“Finding “Normal” And “High Emitting” Emissions: Exploring New Emerging Screening Tools and Methodologies for Gathering Real-World Vehicle Data”

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National Vehicle and Fuel Emissions Laboratory, Ann Arbor, MI

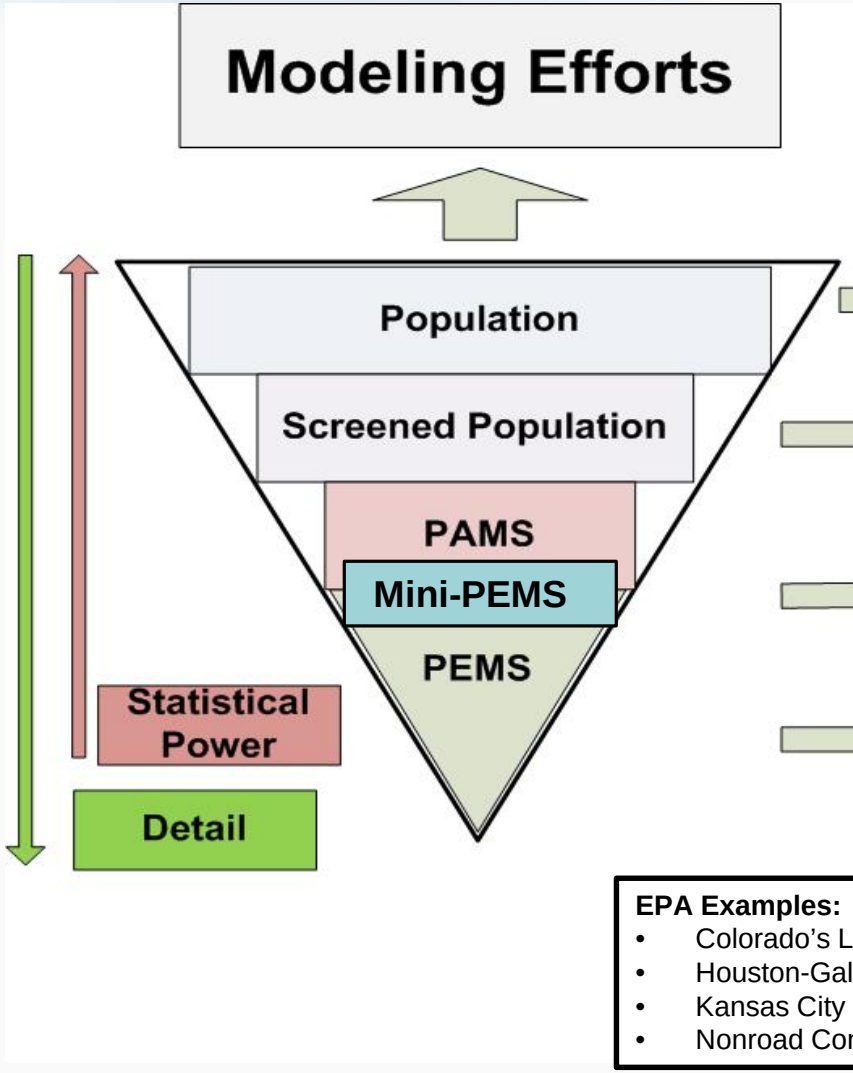
Outline

- Research & Development
- Integrated Design
- Developing a “Suite of Tools”
  - PEMS
  - PAMS
  - Screening Tools (mini-PEMS, RSD, Evap SHED)
- Finding “High” Emitter Vehicle Methods
- Critical Data Fields to Measure
- Outcomes

Research & Development

- Goal: Assess and gather mobile source activity and emission data to better understand the “real-world”
- Focus efforts on improvements in:
  - Data gathering efforts
  - New sampling methodologies
  - Measurement equipment
  - Testing procedures and protocols
  - Modeling efforts

Integrated "Real World" Test Design With a Suite of Tools



Population Data:
- Department of Motor Vehicles
- Port Gate Data
- Fleet Data
- Obtain population and temporal allocation

Emission Screening:
- Remote Sensing tools: HEAT, Portable tent, mini-PEMS
- Random population evaluated for days to months
- Obtain emission "snap shots" to identify high emitter population through license plate

Portable Activity Measurements:
- Hundreds of vehicles measured over several weeks to months in real world
- Obtain activity and temporal allocation

Portable Emission Measurements:
- Less than 100 vehicles measured for one day of operation in real world
- Obtain activity, emissions, and temporal allocation

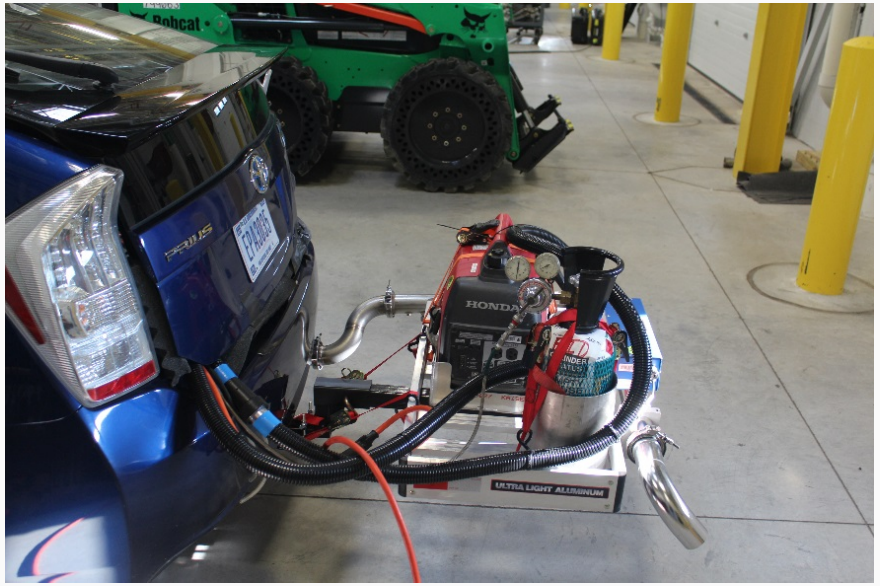
EPA Examples:
- Colorado's Light Duty Vehicle Deterioration and High Emitter Programs
- Houston-Galveston Port Study
- Kansas City Light-Duty Vehicle Test Program
- Nonroad Construction Test Program

