



## **Delaware 2016 Remote Sensing Survey**

Prepared for:

**Department of Natural Resources and Environmental  
Control**

Prepared by:

*Peter M McClintock, Ph.D.*

*Applied Analysis  
California  
pm2pt5@gmail.com*

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# Glossary of Terms and Abbreviations

ADT	Average Daily Traffic
ASM	Acceleration Simulation Mode
Basic I/M	A set of vehicle I/M program inspection requirements defined by the U.S. EPA that may be used in areas not required to implement an Enhanced I/M program; the inspection procedure usually involves idle testing
Clean Screening	The process of identifying vehicles with low emissions that are then exempt from emission inspection at an inspection station
CO	Carbon monoxide
CO <sub>2</sub>	Carbon dioxide
Cutpoint	An emissions level used to classify vehicles as having met an emissions inspection requirement
DNREC	Department of Natural Resources and Environmental Control of the State of Delaware
Enhanced I/M	A set of more rigorous vehicle I/M program inspection requirements defined by the U.S. EPA that usually involves IM240 testing
EPA	United States Environmental Protection Agency
Excess Emissions	Vehicle emissions that exceed an I/M cutpoint
FTP	Federal Test Procedure
g/mi	Grams per mile, the units of measurement for FTP and IM240 tests
GIT	Georgia Institute of Technology
GVWR	Gross Vehicle Weight Rating
HC	Hydrocarbons
High Emitter Identification	The on-road identification of vehicles with high emission levels
I/M	Inspection and maintenance program
Idle Test	A tailpipe emission test conducted when the vehicle is idling and the transmission is not engaged
IM240 Test	A loaded-mode transient tailpipe emission test conducted when the vehicle is driven for up to 240 seconds on a dynamometer, following a specific speed trace that simulates real world driving conditions

KW/t	Kilowatts per metric ton, the units of measurement for vehicle specific power
LDGV	Light-duty Gasoline-powered Vehicle
LDGT	Light-duty Gasoline-powered Truck
NO <sub>x</sub>	Oxides of nitrogen, usually measured as nitric oxide (NO)
OBDII	On board diagnostic system to detect emissions related problems that is required on all 1996 and newer light-duty vehicles
Repairable Emissions	The emission reductions that can be obtained by repairing a vehicle. The amount of repairable emissions is equal to or greater than the amount of excess emissions
RSD	Remote Sensing Device
VIN	Vehicle Identification Number
VDR	Vehicle On-road Record
VMT	Vehicle Miles Traveled
VSP	Vehicle Specific Power; estimated engine power divided by the mass of the vehicle
VTR	Vehicle Test Record

## 1. INTRODUCTION

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The 1990 Federal Clean Air Act Amendments require that I/M Programs be implemented in urbanized areas in certain areas to help achieve or maintain attainment of national air quality standards.

Delaware currently operates a test-only, centralized Low enhanced Inspection and Maintenance Program (LEIM) in New Castle and Kent Counties and an I/M program in Sussex County. Motor vehicle emissions tests are performed on all light-duty vehicles weighing up to 8,500 pounds gross vehicle weight at the Delaware Division of Motor Vehicles. Biennial inspections are required for model years 1968 and newer light duty passenger vehicles and model years 1970 and newer light duty trucks with the exception of the five most recent model years. OBD inspections are performed on all 1996 and newer light-duty vehicles and light-duty trucks equipped with certified on-board diagnostic systems (OBD). The exhaust of non OBD equipped vehicles is inspected with Idle or Two Speed Idle tests that measure HC and CO. Evaporative tests are also performed.

The Clean Air Act Amendments of 1990 require Enhanced I/M program areas to supplement emissions testing at stations with on-road testing. The Department of Natural Resources and Environmental Control (DNREC) contracted Envirotest to conduct a remote sensing device (RSD 0.5%) survey to meet this requirement.

### **Fleet Emissions**

Emissions of 14,162 vehicles were measured on-road in Delaware during September 2016. Of these, 11,892 (84%) were identified as Delaware registrations.

Average hot running emissions of the Delaware registered vehicles were 14 ppm HC hexane, 0.08% CO and 99 ppm NO. Delaware registered light vehicles, 2006 and older models accounted for 33% of on-road activity and for 77%, 63% and 95% of the HC, CO and NO emissions respectively of Delaware registered vehicle HC, CO and NO emissions.

The trucks measured with visible plates were virtually all 10,000 lbs GVWR or less<sup>i</sup>

HC & CO emissions were highest among 1992 and older models. NO emissions were highest among 1995 and older models.

### **High Emitters**

197 (1.9%) of vehicles had HC greater than 250 ppm or CO emissions greater than 2.5% or NO greater than 2000 ppm or smoke greater than 0.4 RSD smoke factor. Details of these high emitters are provided in section VI.

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<sup>i</sup> . Heavy-duty trucks with vertical exhaust stacks are not measured by RSD without a special set-up.

## 2. STUDY DESIGN

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Section 51.371 of the Code of Federal Regulation (CFR) covering Enhanced I/M programs defines on-road testing as the measurement of HC, CO, NO<sub>x</sub> and/or CO<sub>2</sub> emissions on any road or roadside in the non-attainment area or the I/M program area. On road testing is required in enhanced I/M areas and is an option for basic I/M areas.

The general requirements specified in CFR 51.371 are:

- On-road testing is to be part of the emission testing system, but is to be a complement to testing otherwise required.
- On-road testing is not required in every season or on every vehicle but shall evaluate the emission performance of 0.5% of the subject fleet, including any vehicles that may be subject to the follow-up inspection provisions of paragraph 4 (below), each inspection cycle.
- The on-road testing program shall provide information about the emission performance of in-use vehicles by measuring on-road emissions through the use of remote sensing devices or roadside pullovers including tailpipe emission testing. The program shall collect, analyze and report on-road emissions data.
- Owners of vehicles that have previously been through the normal periodic inspection and passed final retest and found to be high emitters shall be notified that the vehicles are required to pass and out-of-cycle follow-up inspection; notification may be by mailing in the case of remote sensing on-road testing or through immediate notification if roadside pullovers are used.

Following sections describe how these requirements have been fulfilled.

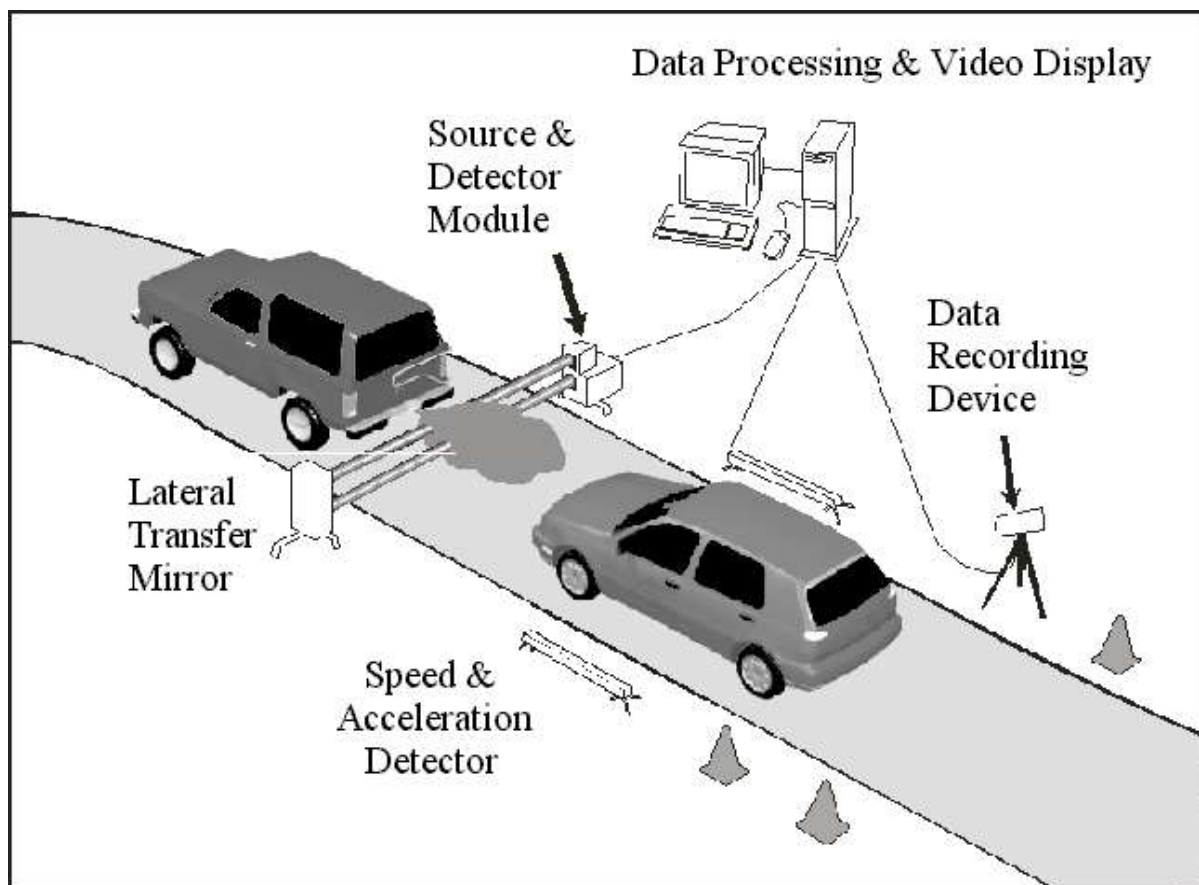
### 2.1 EQUIPMENT DESCRIPTION

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The Delaware survey was performed using a remote sensing RSD4600 system. The RSD4600 detects vehicle emissions when a car drives through an invisible light beam the system projects across a roadway.

Figure 2-1 illustrates the remote sensing equipment set-up. The process of measuring emissions remotely begins when the RSD4600 Source & Detector Module (SDM) sends an infrared (IR) and ultraviolet (UV) light beam across a single lane of road to a lateral transfer mirror. The mirror reflects the beam back across the street (creating a dual beam path) into a series of detectors in the SDM.

FIGURE 2-1 ON-ROAD REMOTE SENSING SET-UP



Fuel specific concentrations of HC, CO, CO<sub>2</sub>, NO<sub>x</sub> and smoke are measured in vehicle exhaust plumes based on their absorption of IR/UV light in the dual beam path. During this process, the data-recording device captures an image of the rear of the vehicle, while the Speed & Acceleration Detector measures the speed of each vehicle.

The RSD units are housed in fully outfitted vans equipped with heating/cooling, a generator, and adequate storage for all components. The vans carry a full complement of road safety equipment and tools for making small repairs. The vans are equipped with additional lighting for testing during pre-dawn and post dusk hours. The new RSD4600 includes the following features:

- Simple and easy setup with laser alignment aids
- Alignment platforms to facilitate a fast and secure alignment result
- Continuous automatic CO<sub>2</sub> for background compensation that minimizes the need for field calibration. (Only one or two calibrations are generally required during a full day of data collection.)
- Fourth generation real-time measurement validation
- Signal sensitivity and accuracy that significantly exceed 2002 California BAR certification standards
- A multi-tasking Windows operating system

- A fuel specific smoke measurement using a UV wavelength that senses the fine particles invisible to traditional visible light opacity meters
- Rugged assemblies that result in high availability.

## **2.2 EQUIPMENT QA/QC AUDITS:**

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### **2.2.1 FACTORY TESTING AND CERTIFICATION**

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When an RSD system is built at the Tucson Technology Center, it undergoes several steps to ensure accuracy. First, the source detector module is bench calibrated. It is then audited using several blends of gas. When the system is fully calibrated and assembled, it is tested again in the parking lot using an audit truck. The unit tests are based on the BAR OREMS specification.

An audit truck is a modified vehicle that uses a long exhaust stack to direct the vehicle engine exhaust upwards and away from the roadway. Audit gases of known concentrations are dispensed through a simulated tailpipe routed to the rear of the audit truck. When the truck is driven past a roadside remote sensing SDM/VTM set of modules, the system measures the pollutant concentrations in the dispensed test gas instead of the vehicle engine exhaust.

The remote sensing unit is setup in a parking lot to avoid interference from other traffic. The auditor drives the audit truck through the remote sensing system 40 times for each gas blend during acceptance testing. Envirotec detector accuracy, including speed and acceleration, will meet the detector accuracy tolerances shown below for at least 97.5% (39/40) runs for each gas. Six different audit gas blends are used to verify the unit accuracy over a range of pollutant concentrations.

#### **2.2.1.1 DETECTOR ACCURACY:**

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The carbon monoxide (CO %) reading will be within  $\pm 10\%$  of the Certified Gas Sample, or an absolute value of  $\pm 0.25\%$  CO (whichever is greater), for a gas range less than or equal to 3.00% CO. Negative values shall be included and will not be rounded to zero. The CO% reading will be within  $\pm 15\%$  of the Certified Gas Sample for a gas range greater than 3.00% CO. Negative values will be included and will not be rounded to zero.

The hydrocarbon reading (recorded in ppm propane) will be within  $\pm 15\%$  of the Certified Gas Sample, or an absolute value of  $\pm 250$  ppm HC, (whichever is greater). Negative values will be included and will not be rounded to zero.

The nitric oxide reading (ppm) will be within  $\pm 15\%$  of the Certified Gas Sample, or an absolute value of  $\pm 250$  ppm NO, (whichever is greater). Negative values shall be included and will not be rounded to zero.

#### **2.2.1.2 SPEED AND ACCELERATION ACCURACY:**

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The vehicle speed measurement will be accurately recorded within  $\pm 1.0$  mile per hour.

The vehicle acceleration measurement will be accurately recorded within  $\pm 0.5$  mile per hour / second.

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### **2.2.2 DAILY SET-UP AND CALIBRATION**

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Units are equipped with an internal calibration gas cell, which has a specific set of concentrations. As part of standard procedure, the operator must first set up the retro reflector on the far side of the road and conduct a mirror alignment check. The RSD unit sends infrared and ultraviolet beams across the roadway. These beams are reflected by the mirror and detected by the RSD unit. The RSD detectors create a voltage in response to particular infrared and ultraviolet frequencies. The presence of proper voltages across all detectors verifies that the RSD unit and the mirror are properly aligned. Second, the unit is calibrated to the calibration cell values.

The next step is to verify the unit calibration. This is referred to as a puff audit. Calibration gas is introduced into the IR/UV path. This is accomplished through a calibration gas cylinder, a stainless steel gas regulator, fittings and tubing to deliver the calibration gas to the source detector module (SDM). The operator will then introduce the calibration gas into the IR/UV path via a spray nozzle at the end of the tube. The instrument displays the readings on the screen. The RSD unit response is automatically compared to the calibration gas and required to be within specification limits.

Calibration for the RSD4600 occurs once at the beginning day and at mid-day if conditions warrant.

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### **2.2.3 EQUIPMENT AUDITS**

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After each daily calibration, the Operator is required to perform an audit to verify an optimal calibration. This is done in the same manner as the calibration except the audits are “earmarked” in the data file with an “A”. If the audit passes a predetermined pass/fail tolerance, the operator is allowed to begin testing vehicles. If not, the operator is required to realign and recalibrate the system until it passes the audit process. The Operator thereafter is prompted by the system to perform an audit every two (2) hours to verify the calibration.

