ tonne of test mass)	6	8.54	7.50	7.34	6.12	7.37
Fuel Consumption (l/kWh)	6	0.67	0.55	0.52	0.46	0.52
Filter Mass (g/km)	6	896.00	747.46	795.80	594.50	702.87
LLSP Mass (g/km)	6	438.25	357.46	419.91	322.66	362.44
APS - PM1.0 (g/km)	3	638.08	554.71	613.69	481.28	311.98
APS - PM1.0 (g/kg fuel)	2	3675.07	3980.32	4486.32	4070.59	2393.62
APS - PM1.0 (g/kWh)	2	2050.98	1683.96	1848.21	1505.58	959.76
APS - PM2.5 (g/km)	3	639.45	555.53	614.77	482.07	313.17
APS - PM2.5 (g/kg fuel)	2	3683.46	3986.42	4494.39	4077.21	2402.71
APS - PM2.5 (g/kWh)	2	2055.31	1686.47	1851.49	1508.04	963.43
APS - PM10 (g/km)	3	669.34	558.24	620.32	486.29	318.74
APS - PM10 (g/kg fuel)	2	3850.08	4007.78	4536.52	4112.79	2445.89
APS - PM10 (g/kWh)	2	2151.72	1694.81	1868.37	1521.10	980.55
TEOM - Total (g/km)	6	620.33	636.43	713.61	529.08	605.93

Table A4-7

NB Vehicles (1980-89)	No of Results	Average CUEDC Emissions (g/km)				
		Congested	Minor	Arterial	Highway	Weighted Total
NOx (g/km)	2	4.50	1.66	1.91	3.72	3.07
CO (g/km)	2	9.93	3.78	4.00	2.68	3.47
CO_2 (g/km)	2	788.23	540.17	556.13	487.54	523.84
O_2 (g/km)	2	861.64	587.75	605.33	531.50	570.82
THC (g/km)	2	4.41	1.53	1.39	0.61	1.11
Opacity - Average (%)	2	1.47	5.73	5.29	15.15	6.91
Opacity - Maximum (%)	2	11.28	41.48	38.60	45.45	34.20
Cumulative Power (kWh)	2	0.34	1.69	1.46	5.07	2.14
Cumulative Power (kWh/ tonne of test mass)	2	0.07	0.32	0.28	1.00	0.42
Fuel Consumption (l/100km)	2	30.43	20.50	21.09	18.37	22.60
Fuel Consumption (l/100km/ tonne of test mass)	2	5.95	4.01	4.13	3.66	4.44
Fuel Consumption (l/kWh)	2	0.94	0.50	0.47	0.44	0.48
Filter Mass (g/km)	2	874.38	713.05	655.63	762.31	440.22
LLSP Mass (g/km)	2	180.95	381.77	253.61	268.62	161.60
APS - PM1.0 (g/km)	2	470.56	694.00	637.40	710.38	682.17
APS - PM1.0 (g/kg fuel)	2	1716.94	4091.50	3619.39	4626.11	4141.88
APS - PM1.0 (g/kWh)	2	1210.07	1788.29	1475.14	1761.59	1715.26
APS - PM2.5 (g/km)	2	471.88	696.78	639.52	718.13	687.72
APS - PM2.5 (g/kg fuel)	2	1721.74	4107.46	3631.03	4676.40	4175.43
APS - PM2.5 (g/kWh)	2	1213.44	1795.03	1479.67	1780.65	1729.08
APS - PM10 (g/km)	2	473.66	707.08	648.88	748.52	709.35
APS - PM10 (g/kg fuel)	2	1728.43	4166.64	3681.95	4873.37	4305.99
APS - PM10 (g/kWh)	2	1218.44	1820.03	1499.25	1855.19	1782.73
TEOM - Total (g/km)	2	455.91	433.43	439.36	496.15	308.35

Table A4-8

NB Vehicles (1990-95)	No of Results	Average CUEDC Emissions (g/km)				
		Congested	Minor	Arterial	Highway	Weighted Total
NOx (g/km)	9	4.36	3.05	3.18	2.85	3.02
CO (g/km)	9	7.17	4.36	4.74	3.27	3.92
CO_2 (g/km)	9	711.50	507.70	522.06	456.98	490.55
O_2 (g/km)	9	777.29	554.15	570.01	498.50	535.32
THC (g/km)	9	1.75	0.69	0.68	0.39	0.56
Opacity - Average (%)	8	4.01	11.75	10.63	24.35	12.69
Opacity - Maximum (%)	8	31.99	55.23	53.79	57.97	49.74
Cumulative Power (kWh)	9	0.34	1.66	1.37	4.67	2.01
Cumulative Power (kWh/ tonne of test mass)	9	0.07	0.34	0.28	0.95	0.41
Fuel Consumption (l/100km)	9	27.10	19.23	19.78	17.24	20.84
Fuel Consumption (l/100km/ tonne of test mass)	9	5.43	3.90	4.01	3.53	4.22
Fuel Consumption (l/kWh)	9	0.86	0.47	0.47	0.44	0.47
Filter Mass (g/km)	9	876.68	789.54	883.38	956.03	905.60
LLSP Mass (g/km)	8	318.07	443.59	398.34	436.47	425.05
APS - PM1.0 (g/km)	6	621.35	753.23	772.66	933.77	933.41
APS - PM1.0 (g/kg fuel)	5	2413.66	4113.37	4433.80	5717.65	5260.53
APS - PM1.0 (g/kWh)	5	1924.13	1836.61	1829.40	2385.20	2368.70
APS - PM2.5 (g/km)	6	624.59	757.23	777.14	940.80	939.88
APS - PM2.5 (g/kg fuel)	5	2426.05	4135.89	4459.70	5760.76	5297.85
APS - PM2.5 (g/kWh)	5	1934.12	1846.65	1840.73	2403.41	2385.40
APS - PM10 (g/km)	6	646.36	785.95	808.26	968.34	967.43
APS - PM10 (g/kg fuel)	5	2509.73	4297.93	4639.04	5949.67	5462.92
APS - PM10 (g/kWh)	5	2001.06	1919.33	1917.20	2477.90	2458.90
TEOM - Total (g/km)	9	581.96	630.77	591.56	656.98	636.67

Table A4-9

NB Vehicles (1996-99)	No of Results	Average CUEDC Emissions (g/km)				
		Congested	Minor	Arterial	Highway	Weighted Total
NOx (g/km)	6	5.08	3.95	4.26	4.16	4.18
CO (g/km)	6	4.44	2.28	2.58	1.12	1.75
CO_2 (g/km)	6	728.10	529.73	556.65	448.17	496.30
O_2 (g/km)	6	794.09	577.38	606.93	488.61	541.08
THC (g/km)	6	1.21	0.59	0.57	0.34	0.47
Opacity - Average (%)	6	2.40	5.59	5.09	7.56	5.16
Opacity - Maximum (%)	6	19.68	36.54	38.45	39.40	33.52
Cumulative Power (kWh)	6	0.35	1.69	1.42	4.90	2.09
Cumulative Power (kWh/ tonne of test mass)	6	0.07	0.36	0.30	1.08	0.45
Fuel Consumption (l/100km)	6	27.50	19.91	20.93	16.78	21.28
Fuel Consumption (l/100km/ tonne of test mass)	6	5.88	4.36	4.51	3.73	4.62
Fuel Consumption (l/kWh)	6	0.87	0.49	0.48	0.42	0.46
Filter Mass (g/km)	6	374.28	350.85	482.38	276.19	302.05
LLSP Mass (g/km)	5	134.19	173.52	162.29	123.03	139.80
APS - PM1.0 (g/km)	6	334.28	332.88	462.86	256.15	232.26
APS - PM1.0 (g/kg fuel)	3	1385.97	2030.03	2701.27	1770.94	1515.19
APS - PM1.0 (g/kWh)	3	1065.31	852.80	1157.86	629.11	592.59
APS - PM2.5 (g/km)	6	335.42	333.71	463.67	257.44	234.07
APS - PM2.5 (g/kg fuel)	3	1390.56	2034.88	2705.81	1780.06	1526.64
APS - PM2.5 (g/kWh)	3	1068.76	854.78	1159.62	632.33	597.01
APS - PM10 (g/km)	6	342.81	339.31	470.30	263.97	244.59
APS - PM10 (g/kg fuel)	3	1420.84	2069.14	2744.63	1827.40	1594.36
APS - PM10 (g/kWh)	3	1091.76	868.98	1174.74	649.05	623.31
TEOM - Total (g/km)	6	243.50	282.69	280.95	220.75	243.68

Table A4-10

ME Vehicles (1980-89)	No of Results	Average CUEDC Emissions (g/km)				
		Congested	Minor	Arterial	Highway	Weighted Total
NOx (g/km)	1	14.55	10.85	19.16	15.22	16.59
CO (g/km)	2	7.95	4.81	6.62	4.73	5.38
CO_2 (g/km)	2	1325.25	997.60	1194.71	939.17	1038.59
O_2 (g/km)	2	1450.02	1090.75	1304.24	1025.03	1134.52
THC (g/km)	1	1.80	0.90	1.06	0.72	0.93
Opacity - Average (%)	2	4.33	9.69	8.17	11.00	8.30
Opacity - Maximum (%)	2	36.19	46.63	57.96	46.88	46.92
Cumulative Power (kWh)	2	0.74	3.39	2.57	3.79	2.62
Cumulative Power (kWh/ tonne of test mass)	2	0.06	0.28	0.21	0.31	0.22
Fuel Consumption (l/100km)	2	49.88	37.45	44.91	35.27	41.88
Fuel Consumption (l/100km/ tonne of test mass)	2	4.12	3.11	3.71	2.92	3.46
Fuel Consumption (l/kWh)	2	0.72	0.52	0.50	0.53	0.53
Filter Mass (g/km)	2	1194.65	1084.22	1301.96	1150.89	1161.55
LLSP Mass (g/km)	2	630.00	660.84	846.35	621.28	679.34
APS - PM1.0 (g/km)	2	1158.28	1012.25	1187.47	1033.18	1065.72
APS - PM1.0 (g/kg fuel)	2	3086.60	3331.98	3424.34	3493.51	3387.53
APS - PM1.0 (g/kWh)	2	1848.85	1461.79	1409.76	1561.77	1511.01
APS - PM2.5 (g/km)	2	1158.95	1013.34	1190.47	1036.21	1067.92
APS - PM2.5 (g/kg fuel)	2	3087.83	3335.38	3432.80	3502.75	3393.96
APS - PM2.5 (g/kWh)	2	1849.66	1463.30	1413.26	1566.04	1513.95
APS - PM10 (g/km)	2	1171.31	1028.74	1221.38	1088.47	1100.78
APS - PM10 (g/kg fuel)	2	3113.32	3383.04	3509.77	3656.76	3484.86
APS - PM10 (g/kWh)	2	1865.79	1484.58	1446.23	1638.00	1556.17
TEOM - Total (g/km)	2	741.73	847.20	1068.80	918.18	910.93

Table A4-11

ME Vehicles (1996-99)	No of Results	Average CUEDC Emissions (g/km)				
		Congested	Minor	Arterial	Highway	Weighted Total
NOx (g/km)	5	13.75	8.91	10.81	7.73	9.20
CO (g/km)	5	4.42	2.30	3.21	1.48	2.32
CO_2 (g/km)	5	1458.41	1039.65	1252.86	965.71	1085.26
O_2 (g/km)	5	1591.06	1133.27	1365.98	1051.59	1182.72
THC (g/km)	5	0.78	0.50	0.51	0.36	0.47
Opacity - Average (%)	5	2.24	4.99	5.05	4.95	4.31
Opacity - Maximum (%)	5	20.47	26.51	26.38	19.29	23.17
Cumulative Power (kWh)	5	0.76	3.42	2.58	3.96	2.68
Cumulative Power (kWh/ tonne of test mass)	5	0.06	0.28	0.21	0.32	0.22
Fuel Consumption (l/100km)	5	54.62	38.88	46.87	36.06	44.11
Fuel Consumption (l/100km/ tonne of test mass)	5	4.46	3.16	3.83	2.94	3.60
Fuel Consumption (l/kWh)	5	0.78	0.53	0.52	0.51	0.54
Filter Mass (g/km)	5	980.98	505.46	804.99	508.68	602.33
LLSP Mass (g/km)	5	549.62	356.33	501.15	298.32	376.61
APS - PM1.0 (g/km)	4	1163.23	499.11	872.27	548.03	694.01
APS - PM1.0 (g/kg fuel)	3	2655.58	1617.53	2339.79	1881.38	2111.65
APS - PM1.0 (g/kWh)	3	1697.53	703.82	974.29	801.85	936.81
APS - PM2.5 (g/km)	4	1164.17	499.72	873.08	548.68	694.72
APS - PM2.5 (g/kg fuel)	3	2657.76	1619.53	2341.98	1883.66	2113.83
APS - PM2.5 (g/kWh)	3	1698.85	704.67	975.20	802.81	937.76
APS - PM10 (g/km)	4	1167.61	502.24	877.91	551.00	698.16
APS - PM10 (g/kg fuel)	3	2665.77	1627.86	2355.14	1891.74	2124.50
APS - PM10 (g/kWh)	3	1703.66	708.18	980.61	806.20	942.39
TEOM - Total (g/km)	5	685.05	464.30	671.14	393.01	494.14

Table A4-12

NC Vehicles (1980-89)	No of Results	Average CUEDC Emissions (g/km)				
		Congested	Minor	Arterial	Highway	Weighted Total
NOx (g/km)	2	11.04	8.95	9.99	8.56	9.10
CO (g/km)	2	7.94	2.43	2.10	1.66	2.26
CO_2 (g/km)	2	1149.05	776.41	793.45	709.14	766.65
O_2 (g/km)	2	1256.53	848.52	867.64	775.03	838.02
THC (g/km)	2	2.55	1.01	0.91	0.71	0.92
Opacity - Average (%)	2	2.17	3.83	5.01	7.97	4.74
Opacity - Maximum (%)	2	24.97	34.76	36.15	34.50	32.59
Cumulative Power (kWh)	2	0.38	2.39	2.31	4.21	2.32
Cumulative Power (kWh/ tonne of test mass)	2	0.04	0.22	0.22	0.39	0.22
Fuel Consumption (l/100km)	2	43.52	29.15	29.75	26.57	32.25
Fuel Consumption (l/100km/ tonne of test mass)	2	4.07	2.72	2.78	2.50	3.02
Fuel Consumption (l/kWh)	2	0.93	0.57	0.50	0.50	0.53
Filter Mass (g/km)	2	1158.45	656.66	683.58	695.21	703.66
LLSP Mass (g/km)	2	491.37	267.48	307.92	321.99	311.96
APS - PM1.0 (g/km)	1	1343.17	546.24	538.64	704.43	655.26
APS - PM1.0 (g/kg fuel)	1	3871.31	2427.92	2312.32	3149.49	2823.66
APS - PM1.0 (g/kWh)	1	3305.60	1119.68	887.75	1359.03	1249.27
APS - PM2.5 (g/km)	1	1343.95	551.48	556.70	730.79	672.81
APS - PM2.5 (g/kg fuel)	1	3873.56	2451.21	2389.87	3267.37	2899.28
APS - PM2.5 (g/kWh)	1	3307.52	1130.42	917.53	1409.90	1282.72
APS - PM10 (g/km)	1	1350.19	561.01	608.25	816.02	726.17
APS - PM10 (g/kg fuel)	1	3891.52	2493.57	2611.18	3648.40	3129.22
APS - PM10 (g/kWh)	1	3322.86	1149.96	1002.49	1574.32	1384.46
TEOM - Total (g/km)	2	754.05	494.15	549.16	560.47	548.91

Table A4-13

NC Vehicles (1990-95)	No of Results	Average CUEDC Emissions (g/km)				
		Congested	Minor	Arterial	Highway	Weighted Total
NOx (g/km)	7	10.37	7.75	8.14	7.62	7.90
CO (g/km)	7	8.08	3.57	3.98	2.88	3.56
CO_2 (g/km)	7	1097.81	819.59	840.31	735.64	798.40
O_2 (g/km)	7	1199.90	894.43	917.40	803.15	871.63
THC (g/km)	7	2.69	1.16	1.09	0.72	1.01
Opacity - Average (%)	7	3.09	5.22	6.22	7.91	5.61
Opacity - Maximum (%)	7	22.94	35.85	35.66	40.13	33.65
Cumulative Power (kWh)	7	0.35	2.48	2.37	4.53	2.43
Cumulative Power (kWh/ tonne of test mass)	7	0.03	0.20	0.19	0.36	0.20
Fuel Consumption (l/100km)	7	41.64	30.84	31.63	27.63	32.93
Fuel Consumption (l/100km/ tonne of test mass)	7	3.31	2.47	2.54	2.22	2.63
Fuel Consumption (l/kWh)	7	0.98	0.58	0.51	0.48	0.53
Filter Mass (g/km)	7	1029.83	780.37	718.02	646.03	715.85
LLSP Mass (g/km)	6	612.68	469.99	452.73	393.10	436.74
APS - PM1.0 (g/km)	5	861.85	662.22	800.68	499.92	654.07
APS - PM1.0 (g/kg fuel)	5	2369.13	2385.23	3207.25	2058.15	2525.82
APS - PM1.0 (g/kWh)	5	1818.06	1128.13	1334.53	849.21	1105.12
APS - PM2.5 (g/km)	5	896.01	683.89	816.26	515.40	671.21
APS - PM2.5 (g/kg fuel)	5	2450.31	2459.25	3266.01	2120.40	2587.66
APS - PM2.5 (g/kWh)	5	1882.72	1163.54	1359.89	874.14	1132.30
APS - PM10 (g/km)	5	953.13	728.34	868.15	564.45	719.63
APS - PM10 (g/kg fuel)	5	2595.13	2623.27	3465.02	2329.07	2775.84
APS - PM10 (g/kWh)	5	2002.24	1242.89	1445.05	961.94	1217.23
TEOM - Total (g/km)	7	661.80	616.41	568.44	507.69	557.69

Table A4-14

NC Vehicles (1996-99)	No of Results	Average CUEDC Emissions (g/km)				
		Congested	Minor	Arterial	Highway	Weighted Total
NOx (g/km)	5	8.07	6.13	5.76	5.29	5.75
CO (g/km)	5	5.22	2.14	1.82	1.08	1.72
CO_2 (g/km)	5	1181.88	860.50	849.81	731.92	813.73
O_2 (g/km)	5	1287.78	936.84	924.80	796.46	885.70
THC (g/km)	5	1.84	0.79	0.68	0.46	0.66
Opacity - Average (%)	5	1.79	1.89	2.08	2.85	2.15
Opacity - Maximum (%)	5	10.05	13.83	18.05	20.99	15.73
Cumulative Power (kWh)	5	0.36	2.47	2.28	4.53	2.41
Cumulative Power (kWh/ tonne of test mass)	5	0.03	0.21	0.19	0.38	0.20
Fuel Consumption (l/100km)	5	44.50	32.24	31.81	27.35	33.97
Fuel Consumption (l/100km/ tonne of test mass)	5	3.70	2.64	2.63	2.23	2.80
Fuel Consumption (l/kWh)	5	0.97	0.60	0.53	0.47	0.53
Filter Mass (g/km)	5	1103.37	372.15	453.31	367.86	422.01
LLSP Mass (g/km)	5	269.03	158.13	164.12	155.09	163.10
APS - PM1.0 (g/km)	5	845.68	365.33	442.55	357.57	396.16
APS - PM1.0 (g/kg fuel)	4	2140.58	1325.91	1600.77	1422.55	1431.52
APS - PM1.0 (g/kWh)	4	1844.29	681.74	733.02	588.05	675.68
APS - PM2.5 (g/km)	5	845.76	365.72	443.01	358.01	396.62
APS - PM2.5 (g/kg fuel)	4	2140.72	1327.22	1602.47	1424.23	1433.15
APS - PM2.5 (g/kWh)	4	1844.47	682.43	733.75	588.73	676.44
APS - PM10 (g/km)	5	848.27	369.37	448.34	363.01	402.26
APS - PM10 (g/kg fuel)	4	2148.23	1340.99	1622.86	1445.08	1455.10
APS - PM10 (g/kWh)	4	1850.23	689.26	742.56	596.94	686.16
TEOM - Total (g/km)	5	523.98	292.21	294.55	253.67	285.73

Table A4-15

NCH Vehicles (1980-89)	No of Results	Average CUEDC Emissions (g/km)				
		Congested	Minor	Arterial	Highway	Weighted Total
NOx (g/km)	2	15.44	11.34	6.01	8.01	13.29
CO (g/km)	2	12.17	6.52	7.32	7.96	7.60
CO_2 (g/km)	2	1963.16	1171.77	1147.98	1136.56	1187.28
O_2 (g/km)	2	2137.26	1276.20	1251.25	1240.89	1294.64
THC (g/km)	2	2.99	0.88	0.93	0.59	0.85
Opacity - Average (%)	2	2.70	7.42	6.56	13.16	7.46
Opacity - Maximum (%)	2	34.75	50.18	56.11	50.70	47.94
Cumulative Power (kWh)	2	0.63	3.90	3.02	8.11	3.91
Cumulative Power (kWh/ tonne of test mass)	2	0.02	0.15	0.12	0.31	0.15
Fuel Consumption (l/100km)	2	74.11	44.09	43.25	42.83	51.07
Fuel Consumption (l/100km/ tonne of test mass)	2	2.83	1.68	1.65	1.63	1.95
Fuel Consumption (l/kWh)	2	0.84	0.50	0.49	0.37	0.44
Filter Mass (g/km)	2	616.71	404.05	565.42	586.97	531.81
LLSP Mass (g/km)	2	75.08	201.69	268.62	314.56	261.61
APS - PM1.0 (g/km)						0.00
APS - PM1.0 (g/kg fuel)						
APS - PM1.0 (g/kWh)						
APS - PM2.5 (g/km)						0.00
APS - PM2.5 (g/kg fuel)						
APS - PM2.5 (g/kWh)						
APS - PM10 (g/km)						0.00
APS - PM10 (g/kg fuel)						
APS - PM10 (g/kWh)						
TEOM - Total (g/km)	2	466.69	362.33	578.70	579.99	513.18

Table A4-16

NCH Vehicles (1990-95)	No of Results	Average CUEDC Emissions (g/km)				
		Congested	Minor	Arterial	Highway	Weighted Total
NOx (g/km)	3	17.51	14.10	13.66	16.78	15.36
CO (g/km)	3	6.75	6.87	4.83	4.23	5.23
CO_2 (g/km)	3	1708.67	1142.56	1130.00	1165.65	1176.47
O_2 (g/km)	3	1865.12	1250.08	1234.97	1275.33	1286.67
THC (g/km)	3	1.39	0.49	0.54	0.35	0.48
Opacity - Average (%)	3	1.18	3.36	2.37	5.55	3.11
Opacity - Maximum (%)	3	14.58	41.67	32.05	46.92	33.81
Cumulative Power (kWh)	3	0.48	3.69	2.62	8.01	3.70
Cumulative Power (kWh/ tonne of test mass)	3	0.02	0.14	0.10	0.31	0.14
Fuel Consumption (l/100km)	3	64.14	42.97	42.39	43.66	48.29
Fuel Consumption (l/100km/ tonne of test mass)	3	2.45	1.64	1.62	1.67	1.85
Fuel Consumption (l/kWh)	3	0.97	0.52	0.55	0.38	0.46
Filter Mass (g/km)	3	940.88	556.31	489.45	480.29	524.97
LLSP Mass (g/km)	3	237.28	223.19	187.70	208.67	209.87
APS - PM1.0 (g/km)	1	956.83	374.71	269.06	320.18	350.02
APS - PM1.0 (g/kg fuel)	1	1941.58	1064.05	796.85	912.01	986.70
APS - PM1.0 (g/kWh)	1	1536.70	410.84	334.03	279.95	355.19
APS - PM2.5 (g/km)	1	968.99	379.45	272.60	324.65	355.02
APS - PM2.5 (g/kg fuel)	1	1966.40	1077.50	807.33	924.73	1000.82
APS - PM2.5 (g/kWh)	1	1554.23	416.03	338.42	283.85	360.27
APS - PM10 (g/km)	1	1043.03	404.28	295.65	346.41	381.71
APS - PM10 (g/kg fuel)	1	2117.35	1148.02	875.60	986.70	1076.03
APS - PM10 (g/kWh)	1	1664.09	443.26	367.03	302.88	387.34
TEOM - Total (g/km)	3	610.80	452.76	440.90	451.78	457.32

Table A4-17

NCH Vehicles (1996-99)	No of Results	Average CUEDC Emissions (g/km)				
		Congested	Minor	Arterial	Highway	Weighted Total
NOx (g/km)	5	11.07	7.67	7.43	8.16	8.01
CO (g/km)	5	6.14	2.37	2.34	1.22	2.03
CO_2 (g/km)	5	1592.27	1117.78	1077.41	1066.19	1107.18
O_2 (g/km)	5	1731.69	1215.52	1171.63	1160.17	1204.36
THC (g/km)	5	1.90	0.71	0.67	0.45	0.64
Opacity - Average (%)	5	1.34	2.31	2.18	3.71	2.38
Opacity - Maximum (%)	5	8.88	16.67	20.56	27.67	18.44
Cumulative Power (kWh)	5	0.44	3.61	2.62	7.04	3.43
Cumulative Power (kWh/ tonne of test mass)	5	0.02	0.14	0.10	0.27	0.13
Fuel Consumption (l/100km)	5	59.83	41.82	40.31	39.80	45.44
Fuel Consumption (l/100km/ tonne of test mass)	5	2.30	1.61	1.55	1.53	1.75
Fuel Consumption (l/kWh)	5	0.98	0.51	0.53	0.40	0.47
Filter Mass (g/km)	5	901.13	422.88	417.64	444.35	453.30
LLSP Mass (g/km)	5	356.59	184.66	189.65	202.55	201.65
APS - PM1.0 (g/km)	2	904.76	480.65	414.29	619.51	662.97
APS - PM1.0 (g/kg fuel)	2	1508.26	1347.90	1206.50	1848.08	1855.68
APS - PM1.0 (g/kWh)	2	1286.10	626.26	547.08	658.59	788.13
APS - PM2.5 (g/km)	2	907.22	481.59	415.09	620.70	663.99
APS - PM2.5 (g/kg fuel)	2	1514.05	1350.68	1209.00	1851.70	1858.58
APS - PM2.5 (g/kWh)	2	1290.76	627.47	548.17	659.88	789.35
APS - PM10 (g/km)	2	934.34	493.11	427.61	649.84	687.20
APS - PM10 (g/kg fuel)	2	1565.16	1382.76	1245.37	1936.31	1922.63
APS - PM10 (g/kWh)	2	1333.95	642.73	565.30	690.08	816.91
TEOM - Total (g/km)	5	618.77	318.40	329.00	397.38	369.72

Table A4-18

ADR Category	Age Group	No of Tests	O_2 raw (g/km)	CO_2 (g/km)	CO (g/km)	NOx (g/km)	HC (g/km)	LLSP (mg/km)	TEOM - total (mg/km)	Filter (mg/km)	Ave Opacity (%)	Max Opacity (%)	APS (mg/km) (< 1 um)	APS (mg/km) (< 2.5 um)	APS (mg/km) (< 10 um)	Fuel Consumption (l/100km)
MC	80 - '89	3	494.36	454.10	3.25	1.72	0.46	360.93	543.52	708.87	11.26	58.15	742.54	745.61	777.31	19.47
	90 - '95	5	475.01	436.88	2.84	1.09	0.11	393.59	606.17	660.28	10.63	60.19	405.48	409.33	424.43	17.89
	96 - '99	5	504.46	464.77	1.18	1.27	0.19	148.10	220.25	266.29	5.76	49.61	255.94	256.66	273.31	20.47
NA	80 - '89	4	481.38	442.48	3.23	1.26	0.08	457.67	459.93	829.87	17.03	50.01	623.07	626.19	637.18	17.14
	90 - '95	9	446.42	410.17	3.28	1.04	0.11	441.72	495.88	538.39	12.53	65.12	354.13	356.93	373.92	16.28
	96 - '99	6	470.64	438.49	3.41	1.84	0.11	362.44	605.93	702.87	14.79	74.12	311.98	313.17	318.74	17.57
NB	80 - '89	2	570.82	523.84	3.47	3.07	1.11	161.60	308.35	440.22	6.91	34.20	682.17	687.72	709.35	22.60
	90 - '95	9	535.32	490.55	3.92	3.02	0.56	425.05	636.67	905.60	12.69	49.74	933.41	939.88	967.43	20.84
	96 - '99	6	541.08	496.30	1.75	4.18	0.47	139.80	243.68	302.05	5.16	33.52	232.26	234.07	244.59	21.28
ME	80 - '89	2	1134.52	1038.59	5.38	16.59	0.93	679.34	910.93	1161.55	8.30	46.92	1065.72	1067.92	1100.78	41.88
	90 - '95	0														
	96 - '99	5	1182.72	1085.26	2.32	9.20	0.47	376.61	494.14	602.33	4.31	23.17	694.01	694.72	698.16	44.11
NC	80 - '89	2	838.02	766.65	2.26	9.10	0.92	311.96	548.91	703.66	4.74	32.59	655.26	672.81	726.17	32.25
	90 - '95	7	871.63	798.40	3.56	7.90	1.01	436.74	557.69	715.85	5.61	33.65	654.07	671.21	719.63	32.93
	96 - '99	5	885.70	813.73	1.72	5.75	0.66	163.10	285.73	422.01	2.15	15.73	396.16	396.62	402.26	33.97
NCH	80 - '89	2	1294.64	1187.28	7.60	13.29	0.85	261.61	513.18	531.81	7.46	47.94				51.07
	90 - '95	3	1286.67	1176.47	5.23	15.36	0.48	209.87	457.32	524.97	3.11	33.81	350.02	355.02	381.71	48.29
	96 - '99	5	1204.36	1107.18	2.03	8.01	0.64	201.65	369.72	453.30	2.38	18.44	662.97	663.99	687.20	45.44