“Suite of Tools” Development: PEMS

- Portable Emission Measurement System (PEMS)
  - Gathers very detailed activity, engine parameters and emissions in “real-world” operations
  - CFR 1065 capable equipment with independent emission measurement
  - Major advancements over 15 years
    - Improvements in size, weight, power
    - Particulate Matter measurements (both filter and second-by-second)
    - Improvement in Vehicle interface
    - Expanding sensors

Quicker PEMS Installation

Bicycle Rack for non-hitch vehicles



Cargo Platform with Vehicle's Hitch

“Suite of Tools” Development: PAMS

- Portable Activity Monitoring System (PAMS)

- Small data loggers interface with on-board vehicle computers to gather very detailed activity and engine parameters in “real-world” operations from light-duty, heavy-duty, and nonroad

- Major advancements:
  - Improvements in size, weight, power
  - GPS, Accelerometer (X,Y,& Z = grade)
  - Add-on additional sensors
  - Vehicle interface

- Data Loggers with Cellular Capability
  - Created a web-based “Dashboard” to monitor data logger and vehicle
  - “Real-time” notification of issues on data logger and/or vehicle and resolve them
  - Allows “Real-time” data analysis

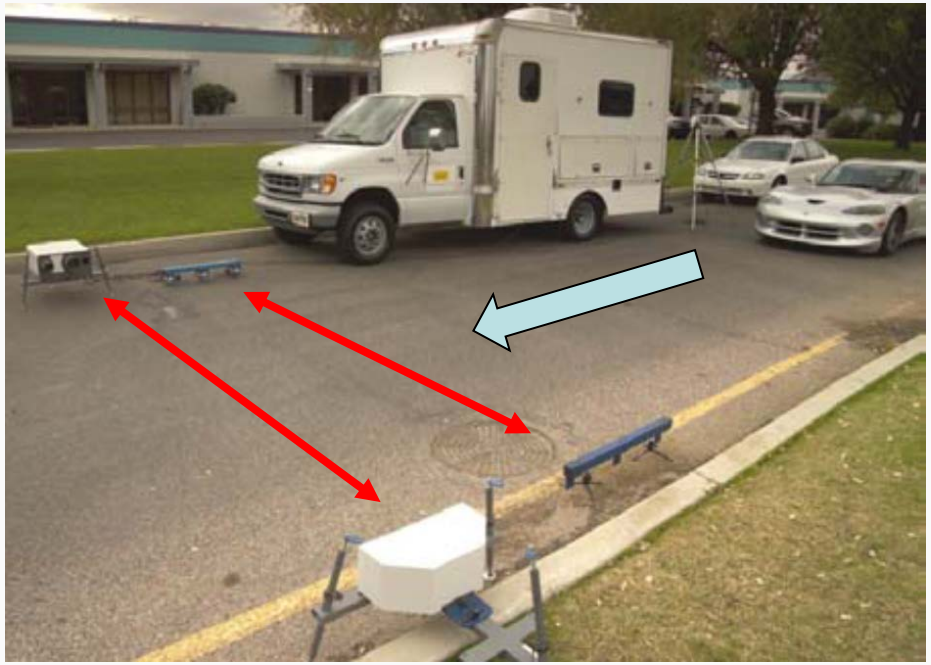
Improvements to Data Gathering

- Standardizing Heavy-Duty SAE J1939 Data Files for PEMS and PAMS
  - Known database structure for quick data analysis
  - Gathering **“key” vehicle parameter fields** at 1 Hz rate
    - Over 150+ channels of engine and aftertreatment parameters - torque, engine rpm, temperatures (coolant, oil, intake air, etc), SCR, NOx, DPF, etc.
    - Additional data gathering efforts underway to determine standard engine fields that exist within the fleet by engine manufacturer and vocational use.
- Developed Light-Duty SAE J1979 Data Files for PEMS and PAMS
- Very Important to have the “**PID Editor**” to allow additional Parameter IDs to be monitored and recorded in both PAMS and PEMS devices.

“Suite of Tools” Development

- Screening Tools
  - Purposes
    - Find “high emitters” within the fleet in the “real-world” and get them repaired
    - Data to support modeling efforts
  - EPA working in partnership to advance these technologies
  - Possible Tools:
    - Remote Sensing Devices
    - Portable SHEDs
    - Mini-PEMS

Screening Devices: Finding High Emitters



ESP

HEAT (EDAR)

Portable SHED

"High Emitter" Categories

- Tailpipe Emissions from light-duty vehicles
- Tailpipe Emissions from heavy-duty vehicles
- Evaporative Emissions from light-duty vehicles