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### **2.2.4 QUARTERLY AUDITS (DRIVE-BY AUDITS)**

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An Audit Truck is used to conduct an on-road audit of the RSD4600 system approximately every three months. The audit truck is outfitted with a gas cylinder rack that holds a maximum of 6 compressed gas cylinders. Each gas cylinder is equipped with a high flow regulator, a high flow solenoid and a Tygon hose, which is adapted to a simulated tailpipe. Inside the truck cab, the audit truck operator has the ability to switch power from solenoid to solenoid to select the appropriate audit gas cylinder for drive-by audits. A traffic cone is placed 60-70 feet preceding the test site. This is used



as a mark to begin the flow of gas to ensure there is an adequate plume of audit gas as the truck passes the RSD4600. The typical gas blends used in the audits are show below:

	HC (ppm)	CO	CO2	NO <sub>x</sub> (ppm)
<b>Blend # 1</b>	500	0.5%	14.70%	3000
<b>Blend # 2</b>	3000	1.00%	14.38%	2000
<b>Blend #3</b>	2000	2.75%	13.10%	500
<b>Blend #4</b>	6000	5.00%	11.55%	250

In addition to the equipment, the operator is also audited for following procedures: site setup, calibration, camera alignment, traffic safety and documentation.

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#### 2.2.5 NO VS. NOX

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The vast majority of nitric oxides emitted from the vehicle tailpipe are in the form of NO. The NO is later oxidized to NO<sub>2</sub> and other oxides of nitrogen, which are collectively referred to as NO<sub>x</sub>. The RSD unit measures NO. To convert from NO to NO<sub>x</sub>, a factor of 1.03 can be applied. For simplicity we refer to NO measurements when reporting results. Charts in sections III and IV report NO values.

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#### 2.2.6 NOX AND HUMIDITY

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Higher humidity reduces vehicle NO and NO<sub>x</sub> emissions. For loaded mode dynamometer tests, humidity correction factors are usually applied to adjust the NO<sub>x</sub> measurements to values that would have been achieved when the water vapor content is 75 grains per lb.

Sections III and IV report actual on-road NO emissions. They have not been adjusted for humidity. Correction factors can be calculated using the weather information recorded by the weather station attached to the RSD van.

For temperatures above 75 F:

$$\text{Correction factor} = e^{(.004977*(H-75) - .004447*(T-75))}$$

For temperatures below 75F:

$$\text{Correction factor} = 1/(1.0 - .0047*(H - 75.0))$$

Where:

H = absolute humidity in grains of water/lb dry air

T = Temperature (F)

Both of these are capped at 2.19.

Water vapor grains per lb are determined using the temperature, relative humidity and barometric pressure:

$$\text{Saturated Vapor Pressure} = (-4.14438 \times 10^{-3} + 5.76645 \times 10^{-3} \times [\text{Temp F}] - 6.32788 \times 10^{-5} \times [\text{Temp F}]^2 + 2.12294 \times 10^{-6} \times [\text{Temp F}]^3 - 7.85415 \times 10^{-9} \times [\text{Temp F}]^4 + 6.55263 \times 10^{-11} \times [\text{Temp F}]^5) \times 25.4$$

$$\text{Grains per lb} = (43.478 \times [\text{Relative Humidity}] \times [\text{Saturated Vapor Pressure}]) / ((([\text{Barometric pressure Hg mm}] - ([\text{Saturated Vapor Pressure}] \times [\text{Relative Humidity}] / 100)))$$

## 2.3 SITE LOCATIONS

Envirotest selected eight sites in Delaware. The sites were selected to:

- Provide a representative sampling of the I/M area fleet.
- Obtain measurements in each county.

Table 2-1 lists the set of site locations visited during the study and the days the site was used. Table 2-2 list the number of passing vehicles measured, valid measurements, active collection hours, valid measurements per hour and the percentage of attempted measurements that were successful. Vehicles that are decelerating often have insufficient exhaust volume for a valid emissions measurement. Between 4,450 and 6,000 valid measurements were obtained in each county.

Figure 2-2 displays the locations of the sites.

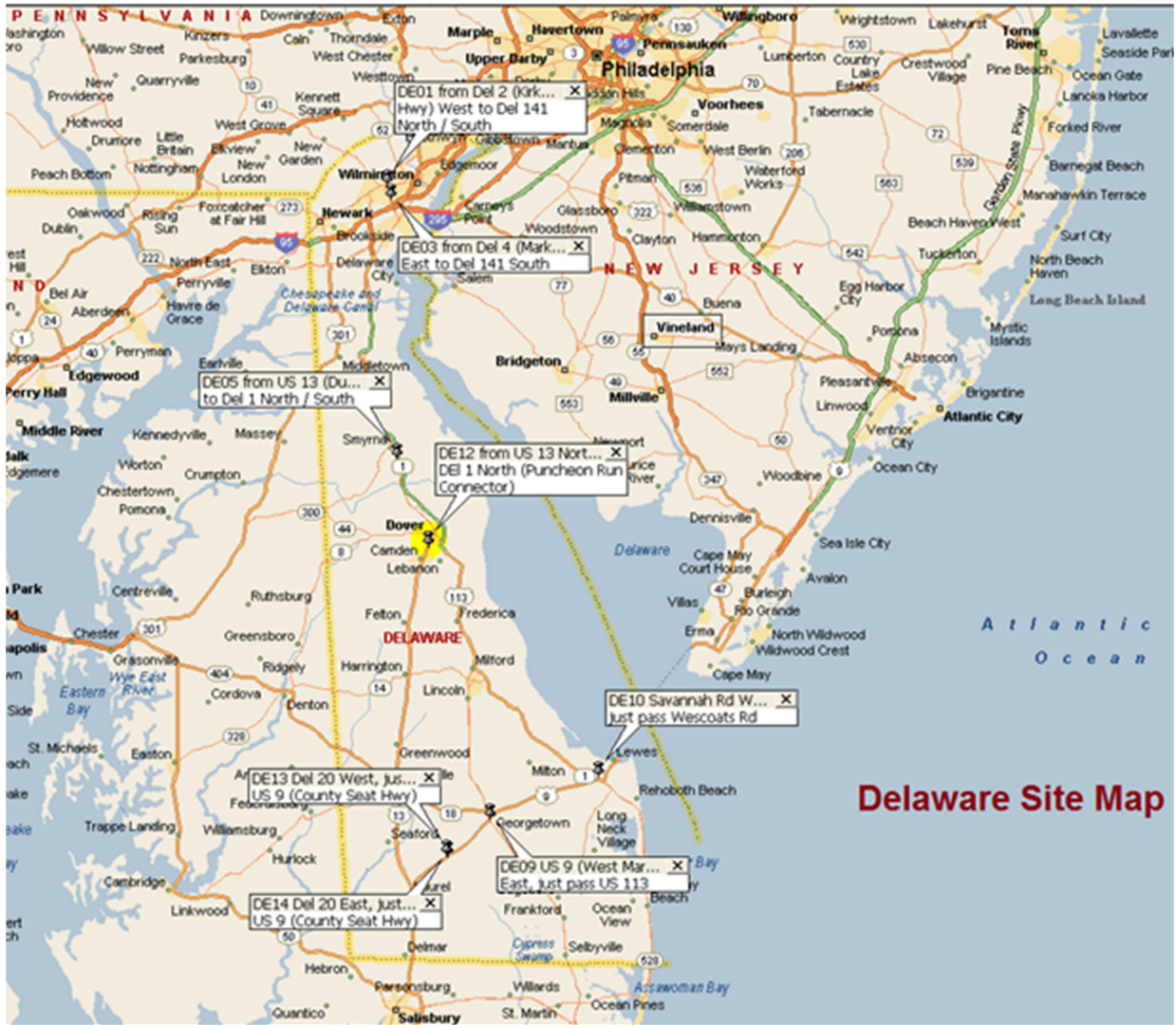
**Table 2-1: Site Locations**

Site	Description	City	County	Slope
DE01	SR 2 (Kirkwood Hyw) to SR 141 N/S	Wilmington	New Castle	0.7
DE03	SR 4 (Market St) EB to SR141 SB	Wilmington	New Castle	2.4
DE05	US 13 (S Dupont Blvd) to SR 1 Korean War Memorial N/ Smyrna		Kent	0.2
DE09	US 9 (W Market St) East, after US 113 (Dupont Blvd)	Georgetown	Sussex	0.4
DE10	US 9 (Savana Rd) West, just pass Wescoats Rd	Lewes	Sussex	0.5
DE12	US 13 North to DE 1 North	Dover	Kent	0.5
DE13	DE 20 West, just past US 9	Seaford	Sussex	0.1
DE14	DE 20 East, just past US 9	Seaford	Sussex	0.1

**Table 2-2: Daily Measurements**

Date	SDM	Site	Start	End	Active Hours	Beam Blocks	Valid Emissions and Speed	Valid %
07-Sep-16	4633	DE13	5:56:47 AM	10:44:20 AM	4.8	751	506	67%
07-Sep-16	4633	DE14	11:48:58 AM	4:00:19 PM	4.2	551	312	57%
08-Sep-16	4633	DE10	6:04:19 AM	5:59:48 PM	11.9	7,016	3,354	48%
09-Sep-16	4633	DE09	7:02:08 AM	1:02:51 PM	6.0	1,919	794	41%
12-Sep-16	4633	DE12	6:33:17 AM	2:49:56 PM	8.3	3,202	775	24%
13-Sep-16	4633	DE05	9:03:24 AM	6:30:06 PM	9.4	2,637	1,650	63%
14-Sep-16	4633	DE05	5:29:22 AM	5:59:29 PM	12.5	4,598	2,832	62%
15-Sep-16	4621	DE01	9:32:32 AM	3:30:27 PM	6.0	2,260	1,938	86%
16-Sep-16	4621	DE03	8:49:20 AM	3:10:10 PM	6.3	4,370	3,973	91%
Total					69.5	27,304	16,134	59%

FIGURE 2-2 SITE LOCATIONS IN DELAWARE



### 2.3.1 WEATHER CONSIDERATIONS

Rain, dense fog, and wet pavement resulting in spray from tires all prevent effective operation of the remote sensing unit since the beam is partially blocked under these conditions. Similarly, cold humid conditions that cause condensation of exhaust plumes are also not productive.

## 2.4 SOURCES OF DATA AND DESCRIPTION OF ELEMENTS

Data used in the analyses in this report come from two primary sources; the RSD unit measurements and the vehicle registration records.

The following description gives a summary of the main tables and data used in the analyses.

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### **2.4.1 RSD MEASUREMENTS**

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For each measurement record the following information is collected:

RSD unit

Date and time

License plate image

HC, CO, CO<sub>2</sub>, and NO measurement

Speed and acceleration

Temperature, barometric pressure, and humidity

Measurement quality indicators: V-valid, X-invalid, E-invalid system exception, O-invalid other, N-NO out of range, S-suspect

Ambients<sup>i</sup>

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### **2.4.2 DATA COLLECTION STATISTICS**

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Unit

Site

Date

Start time

End time

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### **2.4.3 VEHICLE REGISTRATION DATA**

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The license plates of vehicles with Delaware plates measured by RSD were matched by plate to registration records provided by the department to determine the vehicle identification number (VIN) and additional vehicle information, e.g.:

Vehicle identification number (VIN)

Vehicle license plate

Fuel Code

Model year

Make

Body style

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<sup>i</sup> Ambient background levels of HC, CO, CO<sub>2</sub> and NO emissions are measured continuously and are deducted from the emissions levels measured in exhaust plumes of passing vehicles.

EPA vehicle type (LDGV, LDGT1, etc)

County

Zip code

## 2.5 DATA SCREENING

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Envirotest applied the following screening checks to the RSD measurements to ensure the data used for fleet evaluation and fleet comparisons are reasonable and consistent:

- Screening of exhaust plumes
- Screening of hourly observations to check for cold starts;
- Screening of low and high values:
  - HC ppm hexane  $\geq -100$  and  $\leq 50,000$ ;
  - NO ppm  $\geq -500$  and  $\leq 20,000$ ;
  - % CO  $\geq -0.5$  and  $\leq 20$ ;
  - UVSmoke  $\geq -0.2$ .
- Screening of day-to-day variations in emissions values
- Screening for Vehicle Specific Power (VSP) range

The first four of these screening procedures are described in the following paragraphs. The VSP screening is described in section 3.2.

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### 2.5.1 SCREENING OF EXHAUST PLUMES

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The RSD4600 unit takes many measurements of each exhaust plume in the one half second after each vehicle passes the equipment.

The basic gas record validity criteria applied are:

- A gas record is valid if there are at least 5 plume measurements where the sum of the amount of CO<sub>2</sub> and CO gas exceed 10%-cm<sup>i</sup>; or
- A gas record is valid if there are at least 5 plume measurements where the sum of the amount of CO<sub>2</sub> and CO gas exceed 5%-cm and the background gas values are very stable (not changing faster than a specified rate) at the time the front of the vehicle breaks the measurement beam.

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<sup>i</sup> The unit of measurement 10%-cm is a measurement of the amount of a gas in the optical path. In this case, if all the molecules of the gas in the path were collected together into just one centimeter of the path then the concentration of the gas in the one-centimeter would be 10%.

## 2.5.2 SCREENING OF HOURLY OBSERVATIONS

Vehicles operating in cold start mode or under conditions when exhaust plumes condense to steam can appear to have high HC emissions. Spray from wet roads can have a similar effect. Envirotest tabulated for each site and hour the percentage of 2010 and newer vehicles that exceeded 150 ppm HC hexane. The percent of 2010 and newer vehicles that exceed 150 ppm HC is normally low unless temperatures are below 40F when vehicles can trail steam plumes or the road was wet. Higher percentages of 2010 and newer vehicles exceeding 150 ppm HC were observed during the study (Table 2-3a) but few exceeded 250ppm (Figure 2.3b). Average hourly temperature and relative humidity at the RSD van are shown in tables 2-4 and 2-5. After review, it was determined the high values were associated with greater than normal noise on the HC channel of 4633 and was not the result of steam or spray.

Measurements were also screened for the presence of unusually high values or unusually low values.