APPENDIX 5

Figure A5-1

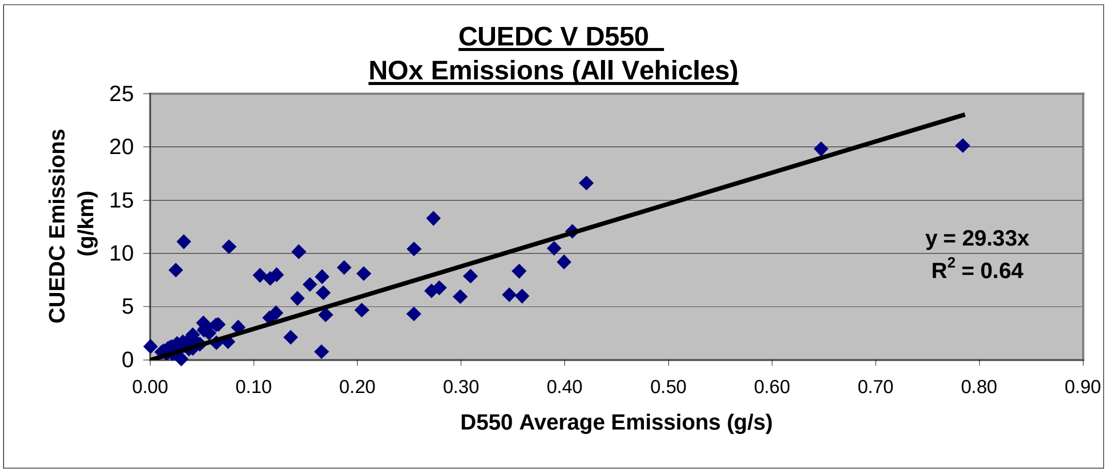


Figure A5-2

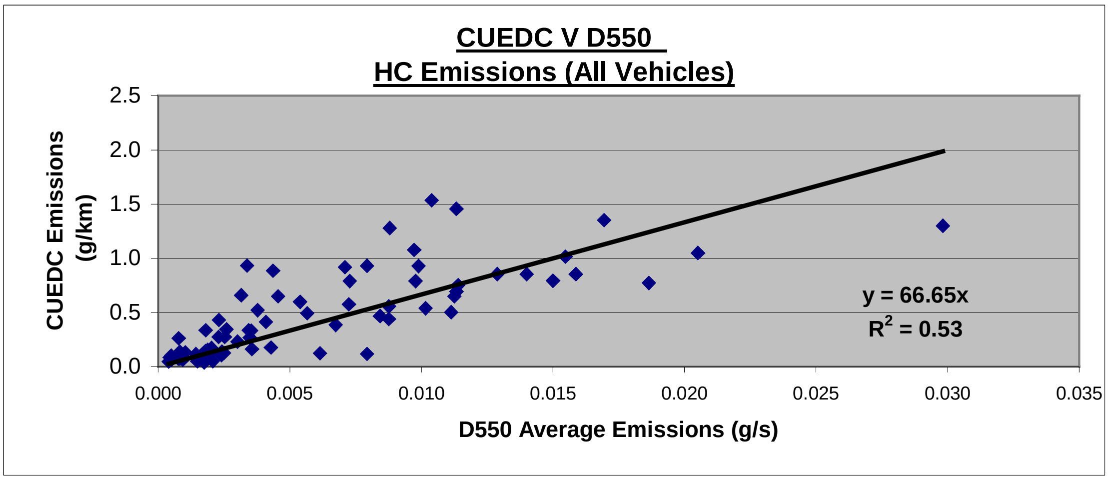


Figure A5-3

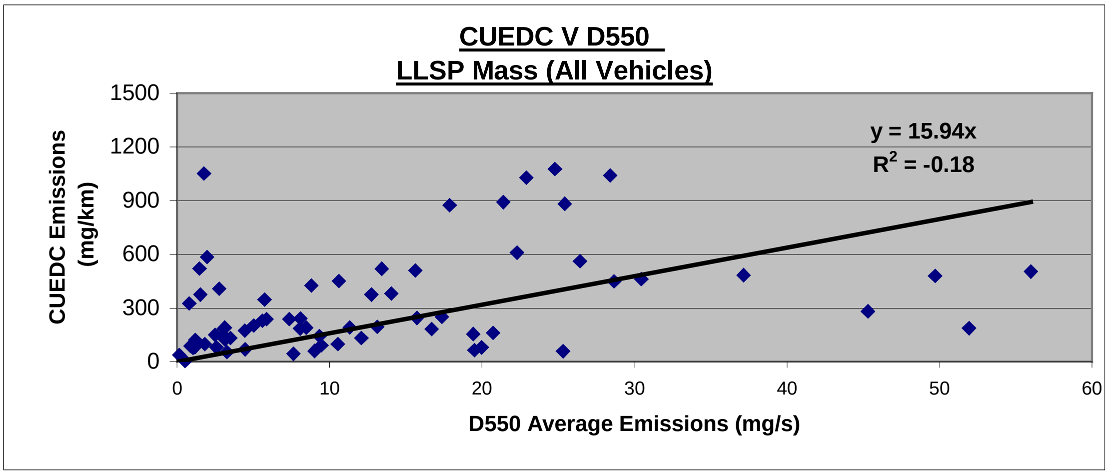


Figure A5-4

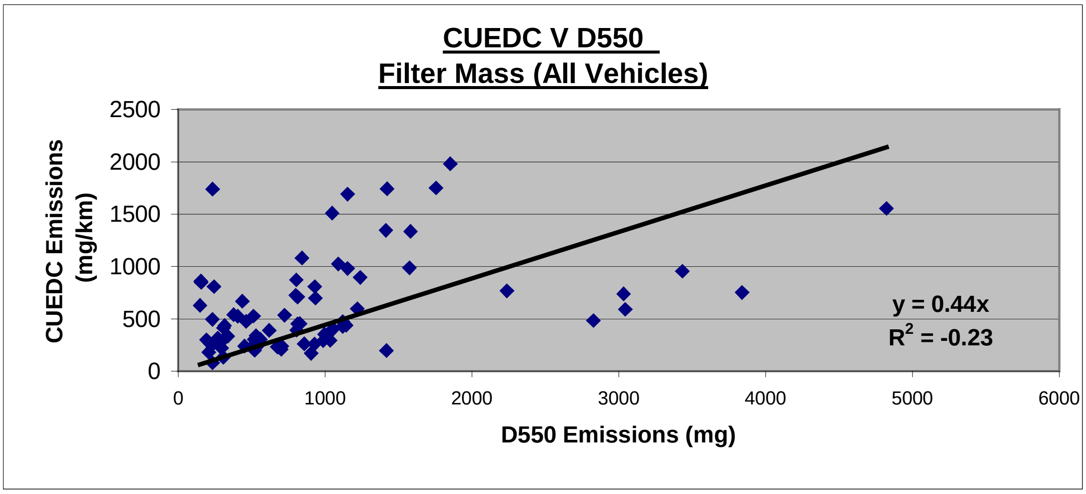


Figure A5-5

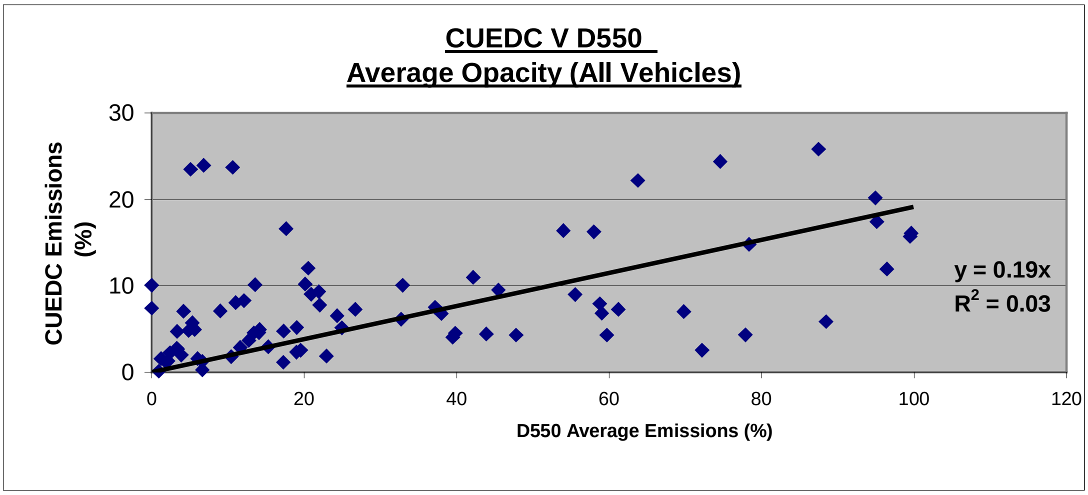


Figure A5-6

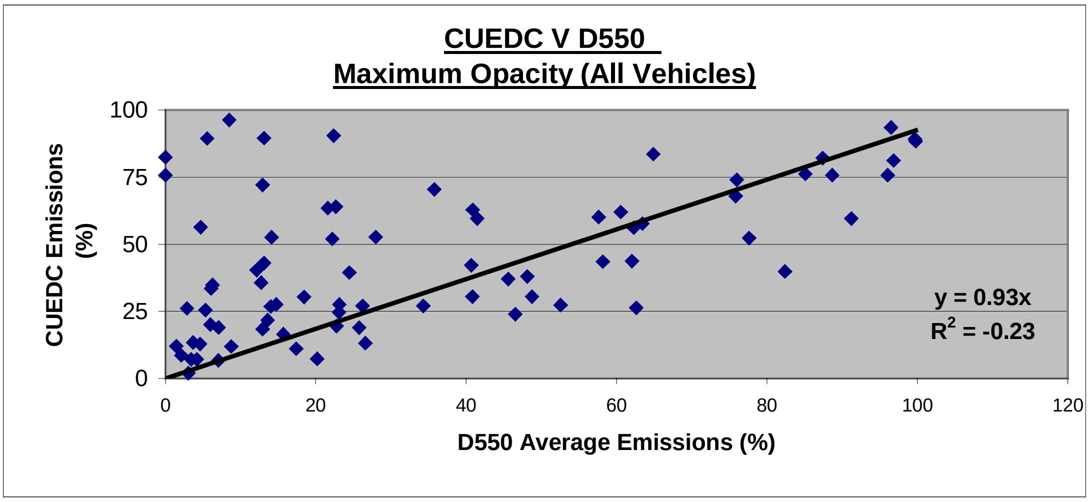


Figure A5-7

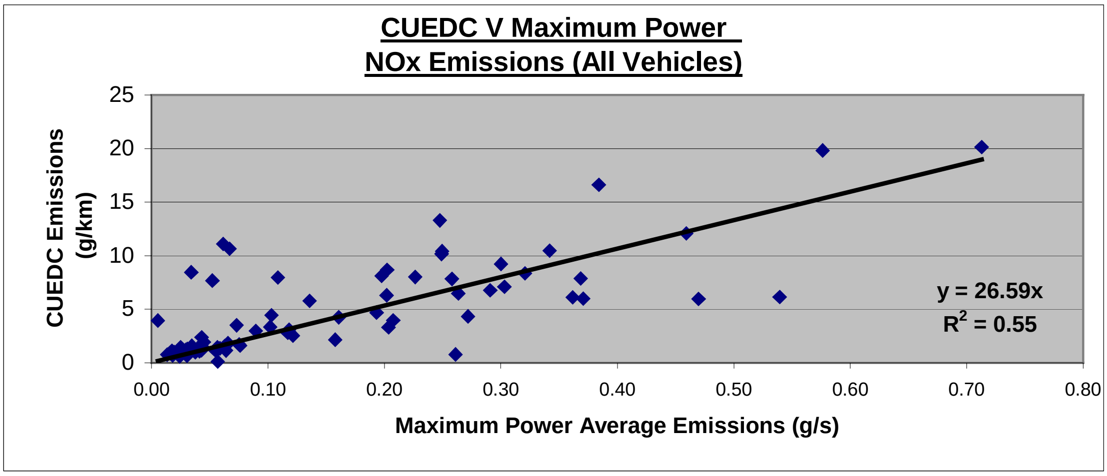


Figure A5-8

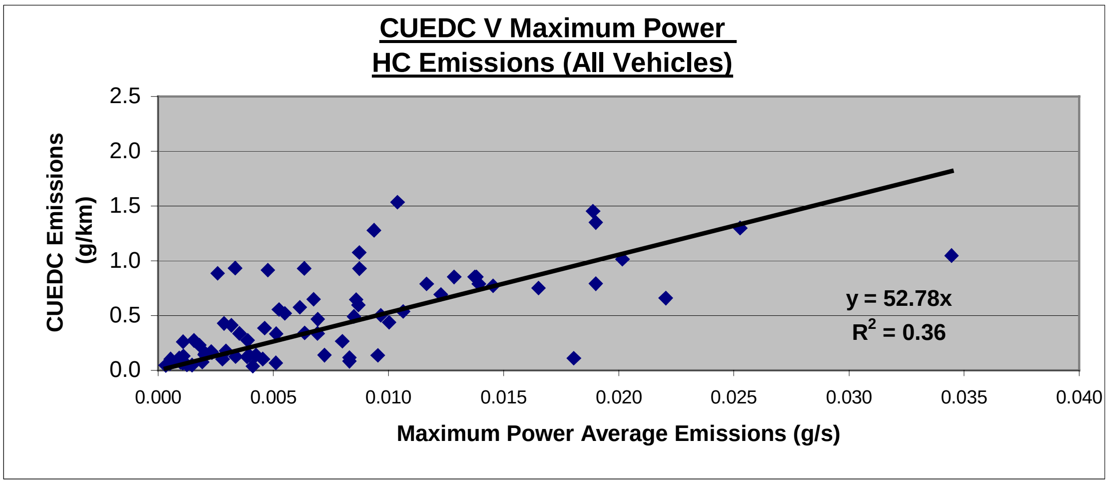


Figure A5-9

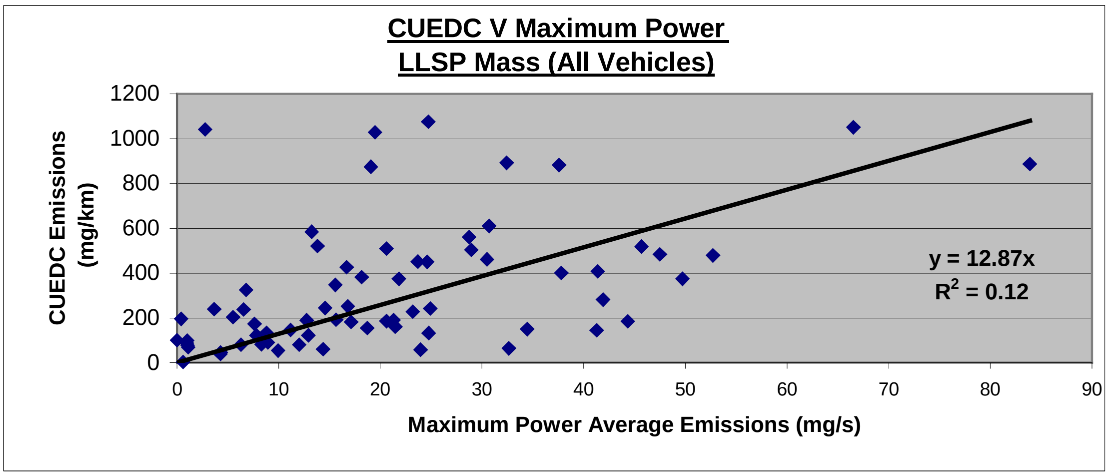


Figure A5-10

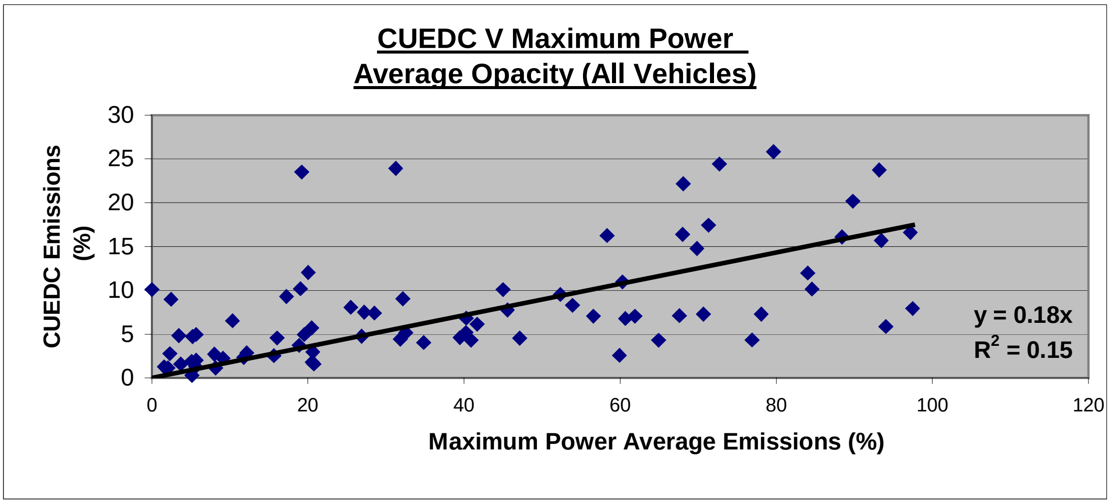


Figure A5-11

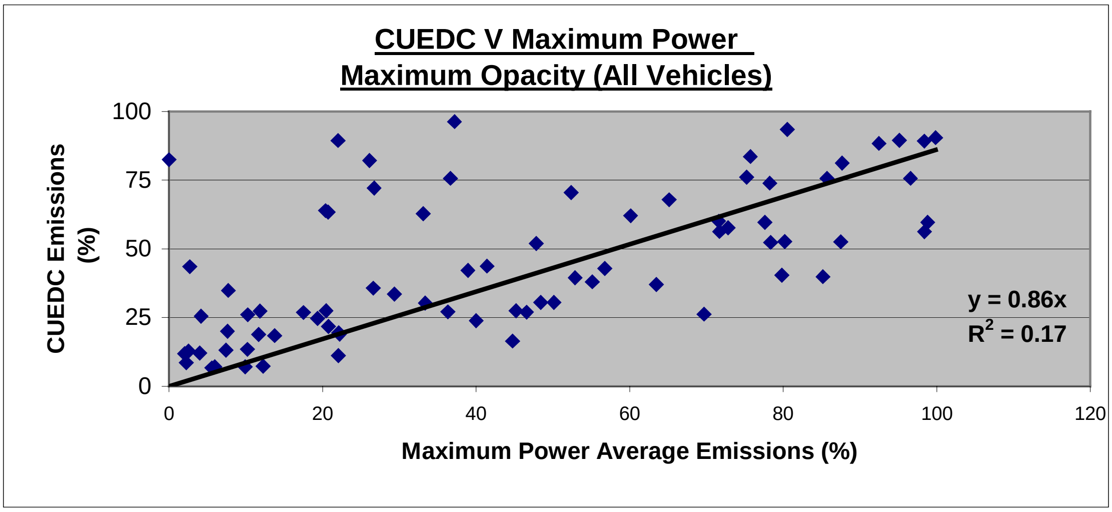


Figure A5-12

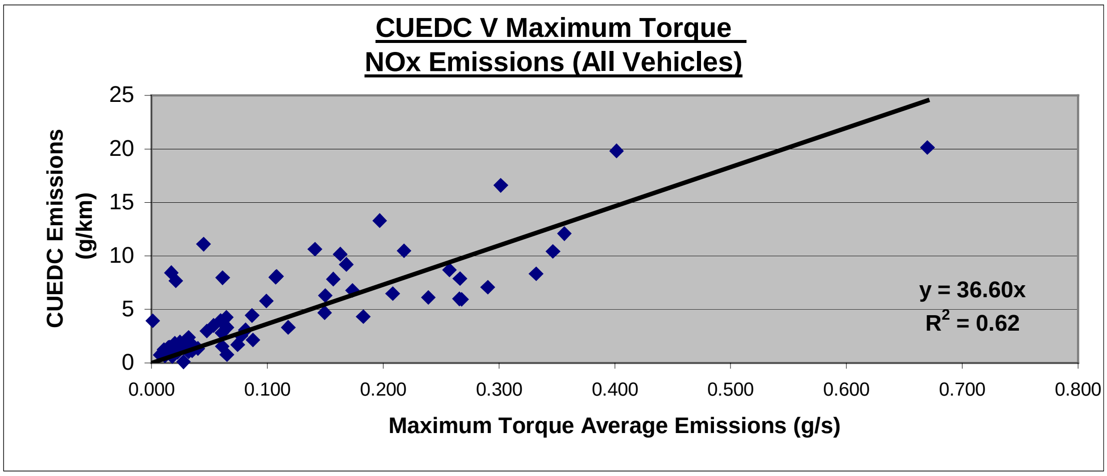


Figure A5-13

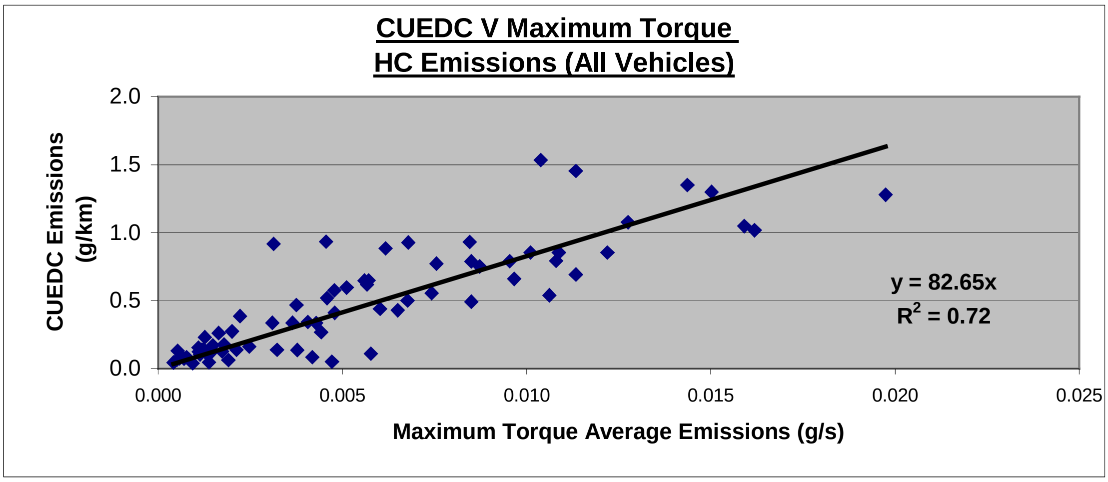


Figure A5-14

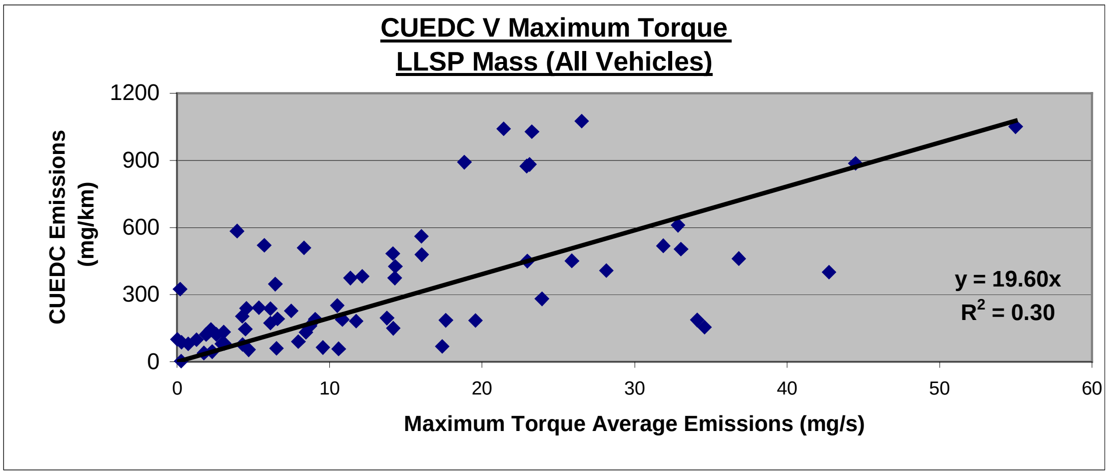


Figure A5-15

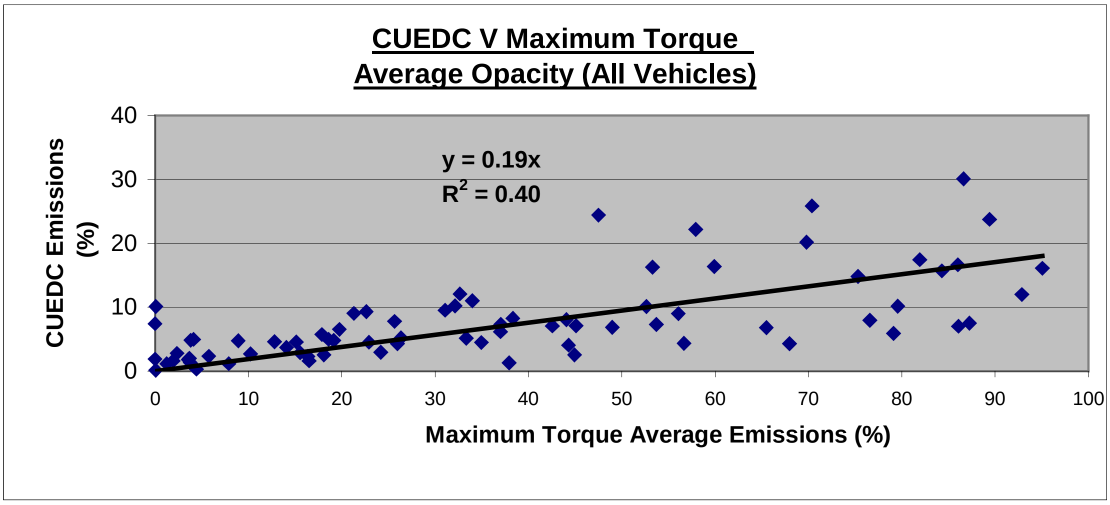


Figure A5-16

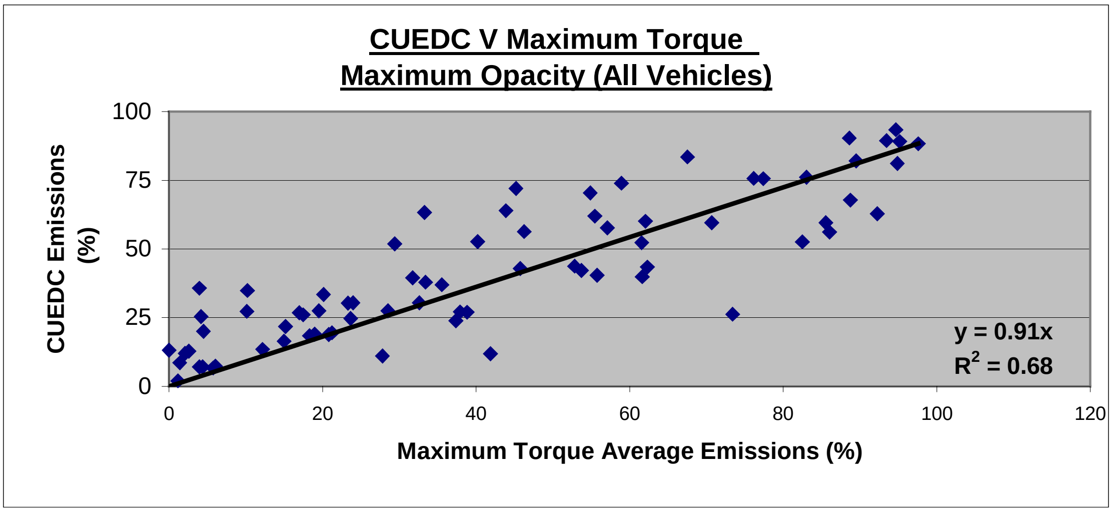


Figure A5-17

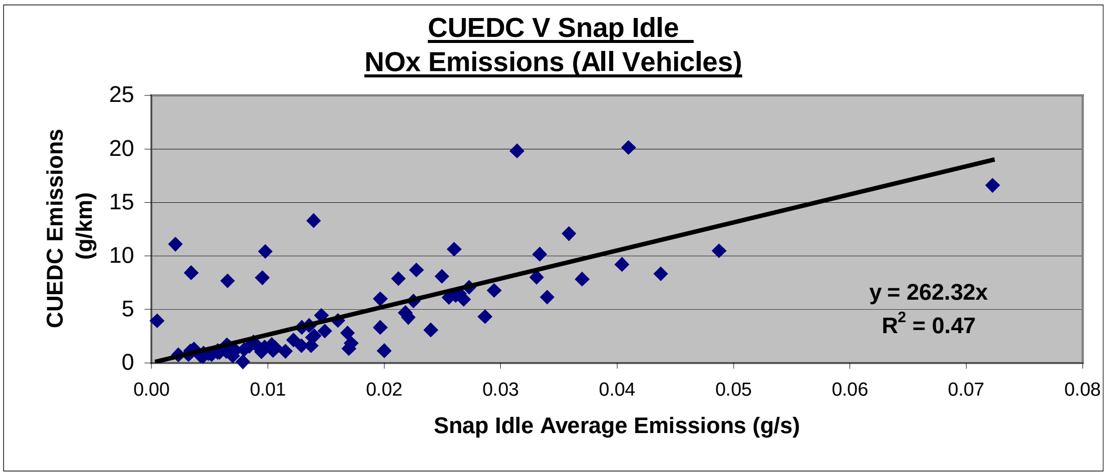


Figure A5-18

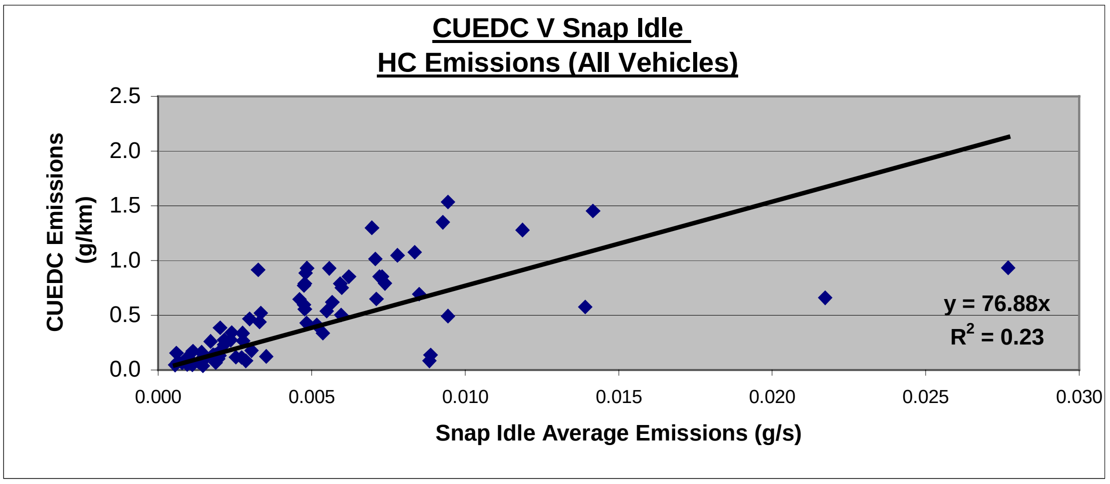


Figure A5-19

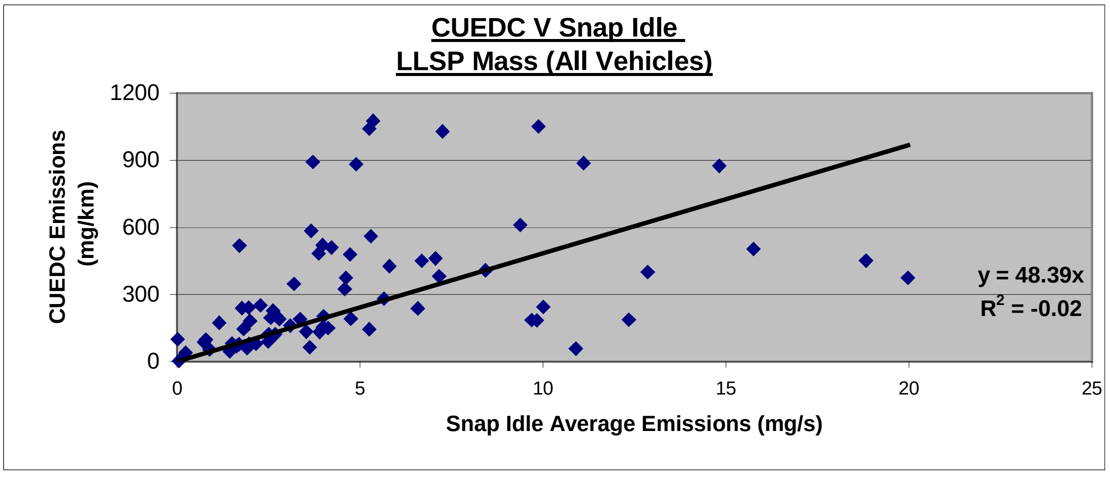


Figure A5-20

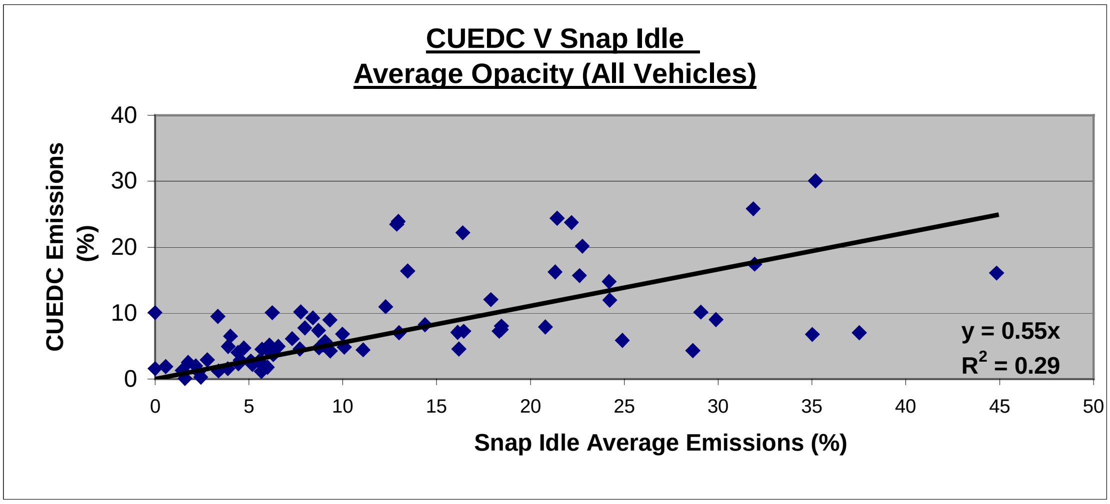


Figure A5-21

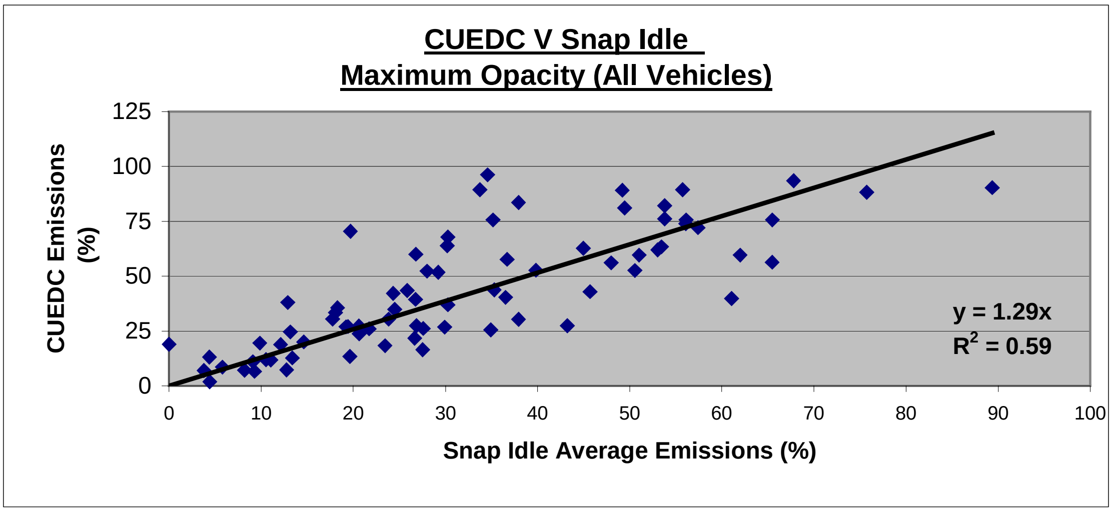


Figure A5-22

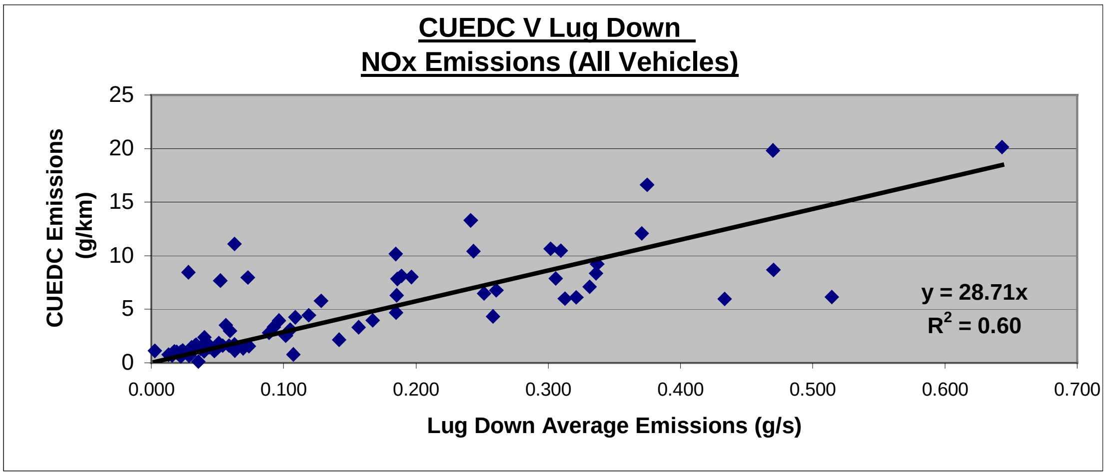


Figure A5-23

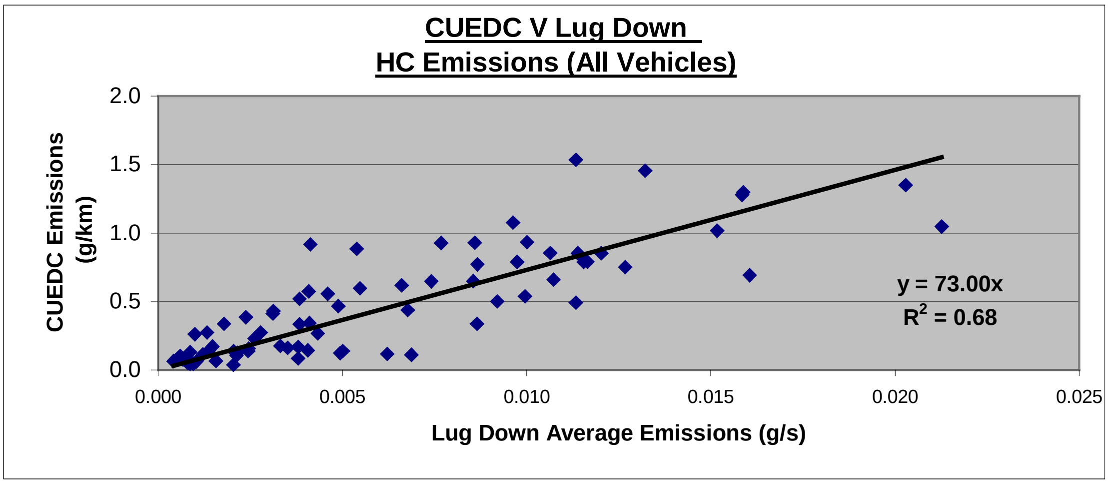


Figure A5-24

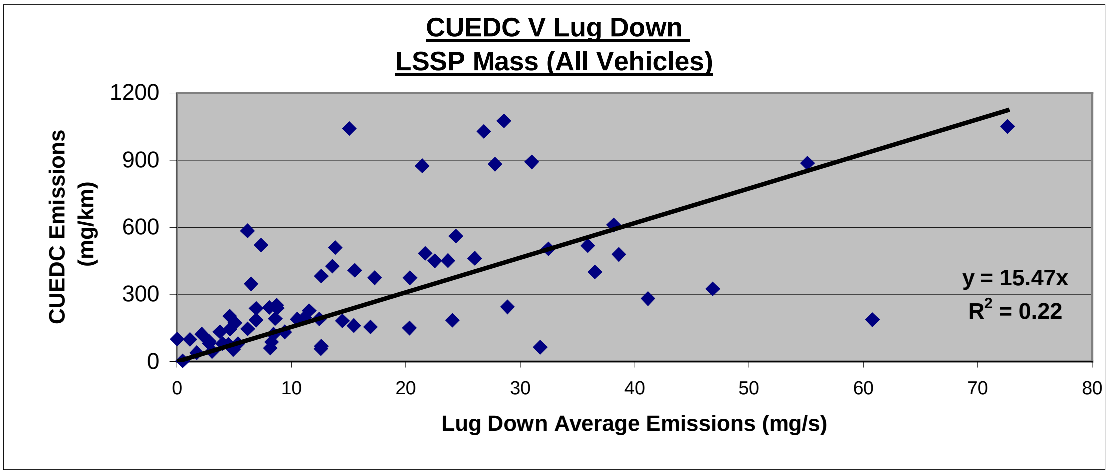


Figure A5-25

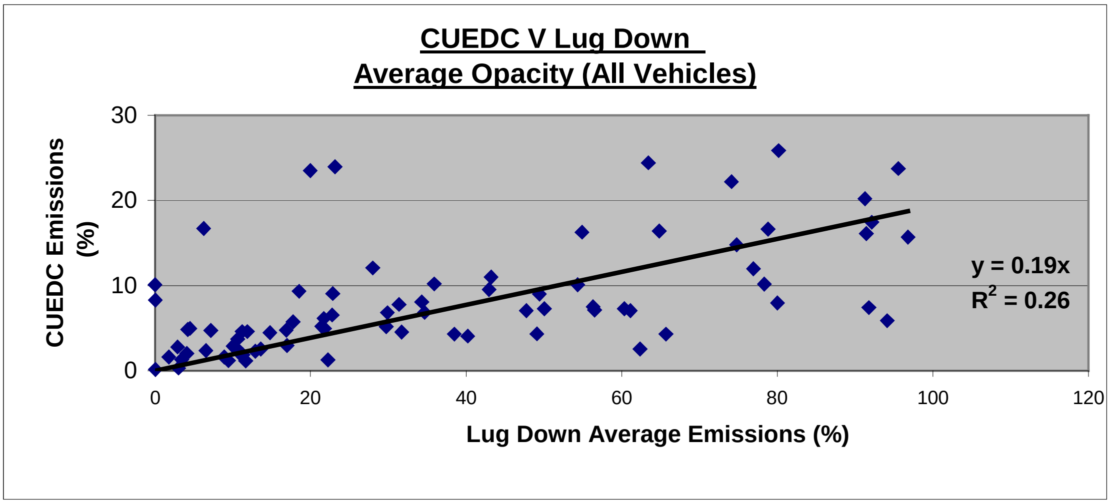