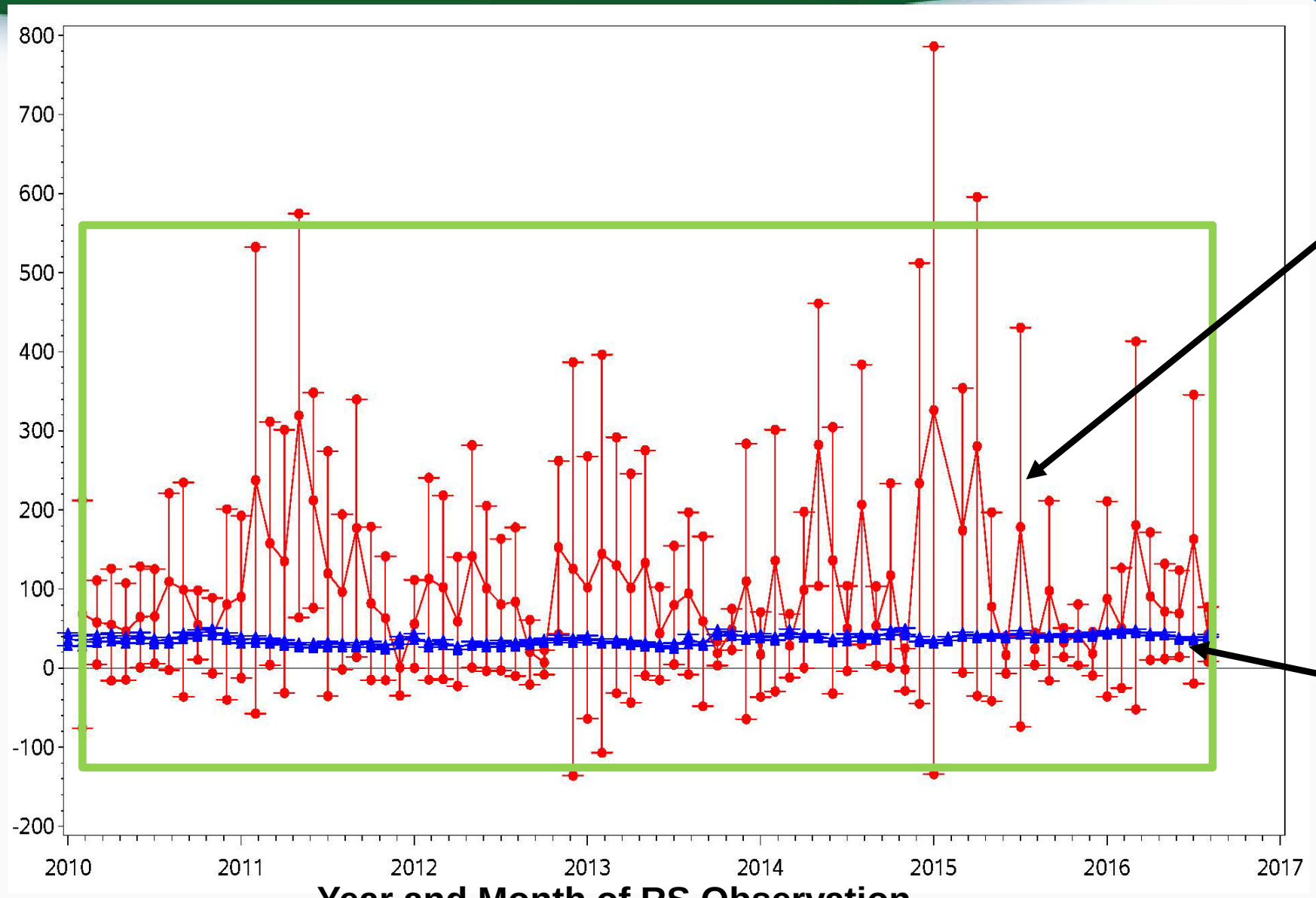
Remote Sensing Devices (RSD)

- Remote sensing advantages
  - Screens hundreds of vehicles a day
  - “Semi-Invisible” to the driver
  - Obtains all types of vehicles – gas, diesel, LD, HD, old, new
  - Can be used to identify “high emitters”

- Limitations of remote sensing
  - Does not tell you whether a vehicle exceeds the certification levels, because it’s only one operating condition
  - The operating condition may not be the same for every vehicle or every RSD location

NOx vs Calendar Year Analysis

(One Vehicle Group's Aggregated Emissions vs Fleet Average)



Each Vehicle Group's emission data aggregated into each month for a vehicle gives a very wide range (95% confidence level)

Note: Concern that the 95% confidence level associated with similar vehicles overlaps fleet average.

Fleet Average for other similar vehicle with same engine size and fuel delivery system with (95% confidence level)

Vehicle Specific Power (VSP)

- The RSD measurements are based on data that have a different operating condition for each location and each vehicle
- To develop a better comparison, the data was analyzed using Vehicle Specific Power (VSP) which is the instantaneous power per unit mass of the vehicle
- The VSP for each RSD measurement was calculated using a “typical” LD vehicle based on -
  - Vehicle speed and acceleration data from the RSD unit
  - Road grade at each of Colorado’s RSD test sites

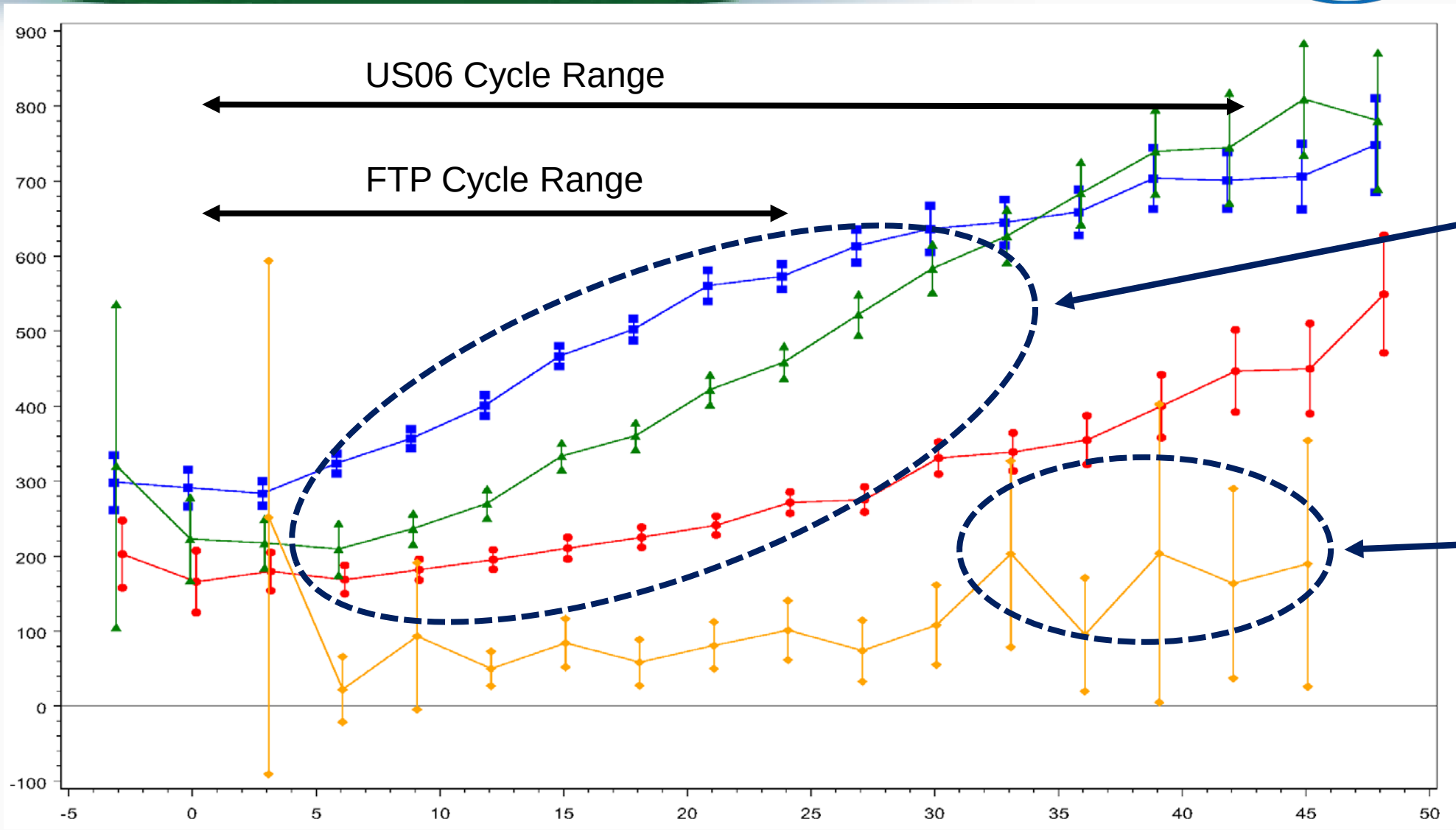
$$VSP = \frac{\frac{d}{dt}(KE + PE) + F_{rolling} v + F_{aero} \left(v^2\right) v}{m}$$