**Table 2-3a: Percentage of 2010 and Newer Models with HC > 150 ppm hexane**

Day	RSD Unit	Site	5	6	7	8	9	10	11	12	13	14	15	16	17	18
7-Sep-16	4633	DE13		0%	0%	0%	3%	0%								
7-Sep-16	4633	DE14								0%	0%	4%				
8-Sep-16	4633	DE10		0%	1%	1%	3%	1%	1%	1%	3%	1%	4%	2%	2%	
9-Sep-16	4633	DE09			0%	4%	5%	0%	0%	0%						
12-Sep-16	4633	DE12		7%	4%	8%	5%									
13-Sep-16	4633	DE05					2%	0%	3%	2%	2%	3%	6%	3%	0%	3%
14-Sep-16	4633	DE05	0%	3%	3%	0%	8%	4%	7%	6%	8%	3%	4%	2%	1%	
15-Sep-16	4621	DE01					0%	0%	0%	0%	2%	0%	0%			
16-Sep-16	4621	DE03				3%	0%	1%	0%	0%	1%	0%	0%			

**Table 2-3b: Percentage of 2010 and Newer Models with HC > 250 ppm hexane**

Day	RSD Unit	Site	5	6	7	8	9	10	11	12	13	14	15	16	17	18
7-Sep-16	4633	DE13		0%	0%	0%	0%	0%								
7-Sep-16	4633	DE14								0%	0%	0%				
8-Sep-16	4633	DE10		0%	0%	1%	0%	1%	1%	0%	1%	0%	1%	1%	0%	
9-Sep-16	4633	DE09			0%	0%	0%	0%	0%	0%						
12-Sep-16	4633	DE12		4%	1%	0%	0%									
13-Sep-16	4633	DE05					1%	0%	0%	0%	0%	0%	2%	0%	0%	0%
14-Sep-16	4633	DE05	0%	0%	0%	0%	0%	0%	2%	2%	0%	2%	1%	0%	0%	
15-Sep-16	4621	DE01					0%	0%	0%	0%	1%	0%	0%			
16-Sep-16	4621	DE03				3%	0%	1%	0%	0%	0%	0%	0%			

**Table 2-4: Hourly Temperature**

Day	Unit	Site	5	6	7	8	9	10	11	12	13	14	15	16	17
7-Sep-16	4633	DE13	23	23	23	24	26	29							
7-Sep-16	4633	DE14							33	33	34	34	34	34	
8-Sep-16	4633	DE10		27	27	28	33	36	37	37	38	38	38	35	37
9-Sep-16	4633	DE09			32	32	32	34	36	39	39				
12-Sep-16	4633	DE12		20	21	24	26	26	28	29	30	31			
13-Sep-16	4633	DE05					25	27	30	31	32	32	31	30	29
14-Sep-16	4633	DE05	23	23	23	25	28	30	32	33	34	35	35	35	35
15-Sep-16	4621	DE01					23	24	25	27	30	32	33		
16-Sep-16	4621	DE03				22	24	27	27	28	30	30	30		

**Table 2-5: Hourly Relative Humidity**

Date	Unit	Site	5	6	7	8	9	10	11	12	13	14	15	16	17
7-Sep-16	4633	DE13	54	53	56	52	48	42							
7-Sep-16	4633	DE14							39	37	33	29	32	30	
8-Sep-16	4633	DE10		56	48	46	38	34	34	35	35	34	41	50	35
9-Sep-16	4633	DE09			38	35	36	37	34	32	30				
12-Sep-16	4633	DE12		49	50	50	38	36	35	31	27	26			
13-Sep-16	4633	DE05					62	49	36	33	31	36	39	39	41
14-Sep-16	4633	DE05	60	55	54	57	54	50	47	41	35	31	29	29	27
15-Sep-16	4621	DE01					38	36	32	28	27	25	25		
16-Sep-16	4621	DE03				49	44	34	33	31	28	27	27		

### 2.5.3 SCREENING OF DAY-TO-DAY VARIATIONS IN EMISSIONS VALUES

Day-to-day decile values were compared for 2010 and newer vehicles. Only a small percentage of these vehicles are expected to have high emissions and we expect the intermediate decile emission values should not vary significantly from day-to-day, from site-to-site or between RSD units. In Figure 2-3, the HC decile values for each day of measurements are plotted side-by-side as an example. This comparison revealed median values for the 2010 and newer models that ranged day-to-day from -6 ppm to +13ppm. Although these variations are within the HC specification of the RSD4600 units they are significant compared to average fleet emissions for newer vehicles.

The most likely explanation is that the variation in daily medians represents the limits of accuracy in the daily instrument set-up. For HC, an adjusted set of values was created by direct addition or subtraction of a daily offset that would set the daily median values to zero. We believe this is appropriate since the median I/M test result for new models is normally zero or very close to zero. The results of the correction are shown in Figure 2-4 and analyses shown later in this report used the adjusted HC values.

Day-to-day decile CO, NO and UV smoke values for 2010 and newer vehicles are shown in Figures 2-5 to 2-7. Median values for CO, NOx and smoke were 0.03%, 6ppm and -0.005 respectively. These small values appear reasonable and adjustments were not applied to these pollutants.