Figure A5-26

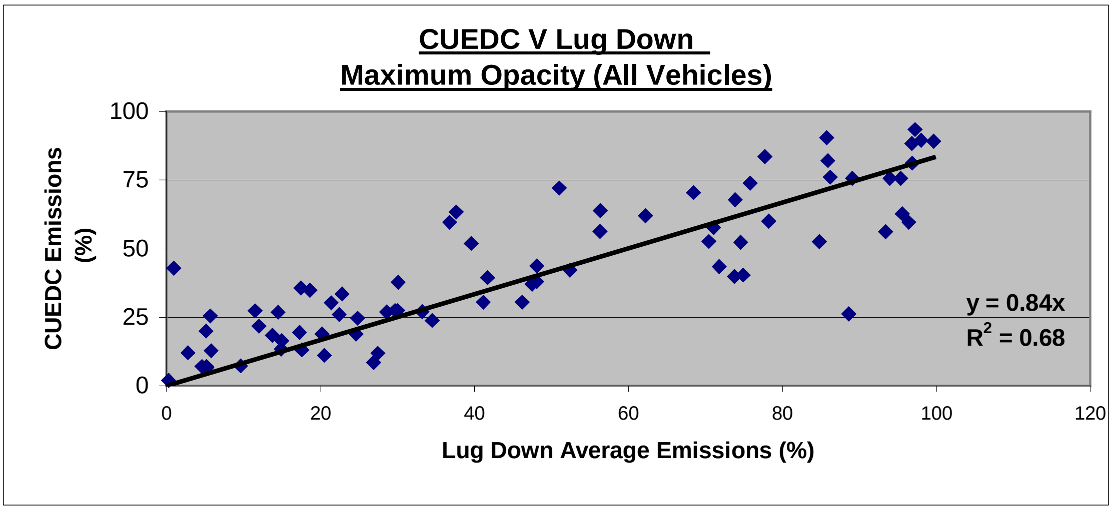


Figure A5-27

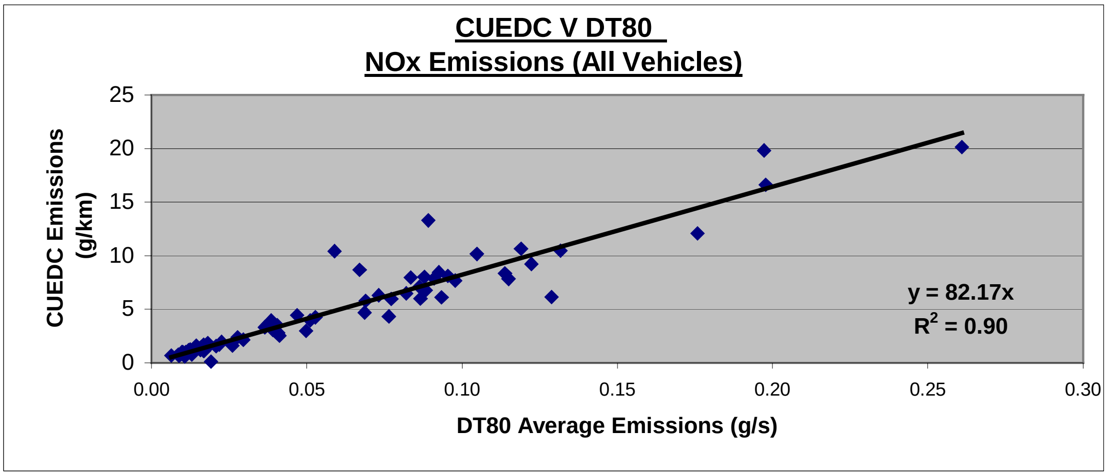


Figure A5-28

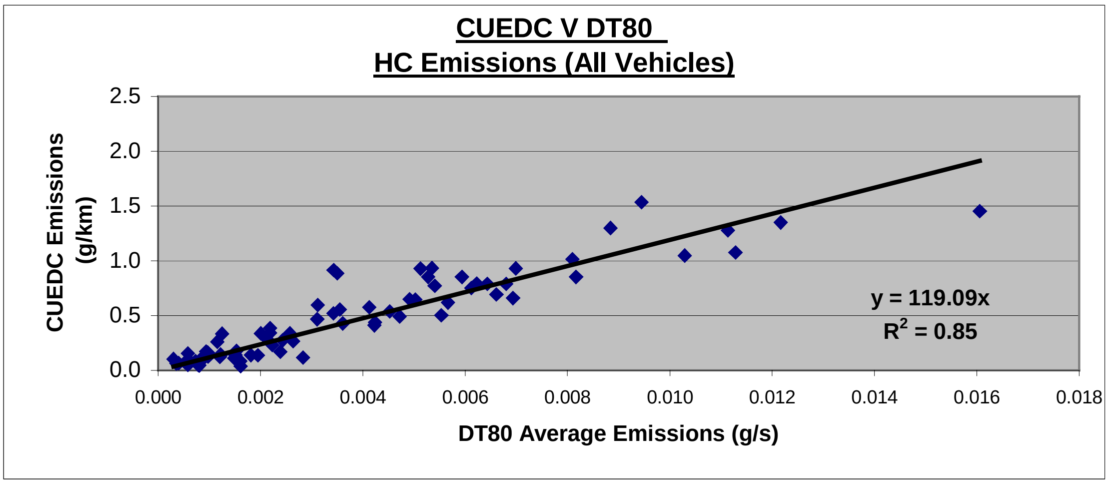


Figure A5-29

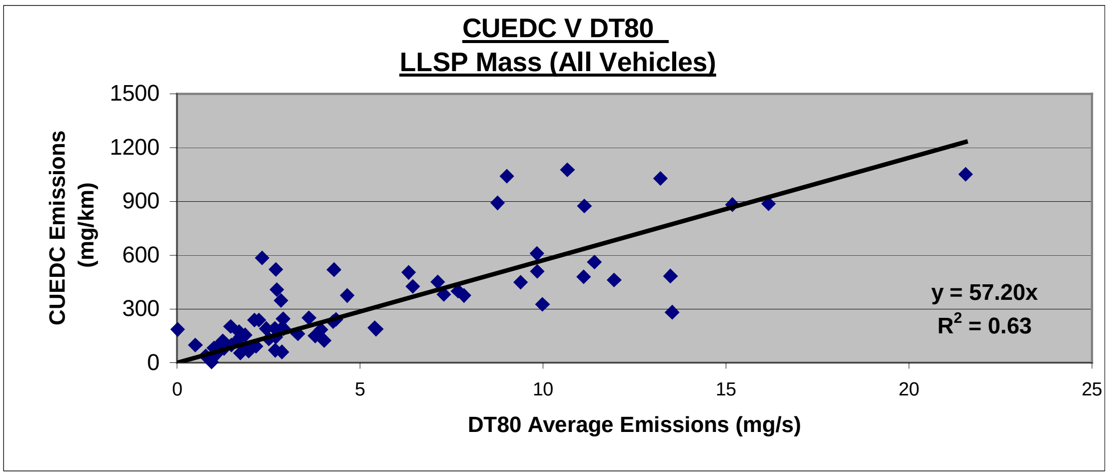


Figure A5-30

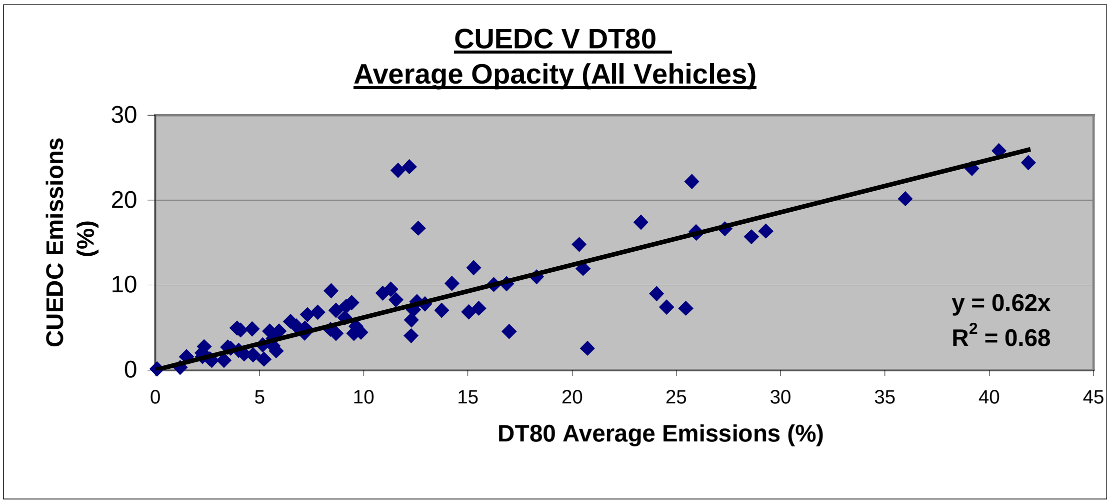


Figure A5-31

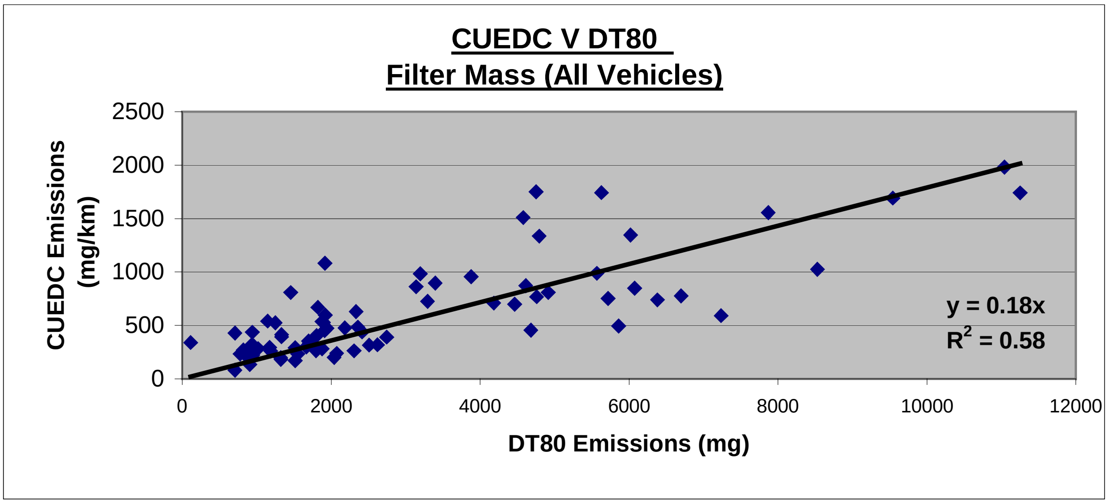


Figure A5-32

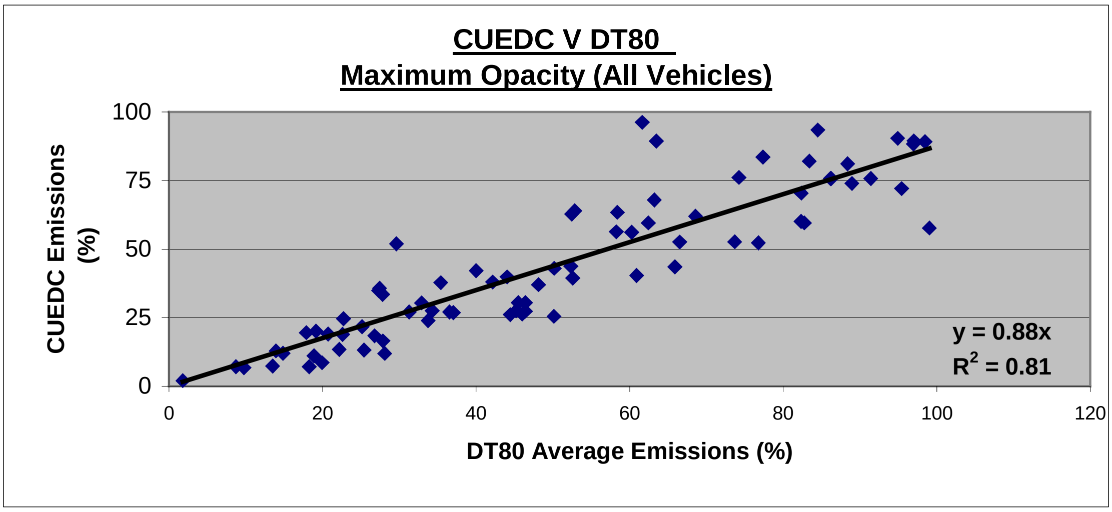


Figure A5-33

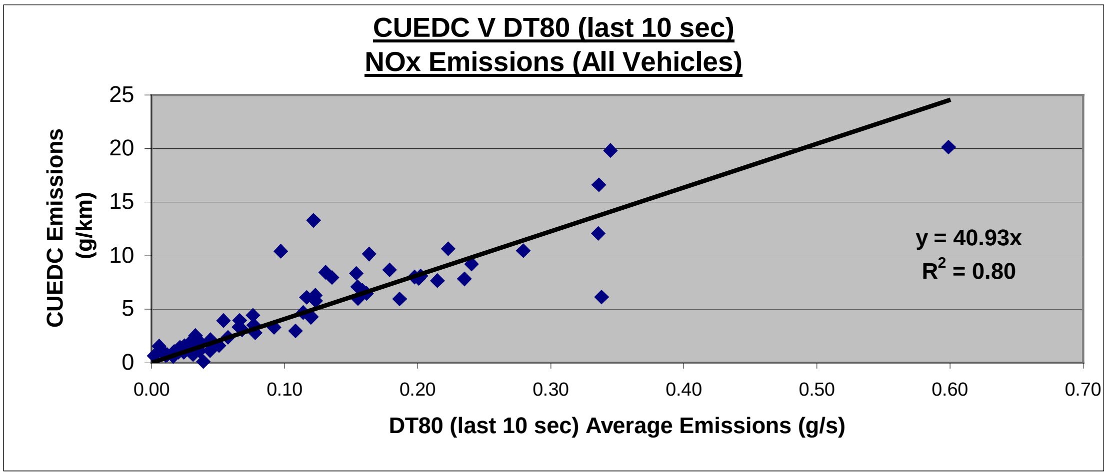


Figure A5-34

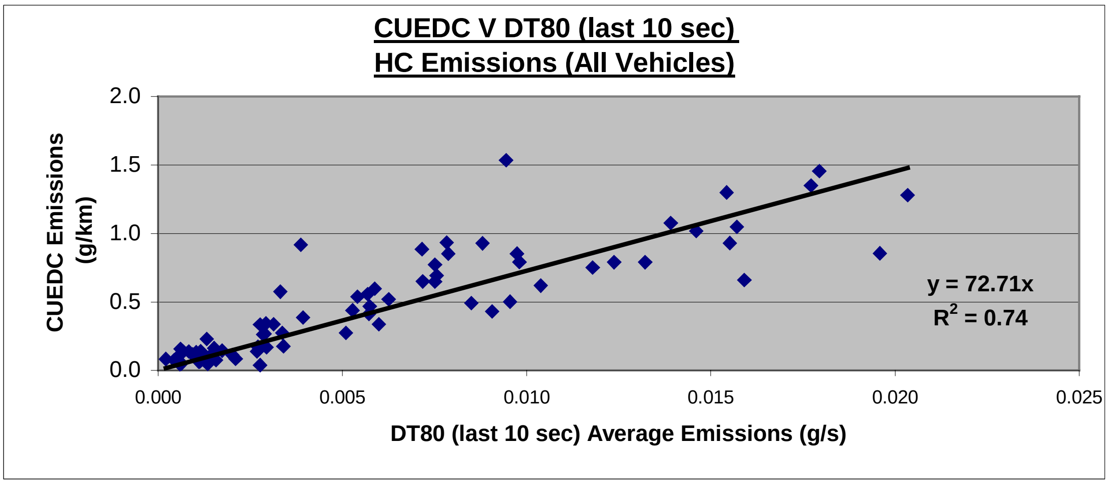


Figure A5-35

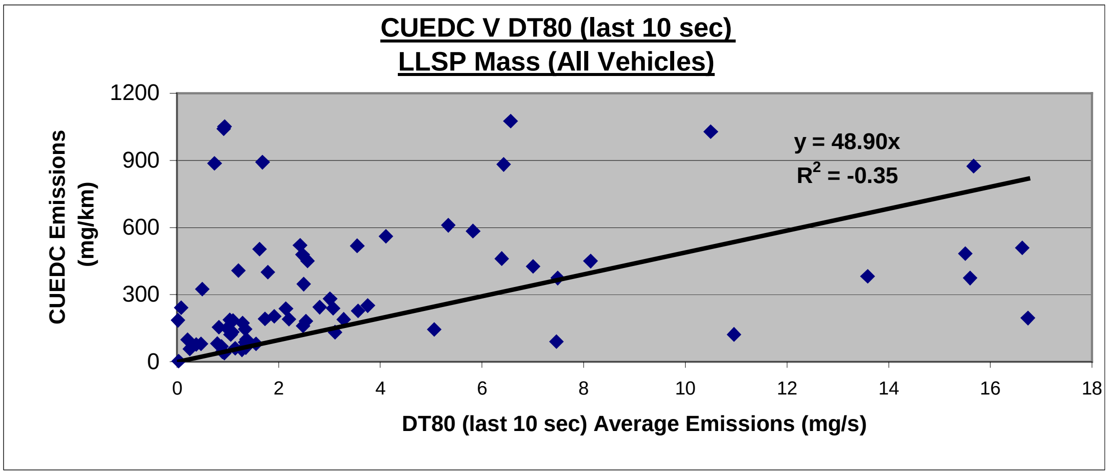


Figure A5-36

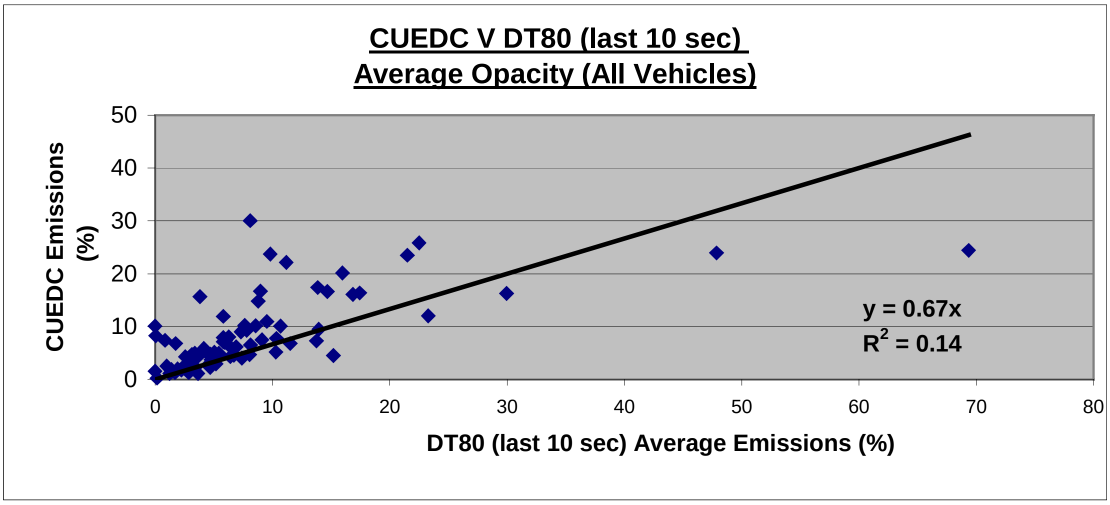


Figure A5-37

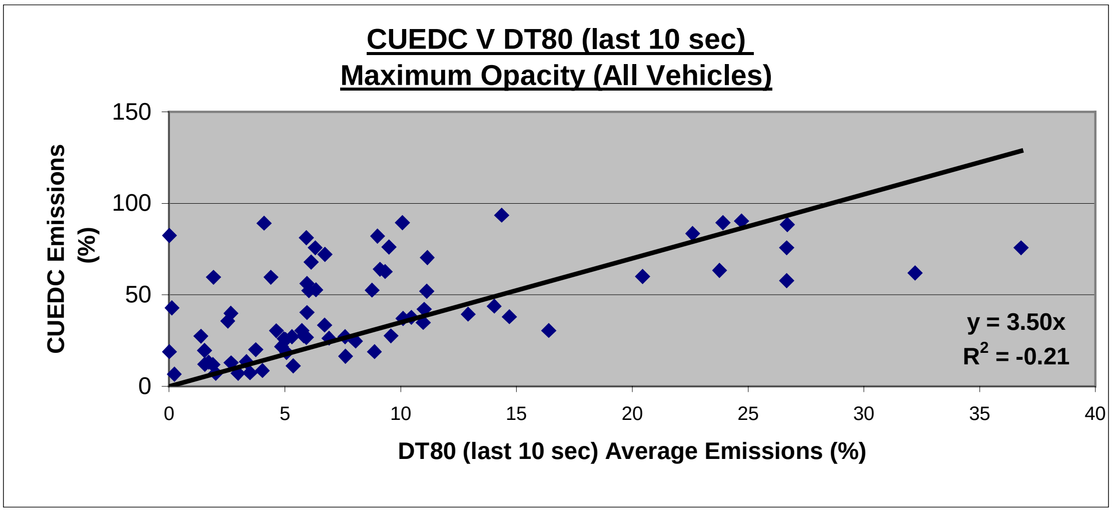


Figure A5-38

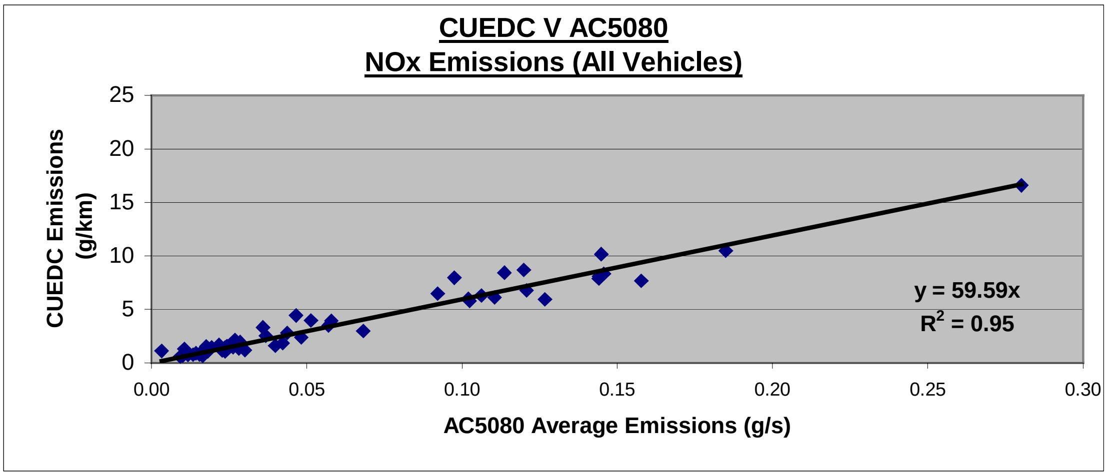


Figure A5-39

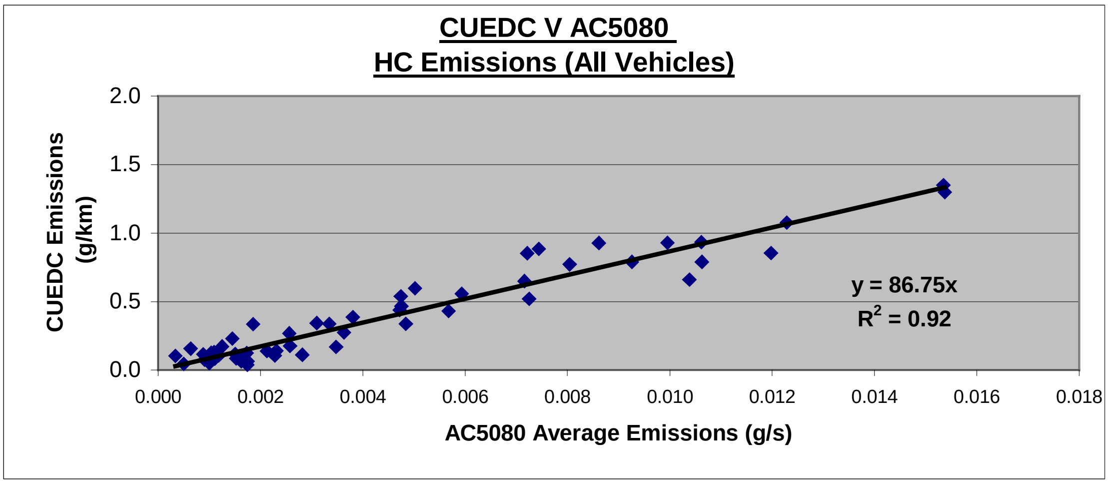


Figure A5-40

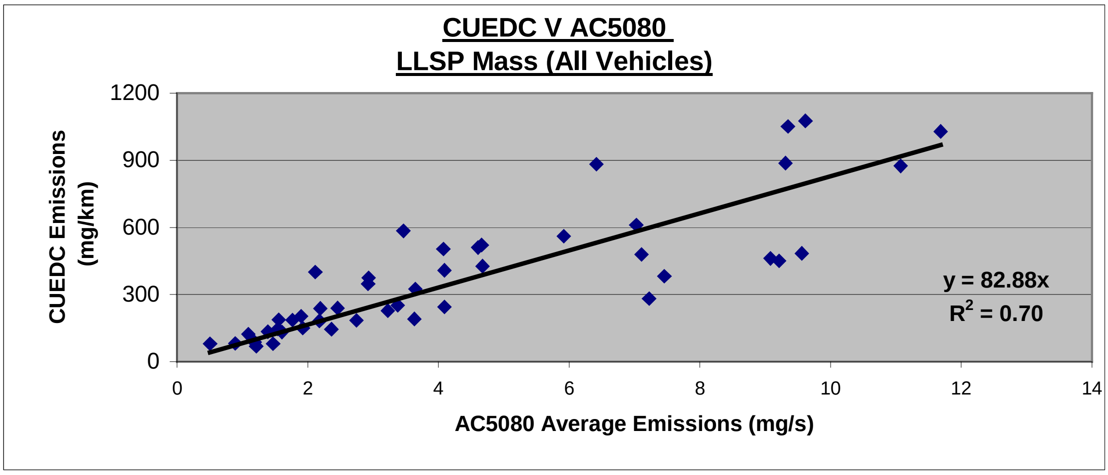


Figure A5-41

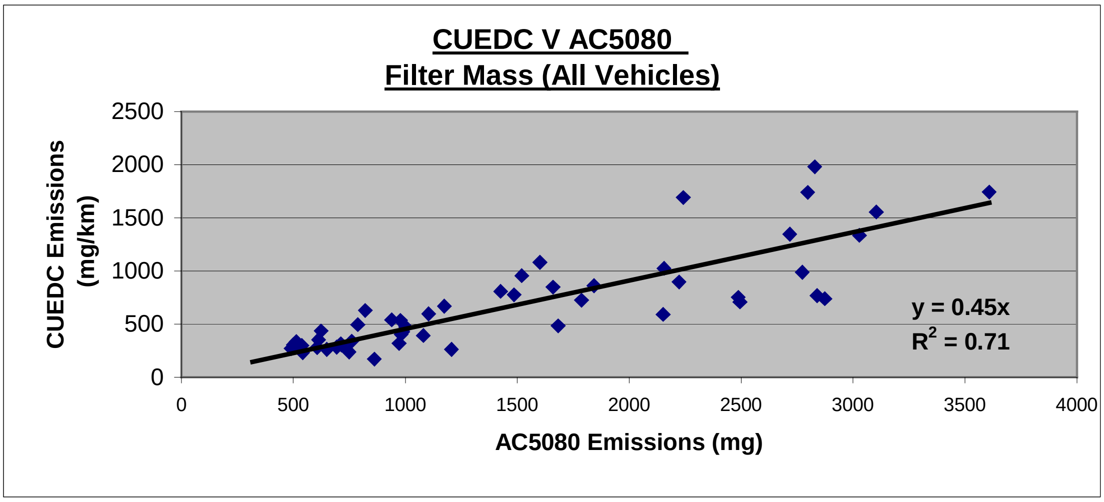


Figure A5-42

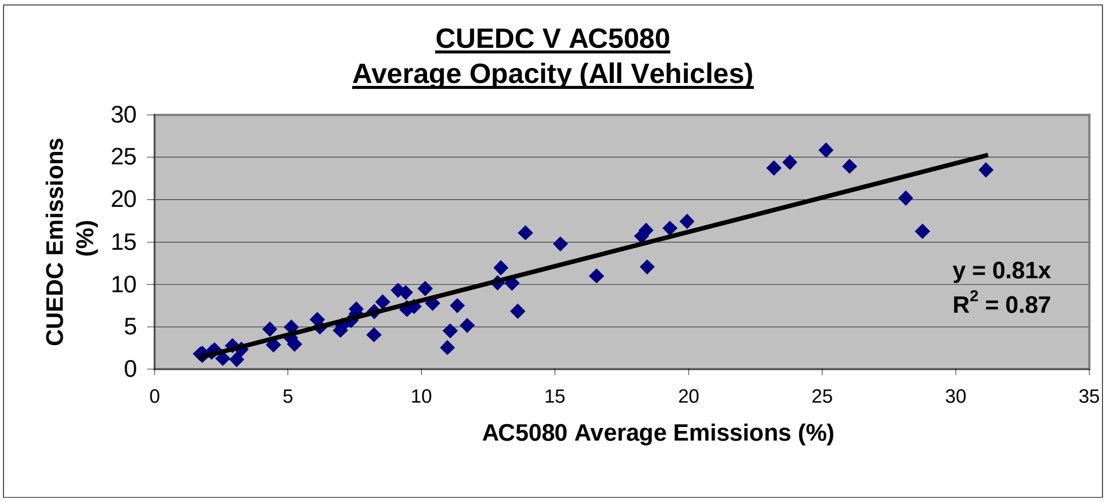


Figure A5-43

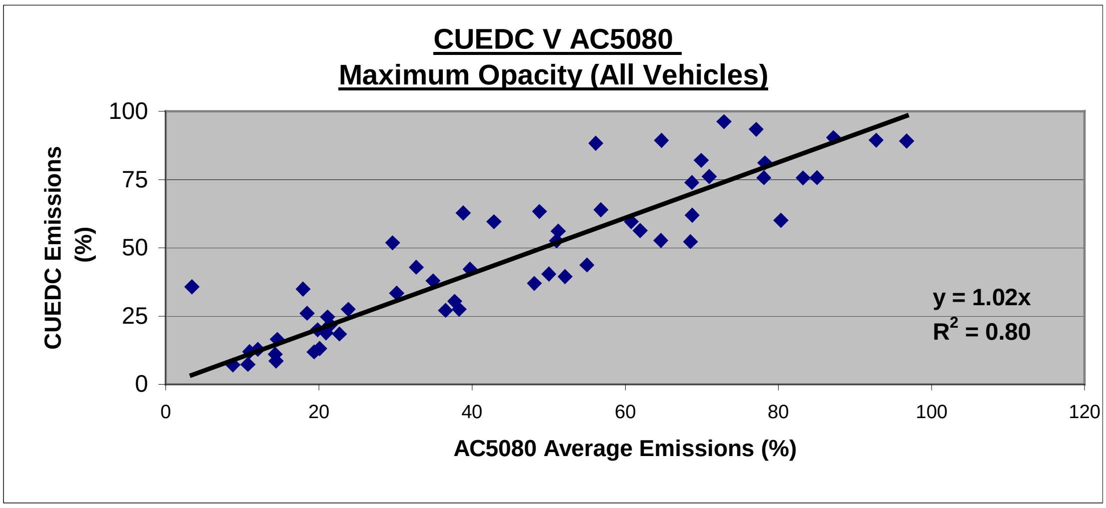


Figure A5-44

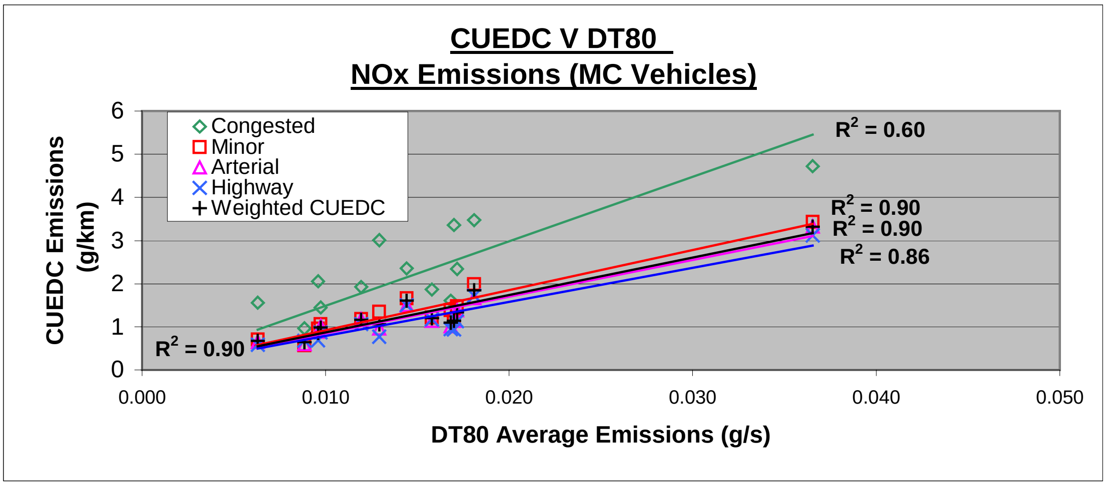


Figure A5-45

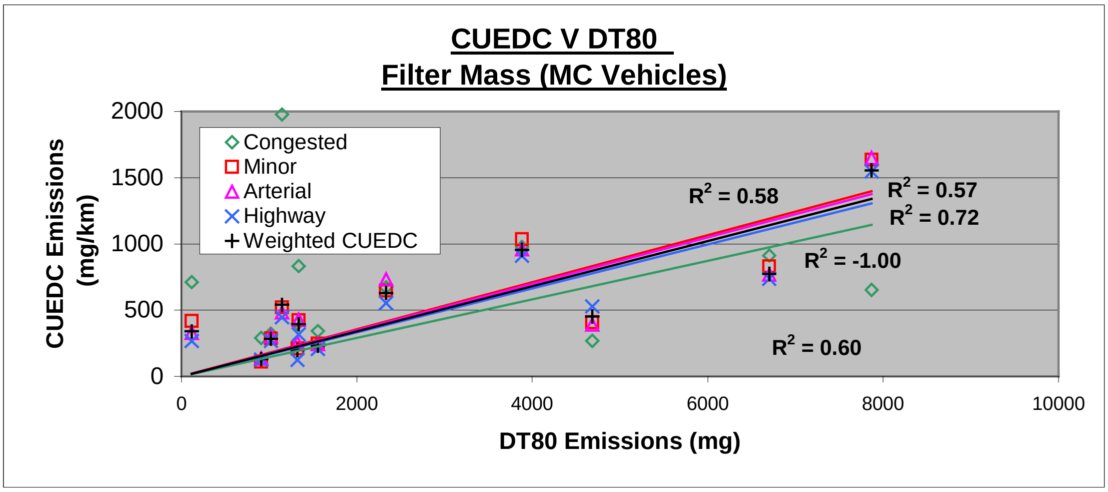


Figure A5-46

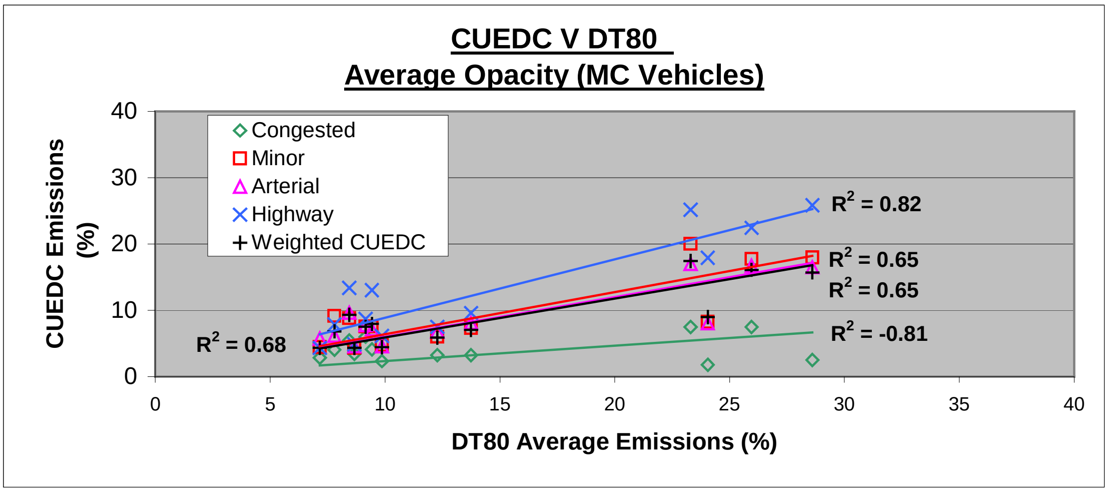


Figure A5-47

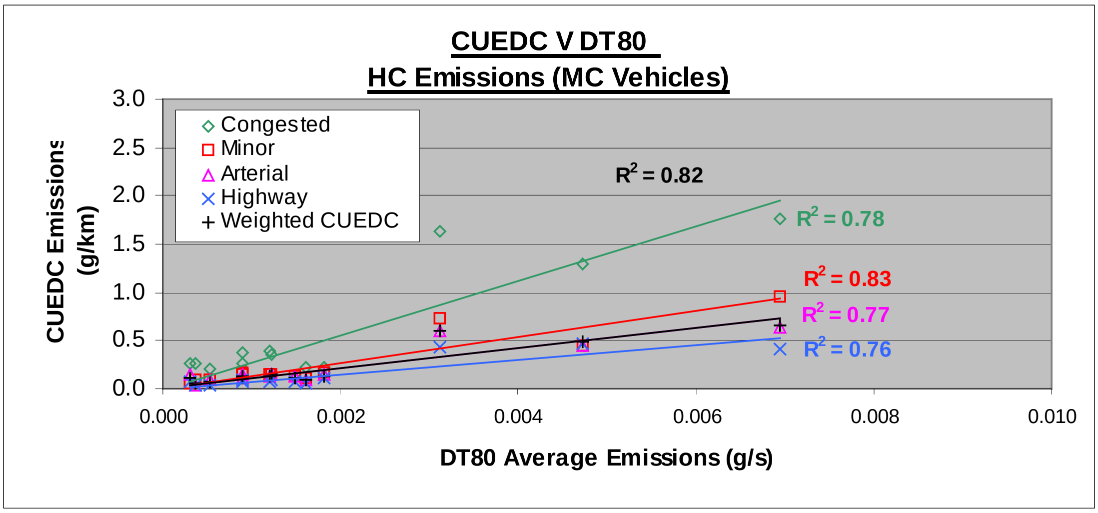


Figure A5-48

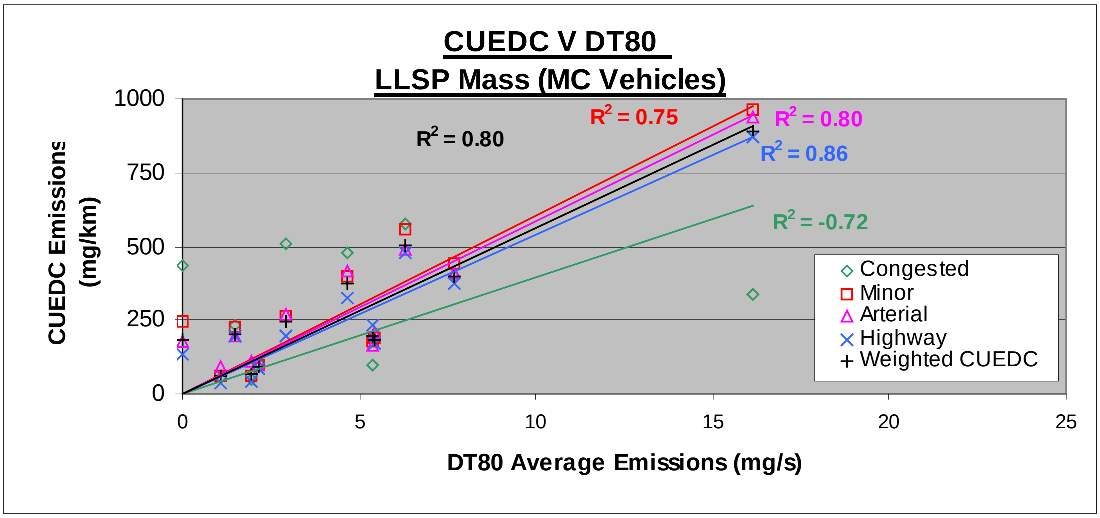


Figure A5-49

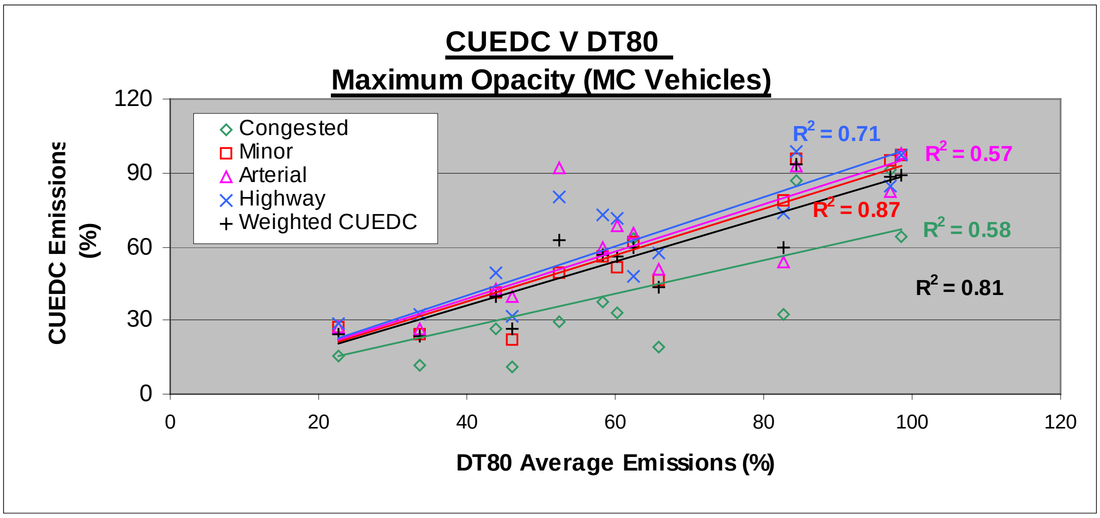


Figure A5-50

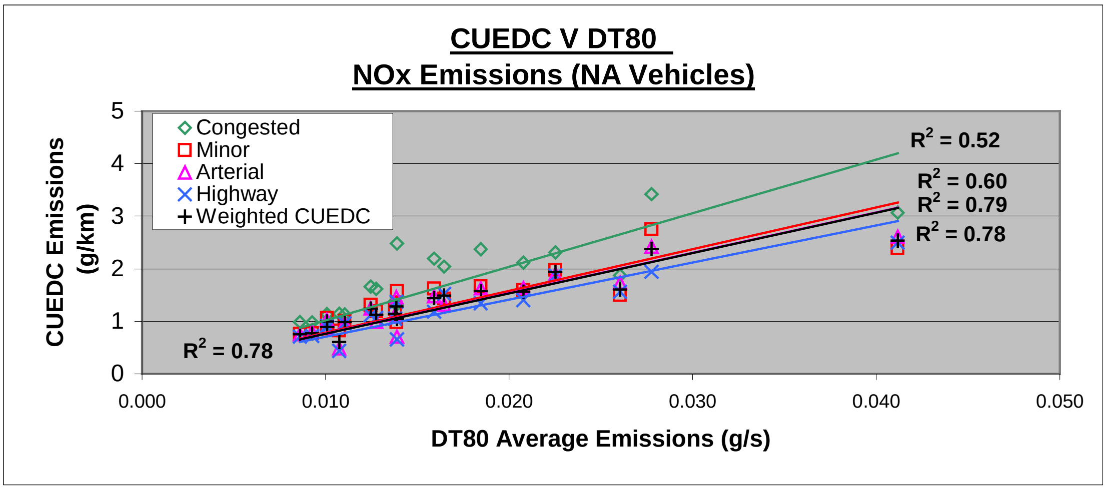