$$VSP_{LDV} = v\left\{1.1a + g\left(\frac{r}{100}\right) + 0.132\right\} + 0.000302v^3$$

VSP	=	Vehicle Specific Power (kw/ton)
a	=	vehicle acceleration (m/s^2)
g	=	acceleration of gravity (9.81 m/s^2)
r	=	road grade (%)
v	=	vehicle speed (m/s)

RSD NOx Emissions by VSP

(Four different vehicle's emissions plotted)

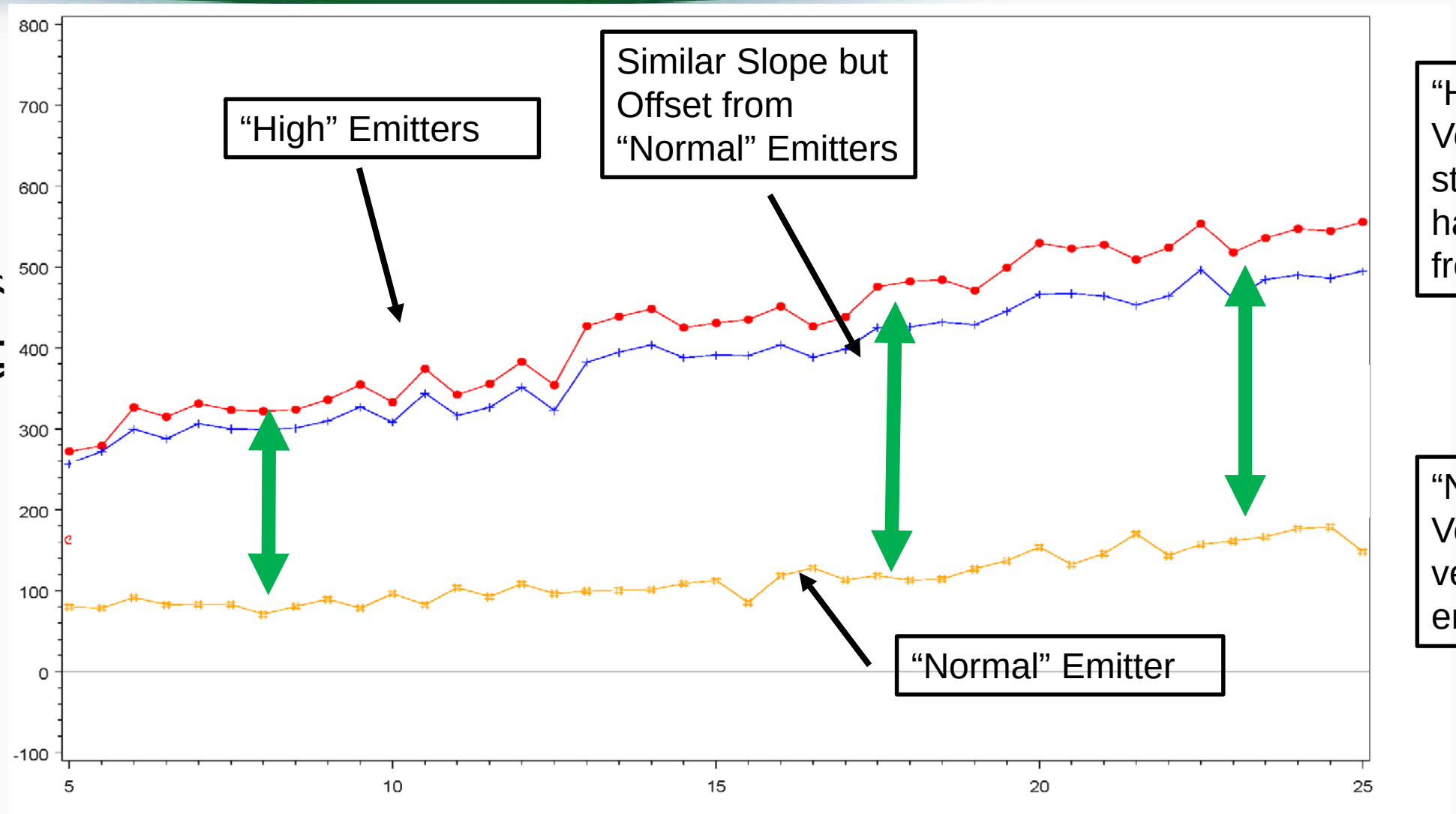


Low error because of large number of measurements within VSP bins (high confidence levels)