FIGURE 2-3 DAILY HC DECILES

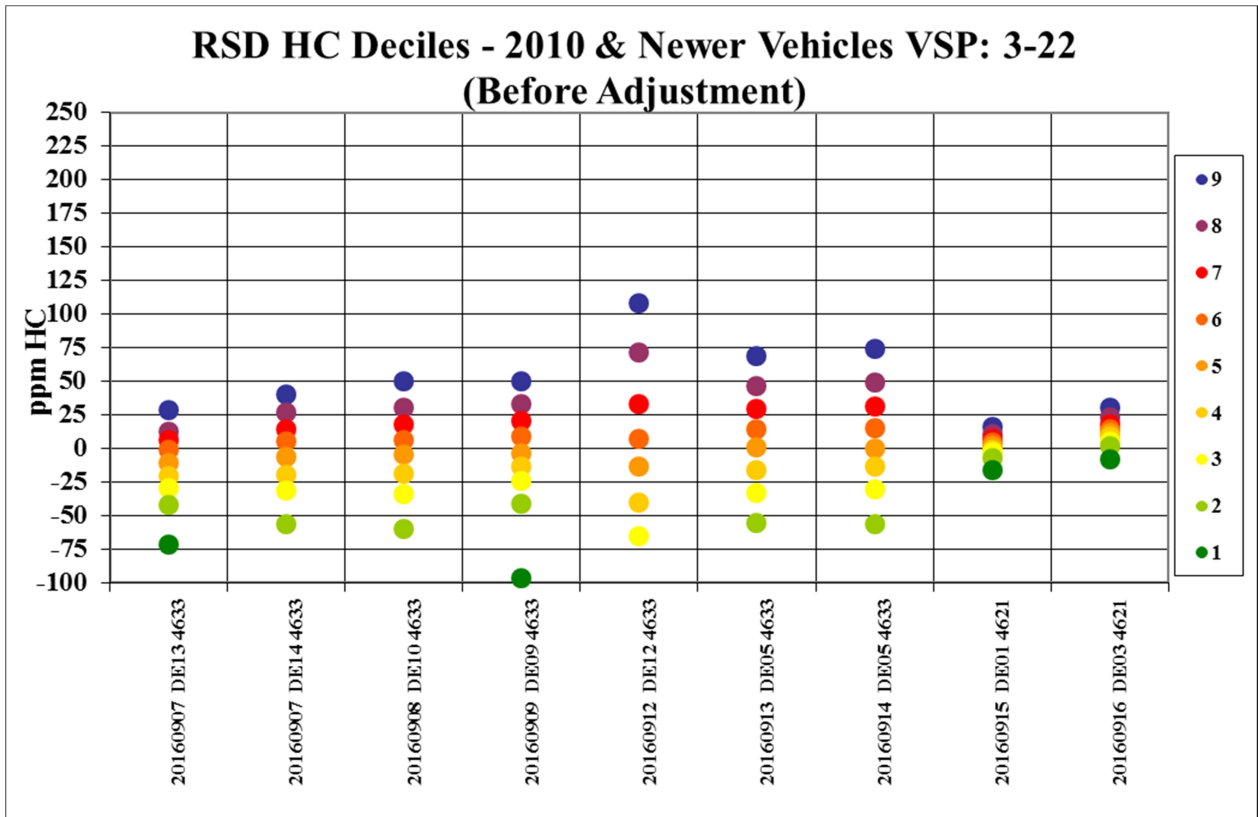


FIGURE 2-4: DAILY HC DECILES – AFTER ADJUSTMENT

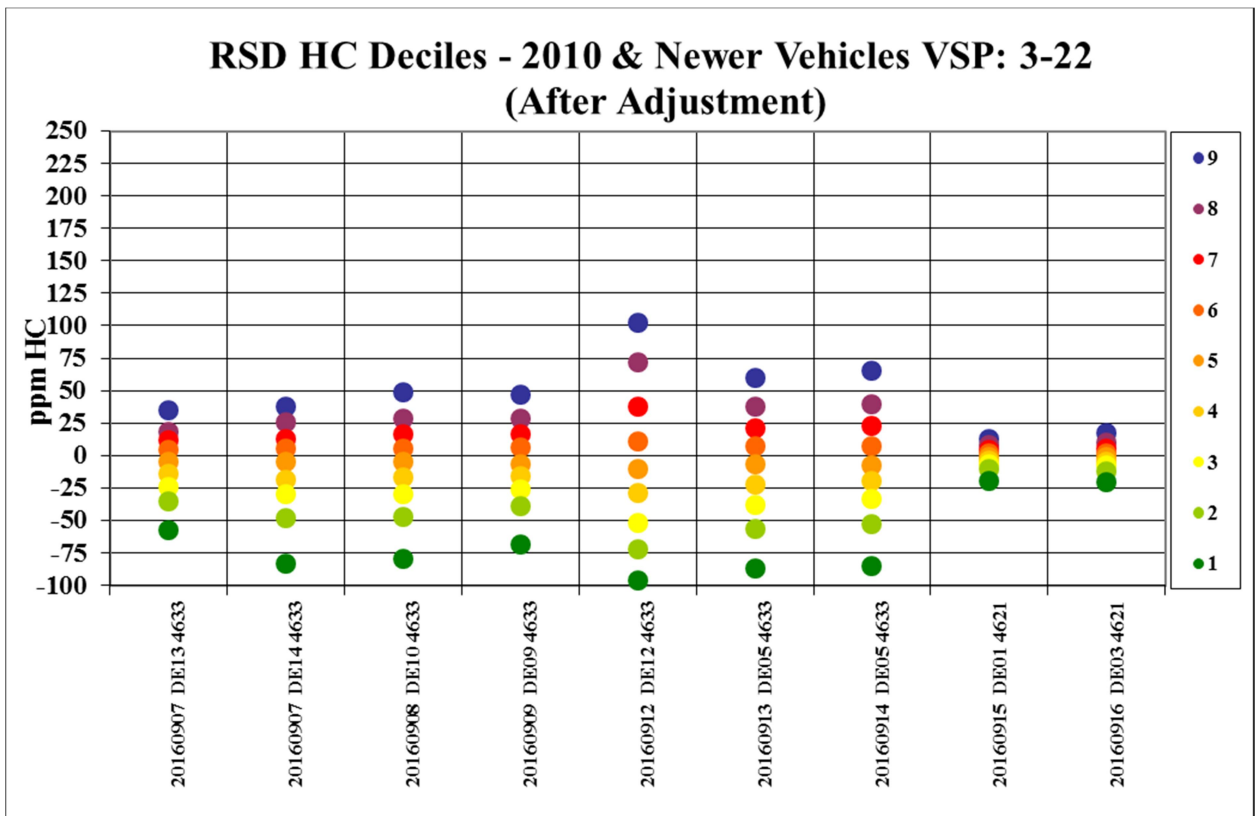


FIGURE 2-5 DAILY CO DECILES

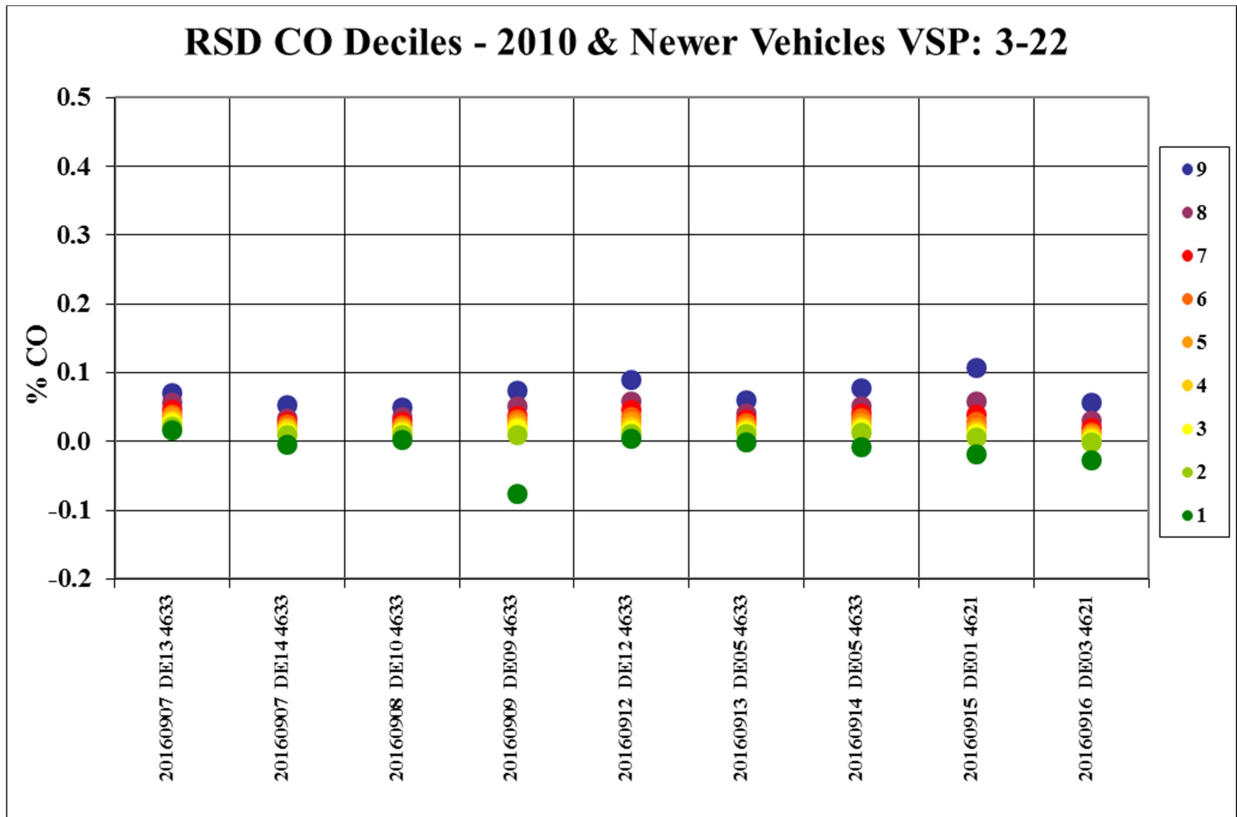


FIGURE 2-6 DAILY NO DECILES

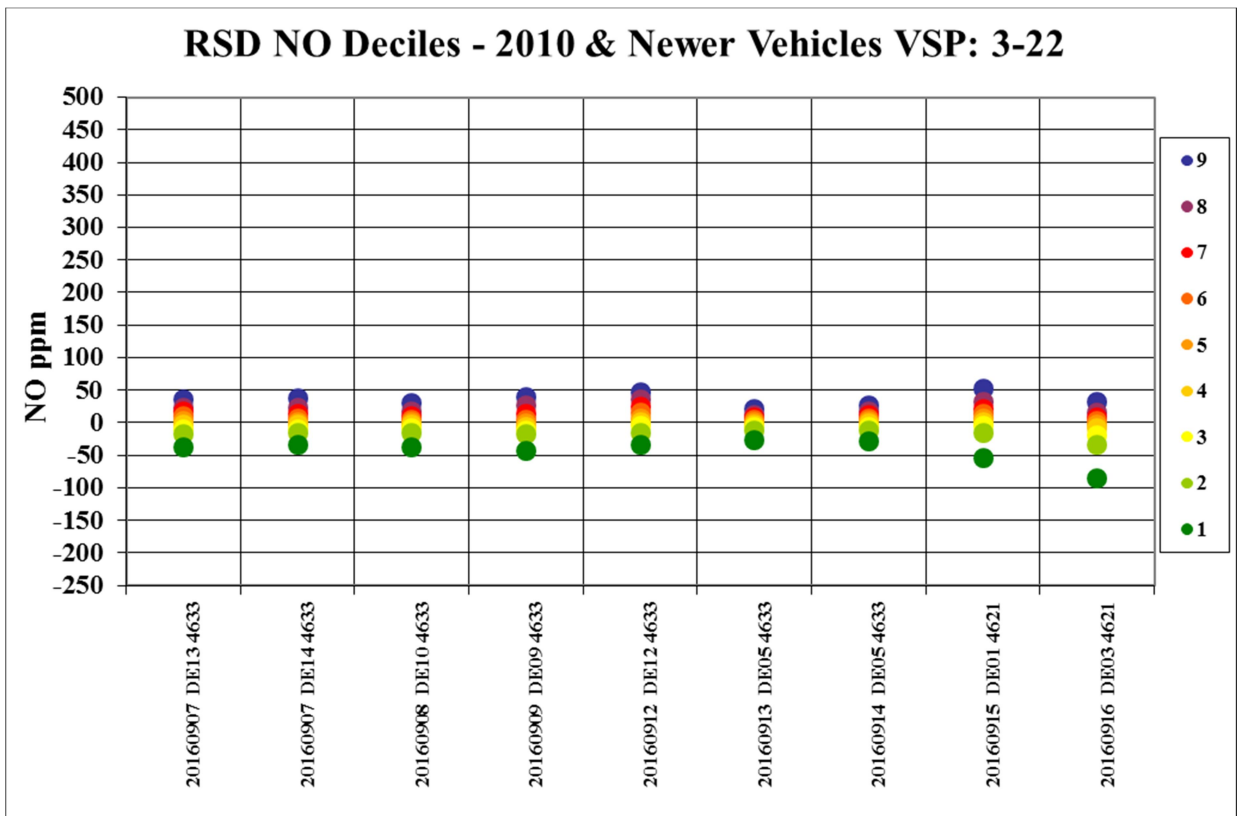
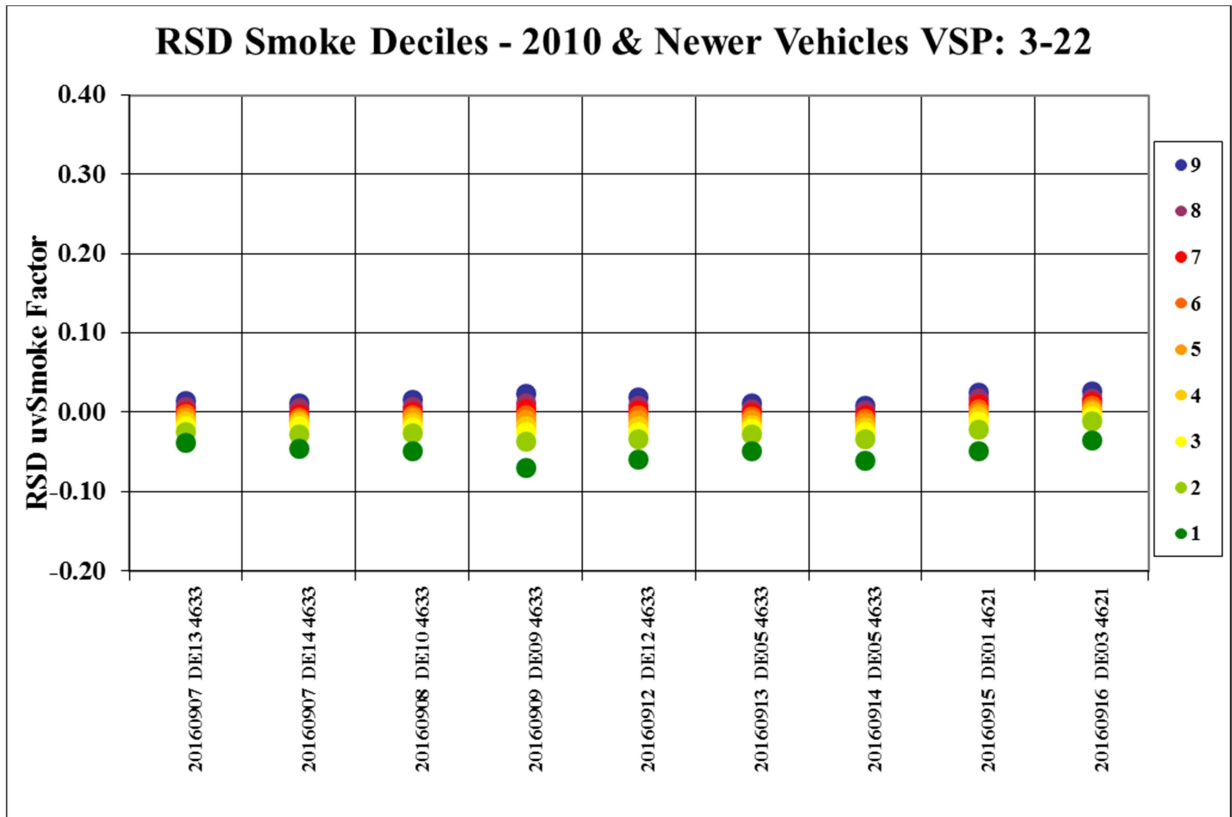


FIGURE 2-7 DAILY SMOKE DECILES



### 3. ANALYSIS OF DATA COLLECTED

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#### 3.1 STATISTICS AND RSD COVERAGE

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The study data collection phase lasted from September 7<sup>th</sup> through September 16<sup>th</sup> using RSD4600 systems 4633 and 4621.

Table 3-1 shows the remote sensing measurements made during eight calendar days of testing in Delaware. A total of 16,134 measurements were made with complete emissions information (speed, acceleration, emissions). This included 1,972 measurements of trucks, trailers, motorcycles and vehicles with out-of-view or obscured plates.

Table 3-2 shows the number of vehicles registered within Delaware and neighboring states. Eighty-four percent of vehicles measured at the survey locations were registered in Delaware, 6% were from Pennsylvania, 4% from Maryland, 3% from New Jersey, 1% from New York, 1% from Virginia, and 2% from other states. Out-of-state plates observed in the September 2016 survey totaled 16% compared to 22% in the August 2015 survey and 16% in the December 2014 survey.

**Table 3-1: Number of Remote Sensing Records by License Plate**

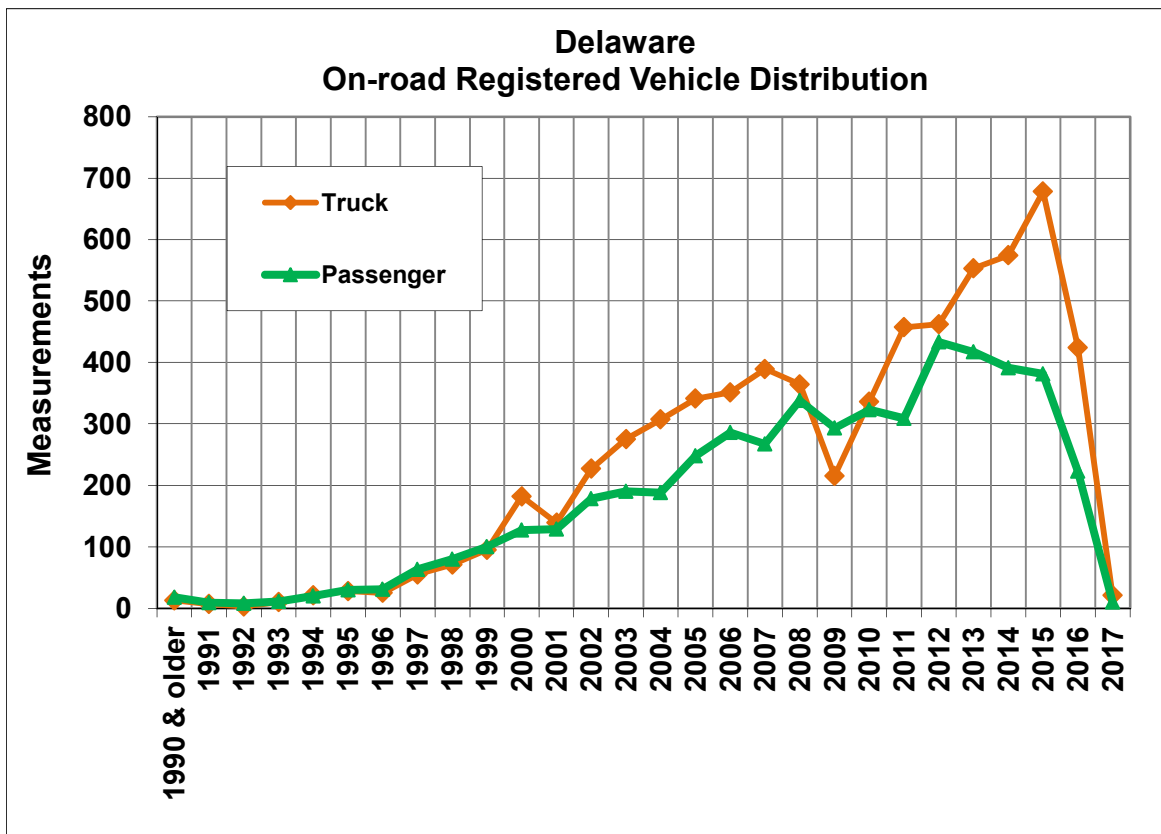
RSD Units	2
Sites	8
Collection-Days	8
Attempted Measurements	27,304
Valid measurements within 3-22 kw/t	16,134
- Trucks, trailers, M/C, out of view or obscured	1,972
Valid measurements within 3-22 kw/t & Tag Edited Plate	14,162
- Other State Plates	2,270
- Delaware Light Vehicle Plates	11,892
Matched to Delaware Registrations	11,766
Unique Delaware Vehicles Identified	10,955
Unique Delaware Vehicles Identified Once	10,234
Unique Delaware Vehicles Identified Twice	671
Unique Delaware Vehicles Identified Three Times	43
Unique Delaware Vehicles Identified Four or More Times	7

**Table 3-2: Valid Remote Sensing Records by State Plate**

State	Count	%
Delaware	11,892	84%
Maryland	570	4%
New Jersey	357	3%
New York	76	1%
Pennsylvania	855	6%
Virginia	90	1%
Other States	322	2%
<b>Total</b>	<b>14,162</b>	<b>100%</b>

Figure 3-1 shows the distribution of the vehicles measured on-road and registered in Delaware that were matched to registration information. The on-road distribution tends to be more skewed towards newer vehicles than the number of registrations. This is because, 1) newer vehicles are more active and 2) there are relatively more inactive older vehicles that still have DMV records. The effects of recession and recovery remain clearly visible in the activity of 2008 model and newer vehicles. Model year 2016 and 2017 sales were incomplete at the time of the survey.

**FIGURE 3-1 MODEL YEAR FRACTIONS OF ON-ROAD LIGHT VEHICLES IN DELAWARE**



## 3.2 VEHICLE SPECIFIC POWER

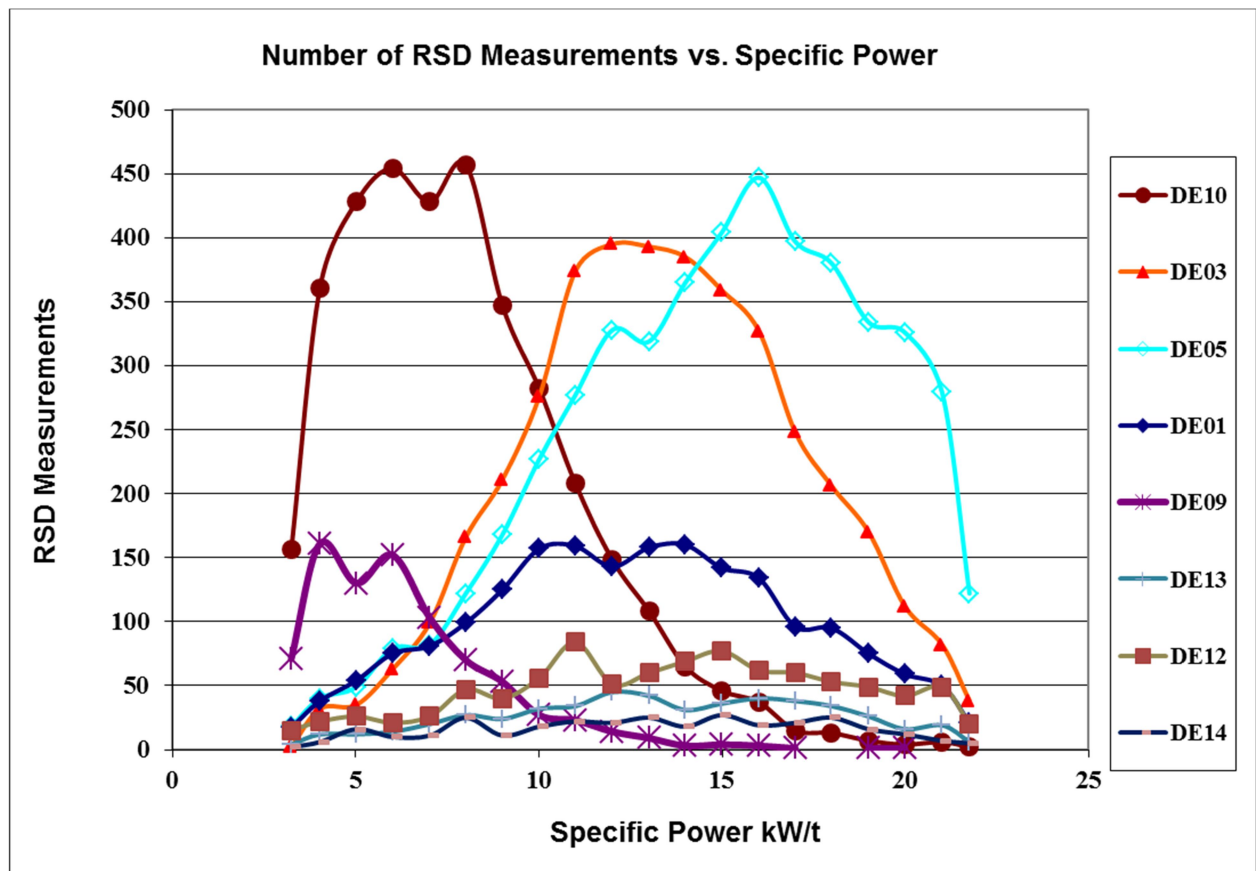
Envirotest used the speed/acceleration and site grade data to determine Vehicle Specific Power (VSP). VSP attempts to normalize the power requirements of the vehicle based upon speed, acceleration and slope at the site. VSP is defined by the following equation:

$$\text{VSP} = 4.364 \cdot \sin(\text{Grade in Deg}/57.3) \cdot \text{Speed} + 0.22 \cdot \text{Speed} \cdot \text{Accel} + 0.0657 \cdot \text{Speed} + 0.000027 \cdot \text{Speed} \cdot \text{Speed} \cdot \text{Speed}$$

Measurements where VSP was between 3 and 22 kW/t were used in subsequent analyses.