Figure A5-51

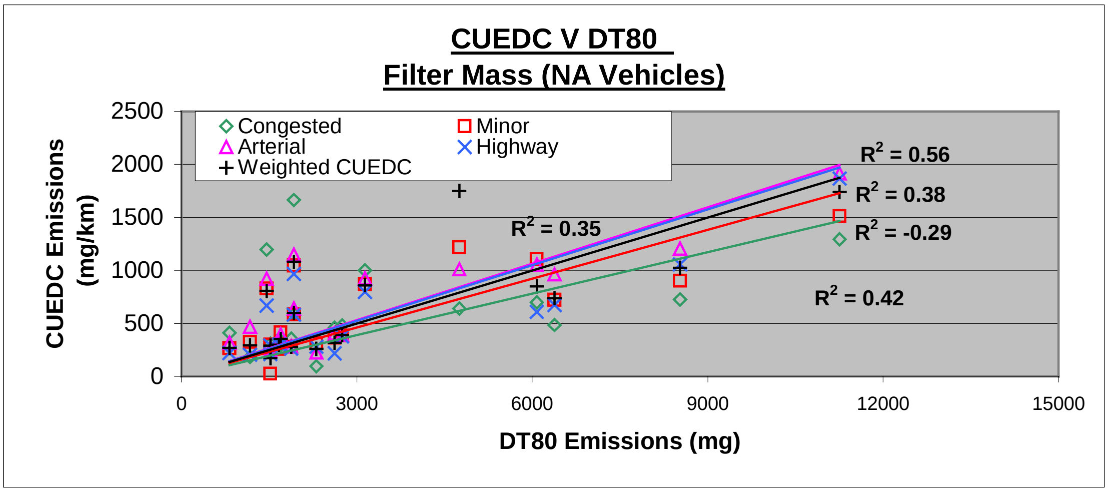


Figure A5-52

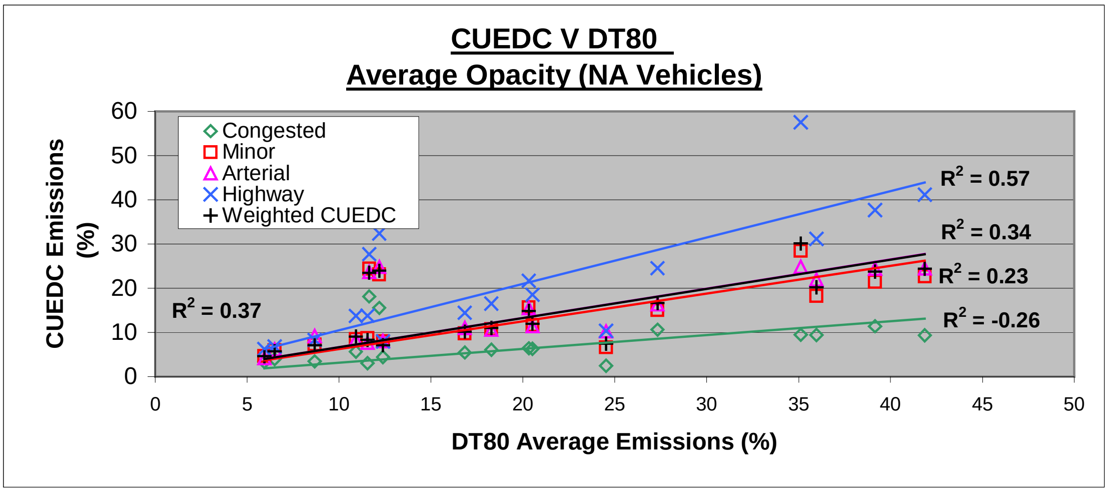


Figure A5-53

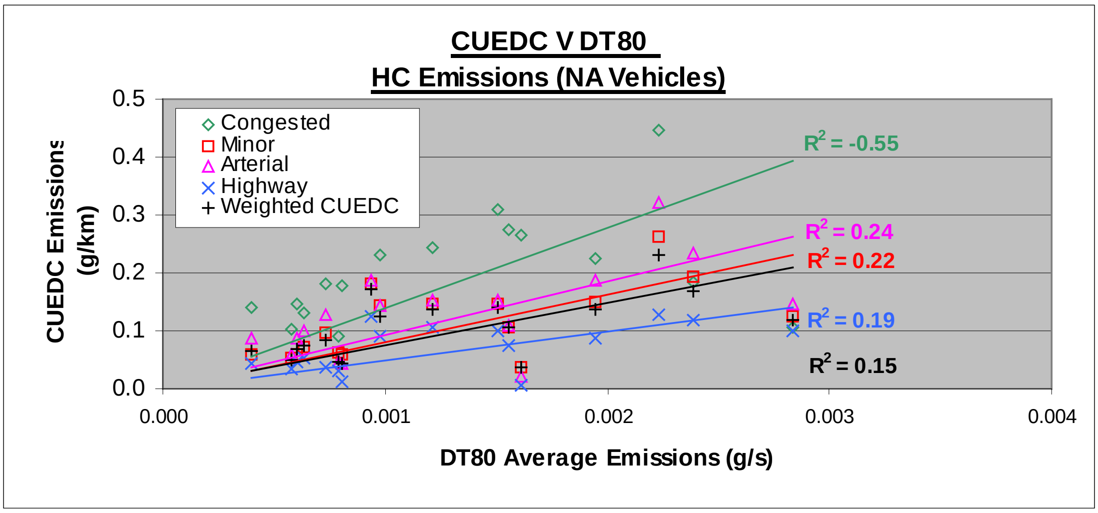


Figure A5-54

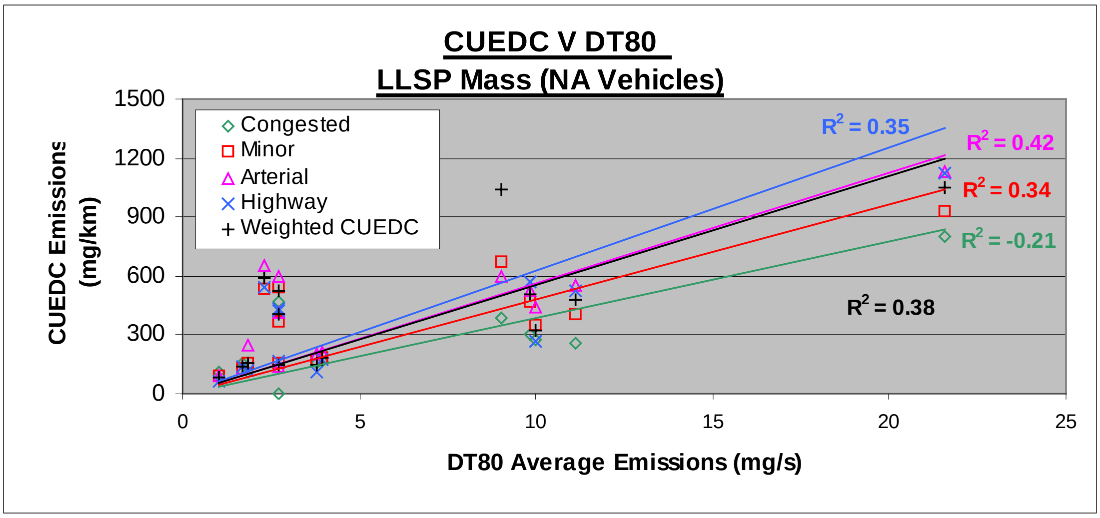


Figure A5-55

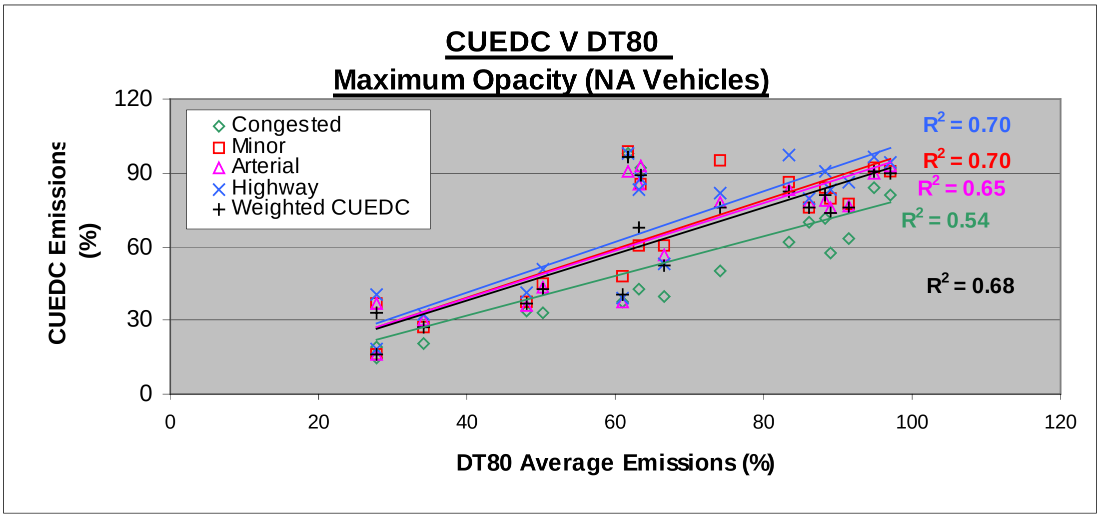


Figure A5-56

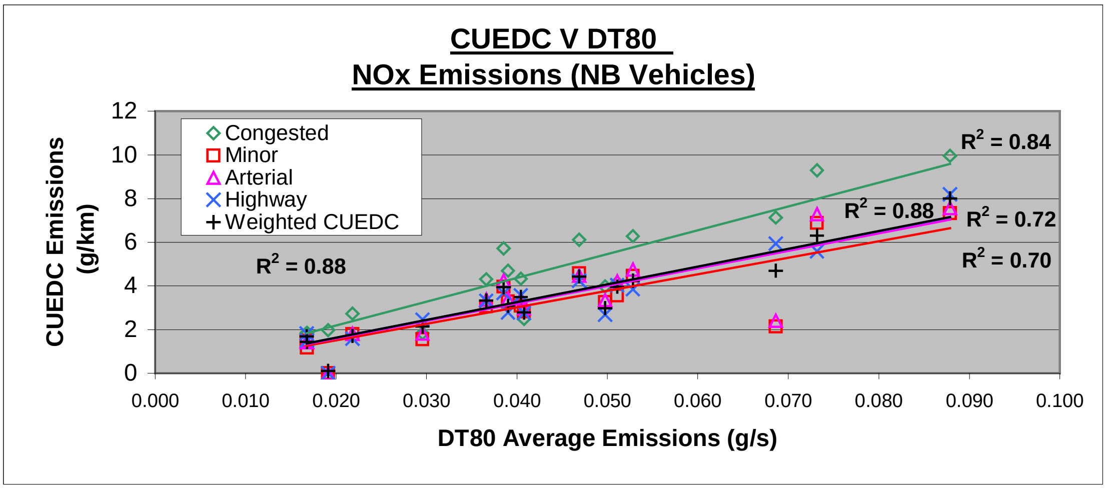


Figure A5-57

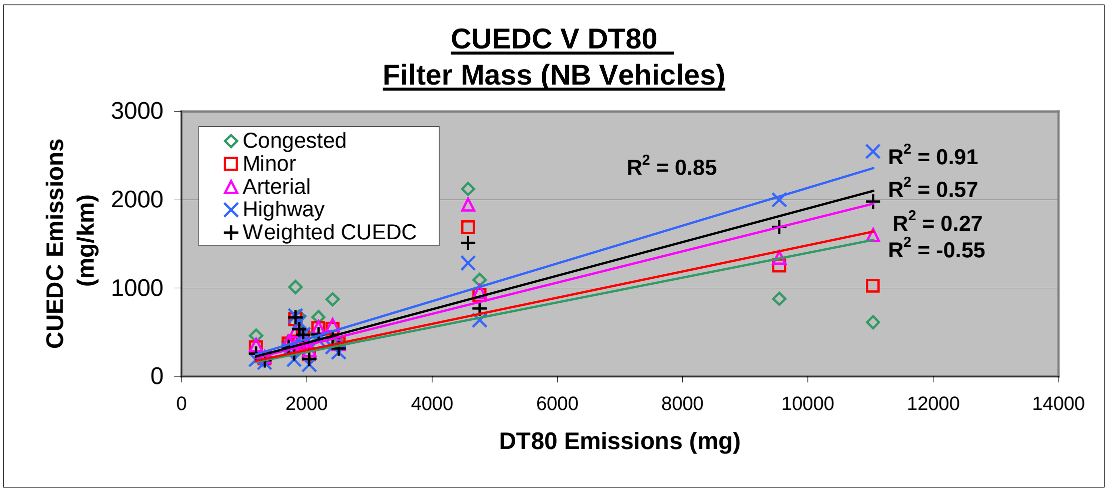


Figure A5-58

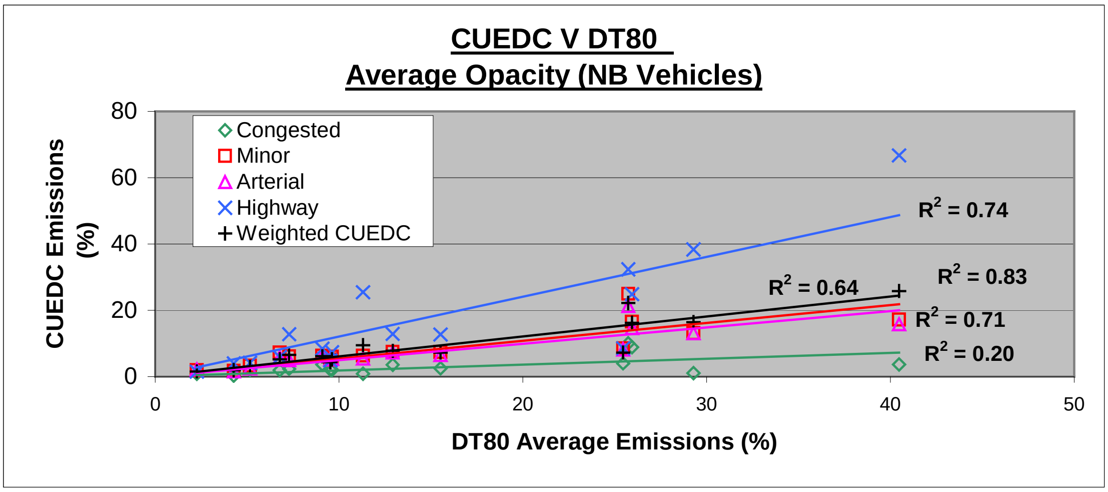


Figure A5-59

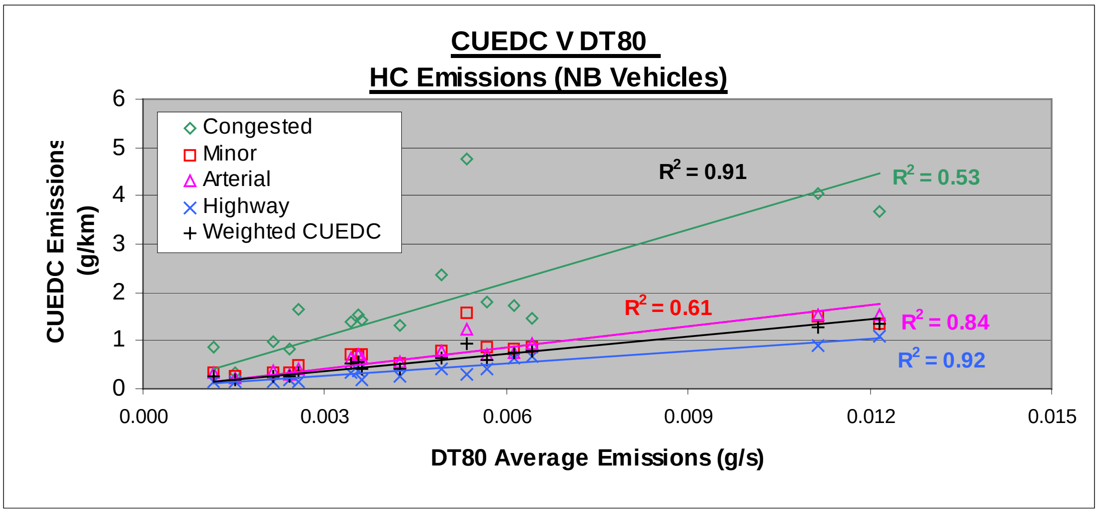


Figure A5-60

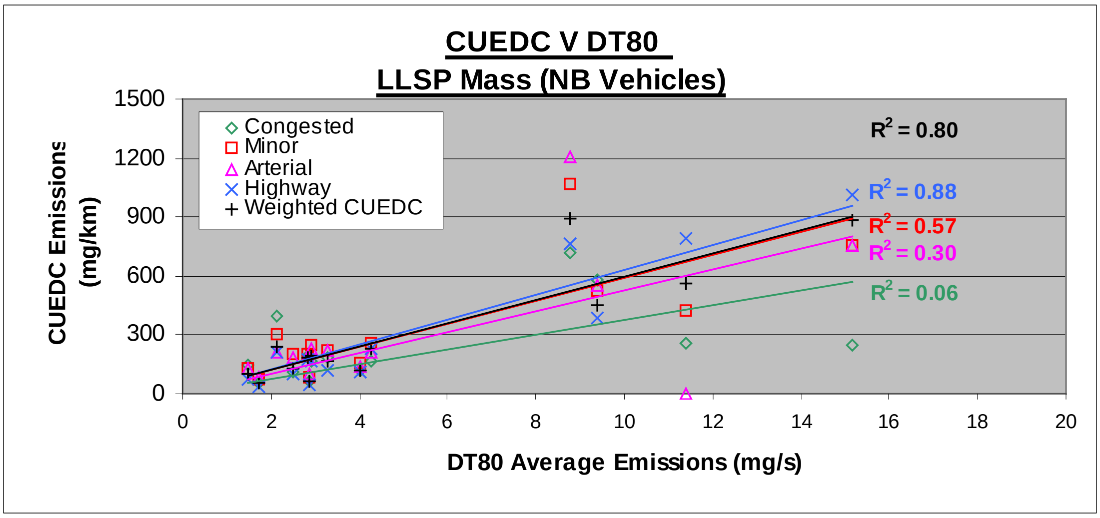


Figure A5-61

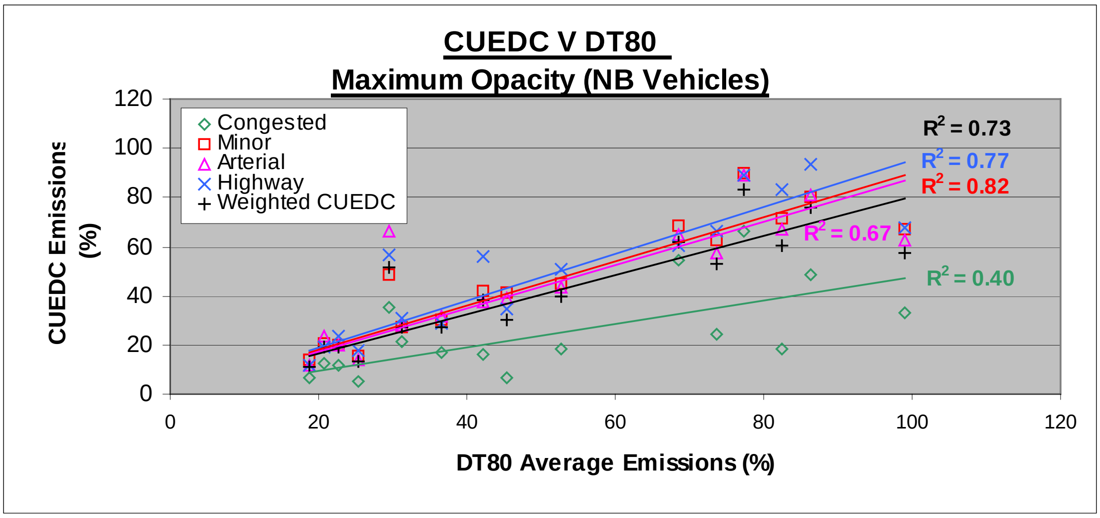


Figure A5-62

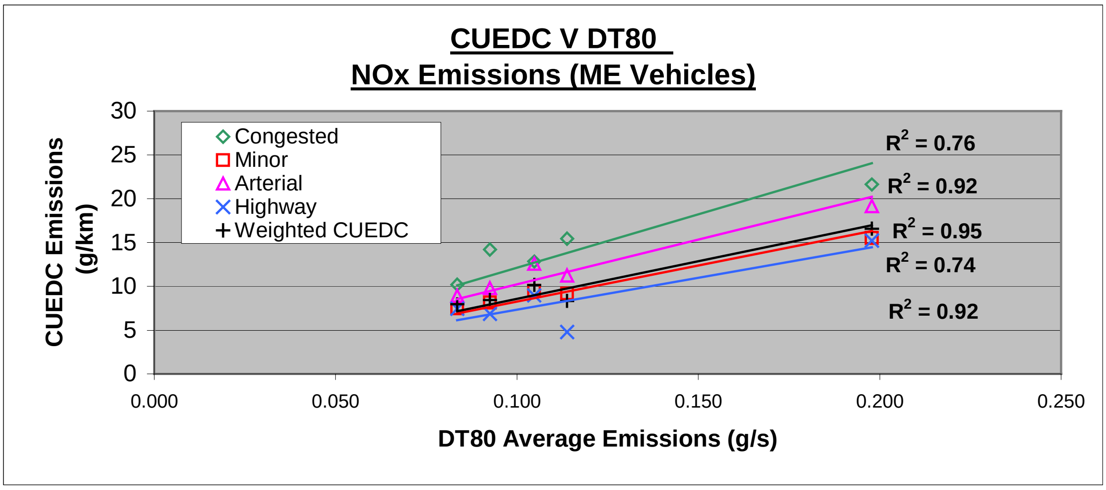


Figure A5-63

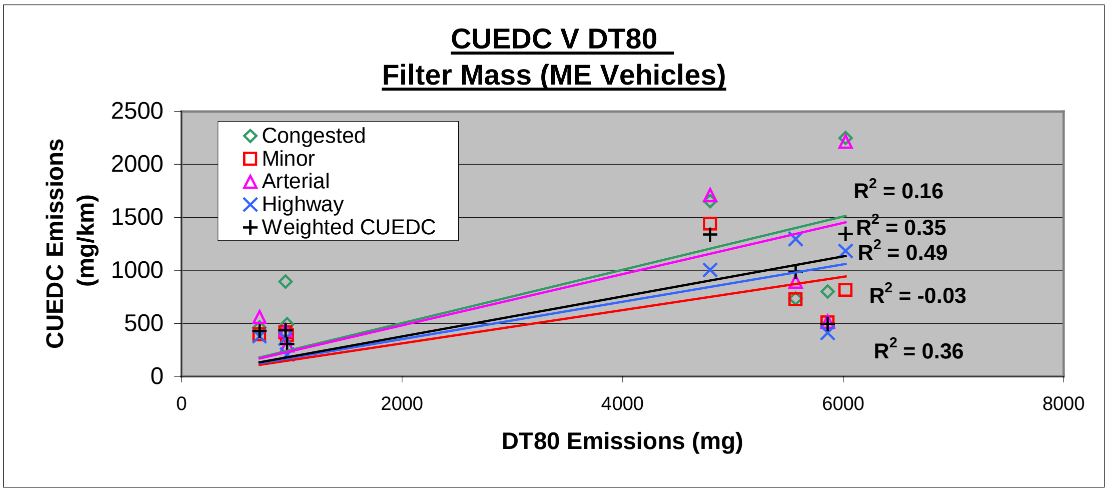


Figure A5-64

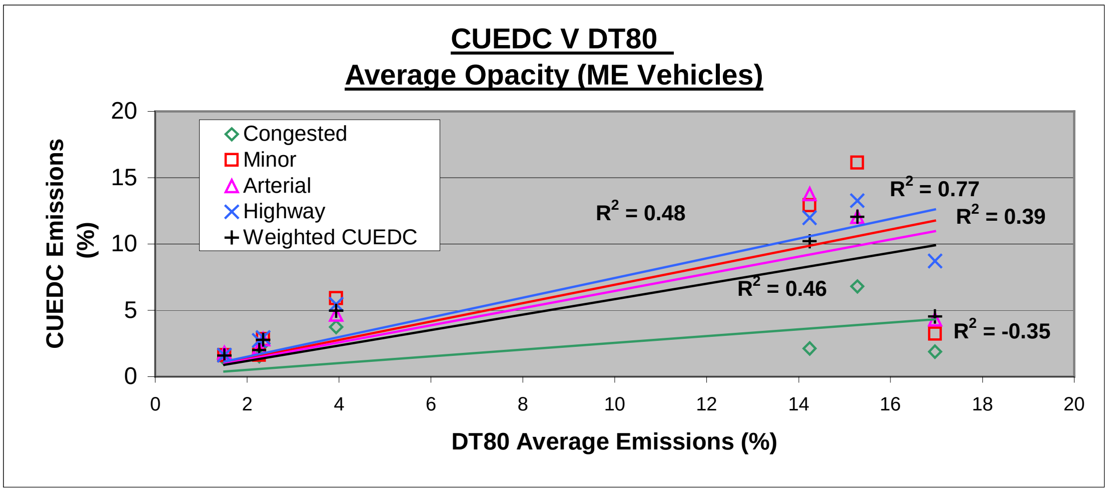


Figure A5-65

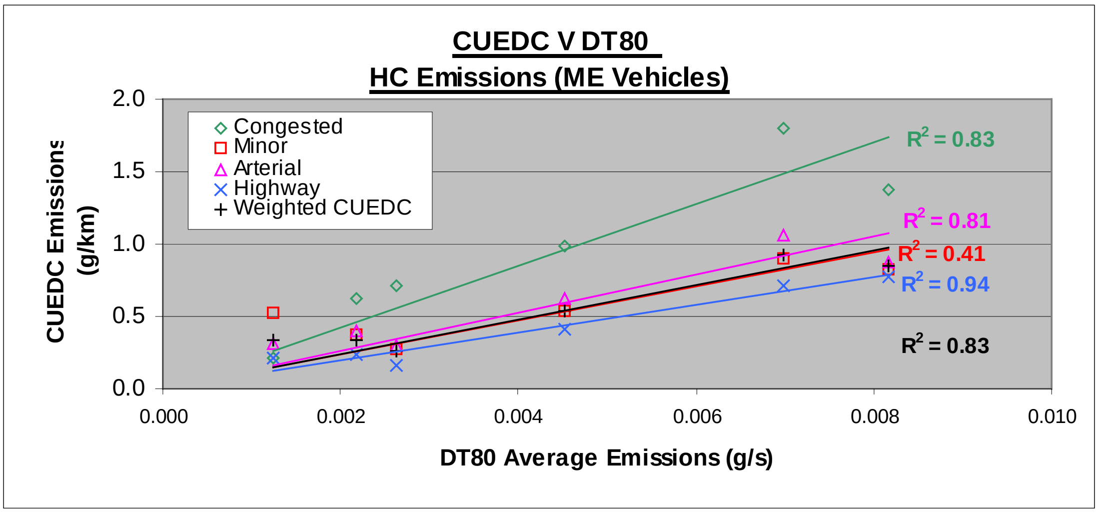


Figure A5-66

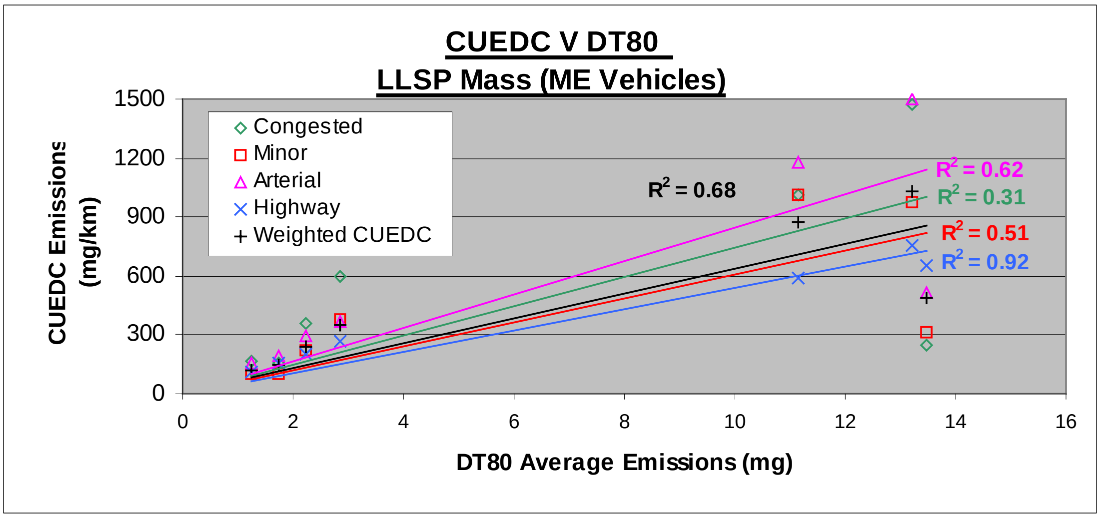


Figure A5-67

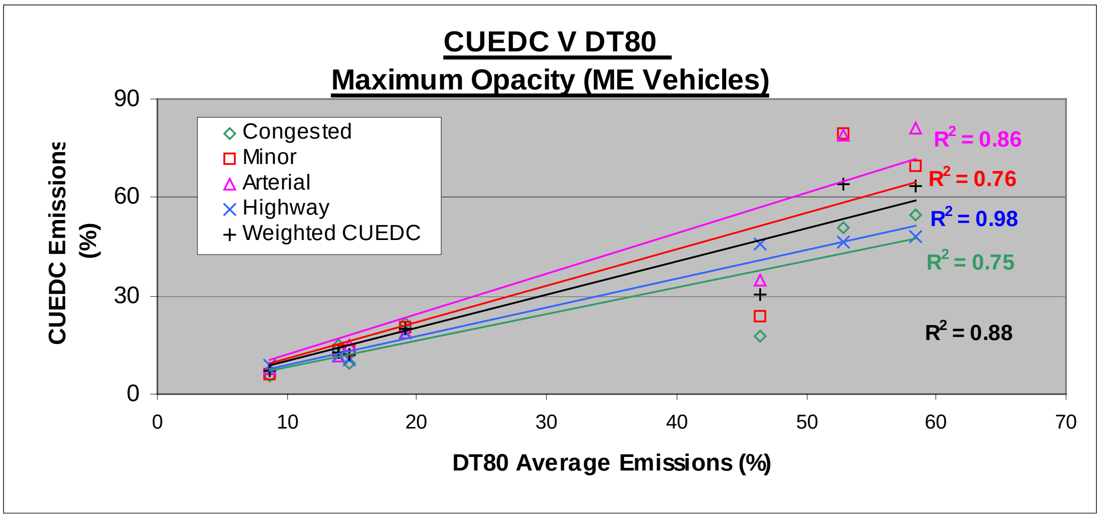


Figure A5-68

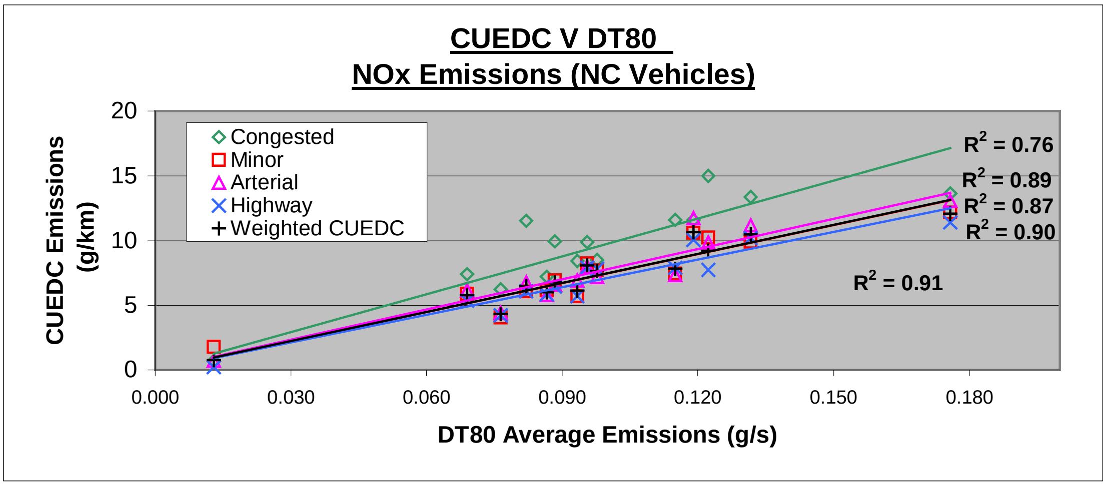


Figure A5-69

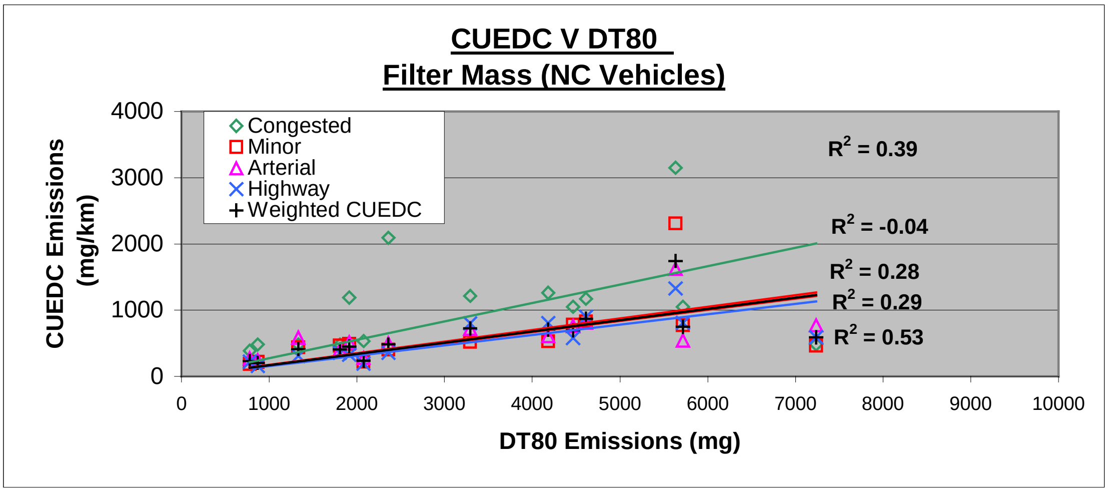


Figure A5-70

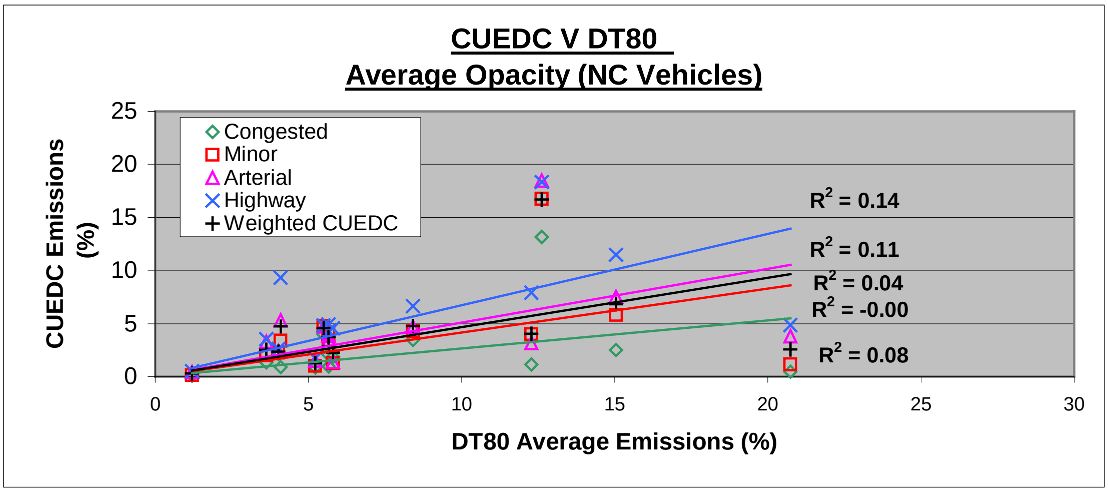


Figure A5-71

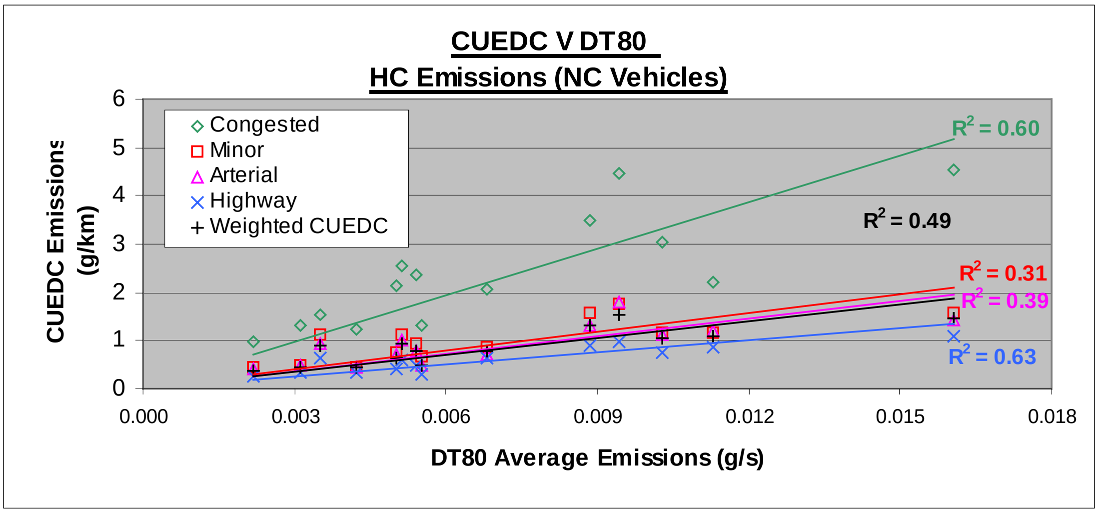


Figure A5-72

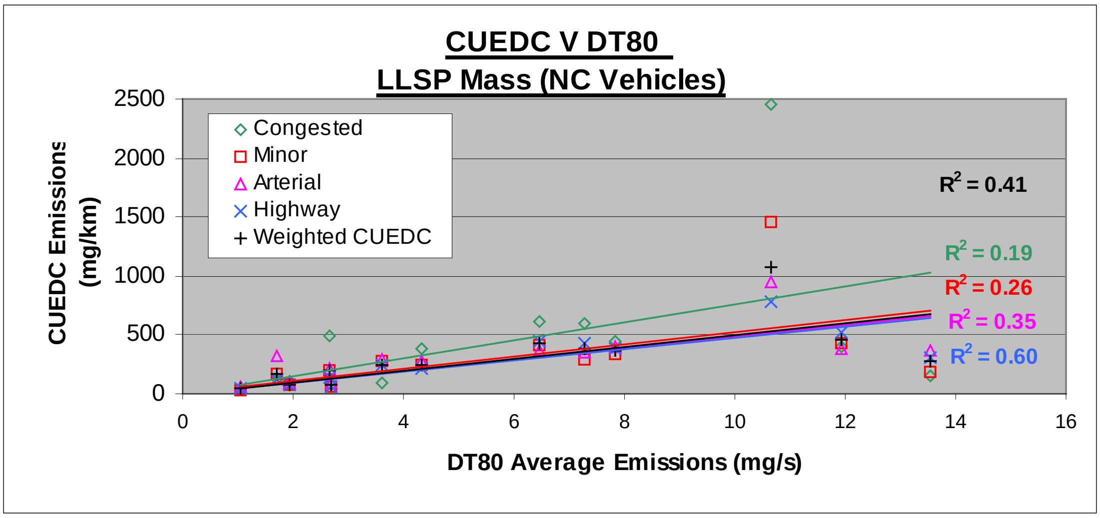


Figure A5-73

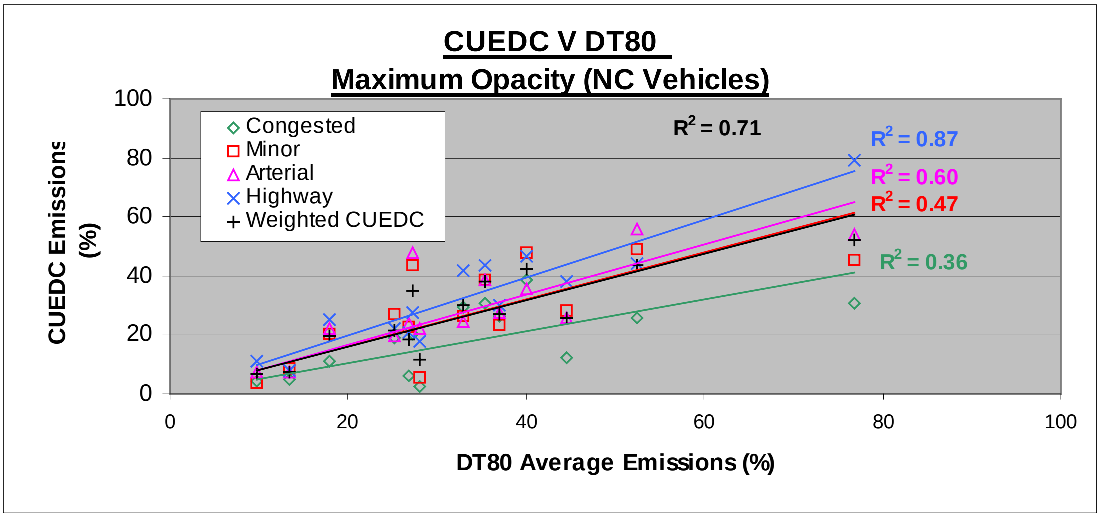


Figure A5-74

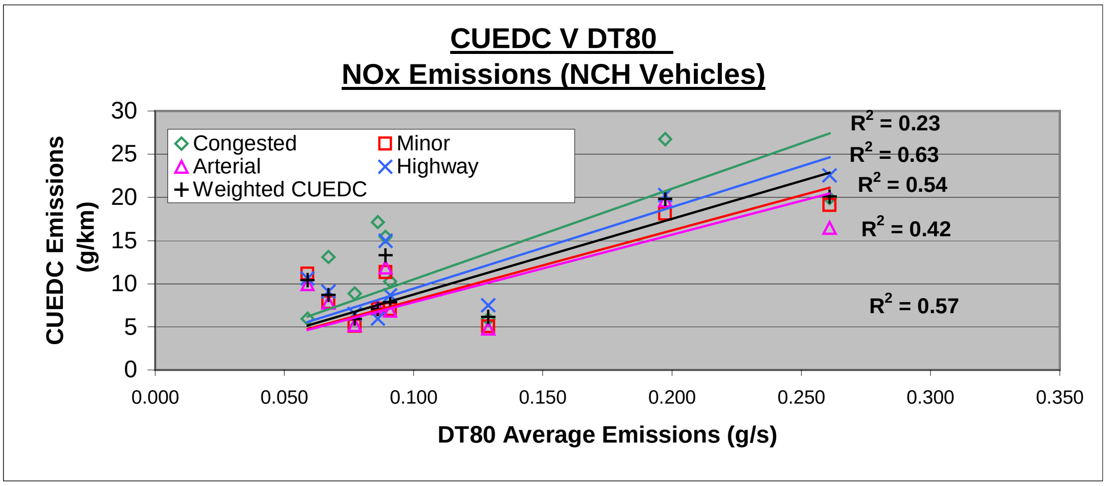


Figure A5-75

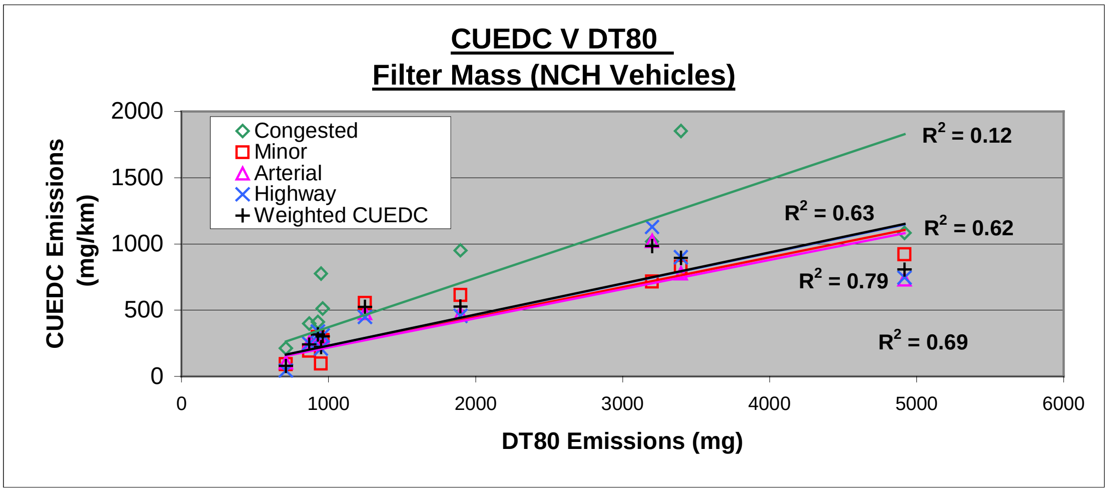