Wider error bands because less data at higher VSP bins (lower confidence levels)

“Normal” and “High” Emitter Categories

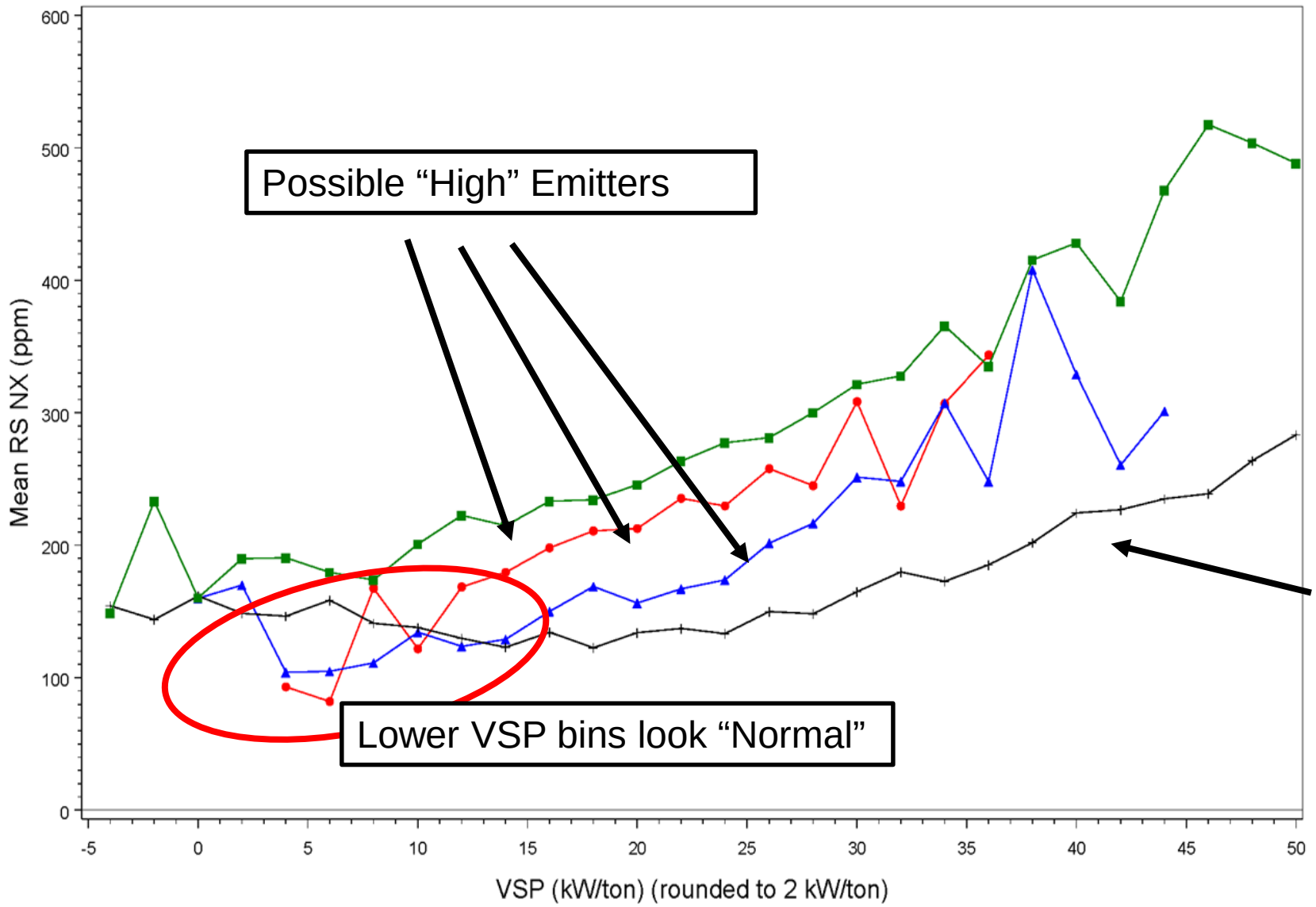
(Two individual vehicle group’s emissions vs Fleet Average)



“High” Emitting Vehicles have a steeper slope but have a large “offset” from “Normal”