Figure 3-2 shows the distribution of VSP at each site. A majority of observations fell within the range of 3 to 22 kW/t, which are considered to be valid readings by Envirotest for program evaluation. Measurements outside of the desired VSP window were not included.

FIGURE 3-2: DISTRIBUTION OF VSP AT SITES



### 3.3 VEHICLE FLEET EMISSION RATES

#### 3.3.1 EMISSION BY JURISDICTION

Envirotest calculated average hydrocarbons (HC), carbon monoxide (CO), and oxides of nitrogen (NO) emission rates of vehicles registered in Delaware and other states.

Table 3-3 and Figures 3-3 to 3-5 compare emissions of vehicles registered in Delaware to those driving in Delaware but registered in other states. Vertical bars on the charts indicate the 95% confidence intervals for emissions values. There were relatively few measurements of out-of-state vehicles observed in Delaware and this resulted in wide confident intervals that often overlap. Thus differences in mean emissions between different jurisdictions in many cases were not statistically significant. Vehicles with out-of-state plates had 39% higher HC emissions, 12% higher CO emissions and 11% higher NO emissions than Delaware plates.

Also shown in Table 3-3 are emissions of 637 vehicles identified as trucks and 34 motorcycles. Trucks had more than three times higher NO emissions than light vehicles. Motorcycles measured had ten to twenty times higher emissions concentrations than the average Delaware light vehicle.

**Table 3-3 Mean Emissions by Jurisdiction**

Name	N	HC ppm	CO %	NO ppm	RSD UV Smoke	VSP kw/t
<b>Delaware</b>	<b>11,892</b>	<b>14</b>	<b>0.08</b>	<b>99</b>	<b>0.002</b>	<b>12.2</b>
Maryland	570	16	0.11	114	(0.000)	11.6
New Jersey	357	12	0.09	110	0.004	13.3
New York	76	13	0.09	32	(0.010)	14.4
Pennsylvania	855	20	0.08	118	0.004	13.0
Virginia	90	20	0.07	137	0.002	12.5
Other	296	35	0.10	92	0.000	12.3
<b>Total Other States</b>	<b>2,244</b>	<b>19</b>	<b>0.09</b>	<b>110</b>	<b>0.002</b>	<b>12.6</b>
<b>Trucks</b>	657	37	0.07	360	0.051	10.2
<b>Motorcycles</b>	34	172	1.90	985	0.122	14.3
<b>Plates Not Readable</b>	1,307	27	0.11	168	0.010	12.5
<b>Total On-road</b>	<b>16,134</b>	<b>17</b>	<b>0.09</b>	<b>119</b>	<b>0.005</b>	<b>12.2</b>

FIGURE 3-3: MEAN HC BY JURISDICTION

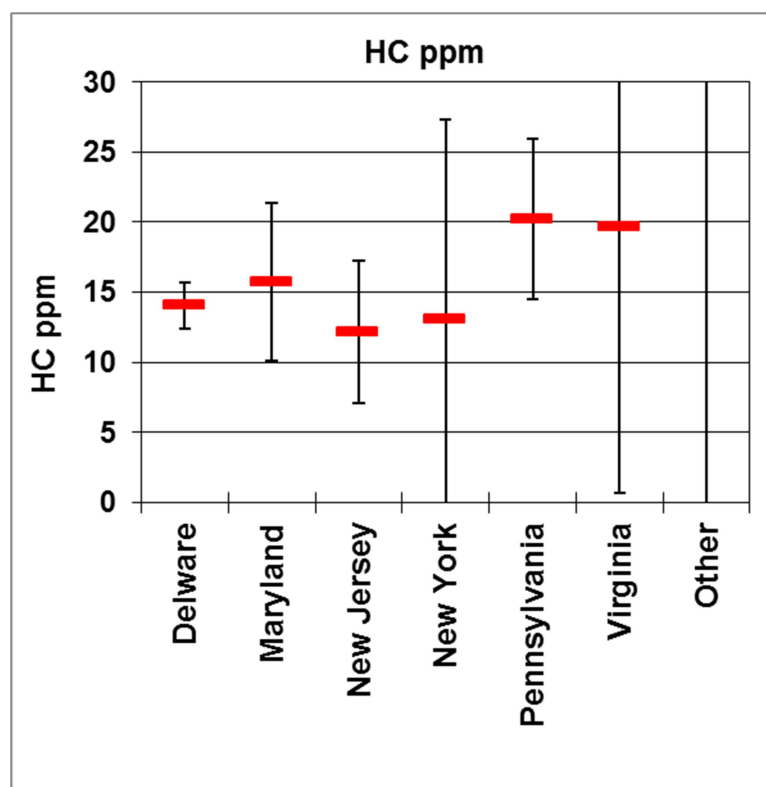


FIGURE 3-4: MEAN CO BY JURISDICTION

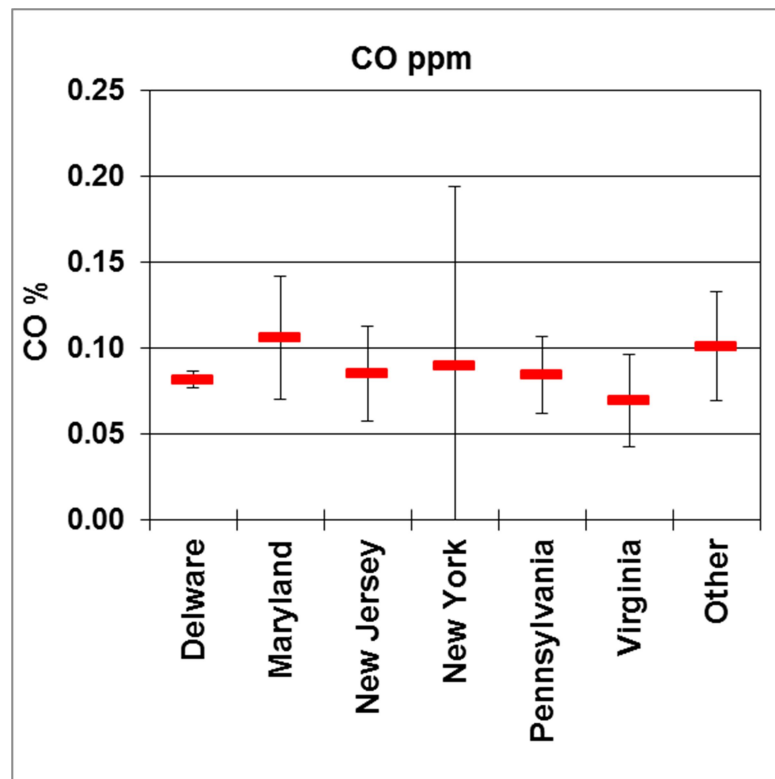




FIGURE 3-5: MEAN NO BY JURISDICTION

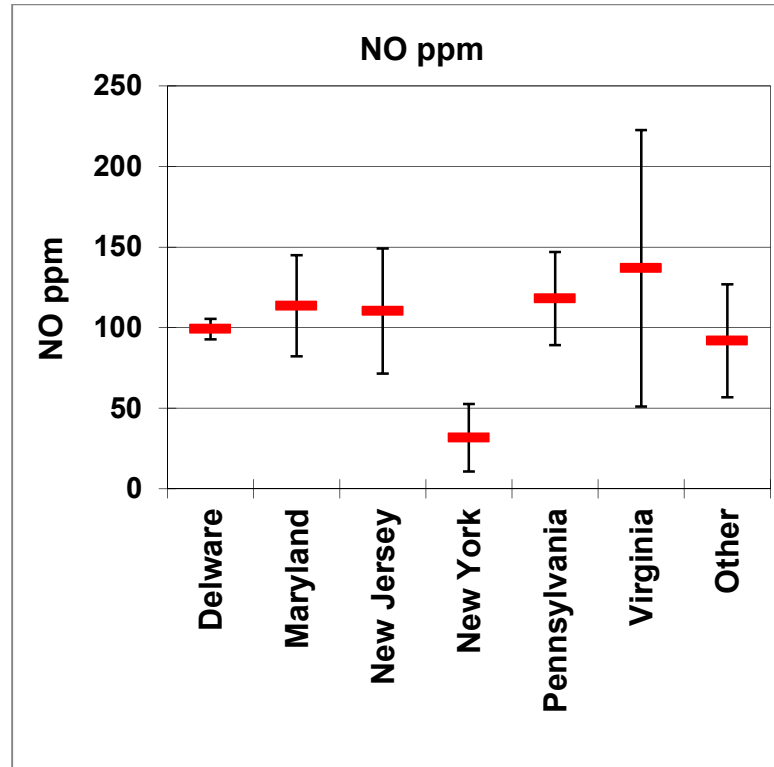
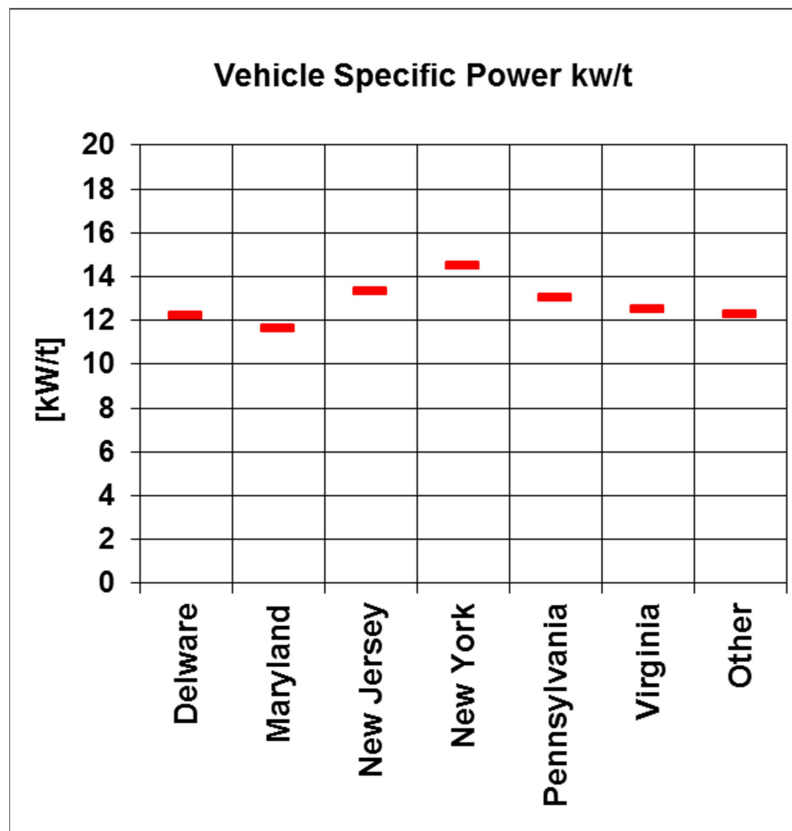


FIGURE 3-6: VSP VS. JURISDICTION



### 3.3.2 DELAWARE AVERAGE EMISSIONS BY MODEL YEAR

Average emissions by model year are shown in Figures 3-7 to 3-9. A number of vehicles have very high emissions that affect the average values for a particular vehicle type and model year. Thus, there is considerable variation in model year averages. On the whole, however, it is apparent that trucks have higher emissions than passenger vehicles of the same age – especially for HC and NO.

A larger survey would allow more accurate assessment of the average emissions by year of passenger vehicles and light trucks.