Figure A5-76

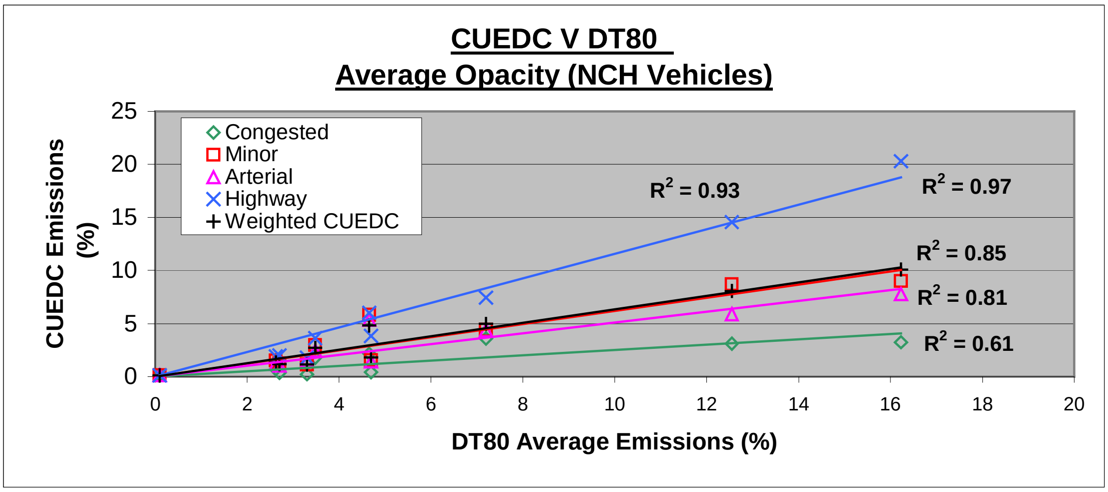


Figure A5-77

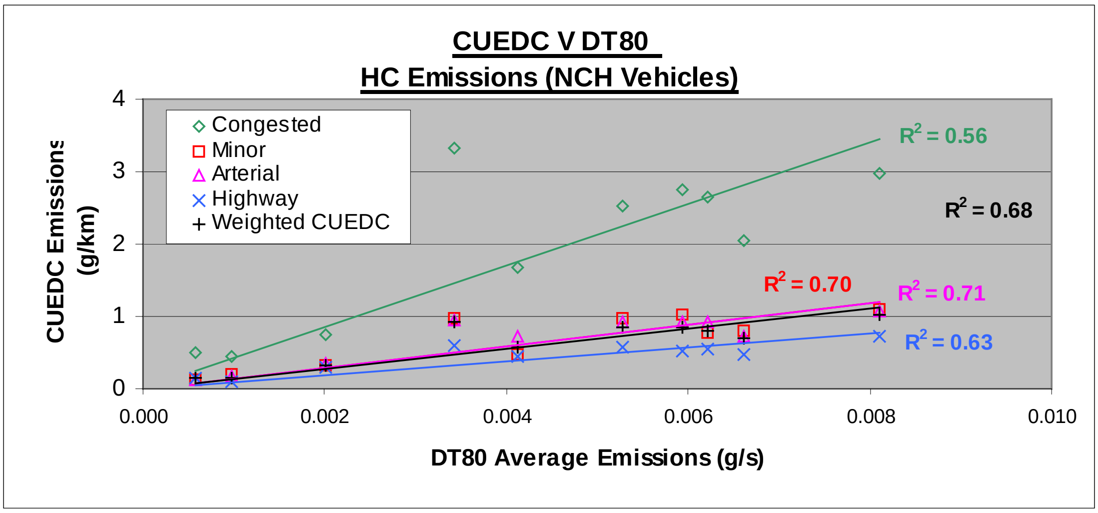


Figure A5-78

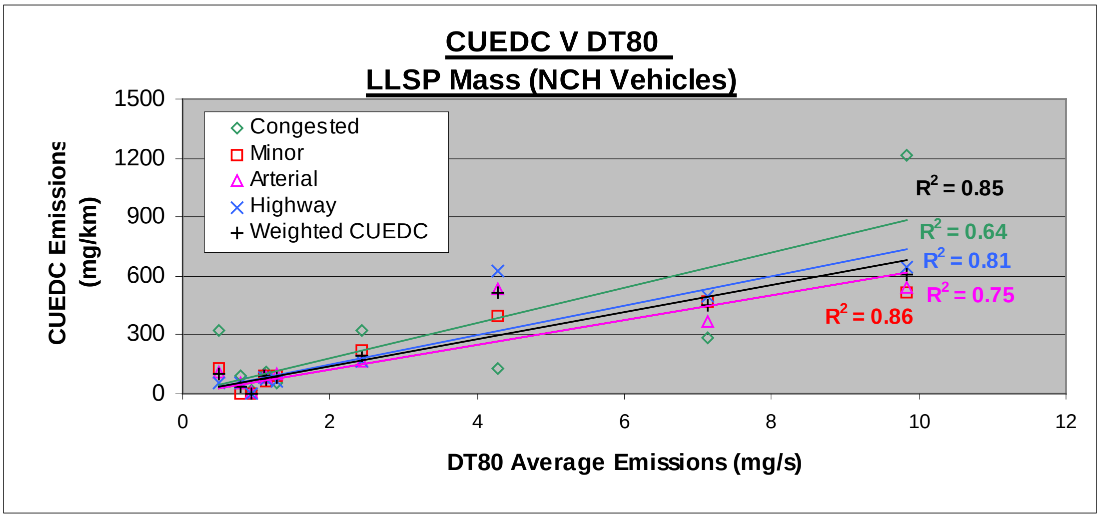


Figure A5-79

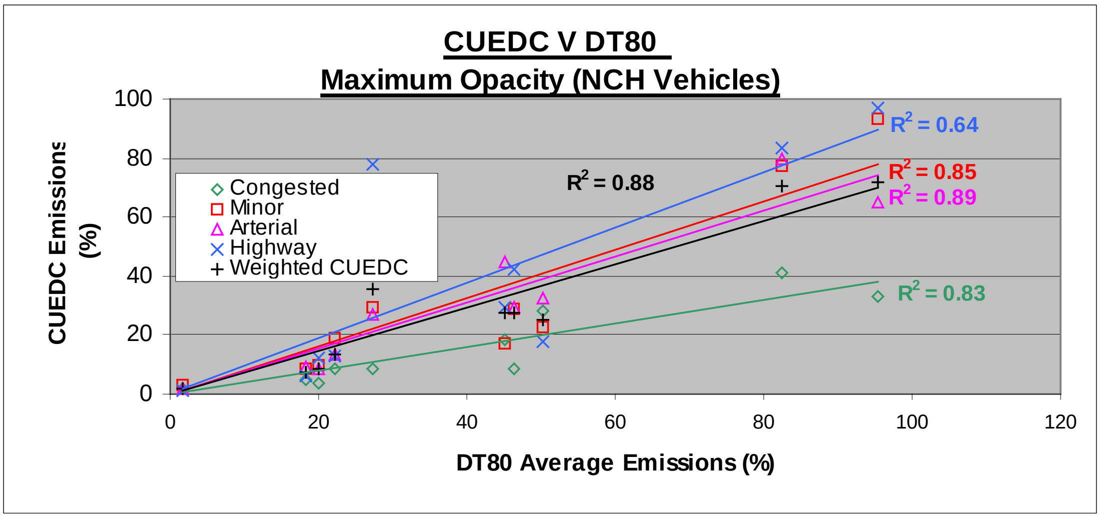


Figure A5-80

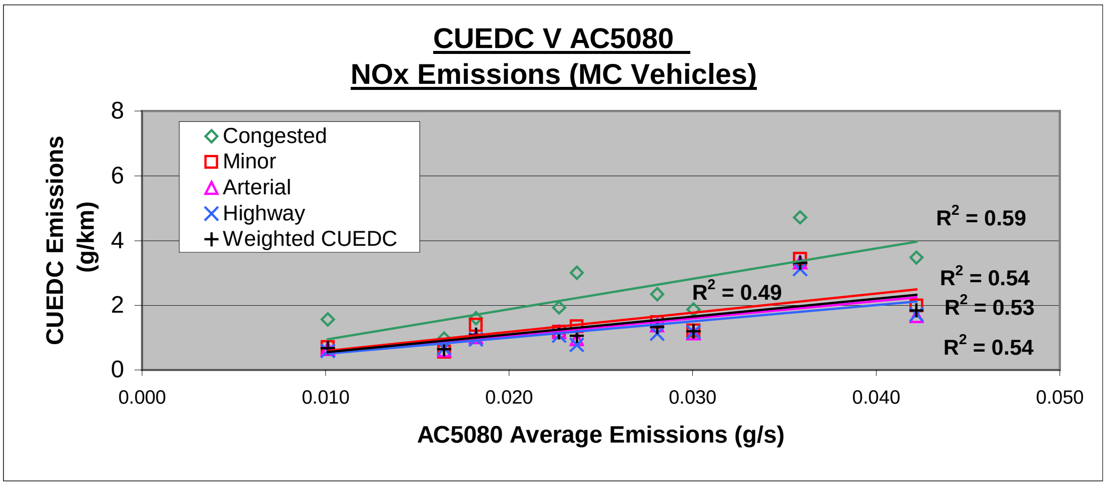


Figure A5-81

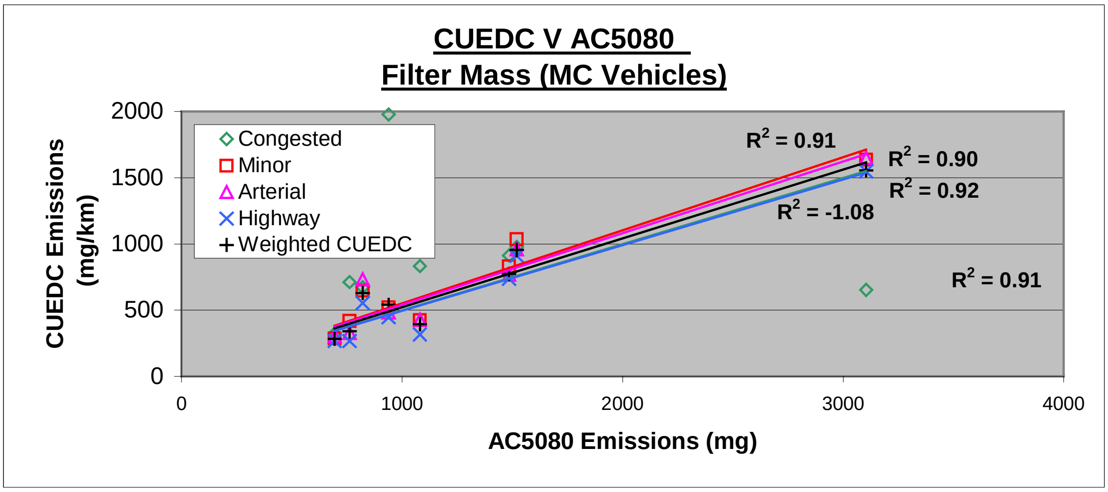


Figure A5-82

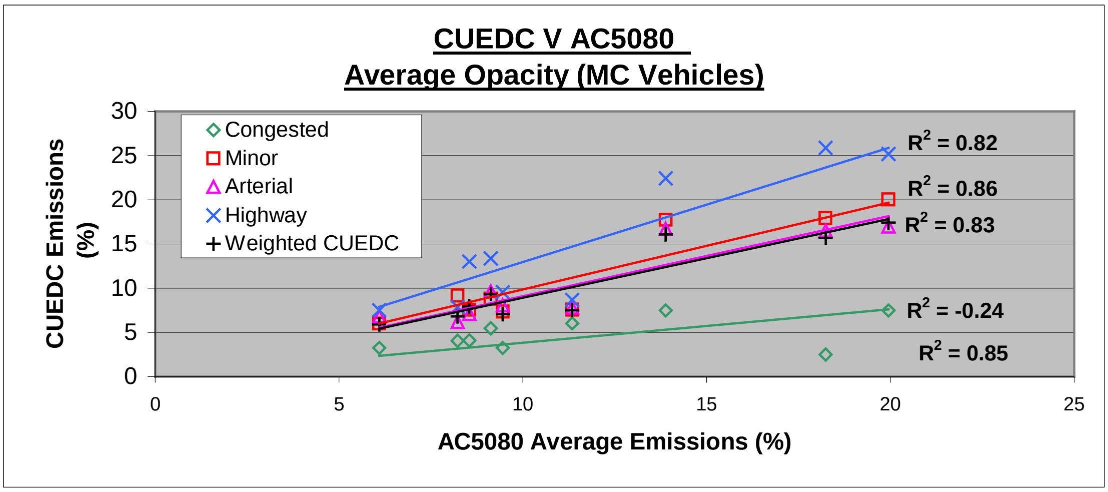


Figure A5-83

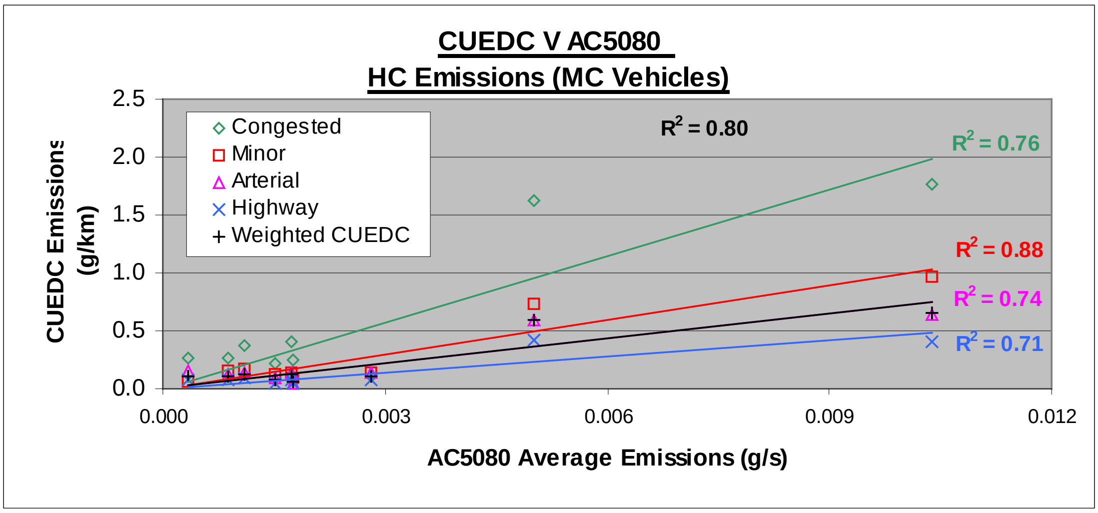


Figure A5-84

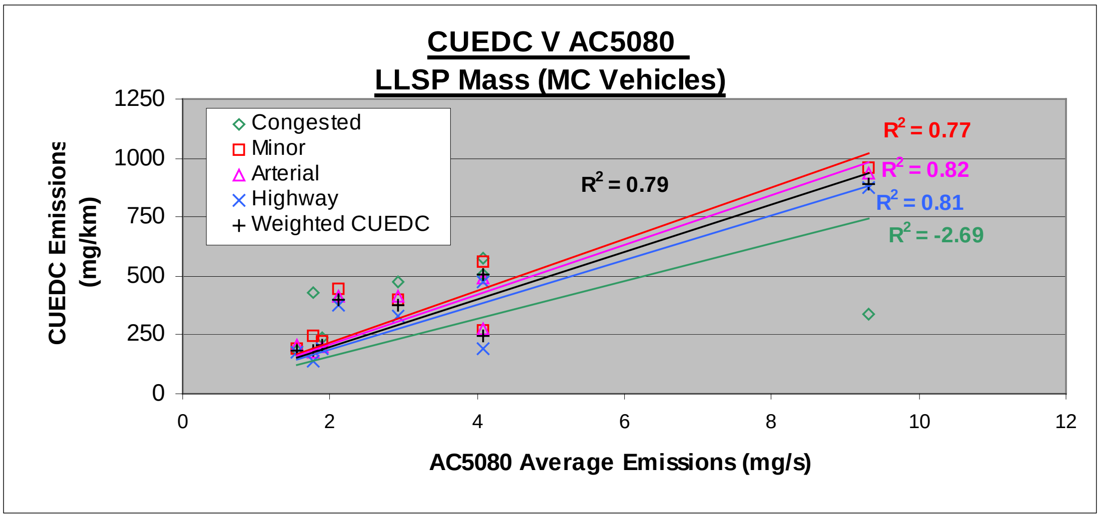


Figure A5-85

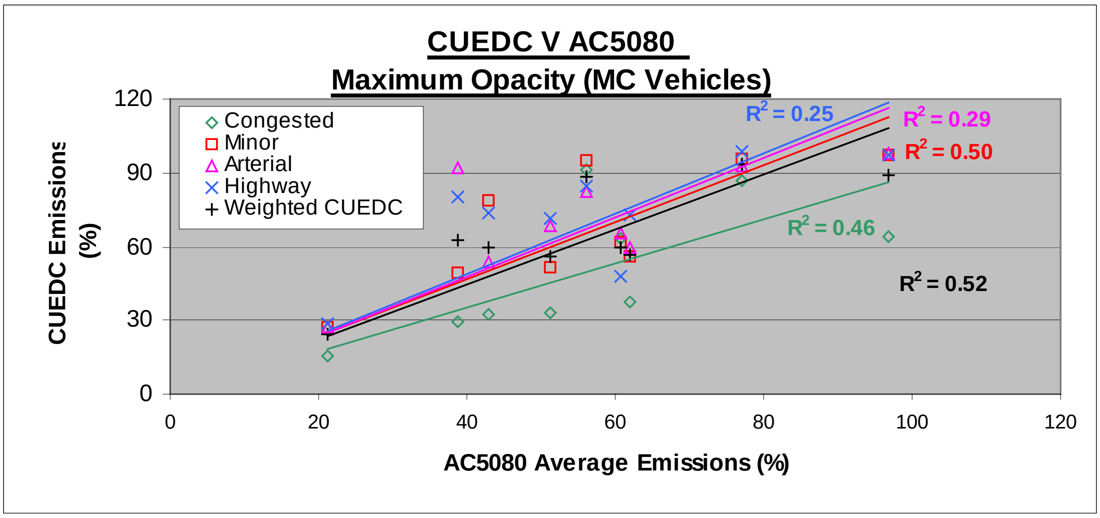


Figure A5-86

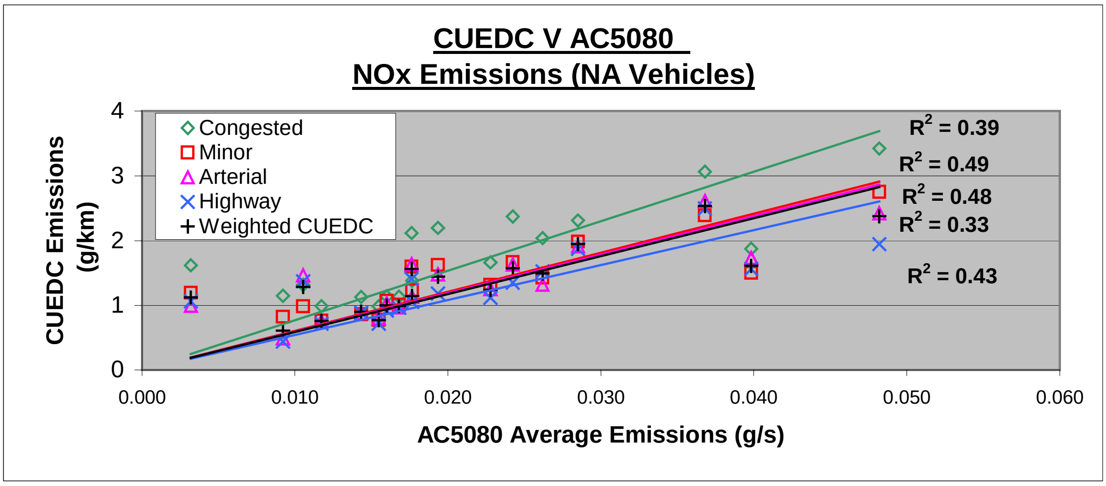


Figure A5-87

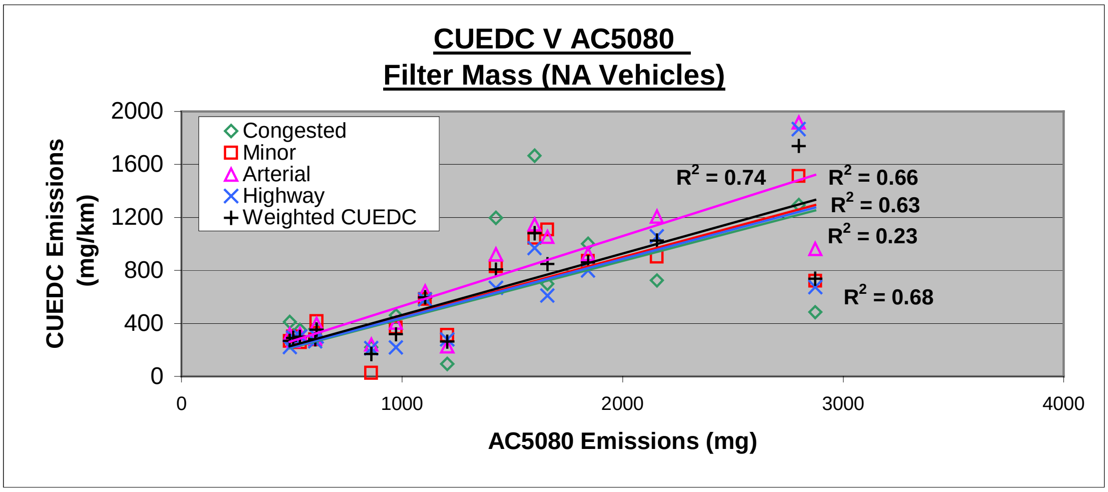


Figure A5-88

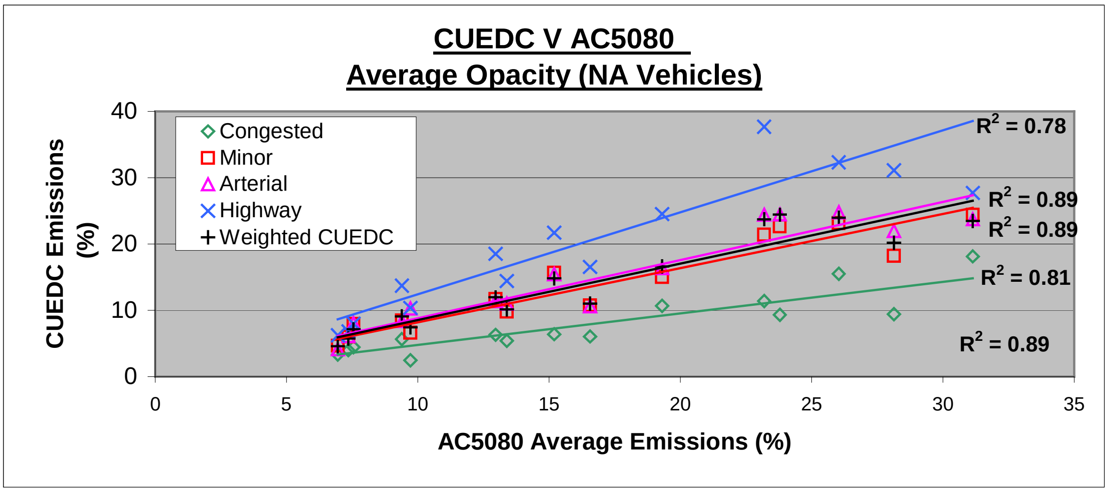


Figure A5-89

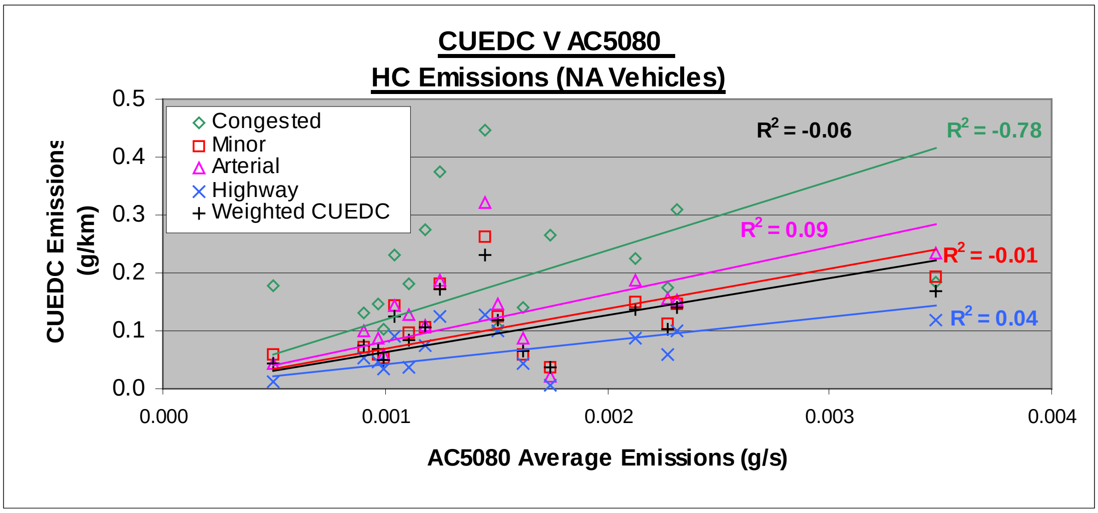


Figure A5-90

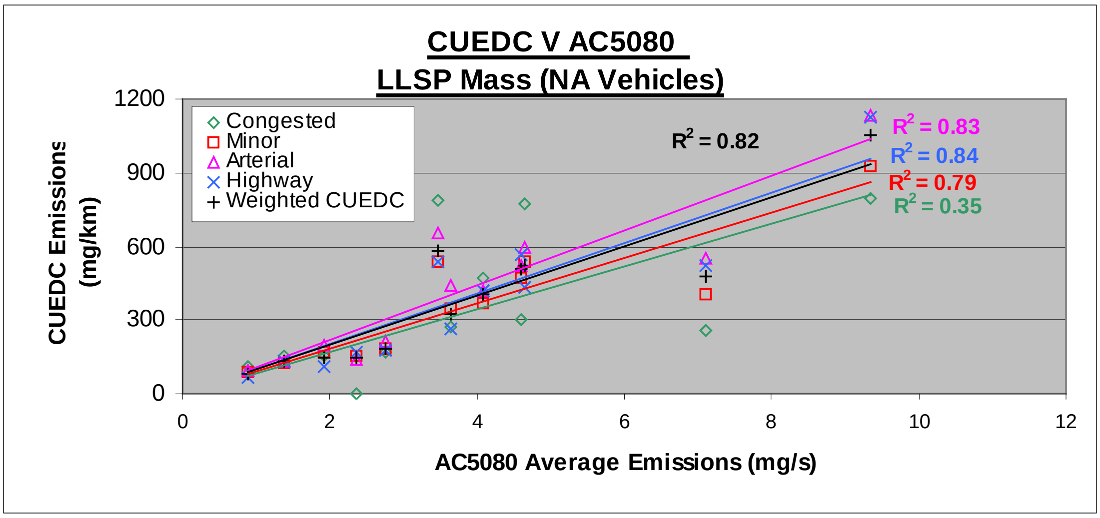


Figure A5-91

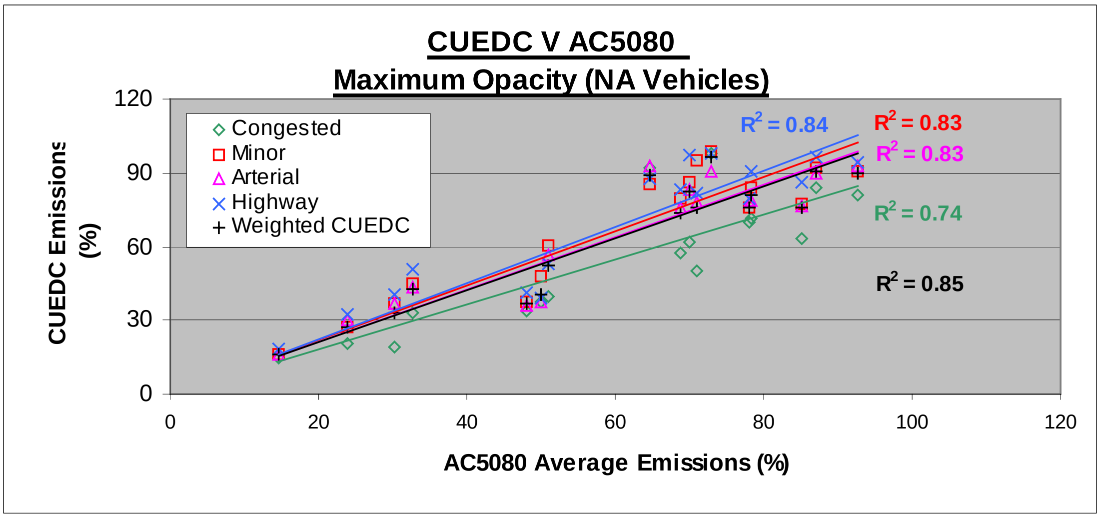


Figure A5-92

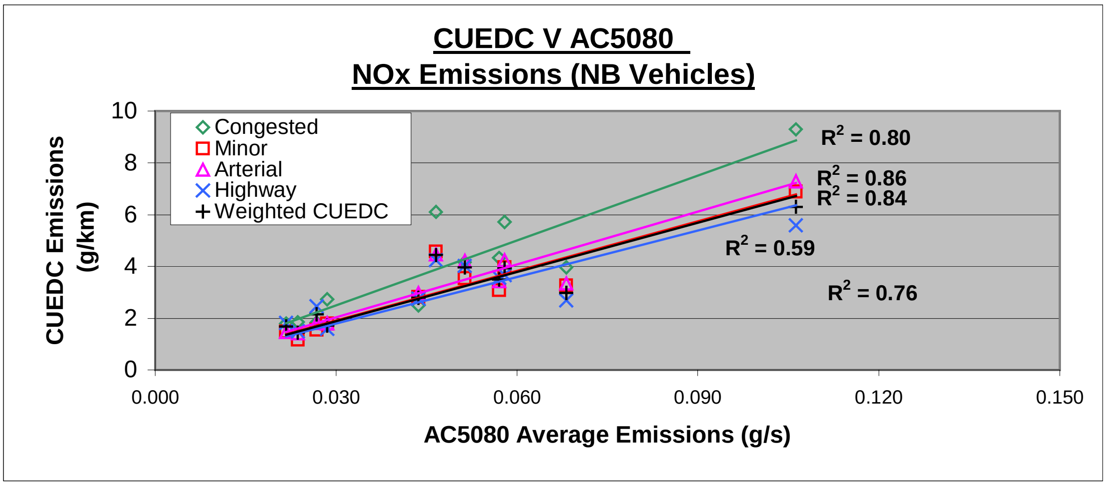


Figure A5-93

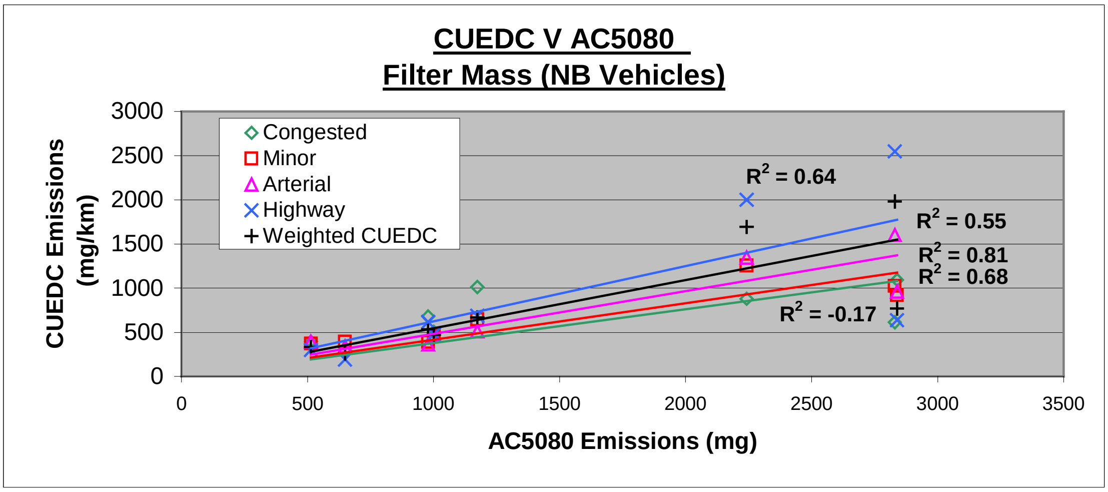


Figure A5-94

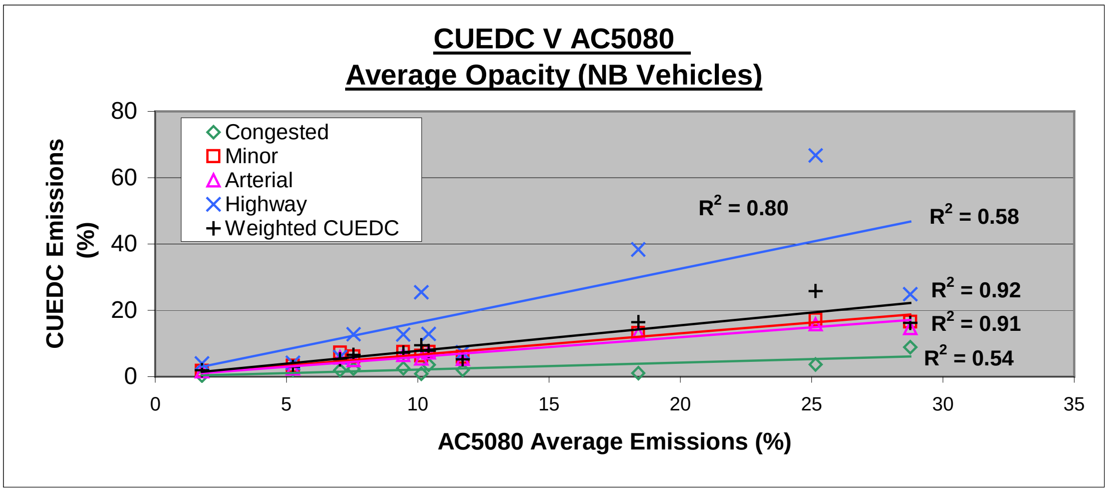


Figure A5-95

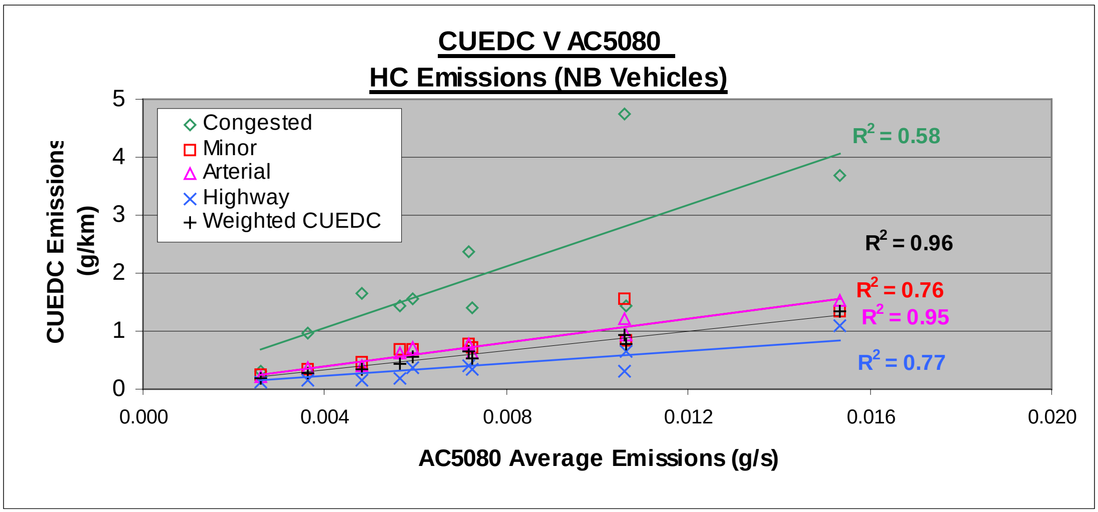


Figure A5-96

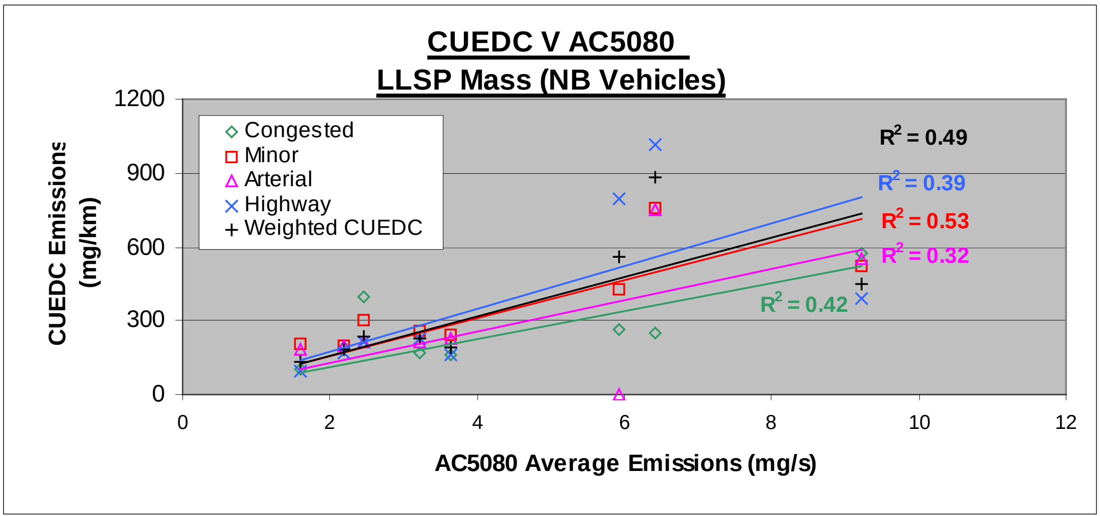


Figure A5-97

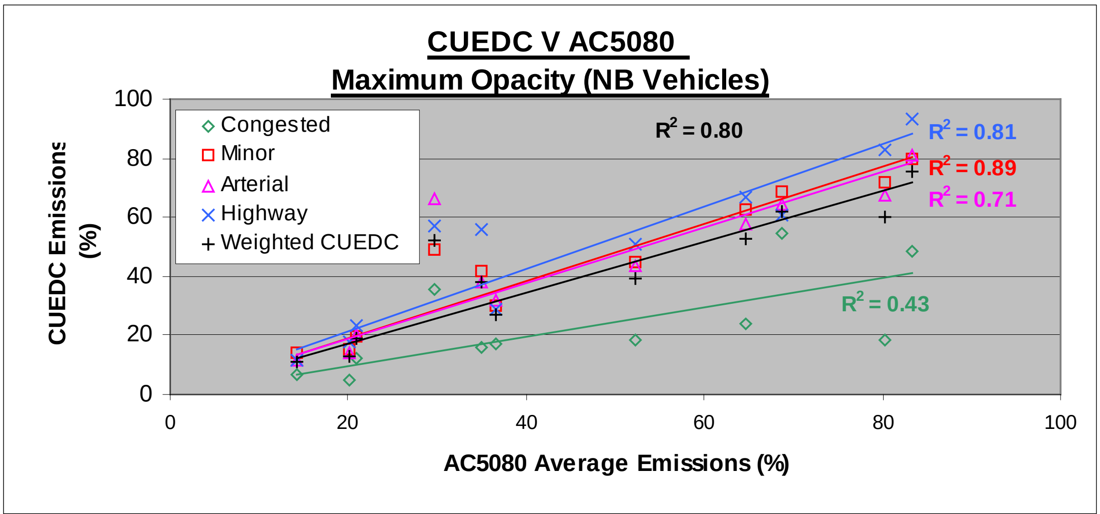


Figure A5-98

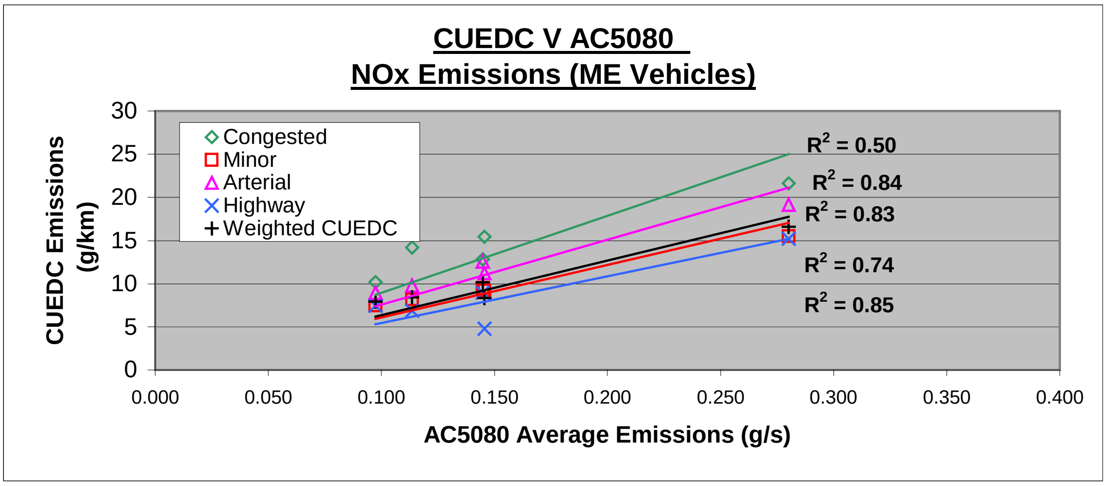


Figure A5-99

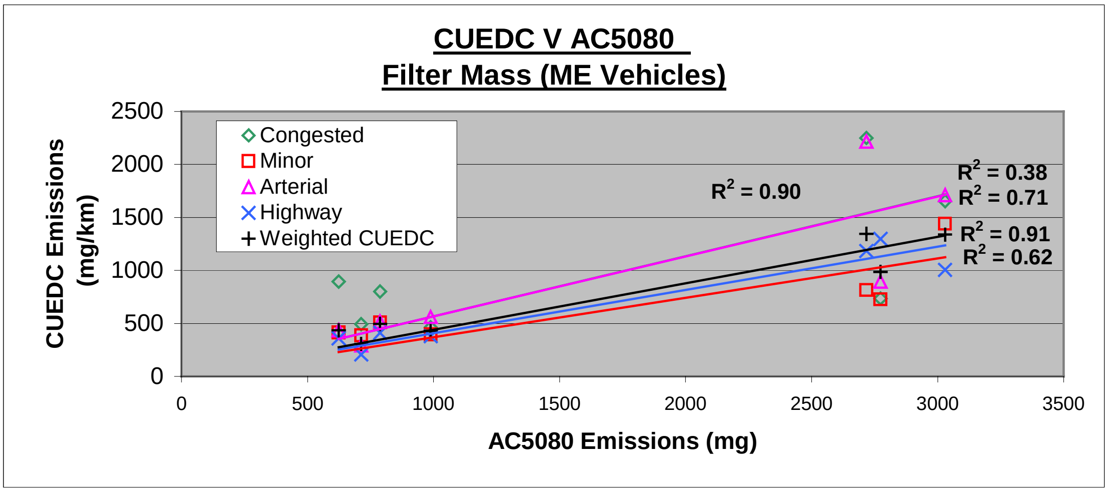


Figure A5-100

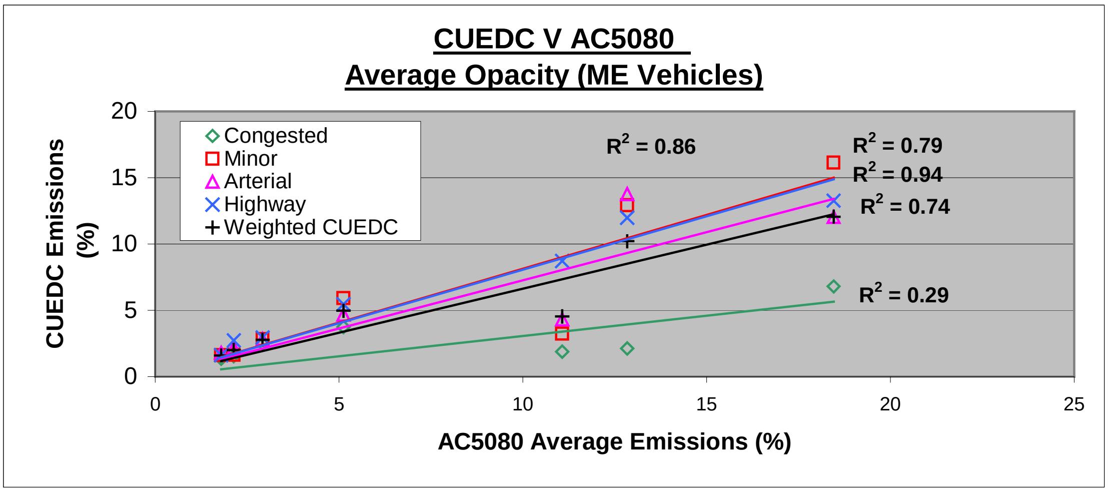