“Normal” Emitting Vehicles have a very low slope of emissions vs power

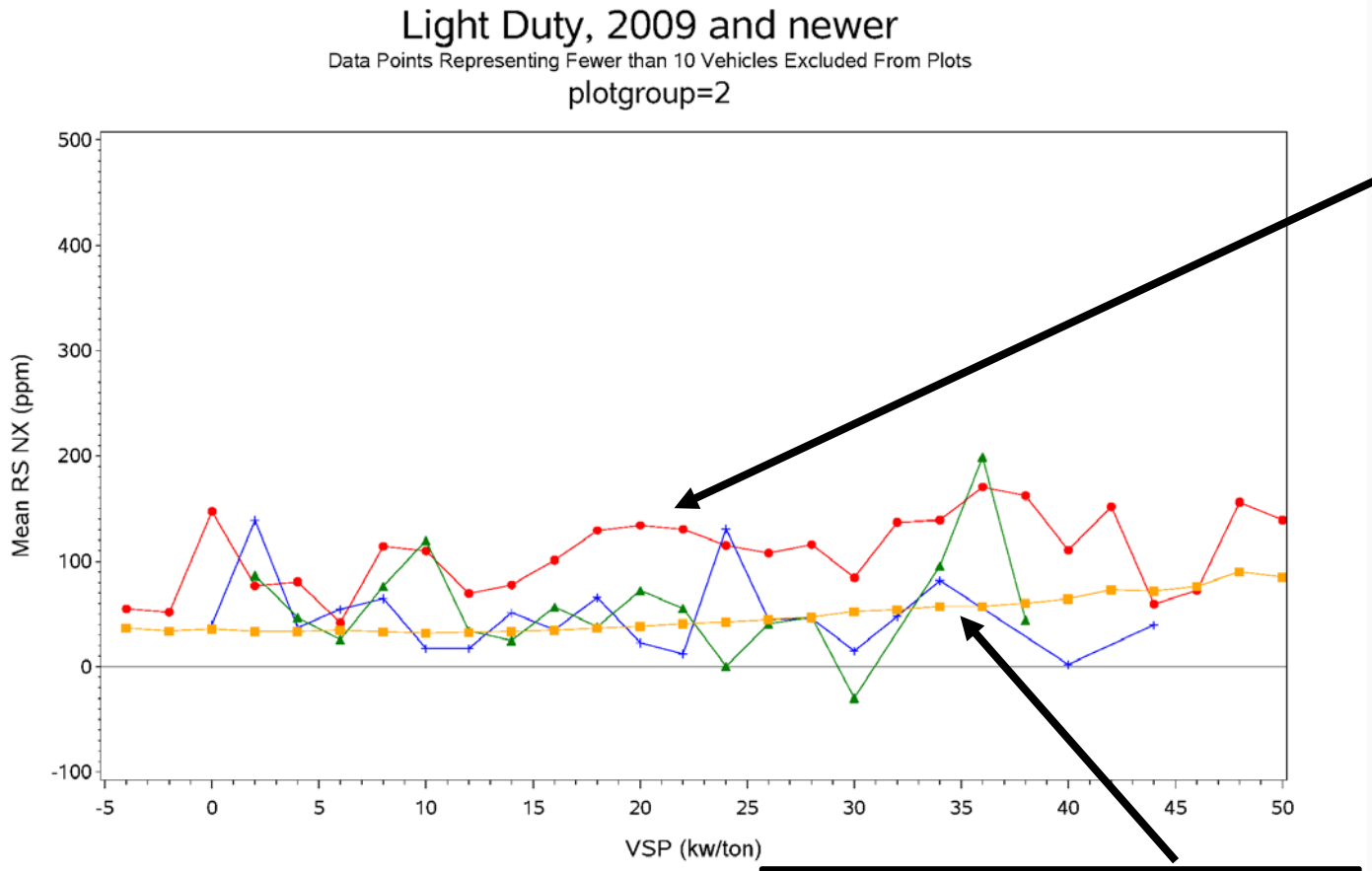
Possible “High Emitting” Vehicles with Different Slope



Possible ”High” Emitting Vehicles: Vehicles have “normal” emissions at lower VSP bins but slope increases as VSP increases above fleet “normal” vehicles

Fleet “Normal” Average Emitter Vehicles

Possible Category of Vehicles: "Higher " Emitting 1st MY and Not Other MYs



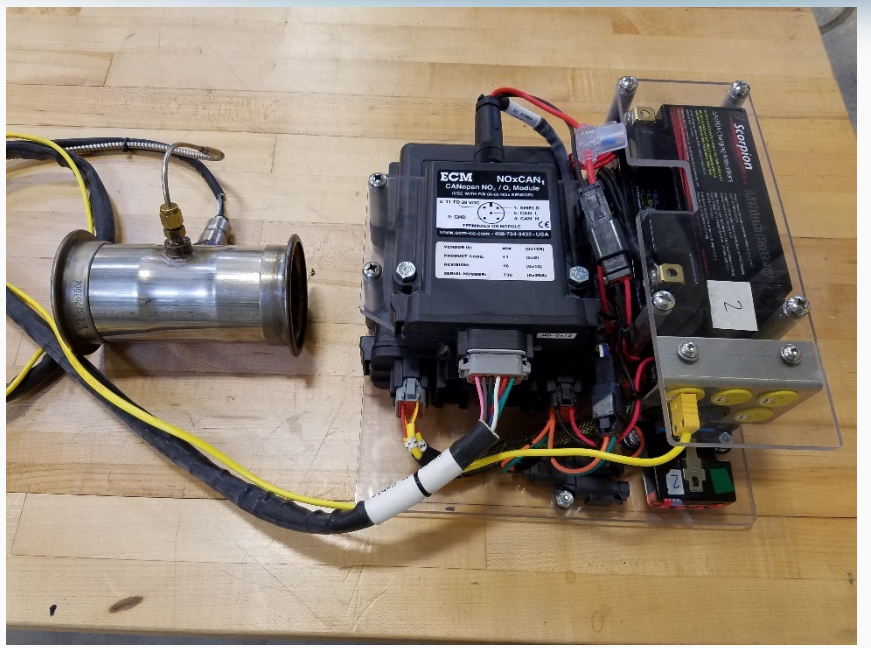
1st Year of new Model has higher overall VSP emissions vs subsequent MYs of same vehicle when compared to fleet ("normal" emitting vehicles) with same engine size

"Normal" Emitting Vehicles

Legend:

- 1st Year Vehicle
- 3rd Year Vehicle
- 4th Year Vehicle
- All Other Vehicles (fleet average)

Screening Devices: Mini-PEMS



EPA's Version

ECM's Version

Sensors: NOx, Exhaust Temperature
GPS
Vehicle Interface
Adding Additional Sensors: CO_2/CO, NH_3, Black Carbon, O_2

What Data Fields are Needed to “Screen” Vehicles and Gather “Real-World” Operations?