FIGURE 3-7: AVERAGE HC EMISSIONS

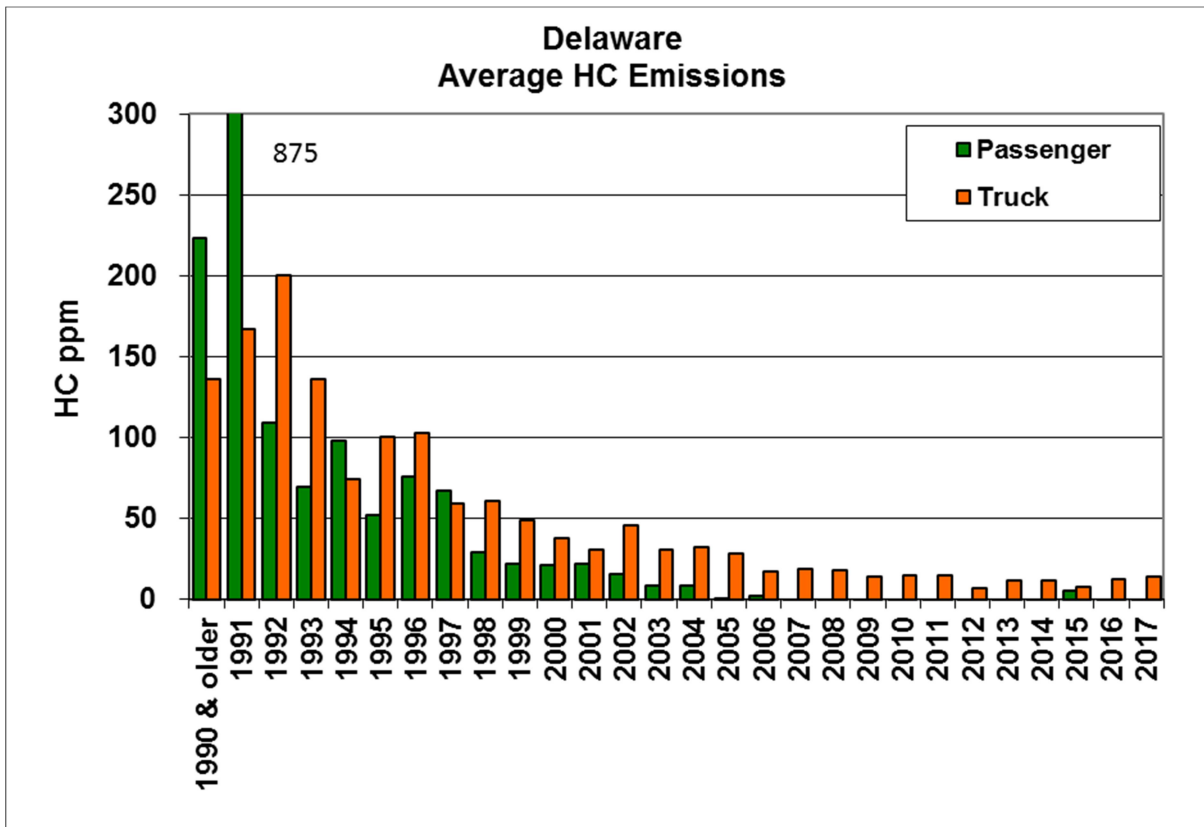


FIGURE 3-8: AVERAGE CO EMISSIONS

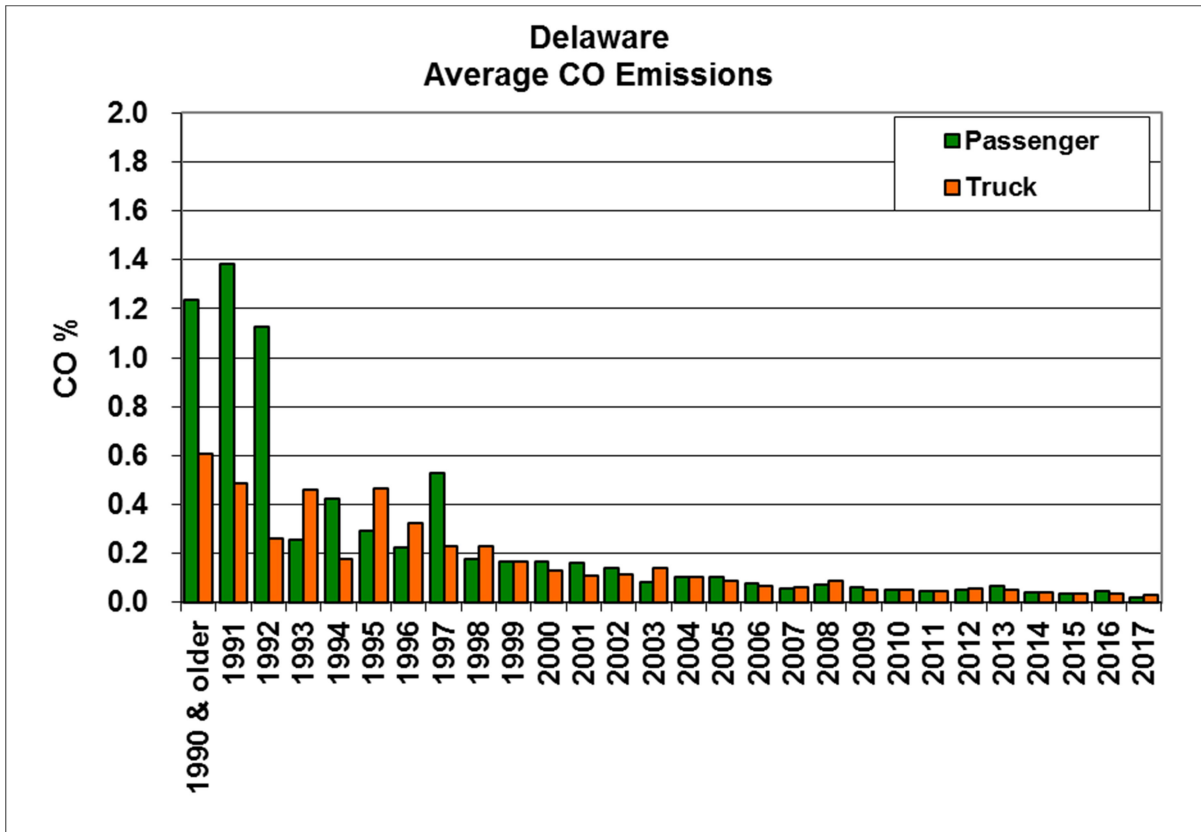
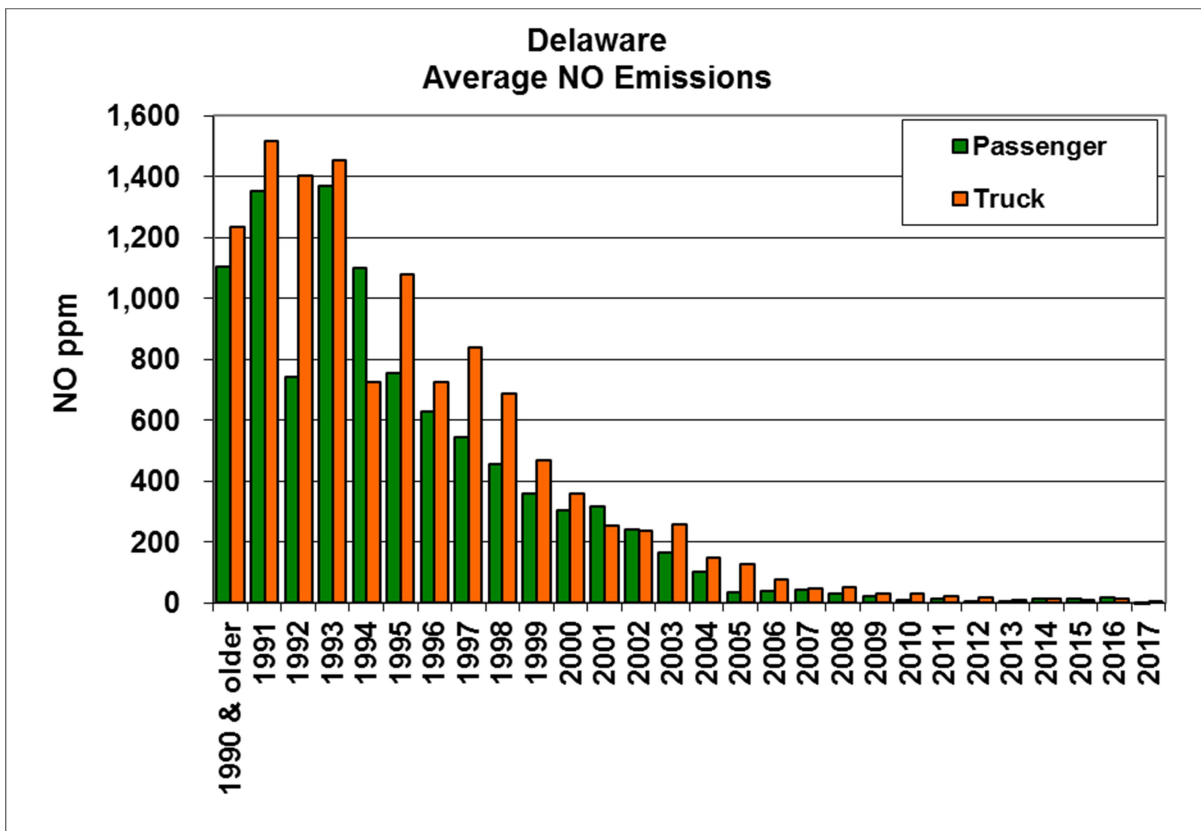


FIGURE 3-9: AVERAGE NO EMISSIONS



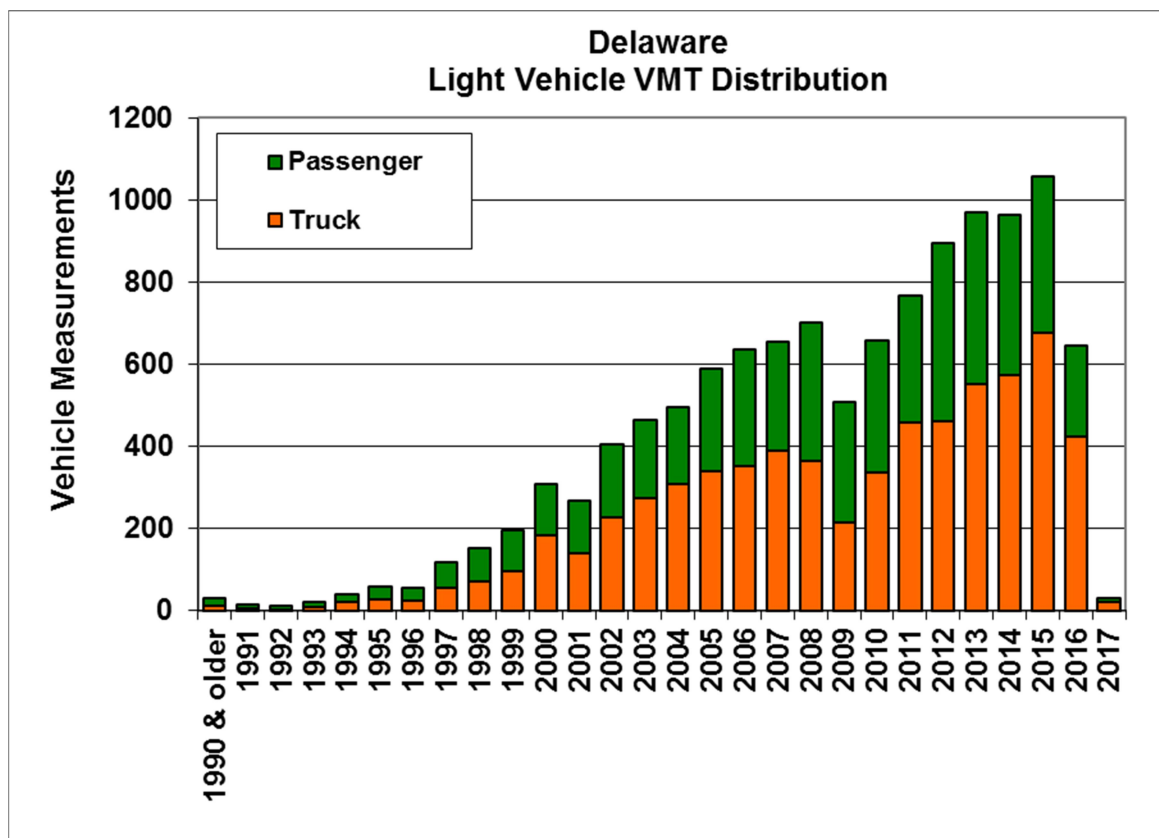
### 3.3.3 APPROXIMATE EMISSION CONTRIBUTIONS BY MODEL YEAR

Figures 3-10 through 3-13 illustrate the contributions to light vehicle VMT. The number of vehicle measurements is approximately representative of VMT. The exhaust emission contributions are calculated using passenger vehicle and light truck fuel economies reported in the US Department of Transportation Fuel Economy Table 1-20<sup>i</sup>. Starting with 2008-model vehicles, the EPA adopted a new protocol for estimating the MPG figures presented to consumers. The new protocol included driving cycles more closely representative of today's traffic and road conditions, as well as increased air conditioner usage.

Contributions of on-road emissions were skewed towards the older vehicles. 2006 and older models accounted for 33% of on-road activity and 77%, 63% and 95% of the HC, CO and NO emissions respectively. Therefore, it is important to maintain the effectiveness of I/M programs for the vehicles over ten years old that have emissions many times those of newer vehicles.

Light trucks contributed 56% of VMT and 85%, 59% and 66% of HC, CO and NO respectively. Light truck observations were skewed more towards newer models than observations of light passenger vehicles. 2007 & newer models were 68% of truck observations vs. 66% of observations of passenger vehicles.

FIGURE 3-10: APPROXIMATE VMT CONTRIBUTION



i

[http://www.rita.dot.gov/bts/sites/rita.dot.gov/bts/files/publications/national\\_transportation\\_statistics/html/table\\_01\\_20.html](http://www.rita.dot.gov/bts/sites/rita.dot.gov/bts/files/publications/national_transportation_statistics/html/table_01_20.html)