Figure A5-101

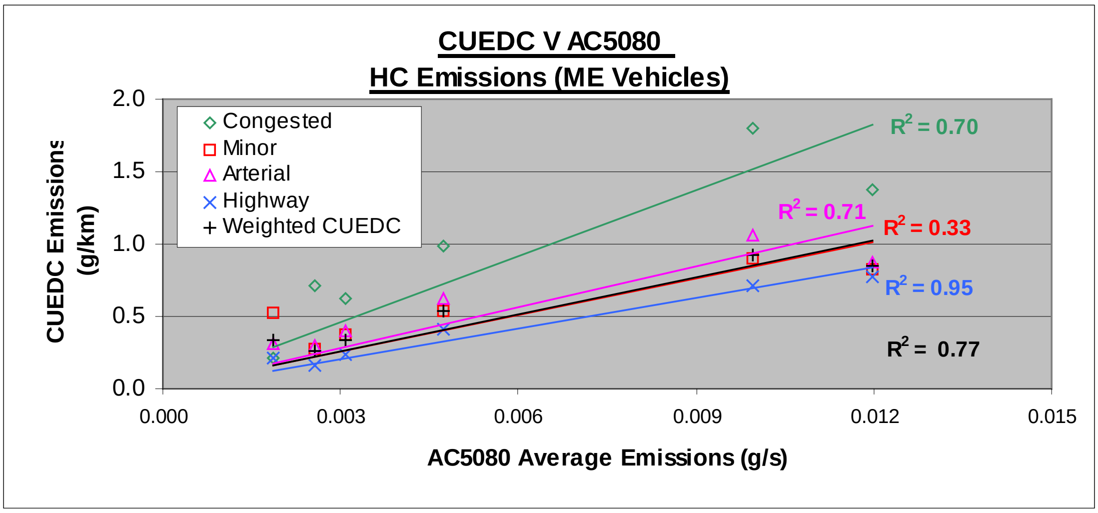


Figure A5-102

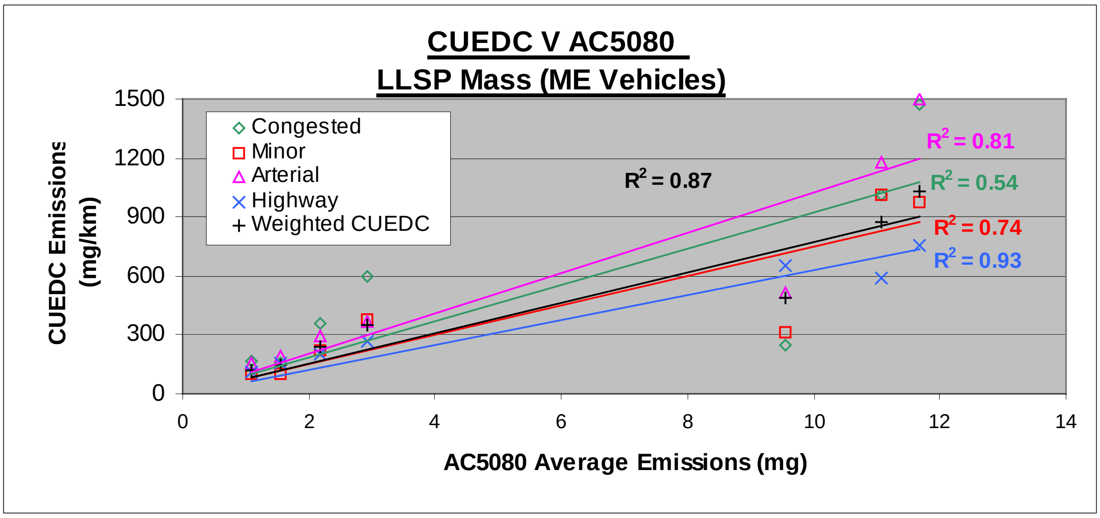


Figure A5-103

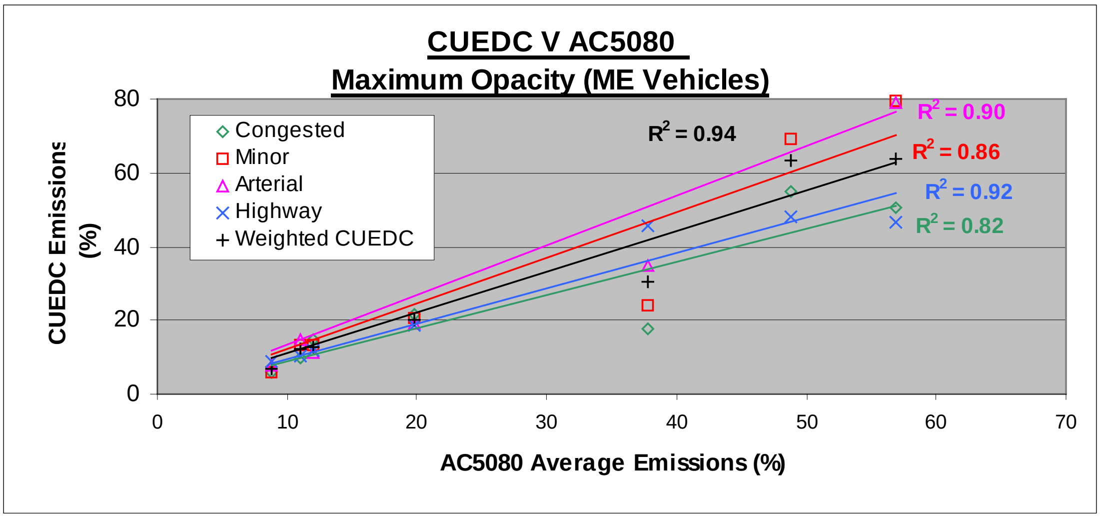


Figure A5-104

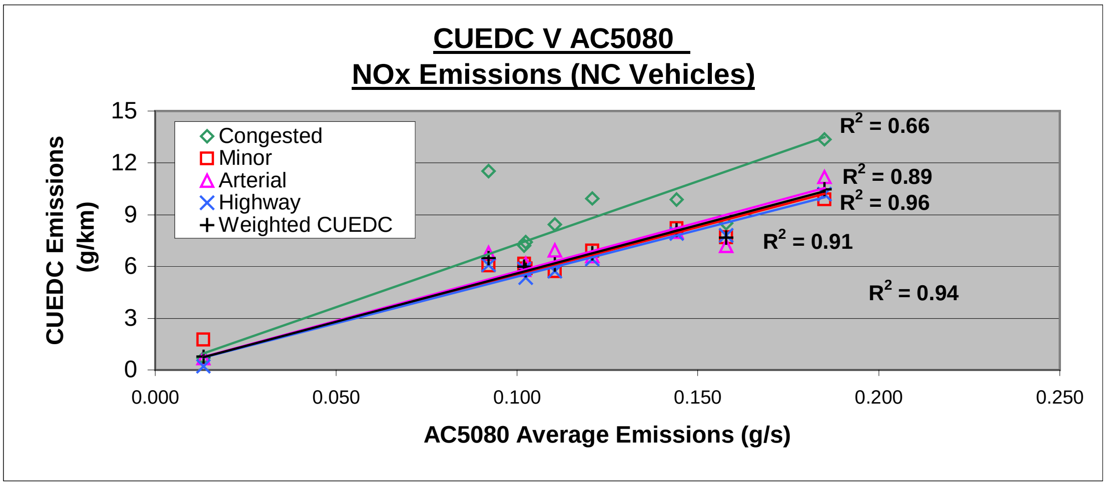


Figure A5-105

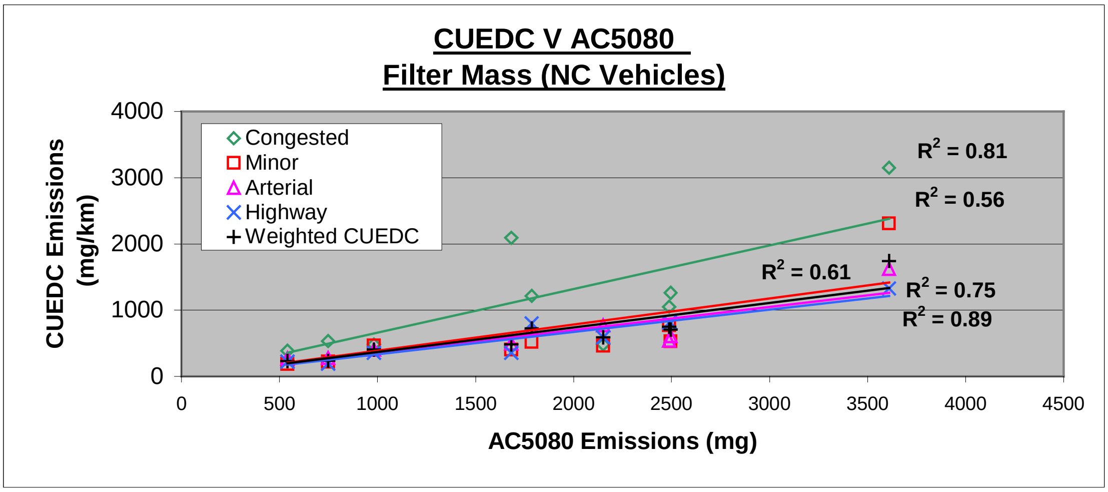


Figure A5-106

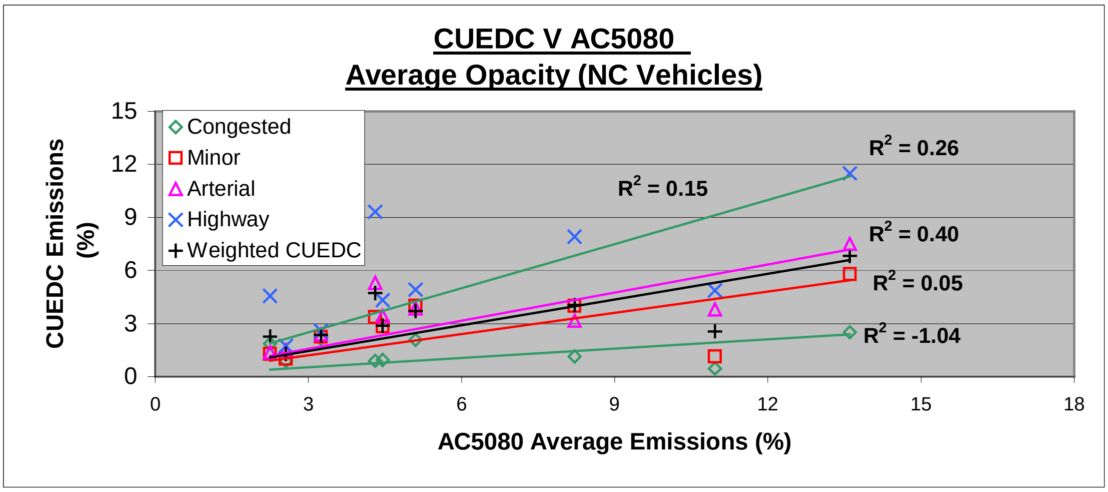


Figure A5-107

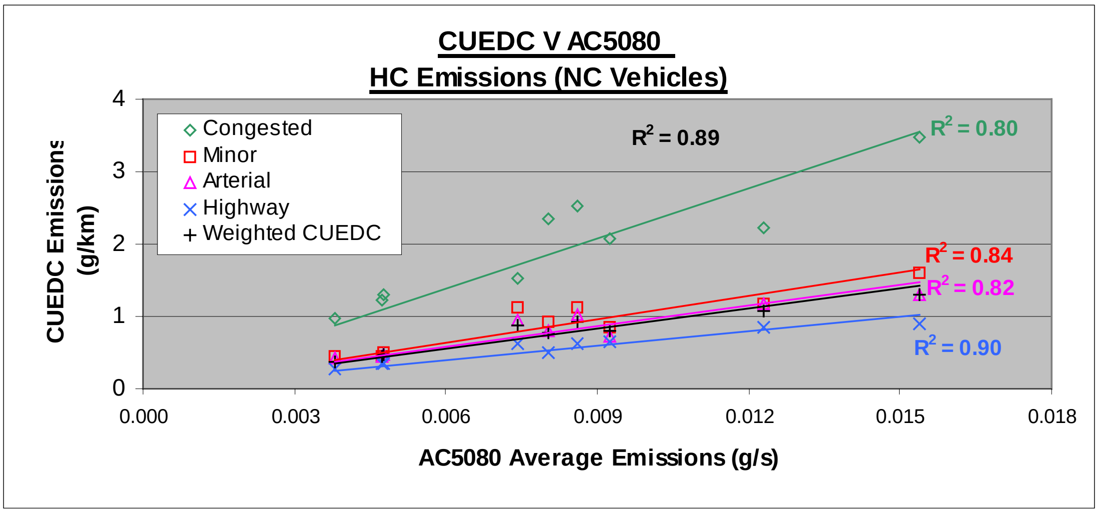


Figure A5-108

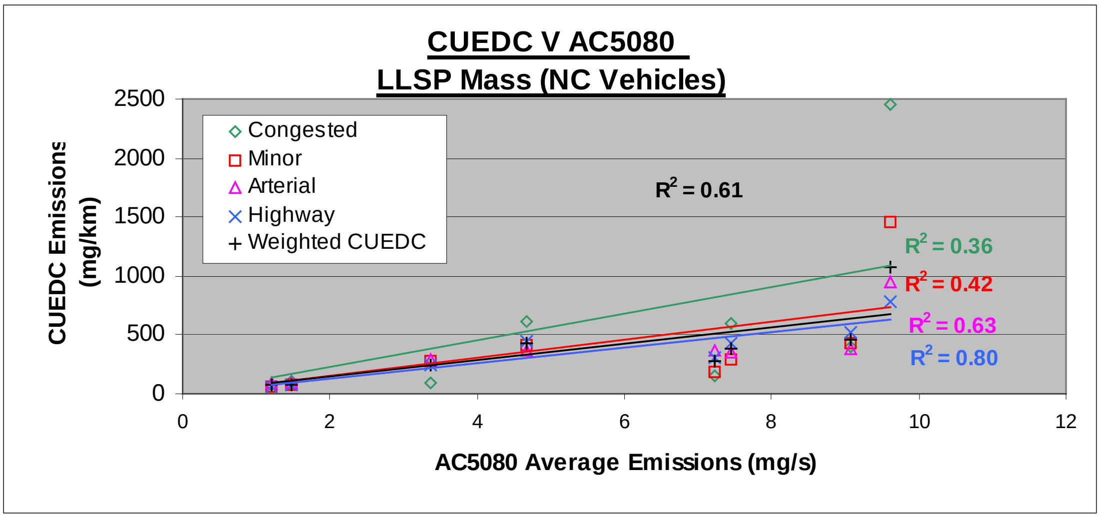


Figure A5-109

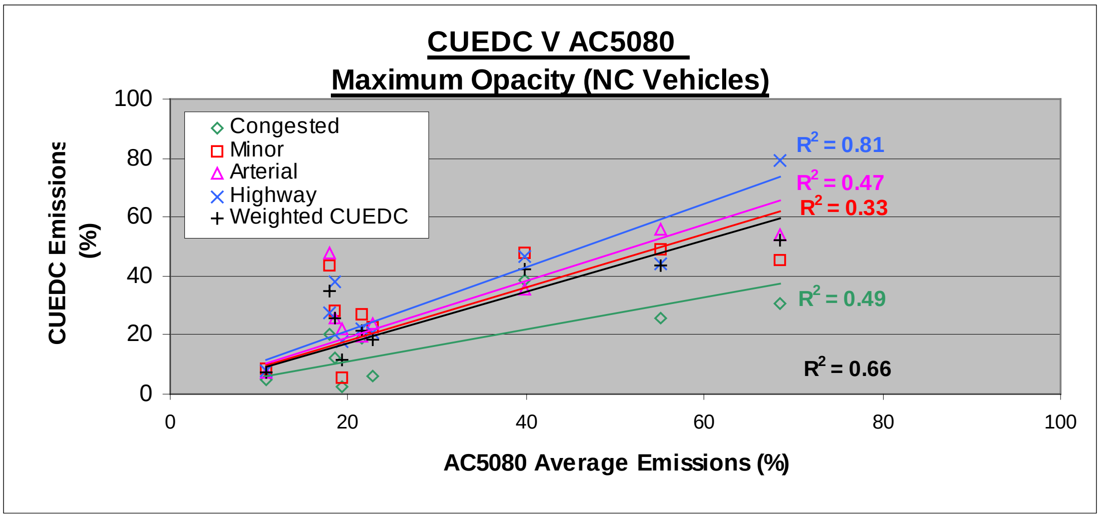


Figure A5-110

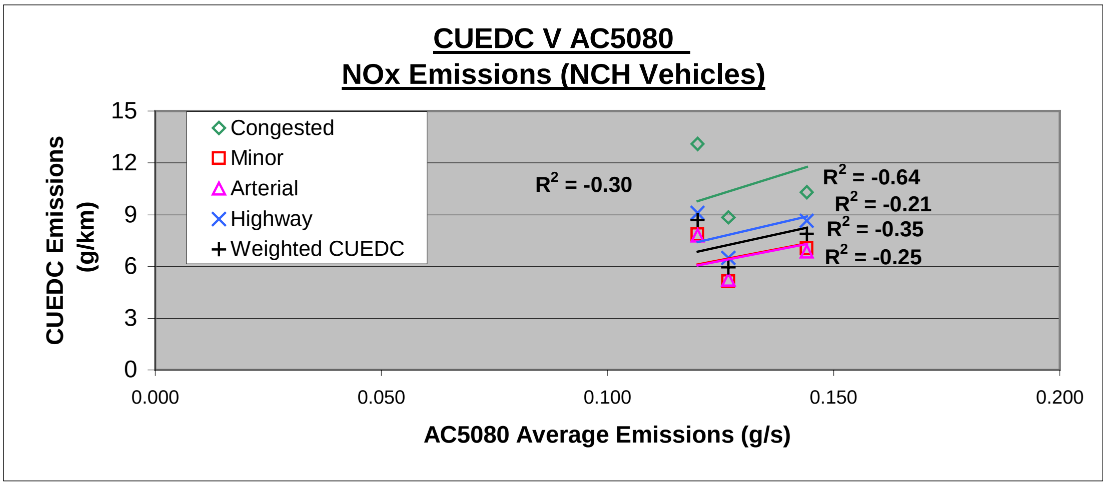


Figure A5-111

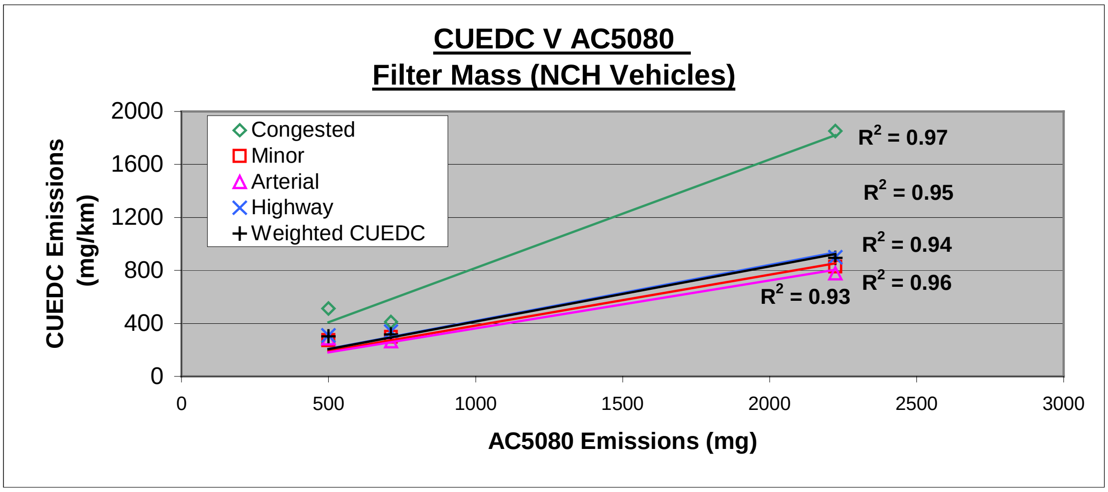


Figure A5-112

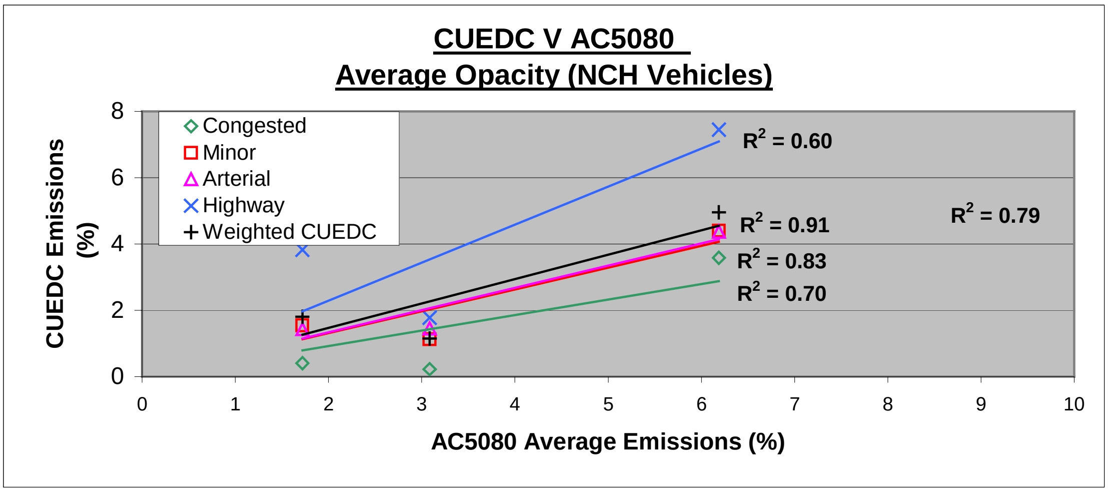


Figure A5-113

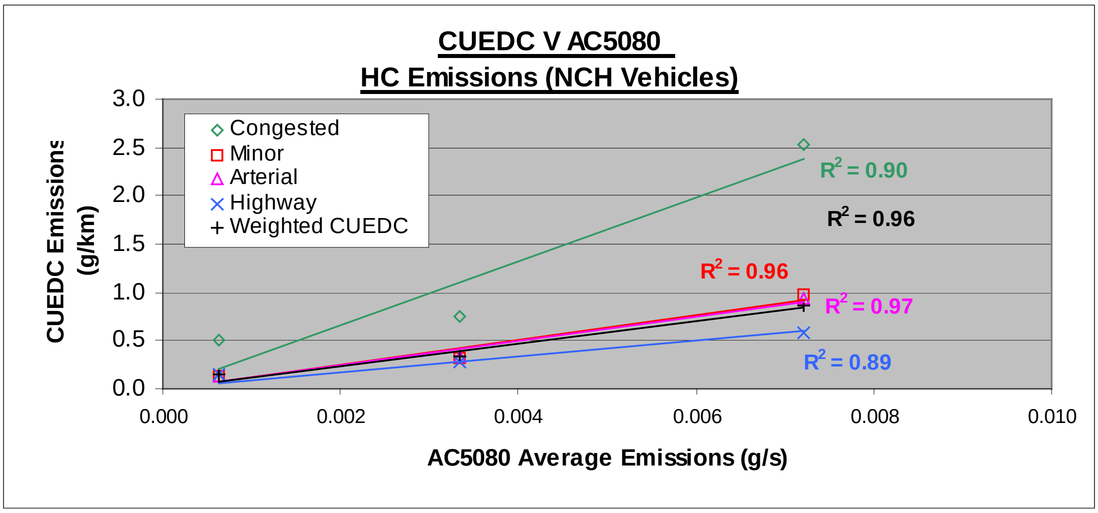


Figure A5-114

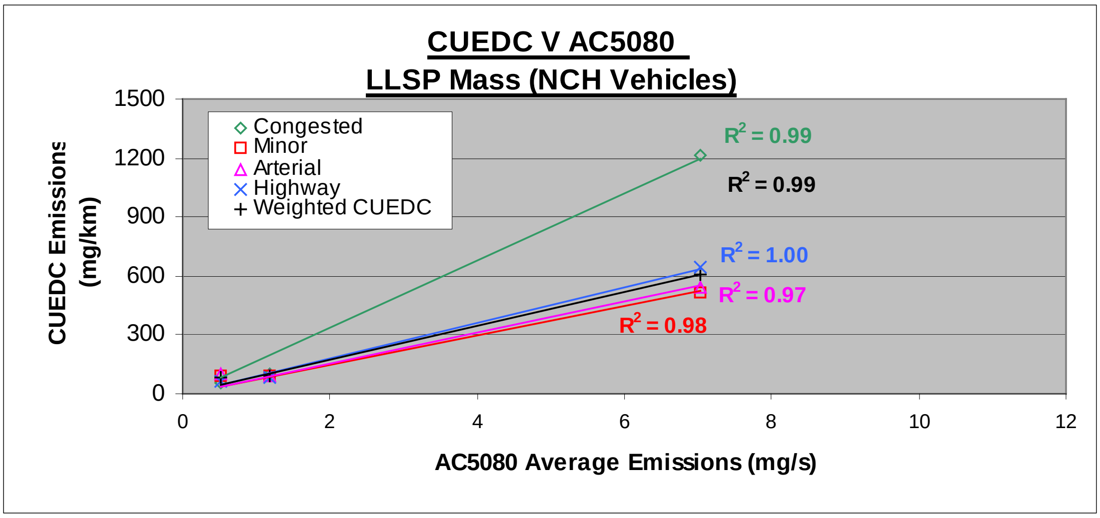


Figure A5-115

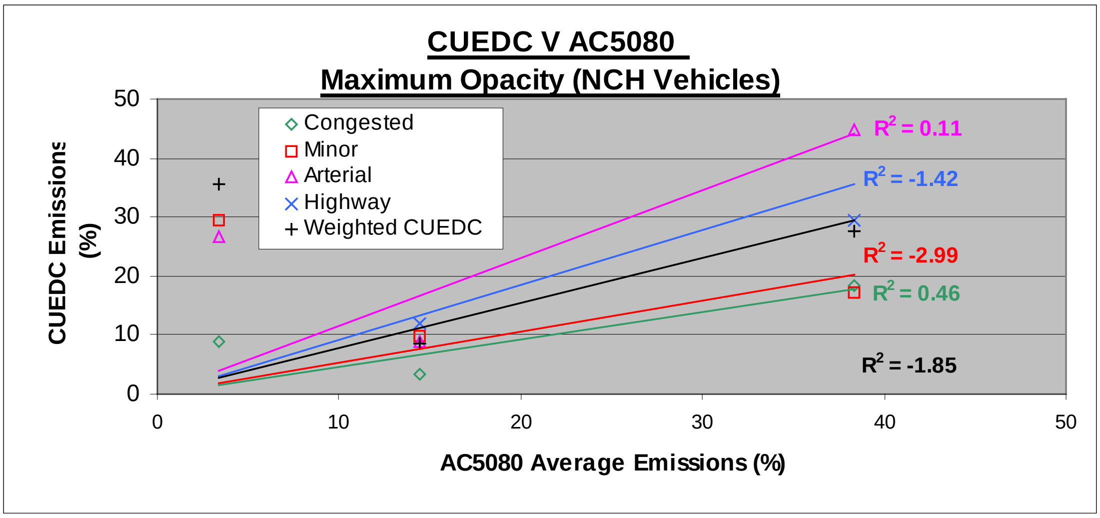


Table A5-1

Short Tests	Correlation Coefficient (R^2) (outliers & erroneous data removed) Average NOx (g/s)	Average HC (g/s)	Average LLSP (mg/s)	Filter mass (mg)	Average Opacity (%)	Maximum Opacity (%)	Rating 1 - best 8 - worst
AC5080	0.95	0.92	0.70	0.71	0.87	0.80	**1**
DT80	0.90	0.85	0.63	0.58	0.68	0.81	**2**
2 speed torque	0.62	0.72	0.30	-	0.40	0.68	3
DT80 last 10s	0.80	0.74	-0.35	-	0.15	-0.21	4
Lug Down	0.60	0.68	0.22	-	0.26	0.68	5
2 speed power	0.55	0.36	0.12	-	0.15	0.17	6
D550	0.64	0.53	-0.18	-0.23	0.03	-0.23	7
Snap idle	0.47	0.23	-0.02	-	0.29	0.59	8