Mini-PEMS/PAMS Data Logger: Data Fields

Allows for Modeling Analysis on:

Date/Time Clock: Engine On/Off Date/Time ECU: Vehicle Speed (if not, use GPS)	• Soak times, starts, idle times, VMT, speed distributions, drive cycle development, use patterns, etc. • Able to calculated VSP if hp and vehicle mass are known
±	±
Additional ECU Fields: Engine Load Fields: (RPM/load%/torque%,etc) DPF/SCR Operations (temps, NOx ppm, etc MAF/MAP/Fuel Rate	• Use Engine load, SCR operation, DPF operation, Engine RPM, etc. • Able to Use Equations for calculating exhaust flow, VSP & g/power • Able to get NOx in ppm/grams in VSP(kW/ton), Power (g/bhphr, g/kW)
±	±
GPS Fields: (lat./long./altitude/vehicle speed) (Note: Signal blocked by underpasses/tall buildings	• Able to cross checking of ECU's vehicle speed/acceleration w/ GPS • GPS Fencing (ports, hoteling, county, city boundaries), road types, etc. • Road Grade load by altitude or enhanced with GIS maps
±	±
External Flowmeter: (Do not need ECU interface)	• Able to cross checking of ECU's MAF/MAP equations w/ independent flow measurement • ECU interface not needed if flowmeter used but losing engine data.
±	±
ECU: Mode $06 Messages	• Able to gather Diagnostic Messages, DTCs and Monitor Readiness

Note: All Data Gathered at 1Hz – second-by-second

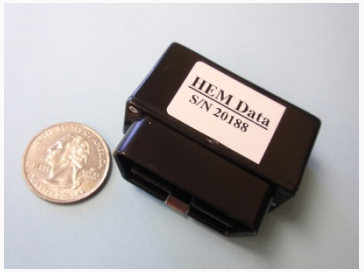
Mini-PEMS/PAMS Data Logger: Emission Sensors Data Fields

Allows for Modeling Analysis on:

NOx Sensor (ppm) Wide Lambda O2 Sensor (ppm)	• Able measure NOx measurement in VSP, ECU data or by flowmeter • Able to measure O2 in exhaust
CO2/CO Sensor (ppm) THC Sensor (ppm)	• Able to conduct carbon balancing with default fuel properties and fuel rate by ECU plus reweight NOx measurements in VSP • Able to look at cold/warm/hot start or vehicle soak emissions • Able to know DPF regeneration events • Able to calculate independent vehicle fuel economy
BC Sensor (ppm)	• Able to know if DPF is cracked for diesel vehicles • Able to know relative if vehicle is PM “high” emitter (diesel/gasoline)
Environmental Sensor	• Able to relate environmental conditions to emissions. (relative humidity, temperature & barometric pressure)
NH3 Sensor (ppm)	• Able to relate diesel “slip” or gasoline cold emissions

Note: All Data Gathered at 1Hz – second-by-second

New Tools: Entry Level

		Equipment Only Costs:
Laboratory Testing: Chassis and/or Engine Dynamometer		~$3,000,000+
		10X
Portable Emissions Measurement Systems (PEMS)		~$200,000-$300,000
		10X
Screening Tools: mini-PEMS		~$20,000-$30,000
		25X
Portable Activity Measurement Systems (PAMS)		~$600 -$1,000

Min-PEMS Characteristics: Screening Vehicles

- Not PEMS (CFR 1065 Compliant)
- Flowmeter: ??
  - Yes and No, if you have proper ECM engine fields being recorded
- ECU (Vehicle Interface)
  - Yes and No, if you have other ways to gather the proper data fields
- Quicker to Install than PEMS
  - Under 30 minutes would be best
- Smaller in size, weight and power
  - Run with LiFePO4 battery for all day multiple vehicle testing
- Quicker calibration by “auto-zeroing” of sensors
- Vehicle Testing time: ~ less than 1 hour depending on type of “screening”
  - Enough time to give data for VSP (0-60 kW/ton) profile
- Overall Accuracy: ±10%
- Length of Performance of Sensors & accuracy range: ??

Outcomes

- EPA is actively seeking partnerships to help gather better data to address present and future research.
- EPA wants to enhance local data gathering efforts to improve our models
- EPA is actively developing tools and methodologies to further support gathering activity and emissions data.
- This includes improvement and support:
  - Better integration and understanding “real-world” emissions on different vehicle and engine technologies
  - Better understanding of engine parameters to emissions in “real-world” operations
  - Better understanding of fleet “high emitters” by screening vehicles

Questions

Contact Information

Mobile Source Emission Factor Research

https://www.epa.gov/moves/mobile-source-emission-factors-research

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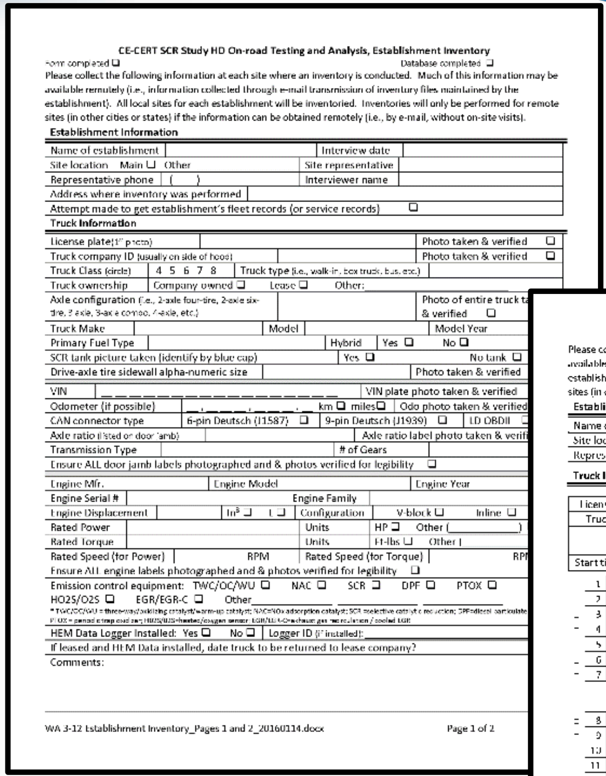
Old Slides

Improvements to “Meta” Vehicle Data

- Developed new standardized vehicle profile documentation forms to accompany test programs using PEMS or PAMS
  - Fleet information: such as vocation and information on other vehicles in the fleet
  - Vehicle Parameters: such as axle ratio, engine information, and transmission information to enhance modeling efforts



CE-CERT SCR Study HD On-road Testing and Analysis, Establishment Inventory

Please collect the following information at each site where an inventory is conducted. Much of this information may be available remotely (i.e., information collected through e-mail transmission of inventory files maintained by the establishment). All local sites for each establishment will be inventoried. Inventories will only be performed for remote sites (in other cities or states) if the information can be obtained remotely (i.e., by e-mail, without on-site visits).