FIGURE 3-11: APPROXIMATE HC CONTRIBUTION

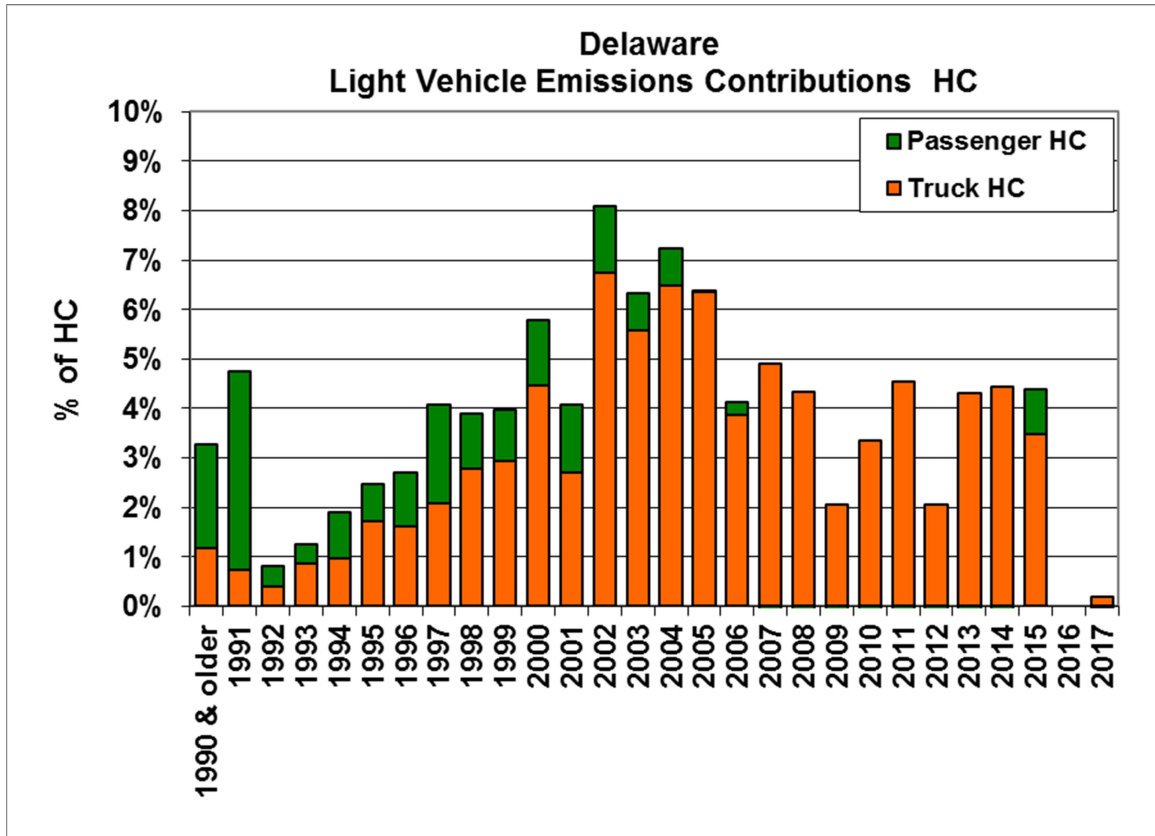


FIGURE 3-12: APPROXIMATE CO CONTRIBUTION

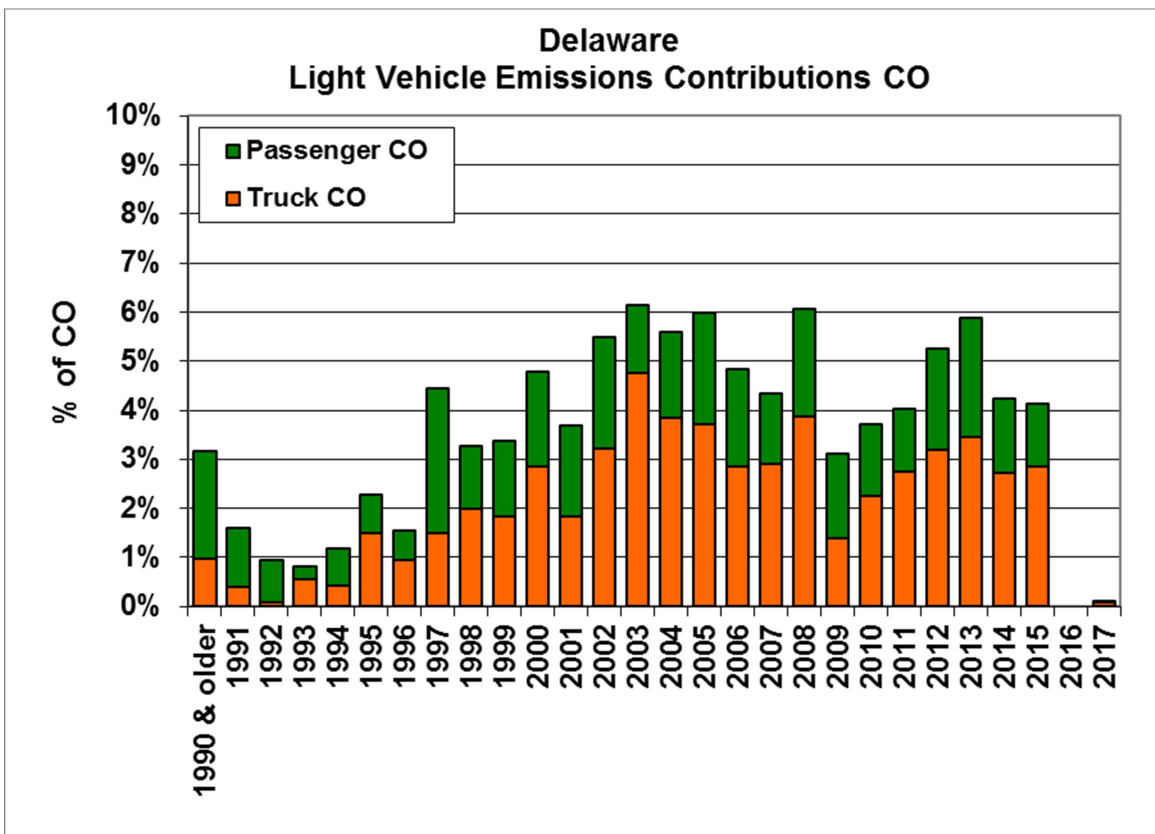
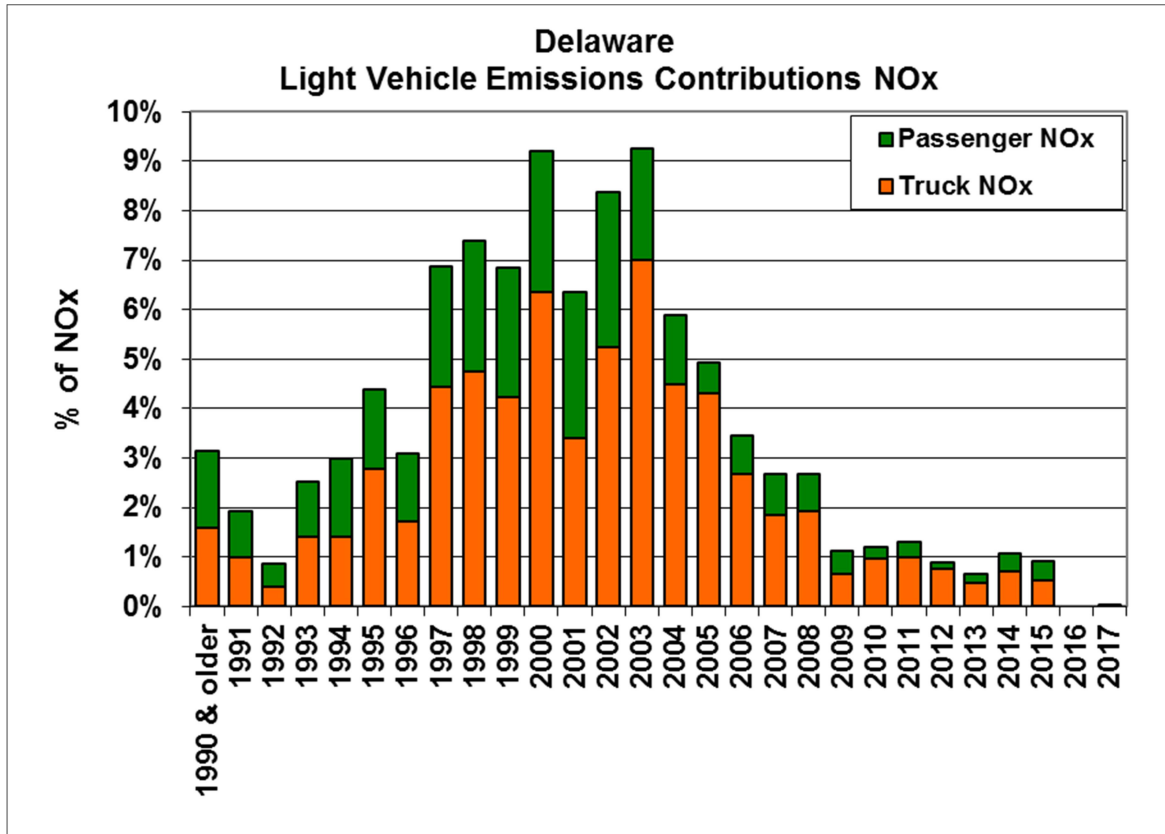


FIGURE 3-13: APPROXIMATE NOX CONTRIBUTION



## 4. HIGH EMITTERS

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In this survey, High emitters were identified using cutpoints of 250ppm HC, 2.5% CO, 2,000ppm NO and 0.4 RSD smoke factor. HC, CO and smoke cutpoints were reduced from 500ppm HC, 3% CO and 0.75 RSD Smoke Factor used in previous years since virtually all vehicles on-road are now OBD models manufactured to meet Tier 1 and Tier 2 standards. These definitions of high emitters are, admittedly, somewhat arbitrary and remain higher than standards typically used in an inspection and maintenance program.

Of the vehicles measured on-road that were identified by plate and matched to a Delaware registration, 197 (1.9%) exceeded one or more of the pollutant cutpoints (Table 4-1). However, the 1.9% of vehicles had average emissions of 284ppm HC, 0.8% CO and 1,574 ppm NO – hundreds of times dirtier than the median vehicle. These high emitting vehicles emitted up to 21%, 19% and 28% of all light vehicle HC, CO and NO.

Table 4-2 shows the combinations of cutpoints that were exceeded. With these cutpoints a majority of the vehicles identified as high emitters were selected for high NO.

Nineteen vehicles (10%) were identified for more than one pollutant.

**Table 4-1: High Emitters**

	Count
Vehicles exceeding one or more cutpoints	197
Emissions cutpoints exceeded:	
HC 250 ppm hexane	86
CO 2.5%	19
NO 2000ppm	106
UV Smoke Factor 0.4	8
Total Cutpoints Exceeded	219

### 4.1 HIGH EMITTER CUTPOINTS VS. IN-USE STANDARDS

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Figures 4-1 to 4-4 illustrate the relationship of the adopted RSD high emitter cutpoints to vehicle in-use standards. We only show standards through 2003 models. Standards for Tier 2 2004 and newer models are the same or lower.

The precise g/mi equivalents for RSD concentration emissions values depend on vehicle fuel economy. Fleet average values of 23 mpg for light passenger vehicles and 17 mpg

for light trucks were derived using DOT<sup>i</sup> mpg values by model year and used to convert RSD concentrations to typical g/mi values.

The selected high emitter cutpoints far exceed the in-use standards.

**Table 4-2 Higher Emitters by Pollutant**

<b>HE Cutpoint Exceedance Combinations</b>	<b>Count</b>
Single pollutant:	
HC Only	68
CO Only	11
NO Only	96
Smoke Only	3
Two Pollutants:	
HC & CO Only	6
HC & NO Only	8
CO & NO Only	0
HC & Smoke Only	1
CO & Smoke Only	1
NO & Smoke Only	0
Three Pollutants:	
HC & CO & NO	0
HC, CO & Smoke	1
HC, NO & Smoke	2
CO, NO & Smoke	0
Jackpot:	
HC, CO, NO & Smoke	0
<b>Total</b>	<b>197</b>