Table A5-2

Short Tests	Standard Deviation Average NOx (g/s)	Average HC (g/s)	Average LLSP (mg/s)	Filter mass (mg)	Average Opacity (%)	Maximum Opacity (%)
AC5080	0.76	0.10	151.33	246.66	2.48	11.97
DT80	1.37	0.15	171.58	288.68	3.92	11.43
2 speed torque	2.76	0.21	235.74	-	5.00	14.36
DT80 last 10s	1.99	0.20	325.95	-	6.47	28.62
Lug Down	2.81	0.22	247.98	-	5.94	14.42
2 speed power	2.99	0.32	264.44	-	6.33	24.04
D550	2.70	0.27	299.30	496.44	6.75	29.48
Snap idle	3.22	0.34	283.69	-	5.75	16.86

Table A5-3

ADR Category	**Short Tests**	**CUEDC v DT80 and AC5080 - R^2 values** Average NOx (g/s)	Average HC (g/s)	Average LLSP (mg/s)	Filter mass (mg)	Average Opacity (%)	Maximum Opacity (%)
MC	DT80	0.90	0.82	0.80	0.60	0.68	0.81
	AC5080	0.54	0.80	0.79	0.91	0.85	0.52
NA	DT80	0.78	0.15	0.38	0.42	0.37	0.68
	AC5080	0.43	-0.06	0.82	0.68	0.89	0.85
NB	DT80	0.88	0.91	0.80	0.85	0.83	0.73
	AC5080	0.76	0.96	0.49	0.64	0.80	0.80
ME	DT80	0.92	0.83	0.68	0.36	0.48	0.88
	AC5080	0.85	0.77	0.87	0.90	0.86	0.94
NC	DT80	0.91	0.49	0.41	0.39	0.08	0.71
	AC5080	0.94	0.89	0.61	0.81	0.15	0.66
NCH	DT80	0.57	0.68	0.85	0.69	0.93	0.88
	AC5080 *	-0.30	0.96	0.99	0.95	0.79	-1.85
All Vehicles	DT80	0.90	0.85	0.63	0.58	0.68	0.81
	AC5080	0.95	0.92	0.70	0.71	0.87	0.80

* Only 3 vehicles tested in this category.

Table A5-4

CUEDC v DT80		R^2 values					
ADR Category	Segments	Average NOx (g/s)	Average HC (g/s)	Average LLSP (mg/s)	Filter mass (mg)	Average Opacity (%)	Maximum Opacity (%)
MC	Congested	0.60	0.70	-0.72	-1.00	-0.81	0.58
	Minor	0.90	0.83	0.75	0.58	0.65	0.87
	Arterial	0.90	0.77	0.80	0.57	0.65	0.57
	Highway	0.86	0.76	0.86	0.72	0.82	0.71
	Weighted CUEDC	0.90	0.82	0.80	0.60	0.68	0.81
NA	Congested	0.52	-0.55	-0.21	-0.29	-0.26	0.54
	Minor	0.60	0.22	0.34	0.38	0.23	0.70
	Arterial	0.79	0.24	0.42	0.56	0.34	0.65
	Highway	0.78	0.19	0.35	0.35	0.57	0.70
	Weighted CUEDC	0.78	0.15	0.38	0.42	0.37	0.68
NB	Congested	0.84	0.53	0.06	-0.55	0.20	0.40
	Minor	0.70	0.61	0.57	0.27	0.64	0.82
	Arterial	0.72	0.84	0.30	0.57	0.71	0.67
	Highway	0.88	0.92	0.88	0.91	0.74	0.77
	Weighted CUEDC	0.88	0.91	0.80	0.85	0.83	0.73
ME	Congested	0.76	0.83	0.31	0.16	-0.35	0.75
	Minor	0.95	0.41	0.51	-0.03	0.39	0.76
	Arterial	0.92	0.81	0.62	0.35	0.46	0.86
	Highway	0.74	0.94	0.92	0.49	0.77	0.98
	Weighted CUEDC	0.92	0.83	0.68	0.36	0.48	0.88
NC	Congested	0.76	0.60	0.19	-0.04	0.00	0.36
	Minor	0.87	0.31	0.26	0.28	0.04	0.47
	Arterial	0.89	0.39	0.35	0.29	0.11	0.60
	Highway	0.90	0.63	0.60	0.53	0.14	0.87
	Weighted CUEDC	0.91	0.49	0.41	0.39	0.08	0.71
NCH	Congested	0.23	0.56	0.64	0.12	0.61	0.83
	Minor	0.54	0.70	0.86	0.79	0.85	0.85
	Arterial	0.42	0.71	0.75	0.62	0.81	0.89
	Highway	0.63	0.63	0.81	0.63	0.97	0.64
	Weighted CUEDC	0.57	0.68	0.85	0.69	0.93	0.88

Table A5-5

CUEDC v AC5080		R^2 values					
ADR Category	Segments	Average NOx (g/s)	Average HC (g/s)	Average LLSP (mg/s)	Filter mass (mg)	Average Opacity (%)	Maximum Opacity (%)
MC	Congested	0.59	0.76	-2.69	-1.08	-0.24	0.46
	Minor	0.54	0.88	0.77	0.91	0.86	0.50
	Arterial	0.49	0.74	0.82	0.90	0.83	0.29
	Highway	0.53	0.71	0.81	0.92	0.82	0.25
	Weighted CUEDC	0.54	0.80	0.79	0.91	0.85	0.52
NA	Congested	0.39	-0.78	0.35	0.23	0.81	0.74
	Minor	0.48	-0.01	0.79	0.63	0.89	0.83
	Arterial	0.49	0.09	0.83	0.74	0.89	0.83
	Highway	0.33	0.04	0.84	0.66	0.78	0.84
	Weighted CUEDC	0.43	-0.06	0.82	0.68	0.89	0.85
NB	Congested	0.80	0.58	0.42	-0.17	0.54	0.43
	Minor	0.84	0.76	0.53	0.68	0.92	0.89
	Arterial	0.86	0.95	0.32	0.81	0.91	0.71
	Highway	0.59	0.77	0.39	0.55	0.58	0.81
	Weighted CUEDC	0.76	0.96	0.49	0.64	0.80	0.80
ME	Congested	0.50	0.70	0.54	0.38	0.54	0.43
	Minor	0.83	0.33	0.74	0.62	0.92	0.89
	Arterial	0.84	0.71	0.81	0.71	0.91	0.71
	Highway	0.74	0.95	0.93	0.91	0.58	0.81
	Weighted CUEDC	0.85	0.77	0.87	0.90	0.86	0.94
NC	Congested	0.66	0.80	0.19	0.56	-1.04	0.36
	Minor	0.91	0.84	0.26	0.61	0.05	0.47
	Arterial	0.89	0.82	0.35	0.75	0.40	0.60
	Highway	0.96	0.90	0.60	0.89	0.26	0.87
	Weighted CUEDC	0.94	0.89	0.61	0.81	0.15	0.66
NCH *	Congested	-0.64	0.90	0.99	0.97	0.70	0.46
	Minor	-0.25	0.96	0.98	0.96	0.83	-2.99
	Arterial	-0.35	0.97	0.97	0.93	0.91	0.11
	Highway	-0.21	0.89	1.00	0.94	0.60	-1.42
	Weighted CUEDC	-0.30	0.96	0.99	0.95	0.79	-1.85

* Only 3 vehicles tested in this category.

APPENDIX 6

1. SHORT TEST CORRELATIONS WITH CUEDCS

1.1 OVERALL TEST FLEET CORRELATION

It should be noted that the AC50/80 short test (designed by Parsons in discussion with the California Air Resources Board (CARB)) was introduced into this Project part way through the testing program, by agreement with the Project Manager. AC50/80 tests were subsequently conducted on 56 vehicles out of the 80-vehicle sample. All other short tests were carried out on all 80 vehicles. It should also be noted that due to instrument, vehicle or operational problems some pollutant measurements are based on a reduced sample size.

Sample Pearson correlation coefficients were obtained for all short tests and regression analyses were obtained for the model fitted through the origin. All data were used and sample size is given in parentheses. The correlation coefficients (r) are given in Table A6.1 below.

Note: The Pearson correlation coefficient, r, is a measure of the degree of association between CUEDC emission and the emission obtained from a short test. The coefficient of determination, R^2, may be obtained by dividing the sum of squares due to regression by the total sum of squares. This has been down and tabulated in table A6.3.

A value of r near 1 indicates close agreement between the two variables, while a value near zero indicates poor agreement.

Table A6 1: Pearson sample correlation coefficients (r) for weighted CUEDCs vs Short Tests pooled over all ADR and Year of Manufacture categories.

	Av NOx	Av HC	Av LLSP	Filter Mass	Av Opacity	Max Opacity
AC5080	0.97 (55)	0.96 (53)	0.84 (46)	0.84 (51)	0.92 (54)	0.86 (56)
DT80	0.95 (77)	0.92 (76)	0.81 (70)	0.80 (77)	0.81 (78)	0.88 (78)
2-SpTorque	0.83 (77)	0.86 (75)	0.63 (69)	NA	0.67 (76)	0.84 (74)
DT80 10s	0.90 (77)	0.87 (75)	0.32 (70)	NA	0.65 (75)	0.49 (73)
Lug-Down	0.80 (78)	0.83 (76)	0.57 (70)	NA	0.57 (79)	0.82 (76)
2-Sp Power	0.77 (78)	0.67 (75)	0.49 (69)	NA	0.48 (77)	0.57 (77)
D550	0.83 (76)	0.77 (74)	0.36 (68)	0.41 (76)	0.48 (78)	0.49 (78)
Snap Idle	0.69 (78)	0.61 (75)	0.41 (70)	NA	0.62 (77)	0.78 (77)

A summary of the Residual Standard Error (RSE) values for the two regression models, with or without intercept term, is given in Table A6.2. All total emissions over the four CUEDC segments were weighted for kms travelled. The RSE for the model with the intercept term is given in parentheses.

Table A6 2: Residual Standard Error values.

	Av NOx (g/s/km)	Av HC (g/s/km)	Av LLSP (mg/s/km)	Filter Mass (mg/km)	Av Opacity (%/km)	Max Op (%/km)
AC5080	0.76 (0.75)	0.10 (0.10)	151.33 (150.02)	246.66 (248.09)	0.15 (0.15)	0.81 (0.80)
DT80	1.37 (1.38)	0.15 (0.15)	171.58 (166.41)	288.68 (268.22)	0.23 (0.23)	0.73 (0.74)
2-SpTorque	2.76 (2.54)	0.21 (0.20)	235.73 (221.36)	NA	0.28 (0.27)	0.91 (0.82)
DT80 10s	1.99 (1.93)	0.20 (0.19)	325.95 (267.33)	NA	0.37 (0.30)	1.73 (1.32)
Lug-Down	2.81 (2.71)	0.22 (0.22)	247.97 (231.09)	NA	0.34 (0.32)	0.92 (0.84)
2-Sp Power	2.99 (2.87)	0.32 (0.30)	264.44 (247.70)	NA	0.37 (0.34)	1.48 (1.26)
D550	2.70 (2.49)	0.27 (0.25)	299.30 (259.58)	496.45 (410.74)	0.39 (0.34)	1.76 (1.36)
Snap Idle	3.22 (3.22)	0.34 (0.31)	283.69 (257.67)	NA	0.32 (0.30)	0.99 (0.96)

The emission results for all vehicles, over each short test, were plotted against the corresponding 'weighted results' achieved over the applicable CUEDC. These plots are shown in appendix 5 as figures A5-1 to A5-43. These figures include the corresponding coefficients of determination (R^2), which are tabulated in table A6-3.

Table A6 3: Coefficients of Determination (R^2) for all Short Tests v CUEDCs

	Correlation Coefficient^2) (outliers & erroneous data						
Short Tests	Average NOx (g/s)	Average HC (g/s)	Average LLSP (mg/s)	Filter mass (mg)	Average Opacity (%)	Maximum Opacity (%)	Rating 1 - best 8 -
AC508	0.95	0.92	0.70	0.71	0.87	0.80	**1**
DT80	0.90	0.85	0.63	0.58	0.68	0.81	**2**
2 speed	0.62	0.72	0.30	-	0.40	0.68	3
DT80 last	0.80	0.74	-0.35	-	0.15	-0.21	4
Lug	0.60	0.68	0.22	-	0.26	0.68	5
2 speed	0.55	0.36	0.12	-	0.15	0.17	6
D550	0.64	0.53	-0.18	-0.23	0.03	-0.23	7
Snap	0.47	0.23	-0.02	-	0.29	0.59	8

Note 1*: a few points considered outliers have not been included in the calculations.*
Note 2: *R-squared (R^2) values tabulated in table A6.3 above have been calculated using MS Excel.*

The 'rating' given in the right hand column is a guide only based upon assessment of the correlation with the CUEDC and not any other criteria such as cost, practicality, effectiveness, etc. These factors are discussed in section 6.4.

The two transient short test (AC5080, DT80) results show the highest correlation with the 'weighted results' of the CUEDCs, across all emissions. All other tests show only poor to fair correlation.

1.1.1 Correlation of each short test within each ADR Category

Tables A6.4 to A6.9 provide the coefficients of determination values for each short test for each of the six ADR categories.

Table A6 4: CUEDC v Max Power Correlation, by ADR Category

	CUEDC vs Maximum Power - R^2 values					
ADR Category	Average NOx (g/s)	Average HC (g/s)	Average LLSP (mg/s)	Filter mass (mg)	Average Opacity (%)	Maximum Opacity (%)
MC	0.61	0.24	0.61	-	-0.40	0.02
NA	-0.08	-1.00	-0.41	-	-0.60	-1.21
NB	0.39	0.28	0.55	-	0.52	0.80
ME	-2.00	0.12	-0.16	-	-0.47	-0.15
NC	-0.91	-0.65	0.19	-	-0.68	0.26
NCH	0.17	0.32	0.83	-	0.63	0.65
All Vehicles	0.55	0.36	0.12	-	0.15	0.17

Table A6 5: CUEDC v Max Torque Correlation, by ADR Category

	CUEDC vs Maximum Torque - R^2 values					
ADR Category	Average NOx (g/s)	Average HC (g/s)	Average LLSP (mg/s)	Filter mass (mg)	Average Opacity (%)	Maximum Opacity (%)
MC	0.39	0.63	0.57	-	0.21	0.63
NA	-0.46	-1.19	-0.09	-	0.06	0.80
NB	0.24	0.67	0.70	-	0.72	0.77
ME	-3.22	0.59	0.96	-	0.71	0.85
NC	-0.41	0.47	0.33	-	-0.58	0.27
NCH	0.50	0.34	0.95	-	0.78	0.70
All Vehicles	0.62	0.72	0.30	-	0.40	0.68

Table A6 6: CUEDC v Snap Idle SAE J1667, by ADR Category

ADR Category	CUEDC vs Snap Idle SAE J1167 - R^2 values					
	Average NOx (g/s)	Average HC (g/s)	Average LLSP (mg/s)	Filter mass (mg)	Average Opacity (%)	Maximum Opacity (%)
MC	0.41	0.46	0.19	-	-0.12	0.55
NA	0.55	-1.29	0.09	-	0.00	0.10
NB	0.52	-0.27	0.41	-	0.65	0.63
ME	-3.00	0.66	0.47	-	0.72	0.80
NC	0.23	0.66	0.34	-	0.66	0.51
NCH	-0.06	-0.30	0.22	-	0.42	0.50
All Vehicles	0.47	0.23	-0.02	-	0.29	0.59

Table A6 7: CUEDC v Lug Down, by ADR Category

ADR Category	CUEDC vs Lug Down - R^2 values					
	Average NOx (g/s)	Average HC (g/s)	Average LLSP (mg/s)	Filter mass (mg)	Average Opacity (%)	Maximum Opacity (%)
MC	0.59	0.58	0.22	-	0.24	0.35
NA	-0.05	-0.52	-0.09	-	-0.46	0.59
NB	0.65	0.77	0.80	-	0.77	0.87
ME	-2.55	0.68	0.84	-	0.44	0.71
NC	0.07	0.19	0.25	-	-0.65	0.46
NCH	0.06	0.20	0.96	-	0.78	0.71
All Vehicles	0.60	0.68	0.22	-	0.26	0.68

Table A6 8: CUEDC v D550, by ADR Category

ADR Category	CUEDC vs D550 - R^2 values					
	Average NOx (g/s)	Average HC (g/s)	Average LLSP (mg/s)	Filter mass (mg)	Average Opacity (%)	Maximum Opacity (%)
MC	0.79	0.35	-0.55	0.59	0.14	0.07
NA	0.07	-0.95	-0.82	-0.60	-1.08	-2.91
NB	0.34	0.42	0.51	0.31	0.72	0.58
ME	-3.12	0.46	0.17	0.62	-0.20	0.13
NC	-0.52	-0.44	-0.03	-0.69	-1.11	-0.02
NCH	0.67	0.66	0.89	0.85	0.43	-0.13
All Vehicles	0.64	0.53	-0.18	-0.23	0.03	-0.23

Table A6.9 below presents the two transient tests, the DT80 and the AC50/80 together to enable a direct comparison to be made. The tables demonstrate the variability when the different ADR categories are compared as against the more meaningful vehicle mass is used as presented in the main body at section 6. However, for completeness the ADR categories have been investigated.

Table A6 9: CUEDC v DT80 and AC50/80 Correlation, by ADR Category

ADR Category	Short Tests	CUEDC v DT80 and AC5080 - R^2 values					
		Average NOx (g/s)	Average HC (g/s)	Average LLSP (mg/s)	Filter mass (mg)	Average Opacity (%)	Maximum Opacity (%)
MC	DT80	0.90	0.82	0.80	0.60	0.68	0.81
	AC5080	0.54	0.80	0.79	0.91	0.85	0.52
NA	DT80	0.78	0.15	0.38	0.42	0.37	0.68
	AC5080	0.43	-0.06	0.82	0.68	0.89	0.85
NB	DT80	0.88	0.91	0.80	0.85	0.83	0.73
	AC5080	0.76	0.96	0.49	0.64	0.80	0.80
ME	DT80	0.92	0.83	0.68	0.36	0.48	0.88
	AC5080	0.85	0.77	0.87	0.90	0.86	0.94
NC	DT80	0.91	0.49	0.41	0.39	0.08	0.71
	AC5080	0.94	0.89	0.61	0.81	0.15	0.66
NCH	DT80	0.57	0.68	0.85	0.69	0.93	0.88
	AC5080 *	-0.30	0.96	0.99	0.95	0.79	-1.85
All Vehicles	DT80	0.90	0.85	0.63	0.58	0.68	0.81
	AC5080	0.95	0.92	0.70	0.71	0.87	0.80

* Only 3 vehicles tested in this category.

For both the DT80 and the AC50/80, correlation is generally in the range moderate to very high. In a few cells, correlation is low or very low. At least in part, this variation is explained by variation in test mass and also the small number of vehicle tests represented in each cell, ranging down to just 3 NCH vehicles tested to the AC50/80 short test. The results in these and some other cells are unlikely to be statistically sound.

The non-transient tests have poor to very poor correlation in many more cells than the transient tests, and fewer cells where correlation is high. Therefore, further analysis of the short test results has been focused on the transient tests, ie the AC50/80 and the DT80.

1.1.2 Correlation across Road Flow Condition

Tables A6.11 and A6.12 (A5-4 and A5-5) show the correlation of the DT80 and AC50/80 short test results with those of the four traffic flow conditions and weighted result of the CUEDCs, by ADR category.

Table A6 10: CUEDC v DT80 Correlation for Traffic Flow, by ADR Category

CUEDC v DT80		R^2 values					
ADR Category	**Segments**	Average NOx (g/s)	Average HC (g/s)	Average LLSP (mg/s)	Filter mass (mg)	Average Opacity (%)	Maximum Opacity (%)
MC	Congested	0.60	0.70	-0.72	-1.00	-0.81	0.58
	Minor	0.90	0.83	0.75	0.58	0.65	0.87
	Arterial	0.90	0.77	0.80	0.57	0.65	0.57
	Highway	0.86	0.76	0.86	0.72	0.82	0.71
	Weighted CUEDC	0.90	0.82	0.80	0.60	0.68	0.81
NA	Congested	0.52	-0.55	-0.21	-0.29	-0.26	0.54
	Minor	0.60	0.22	0.34	0.38	0.23	0.70
	Arterial	0.79	0.24	0.42	0.56	0.34	0.65
	Highway	0.78	0.19	0.35	0.35	0.57	0.70
	Weighted CUEDC	0.78	0.15	0.38	0.42	0.37	0.68
NB	Congested	0.84	0.53	0.06	-0.55	0.20	0.40
	Minor	0.70	0.61	0.57	0.27	0.64	0.82
	Arterial	0.72	0.84	0.30	0.57	0.71	0.67
	Highway	0.88	0.92	0.88	0.91	0.74	0.77
	Weighted CUEDC	0.88	0.91	0.80	0.85	0.83	0.73
ME	Congested	0.76	0.83	0.31	0.16	-0.35	0.75
	Minor	0.95	0.41	0.51	-0.03	0.39	0.76
	Arterial	0.92	0.81	0.62	0.35	0.46	0.86
	Highway	0.74	0.94	0.92	0.49	0.77	0.98
	Weighted CUEDC	0.92	0.83	0.68	0.36	0.48	0.88
NC	Congested	0.76	0.60	0.19	-0.04	0.00	0.36
	Minor	0.87	0.31	0.26	0.28	0.04	0.47
	Arterial	0.89	0.39	0.35	0.29	0.11	0.60
	Highway	0.90	0.63	0.60	0.53	0.14	0.87
	Weighted CUEDC	0.91	0.49	0.41	0.39	0.08	0.71
NCH	Congested	0.23	0.56	0.64	0.12	0.61	0.83
	Minor	0.54	0.70	0.86	0.79	0.85	0.85
	Arterial	0.42	0.71	0.75	0.62	0.81	0.89
	Highway	0.63	0.63	0.81	0.63	0.97	0.64
	Weighted CUEDC	0.57	0.68	0.85	0.69	0.93	0.88

Table A6 11: CUEDC v AC50/80 Correlation for Traffic Flow, by ADR Category

CUEDC v AC5080		R^2 values					
ADR Category	Segments	Average NOx (g/s)	Average HC (g/s)	Average LLSP (mg/s)	Filter mass (mg)	Average Opacity (%)	Maximum Opacity (%)
MC	Congested	0.59	0.76	-2.69	-1.08	-0.24	0.46
	Minor	0.54	0.88	0.77	0.91	0.86	0.50
	Arterial	0.49	0.74	0.82	0.90	0.83	0.29
	Highway	0.53	0.71	0.81	0.92	0.82	0.25
	Weighted CUEDC	0.54	0.80	0.79	0.91	0.85	0.52
NA	Congested	0.39	-0.78	0.35	0.23	0.81	0.74
	Minor	0.48	-0.01	0.79	0.63	0.89	0.83
	Arterial	0.49	0.09	0.83	0.74	0.89	0.83
	Highway	0.33	0.04	0.84	0.66	0.78	0.84
	Weighted CUEDC	0.43	-0.06	0.82	0.68	0.89	0.85
NB	Congested	0.80	0.58	0.42	-0.17	0.54	0.43
	Minor	0.84	0.76	0.53	0.68	0.92	0.89
	Arterial	0.86	0.95	0.32	0.81	0.91	0.71
	Highway	0.59	0.77	0.39	0.55	0.58	0.81
	Weighted CUEDC	0.76	0.96	0.49	0.64	0.80	0.80
ME	Congested	0.50	0.70	0.54	0.38	0.54	0.43
	Minor	0.83	0.33	0.74	0.62	0.92	0.89
	Arterial	0.84	0.71	0.81	0.71	0.91	0.71
	Highway	0.74	0.95	0.93	0.91	0.58	0.81
	Weighted CUEDC	0.85	0.77	0.87	0.90	0.86	0.94
NC	Congested	0.66	0.80	0.19	0.56	-1.04	0.36
	Minor	0.91	0.84	0.26	0.61	0.05	0.47
	Arterial	0.89	0.82	0.35	0.75	0.40	0.60
	Highway	0.96	0.90	0.60	0.89	0.26	0.87
	Weighted CUEDC	0.94	0.89	0.61	0.81	0.15	0.66
NCH *	Congested	-0.64	0.90	0.99	0.97	0.70	0.46
	Minor	-0.25	0.96	0.98	0.96	0.83	-2.99
	Arterial	-0.35	0.97	0.97	0.93	0.91	0.11
	Highway	-0.21	0.89	1.00	0.94	0.60	-1.42
	Weighted CUEDC	-0.30	0.96	0.99	0.95	0.79	-1.85

* Only 3 vehicles tested in this category.

The variation in correlation across the different traffic flow segments is quite pronounced. Generally, correlation ranges between fair and very good, but in a number of cases, correlation is poor or very poor. Again in part, this is explained by the statistically small number of vehicles tested in each ADR category (especially NCH) and the variations in test mass previously discussed.

The underlying scatterplots from which the above coefficients of determination are derived, are shown in appendix 5, as figures A5-1 to A5- 72. As examples, the plots for NOx, LLSP particulate mass and Filter particulate mass for MC and NCH vehicles are shown here in figures A6.1 to A6.12.

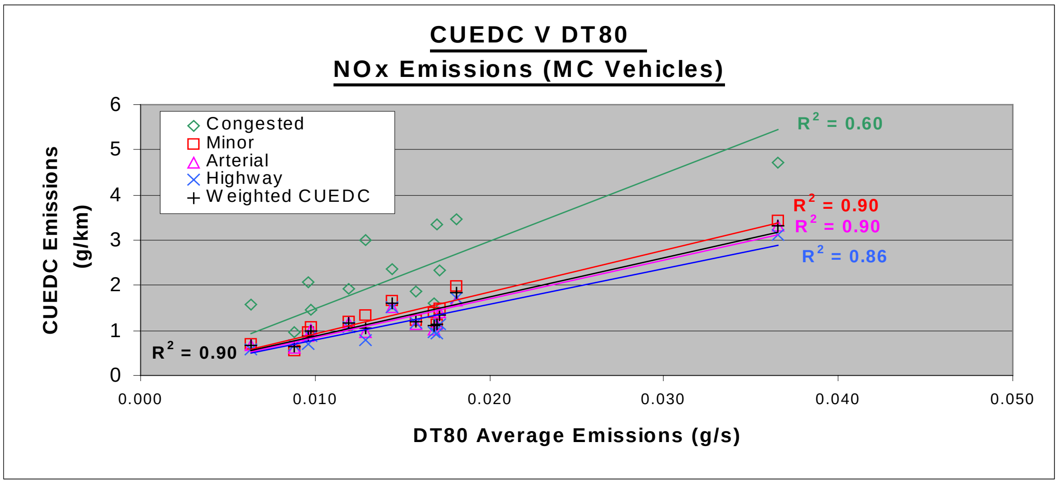


Figure A6 1: NOx - CUEDC v DT80– MC Vehicles

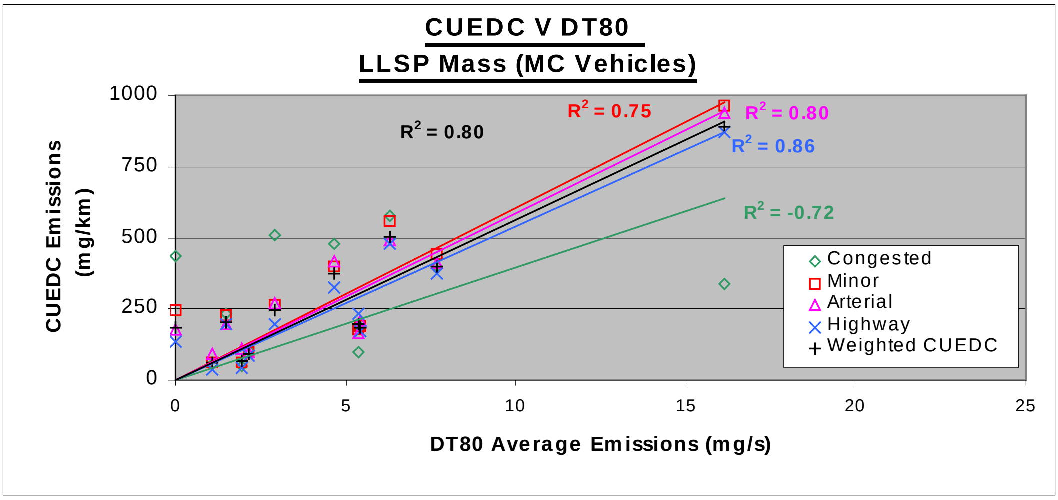


Figure A6 2: LLSP Mass - CUEDC v DT80– MC Vehicles

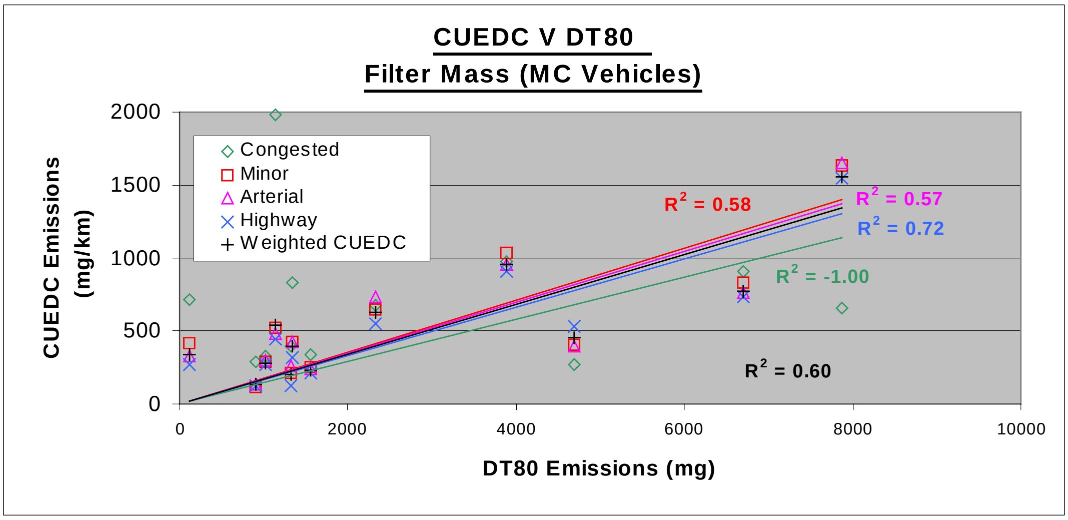


Figure A6 3: Filter Mass - CUEDC v DT80– MC Vehicles

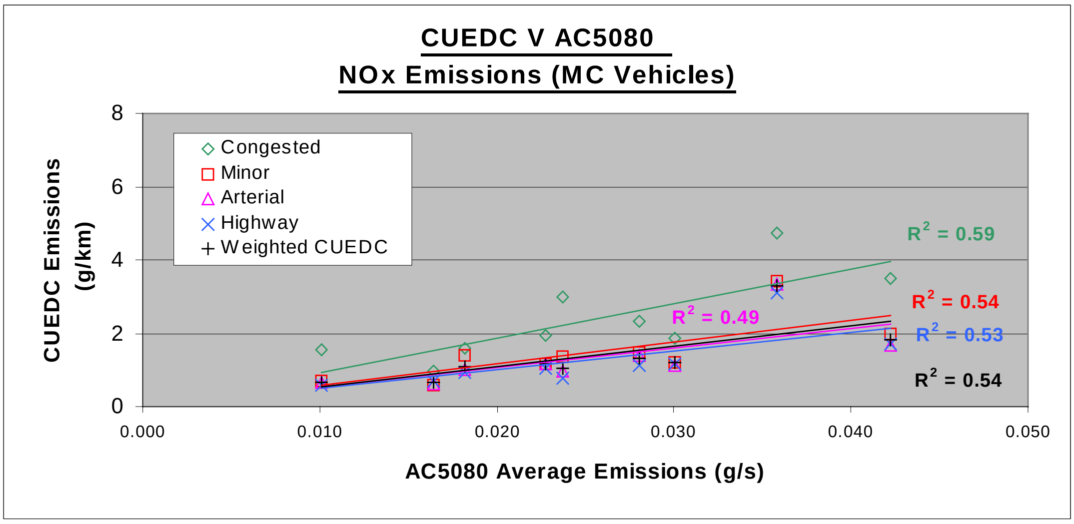


Figure A6 4: NOx - CUEDC v AC50/80– MC Vehicles

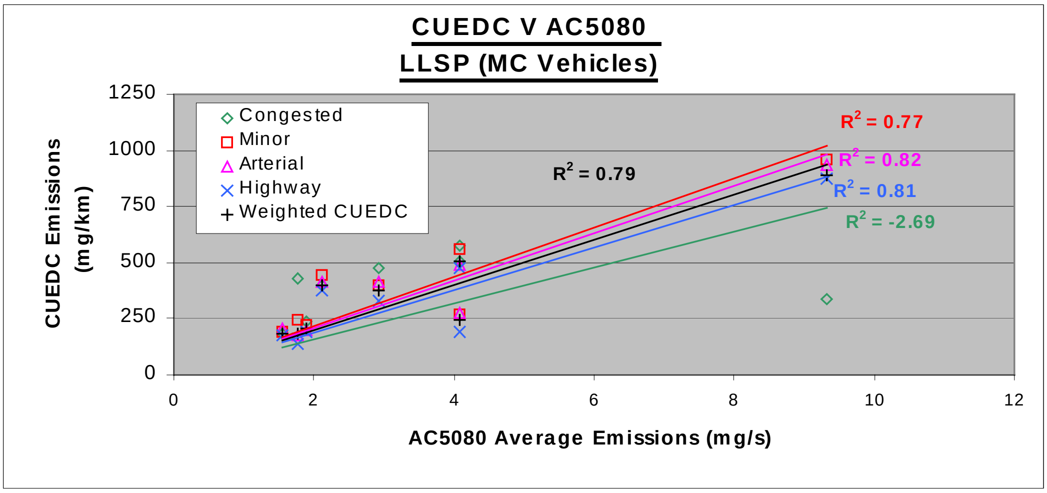


Figure A6 5: LLSP Mass - CUEDC v AC50/80– MC Vehicles

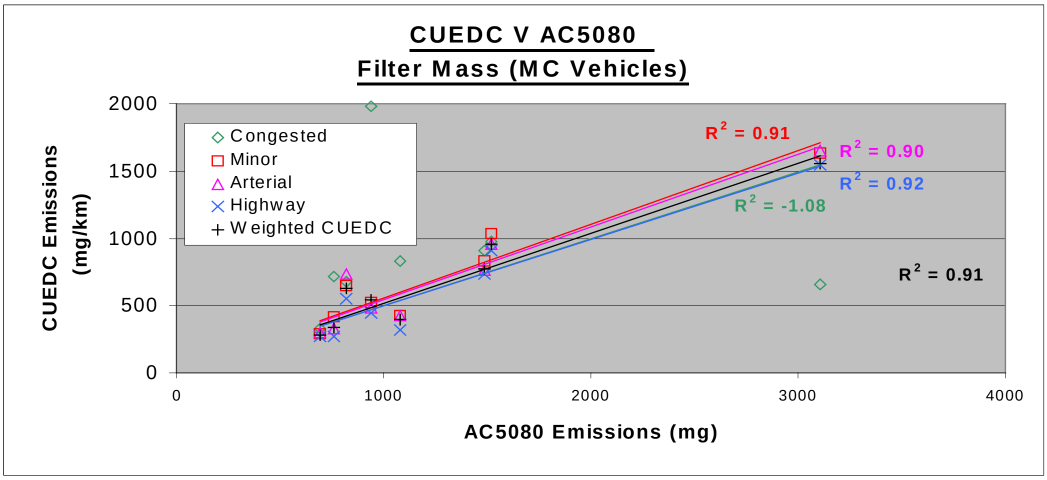


Figure A6 6: Filter Mass - CUEDC v AC50/80– MC Vehicles

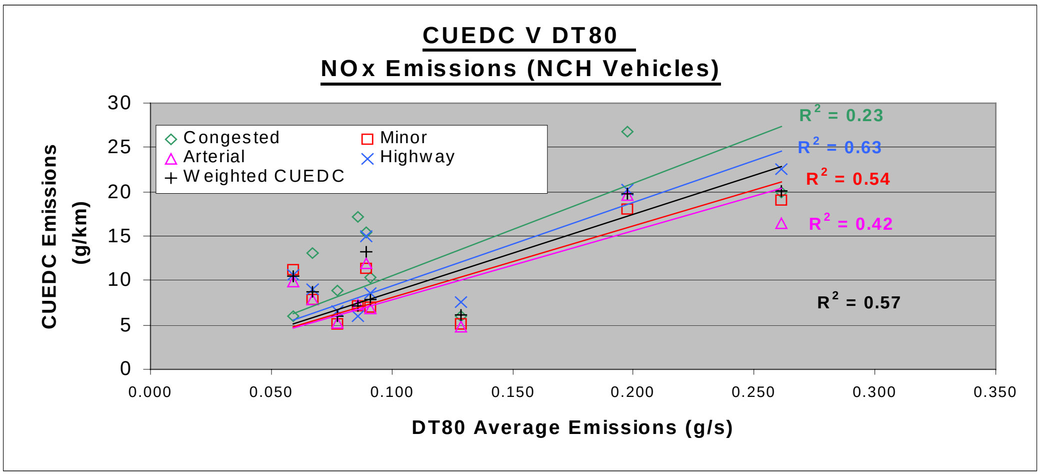


Figure A6 7: NOx - CUEDC v DT80– NCH Vehicles

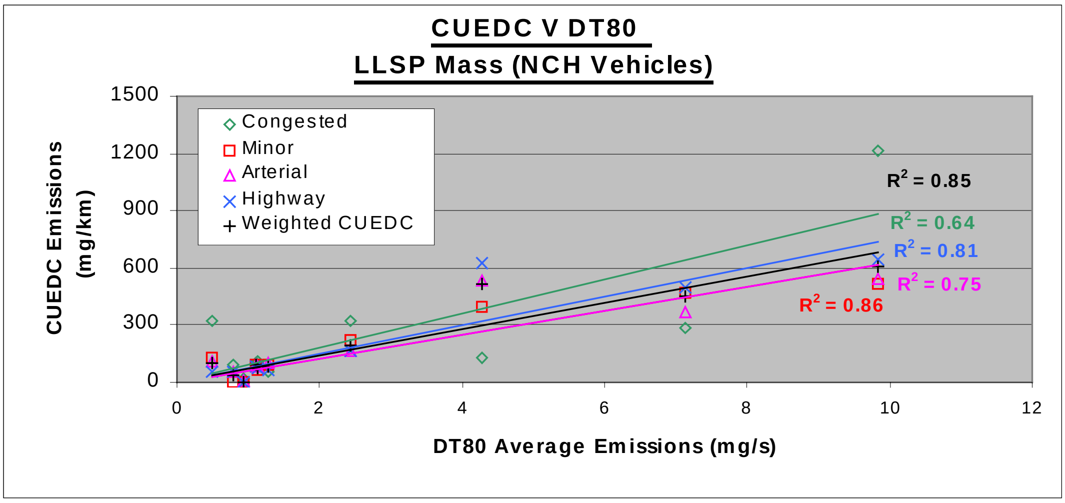


Figure A6 8: LLSP Mass - CUEDC v DT80– NCH Vehicles

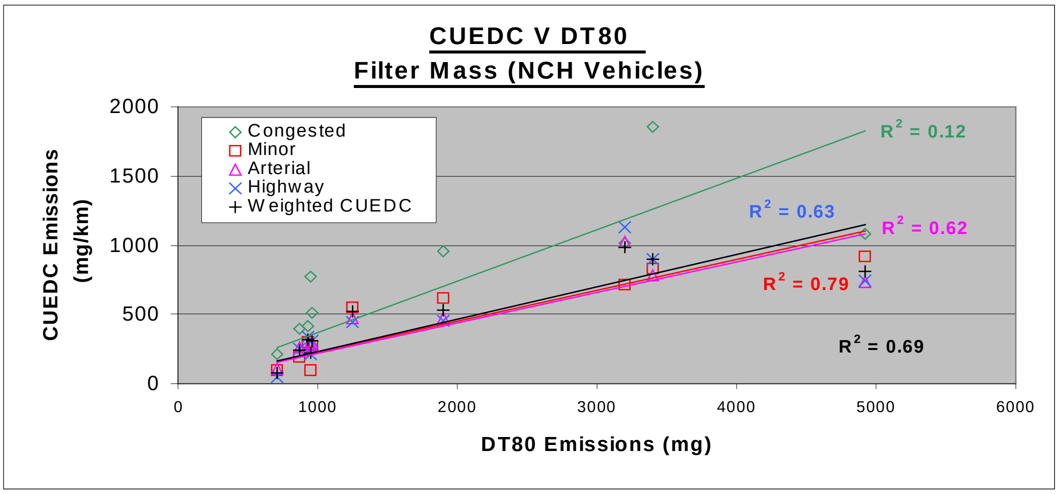


Figure A6 9: Filter Mass - CUEDC v DT80– NCH Vehicles

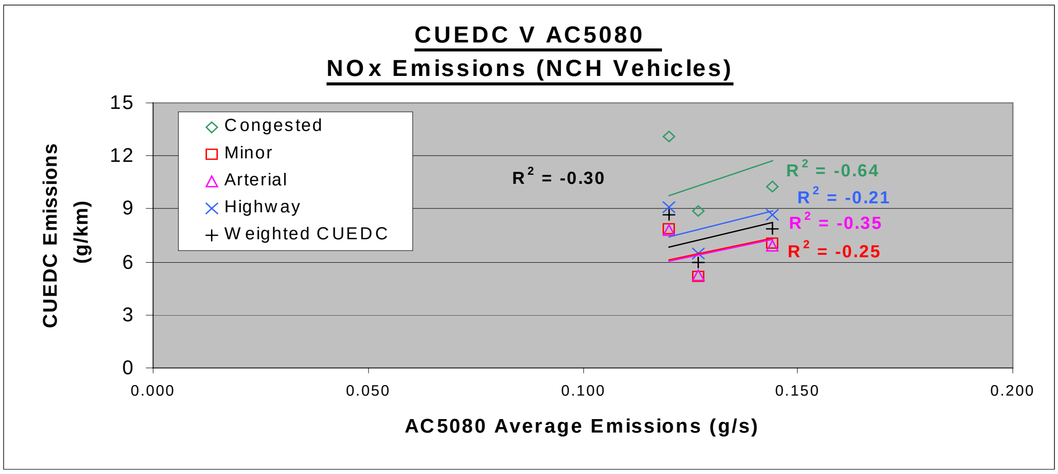


Figure A6 10: NOx - CUEDC v AC50/80– NCH Vehicles

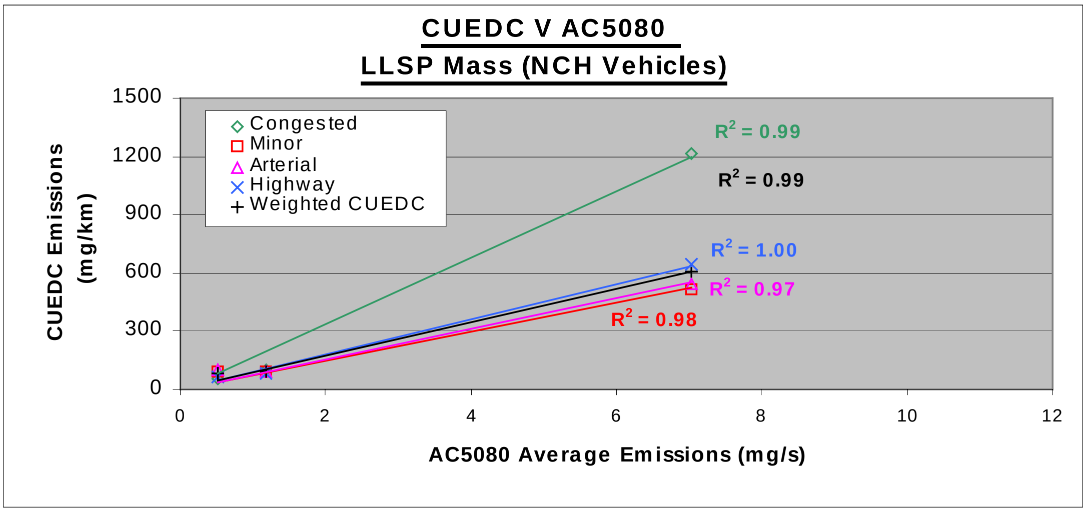


Figure A6 11: LLSP Mass - CUEDC v AC50/80– NCH Vehicles

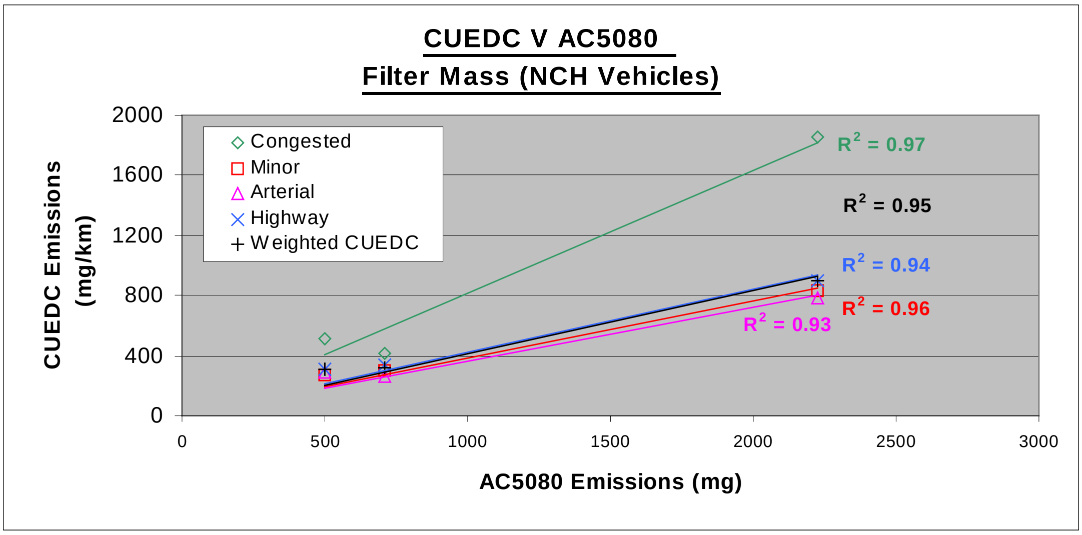


Figure A6 12: Filter Mass - CUEDC v AC50/80– NCH Vehicles

From these scatterplots, it can be seen that the correlations are based on small and varying populations depending on the ADR category and therefore caution should be used when interpreting the data. Reference should be made to the discussion in the main body of the report, section 6 regaing ADR category vs test mass correlations.

APPENDIX 7

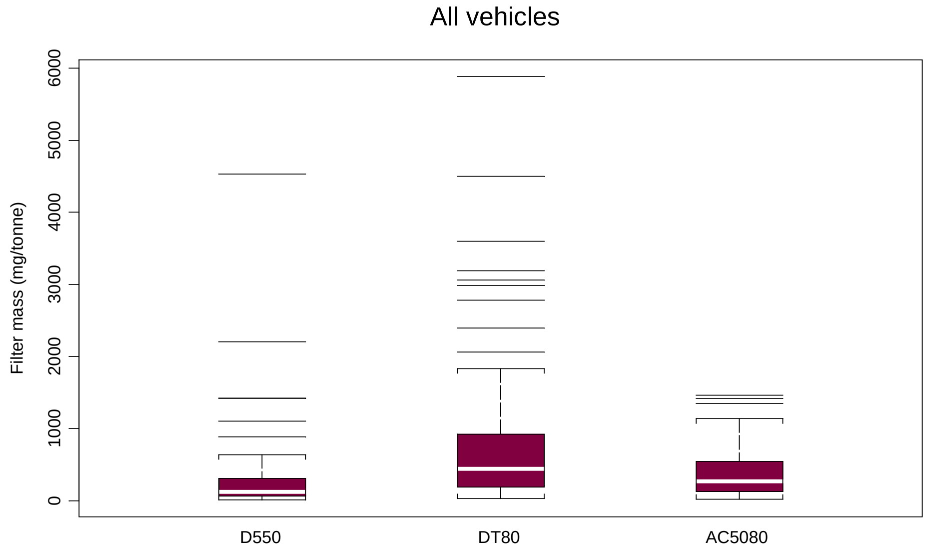


Figure A7 1

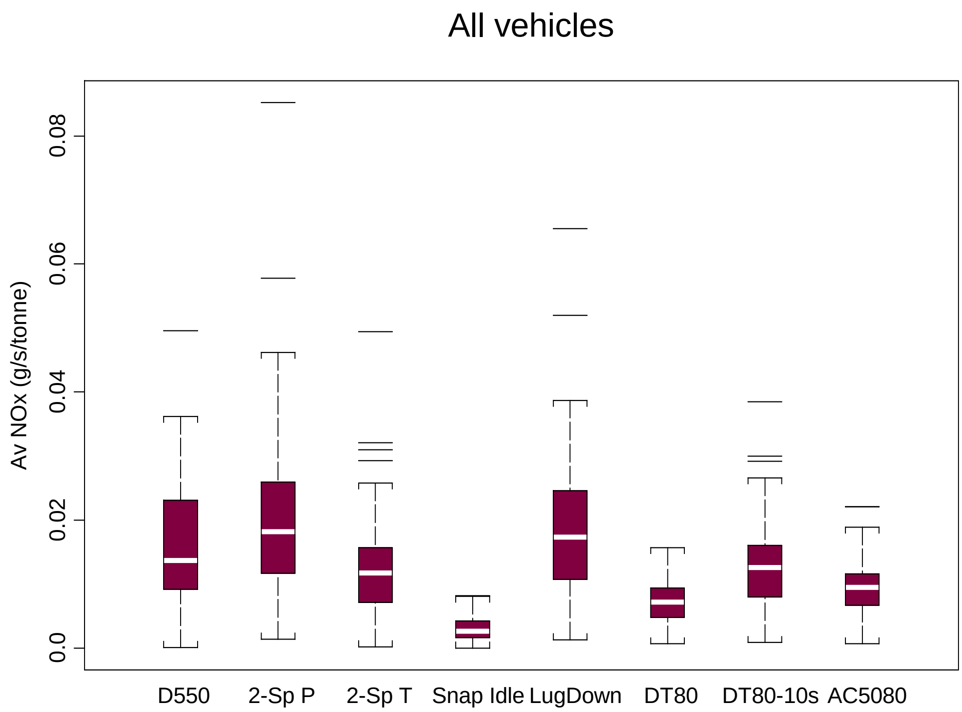


Figure A7 2

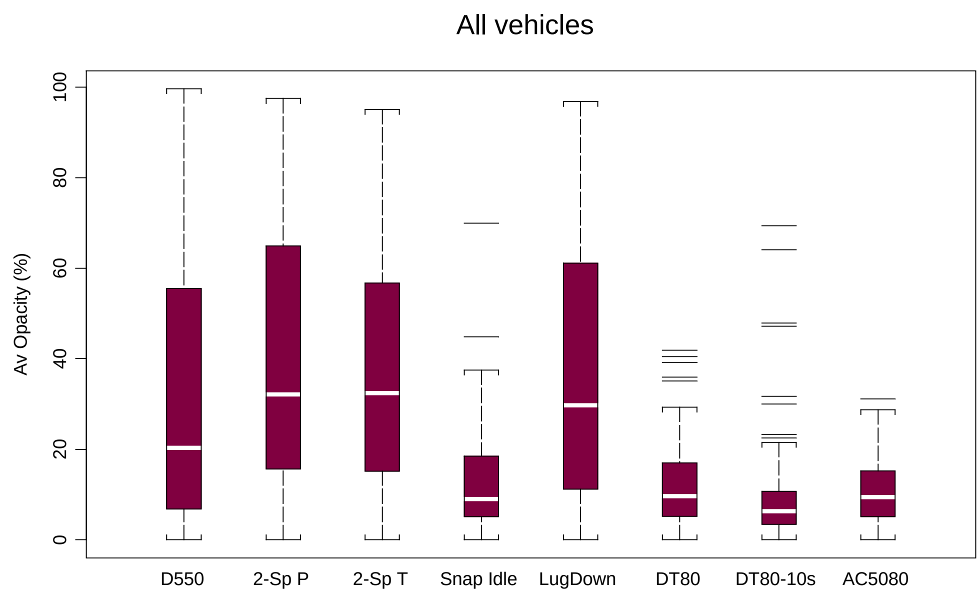


Figure A7 3

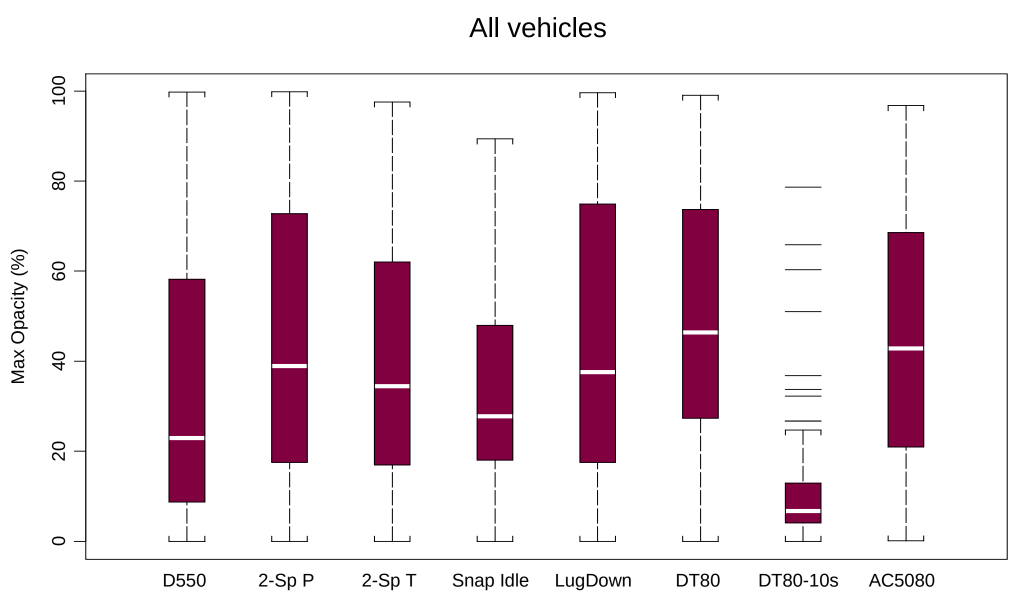


Figure A7 4

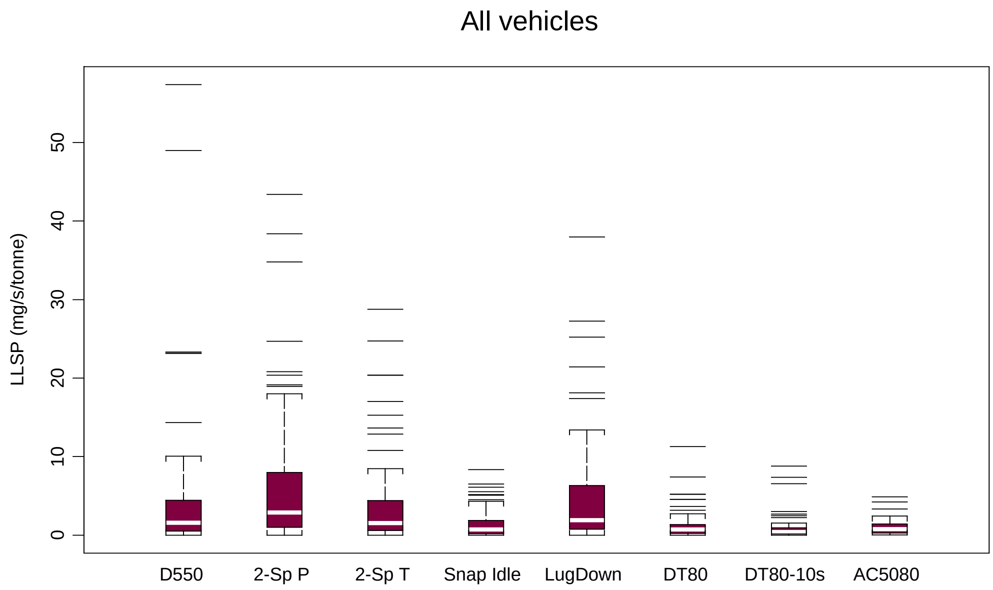

All vehicles
LLSP (mg/s/tonne)
0
10
20
30
40
50
D550
2-Sp P
2-Sp T
Snap Idle
LugDown
DT80
DT80-10s
AC5080

Figure A7 5

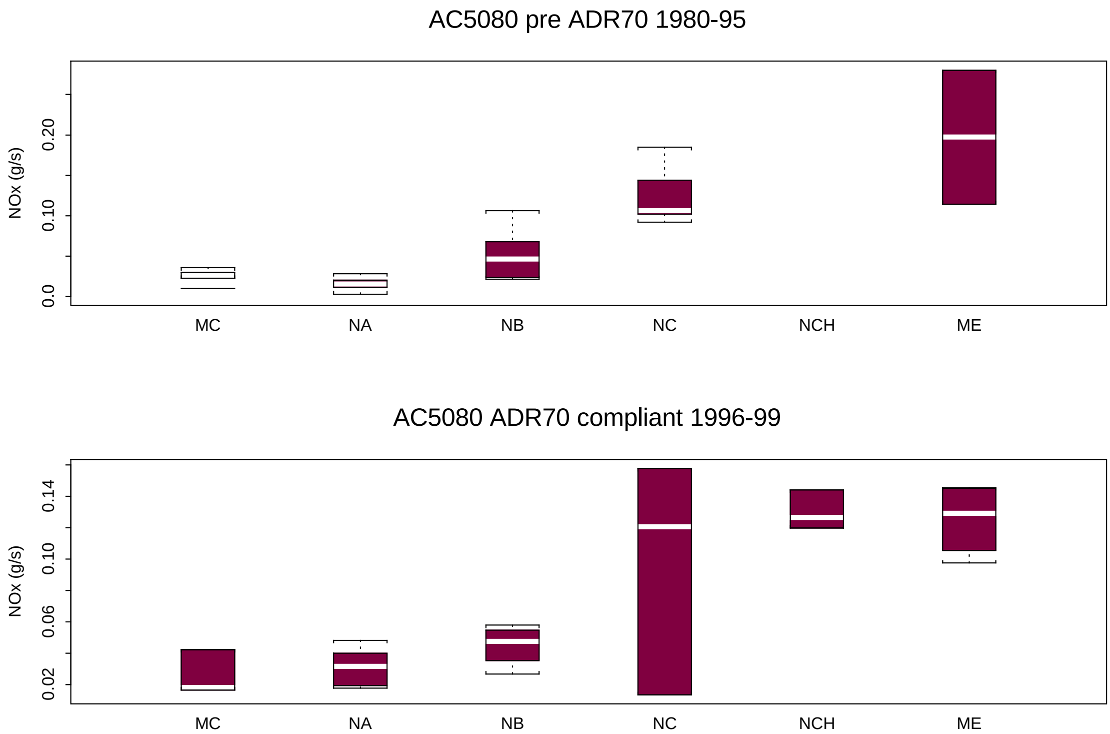


Figure A7 6

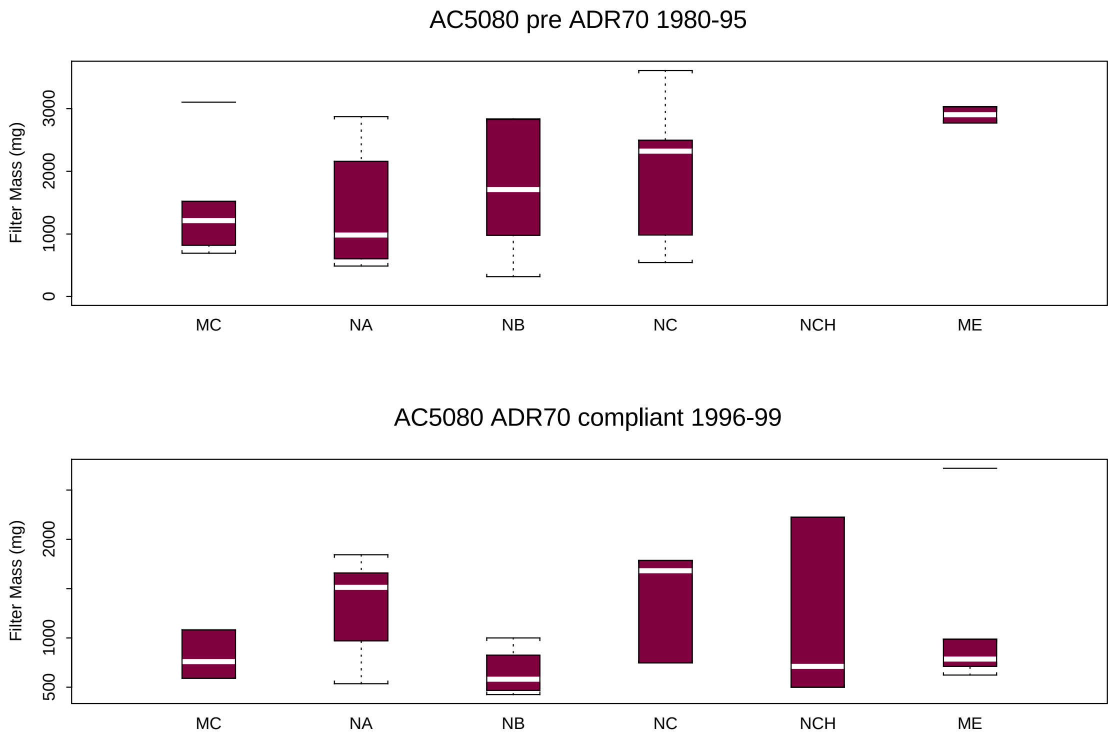
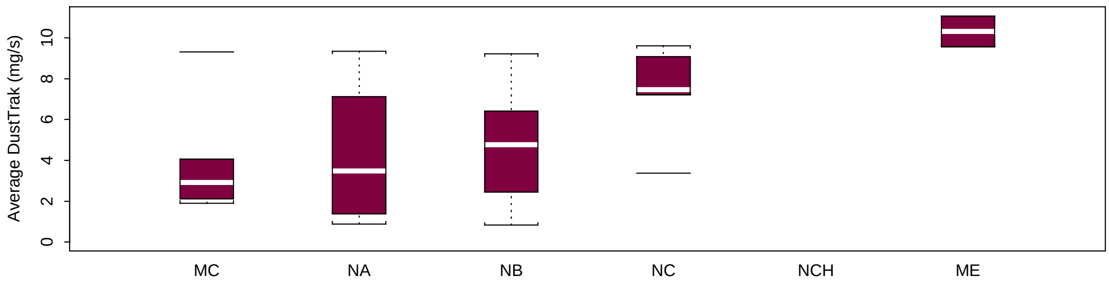


Figure A7 7

AC5080 pre ADR70 1980-95



AC5080 ADR70 compliant 1996-99

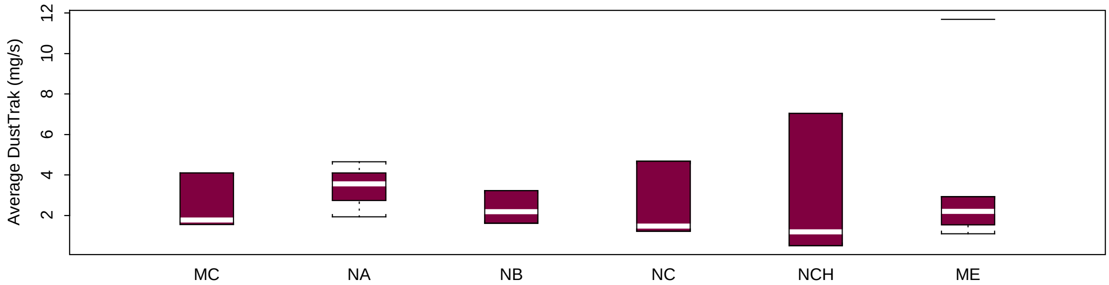
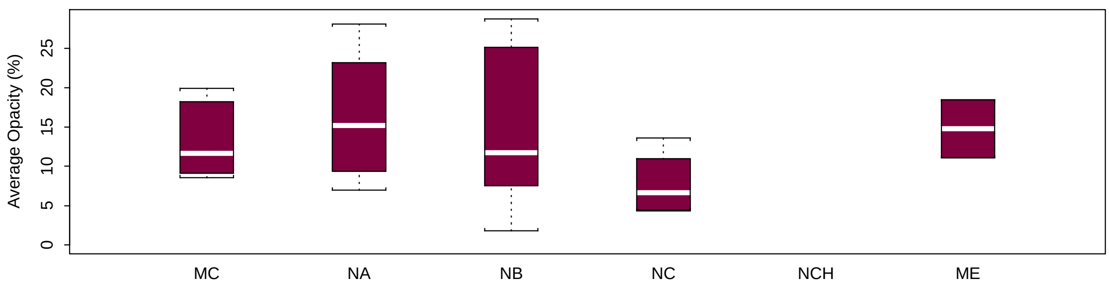


Figure A7-12

AC5080 pre ADR70 1980-95



AC5080 ADR70 compliant 1996-99

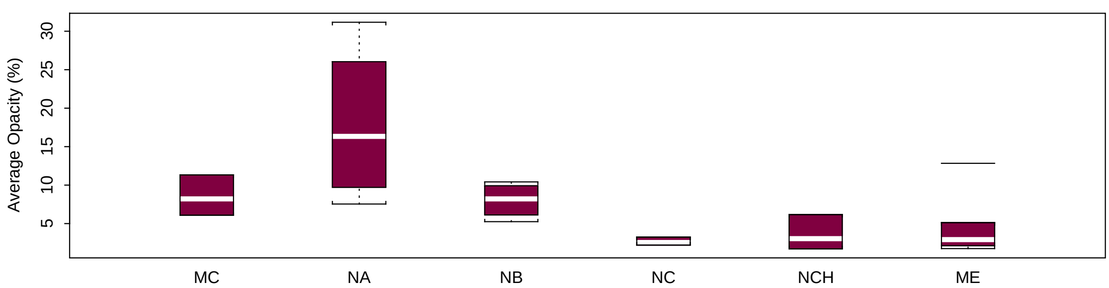
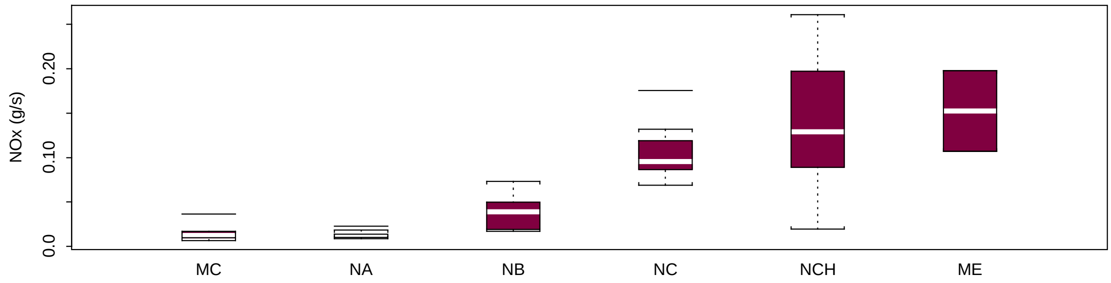


Figure A7-13

DT80 pre ADR70 1980-95



DT80 ADR70 compliant 1996-99

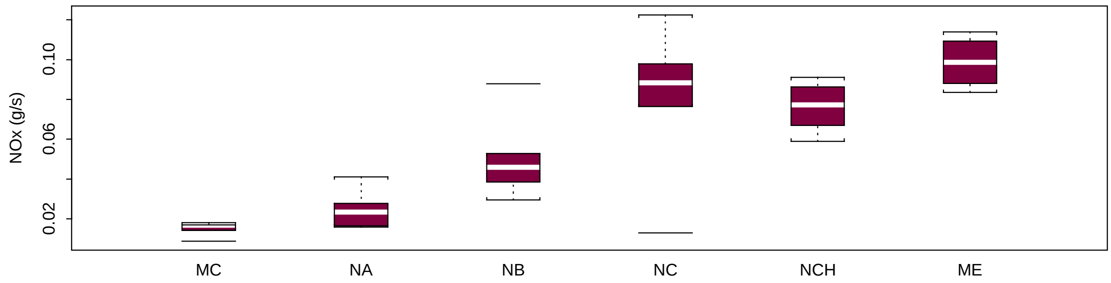
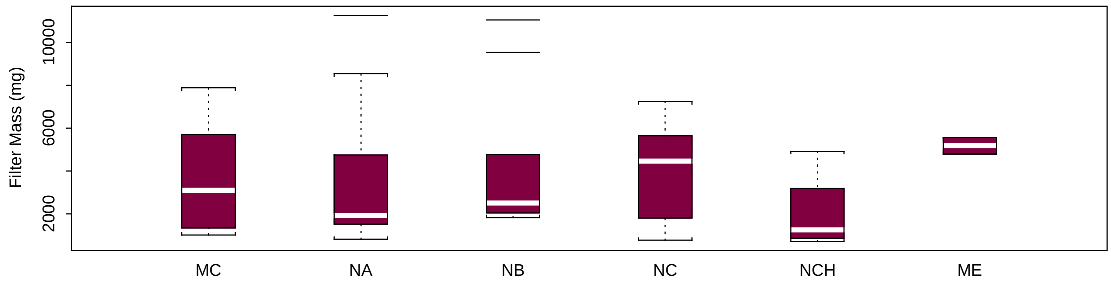


Figure A7-14

DT80 pre ADR70 1980-95



DT80 ADR70 compliant 1996-99

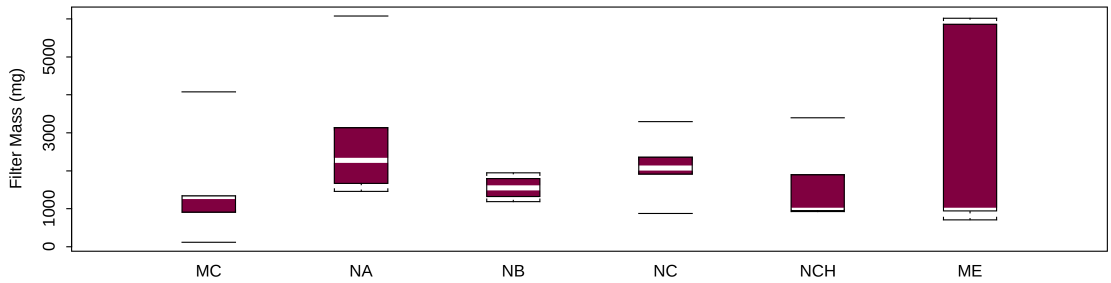


Figure A7-15

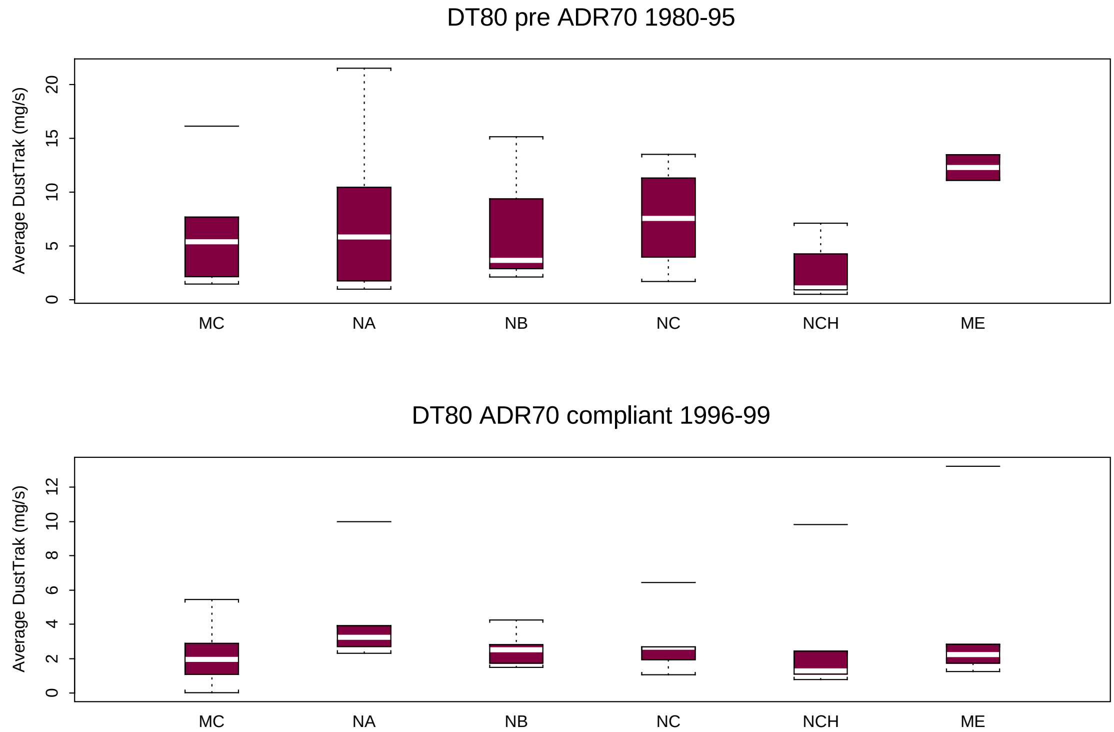


Figure A7-16