FIGURE 4-1 HIGH EMITTER HC VS. IN-USE STANDARDS

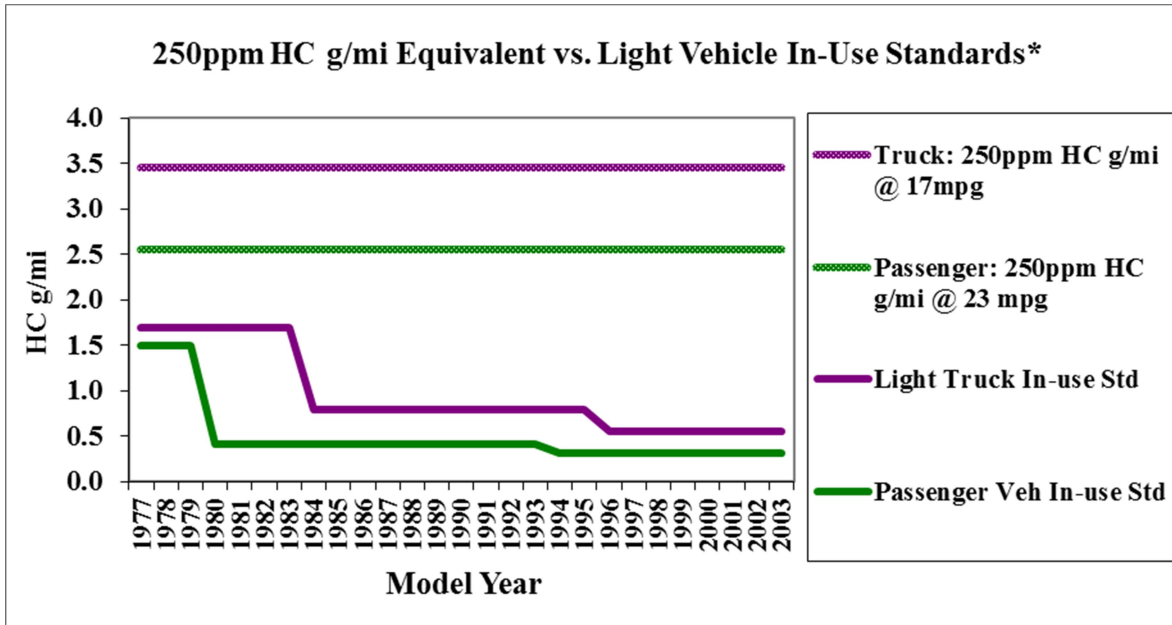


FIGURE 4-2 HIGH EMITTER CO VS. IN-USE STANDARDS

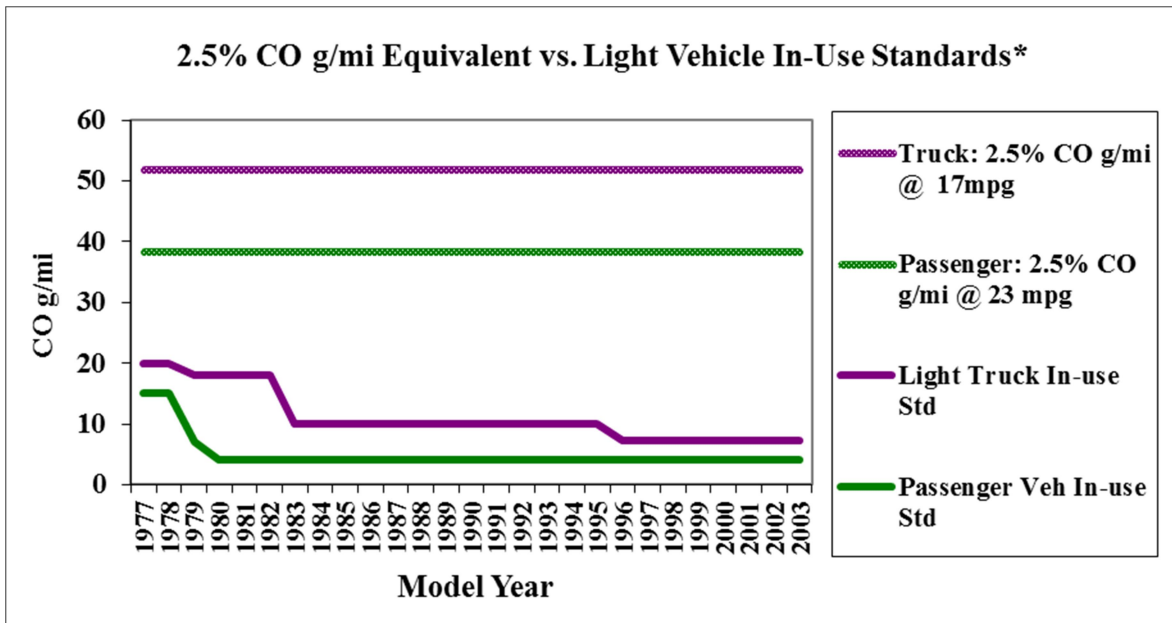


FIGURE 4-3 HIGH EMITTER NOX VS. IN-USE STANDARDS

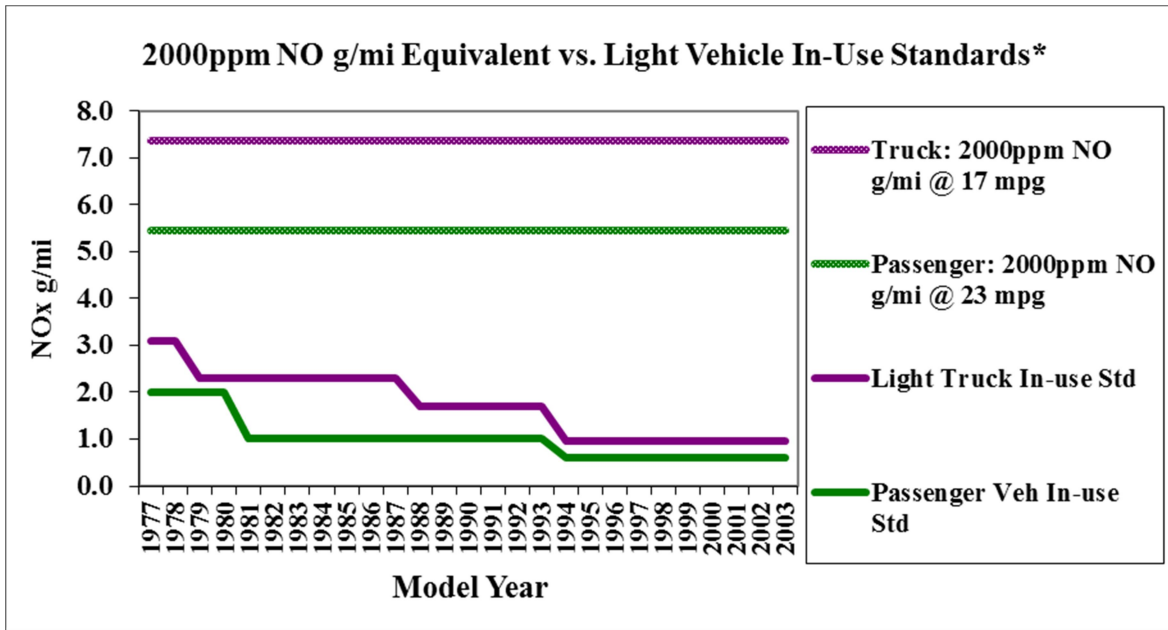
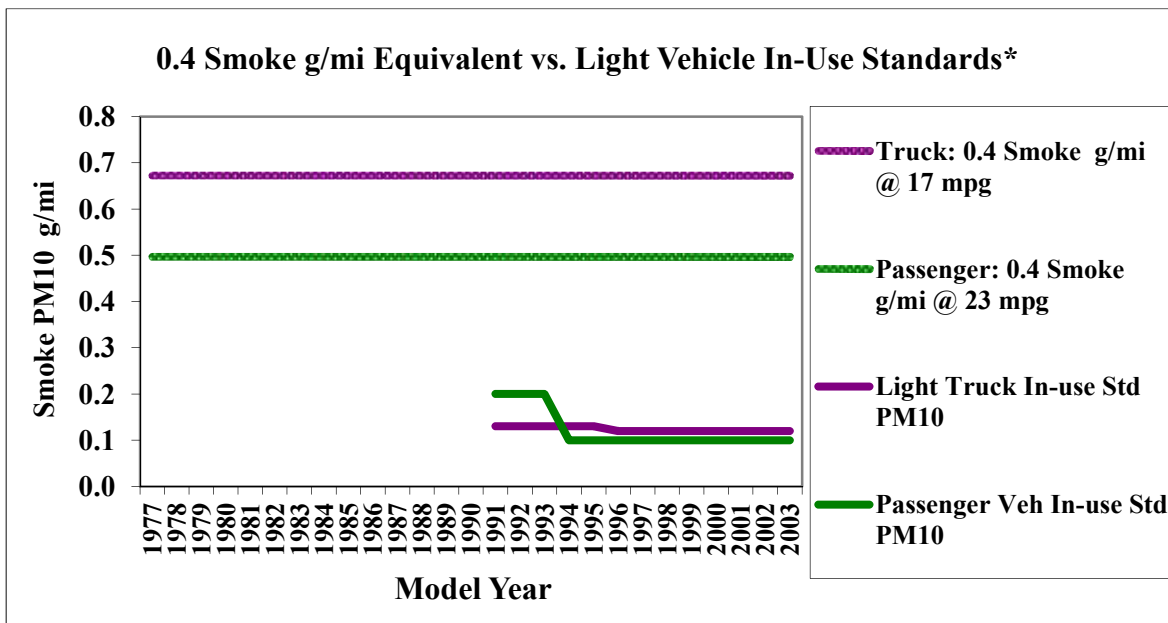


FIGURE 4-4 HIGH EMITTER VS. PM10 IN-USE STANDARDS



## 4.2 HIGH EMITTER RATES

High emitter rates varied dramatically by model year, with the oldest models having rates of over 25% and 2007 and newer models having virtually no high emitters (Figure 4-5). Fortunately, relatively few of the oldest models remain in operation. On a positive note, high emitter rates among models less than ten years old remained low – an average of 0.4% vs. 5.1% for older models. Models 2006 and older were 33% of

vehicles measured and 87% of high emitters. Manufacturers improved component quality considerably to meet OBD-II requirements. These improvements, combined with the engine warning light that alerts owners to emissions problems, are responsible for the low rates of high emitters observed in vehicles up to ten years old at the time of the survey.

Figure 4-6 shows the number of high emitters by model year. The greatest numbers of high emitters were 1995-2006 models. A larger dataset is required to confirm more precise rates of high emitters by model year

Eight vehicles with high smoke factors are listed in Table 4-3. These all had high HC emissions or were diesels. Several of the gasoline smokers also had high CO and/or high NO.

### 4.3 HIGH EMITTERS WITH MULTIPLE MEASUREMENTS

Table 4-4 lists RSD measurements for the two high emitters with two measurements. In both cases, vehicles exceeded NO cutpoints on both measurements.

FIGURE 4-5: PERCENT OF HIGH EMITTERS BY MODEL YEAR

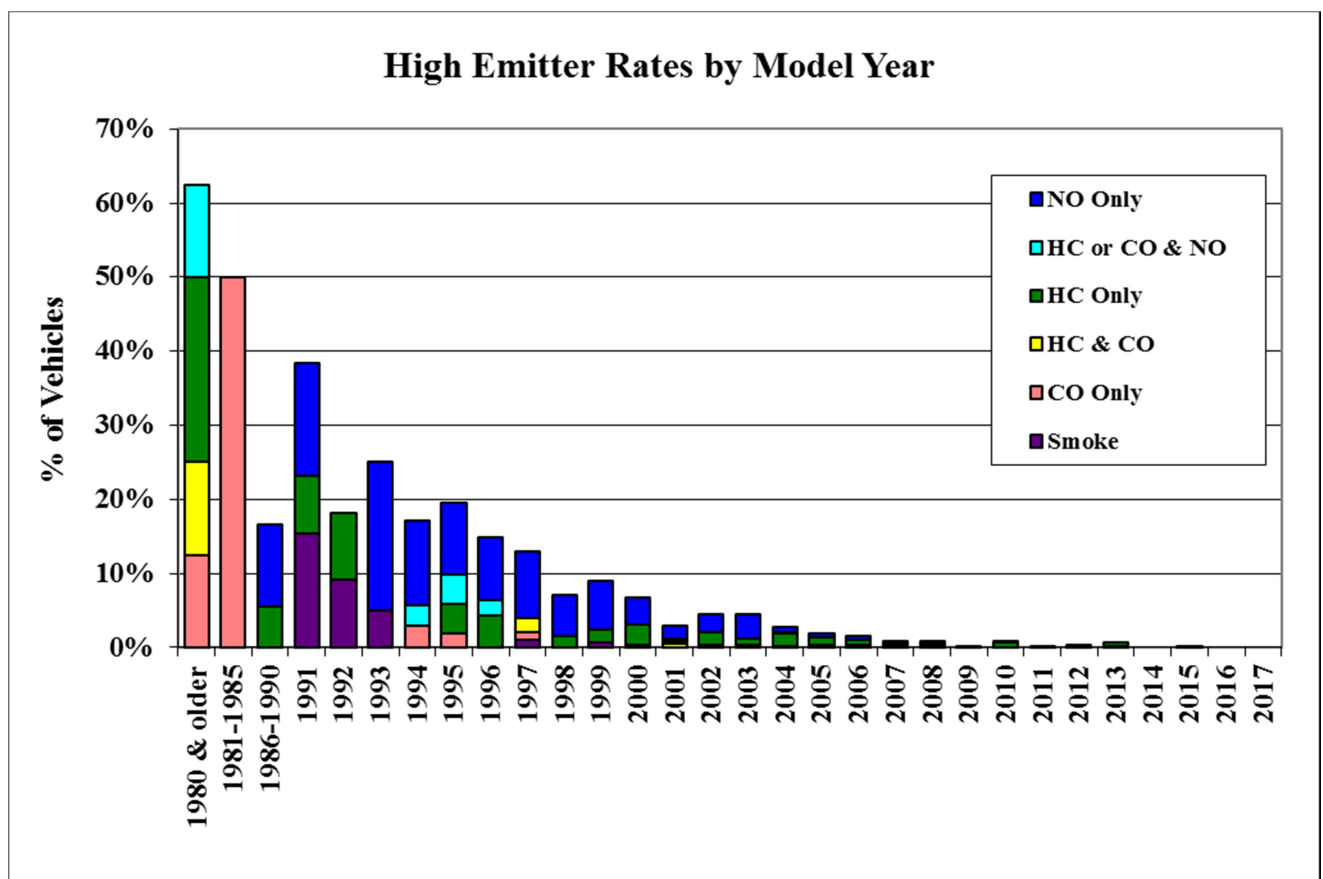


FIGURE 4-6: NUMBER OF HIGH EMITTERS BY MODEL YEAR

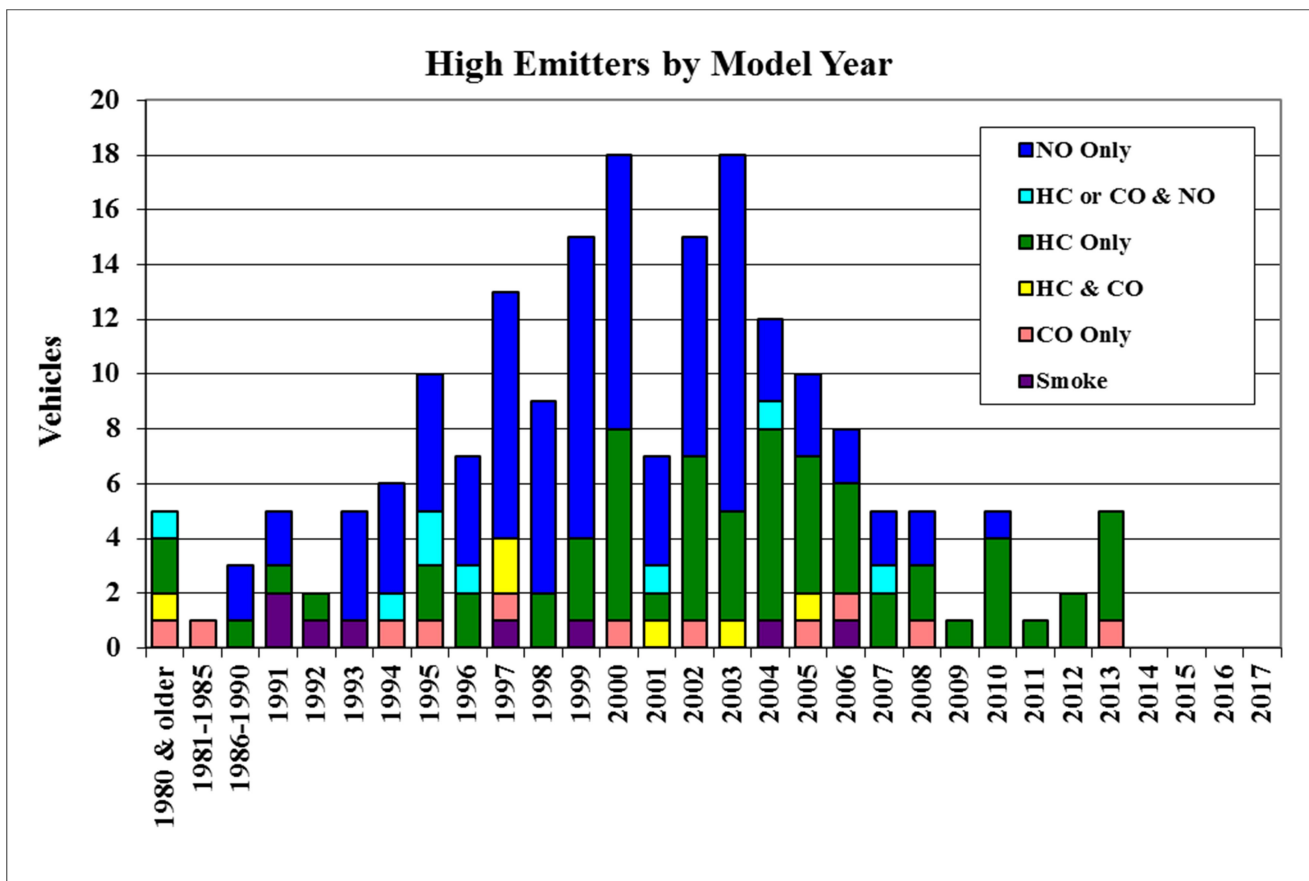


Table 4-3: Smoking Vehicles

VIN	MY	Make	Mod	Fuel	HC Cutpoint	HC ppm	CO Cutpoint	%CO	NO Cutpoint	ppm NO	Smoke Cutpoint	UV Smoke
1GTDC14H9ME503274	1991	GMC	SRA	G	250	323	2.5	0.2	2000	2290	0.4	0.86
4T1SV21EXMU387506	1991	TOYT	CAM	G	250	6732	2.5	5.4	2000	1186	0.4	0.56
2MELM75W4NX710291	1992	MERC	MAR	G	250	243	2.5	4.1	2000	1724	0.4	0.47
1GTEC14Z9PE539239	1993	GMC	SRA	G	250	409	2.5	2.5	2000	1286	0.4	0.48
1NXBA02E2VZ567952	1997	TOYT	COA	G	250	506	2.5	0.5	2000	3831	0.4	0.85
WVWGF31J3XW370971	1999	VOLK	GOL	D	250	65	2.5	0.6	2000	886	0.4	0.87
3VWRR69M54M084614	2004	VOLK	JET	D	250	60	2.5	1.2	2000	834	0.4	0.69
WD8PD144765954556	2006	DODG	SPR	D	250	69	2.5	0.1	2000	112	0.4	1.01

Table 4-4: High Emitters with Two Measurements

VIN	MY	Make	Mod	Fuel	HC Cutpoint	HC ppm	CO Cutpoint	%CO	NO Cutpoint	ppm NO	Smoke Cutpoint	UV Smoke
1G6KS6985GU814133	1986	CADI	SEV	G	250	96	2.5	0.5	2000	2902	0.4	0.07
1G6KS6985GU814133	1986	CADI	SEV	G	250	-27	2.5	0.2	2000	2902	0.4	0.03
KMHDN45D01U193519	2001	HYUN	ELN	G	250	186	2.5	0.7	2000	2448	0.4	0.22
KMHDN45D01U193519	2001	HYUN	ELN	G	250	214	2.5	0.7	2000	2486	0.4	0.24



## 5. FINDINGS

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Following are the results of the RSD survey:

- Average emissions of Delaware registered light vehicles were 14 ppm HC hexane, 0.08% CO and 99 ppm NO.
- Tier 2 models, 2006 and newer, appear so far to have very well controlled emissions.
- Contributions of on-road emissions were skewed towards the older vehicles. Among Delaware registered light vehicles, 2006 and older models accounted for 33% of on-road activity and for 77%, 63% and 95% of the HC, CO and NO emissions respectively.
- A small fraction of vehicles had very high emissions and contributed a substantial portion of light vehicle emissions:
  - 197 (1.9%) of vehicles had HC greater than 250 ppm or CO emissions greater than 2.5% or NO greater than 2000 ppm or smoke greater than 0.4 RSD smoke factor.
  - These high emitting vehicles emitted up to 40%, 12% and 18% of all light vehicle HC, CO and NO.
- Eight-four percent of vehicles measured at the survey locations were registered in Delaware, 6% were from Pennsylvania, 4% from Maryland, 3% from New Jersey, 1% from New York, 1% from Virginia, and 2% from other states. Out-of-state plates observed in the September 2016 survey totaled 16% compared to 22% in the August 2015 survey.