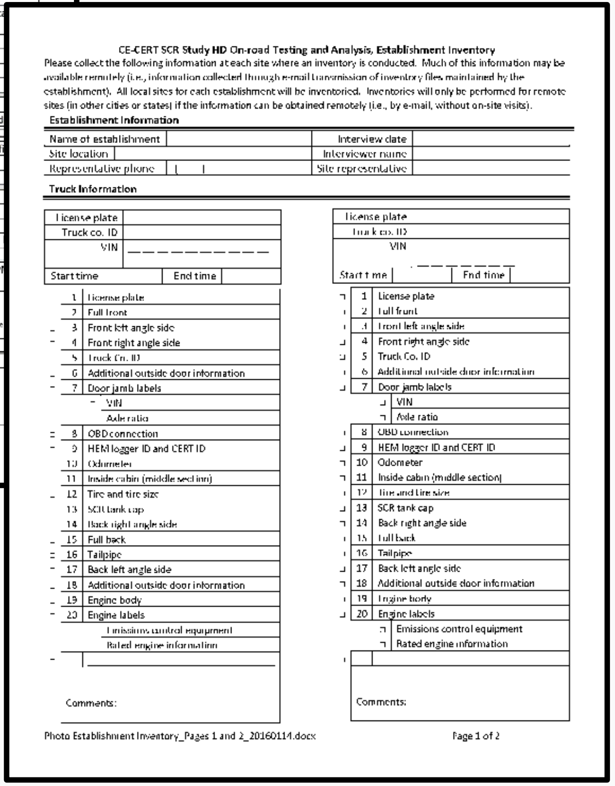
Establishment Information

Name of establishment | Interview date
Site location Main ❑ Other | Site representative
Representative phone ( ) | Interviewer name
Address where inventory was performed
Attempt made to get establishment's fleet records (or service records) ❑

Truck Information

License plate | Photo taken & verified ❑
Truck company ID | Photo taken & verified ❑
Truck Class (circle) 4 5 6 7 8 | Truck type
Truck ownership Company owned ❑ Lease ❑ Other:
Axle configuration | Photo of entire truck taken & verified ❑
Truck Make | Model | Model Year
Primary Fuel Type | Hybrid Yes ❑ No ❑
SCR tank picture taken (identify by blue cap) Yes ❑ No tank ❑
Drive-axle tire sidewall alpha-numeric size | Photo taken & verified
VIN | VIN plate photo taken & verified
Odometer (if possible) km ❑ miles ❑ | Odo photo taken & verified
CAN connector type 6-pin Deutsch (J1587) ❑ 9-pin Deutsch (J1939) ❑ LD OBDII
Axle ratio | Axle ratio label photo taken & verified
Transmission Type | # of Gears
Ensure ALL door jamb labels photographed and & photos verified for legibility ❑
Engine Mfr. | Engine Model | Engine Year
Engine Serial # | Engine Family
Engine Displacement | Configuration V-block ❑ Inline ❑
Rated Power | Units HP ❑ Other
Rated Torque | Units Ft-lbs ❑ Other
Rated Speed (for Power) RPM | Rated Speed (for Torque) RPM
Ensure ALL engine labels photographed and & photos verified for legibility ❑
Emission control equipment: TWC/OC/WU ❑ NAC ❑ SCR ❑ DPF ❑ PTOX ❑
HO2S/O2S ❑ EGR/EGR-C ❑ Other
HEM Data Logger Installed: Yes ❑ No ❑ | Logger ID (if installed):
If leased and HEM Data installed, date truck to be returned to lease company?
Comments:

WA 3-12 Establishment Inventory_Pages 1 and 2_20160114.docx | Page 1 of 2



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Establishment Information

Name of establishment | Interview date
Site location | Interviewer name
Representative phone ( ) | Site representative

Truck Information

License plate
Truck co. ID
VIN
Start time | End time

1 License plate
2 Full front
3 Front left angle side
4 Front right angle side
5 Truck Co. ID
6 Additional outside door information
7 Door jamb labels
VIN
Axle ratio
8 OBD connection
9 HEM logger ID and CERT ID
10 Odometer
11 Inside cabin (middle section)
12 Tire and tire size
13 SCR tank cap
14 Back right angle side
15 Full back
16 Tailpipe
17 Back left angle side
18 Additional outside door information
19 Engine body
20 Engine labels
Emissions control equipment
Rated engine information

Comments:

Photo Establishment Inventory_Pages 1 and 2_20160114.docx | Page 1 of 2

Improvements to Data Analysis:
QA/QC Procedures

- Goal: Quicker QA/QC and then quicker analysis of the data

- Currently developing and implementing an open database and open data analysis structure with our partners
  - Standard database structure: MySQL
  - Standard data analysis and QC/QA techniques: modular designed Scripts in Python and MySQL
  - Standard graphics: R

Improvements to Data Analysis

- Modular QA/QC Design

Step 1	Step 2	Step 3	Step 4
Data Structure & Nomenclature Checks	Date/Time & Vehicle Speed Checks	Engine Parameter Checks	GPS Parameter Checks
Define field names, definitions, etc.	Proper fields defined and validation	Proper field	

Additional Analysis

Allows for immediate data analysis on a per trip and aggregate basis

Soak times, starts, idle times, VMT, speed distributions, drive cycle development, use patterns, etc.

Engine load, SCR operation, DPF operation, Engine RPM, etc.

GPS Fencing (ports, hoteling, county, city boundaries), road types, etc.

RSD Characteristics

- Emissions are measured by infrared (IR) and ultraviolet (UV) light beam across roadway
  - ESP RSD4000, RSD4600 and RSD5000 units are used
- Specific concentrations of HC, CO, CO2, NO and smoke are measured in 50 milliseconds (50 individual measurements recorded).
- Emissions reported as ratios to CO2:
  - CO/CO2
  - CH4/CO2
  - NOx/CO2

Colorado's RSD Program

- RSD program
  - 18 - 22 RSDs used year round
  - Weather: >20F and dry conditions
- Over time, Colorado's RSD has measured ~ 90% of Colorado's fleet of I/M vehicles
- Shared the RSD data with us through existing CRADA
  - EPA will share data results with Colorado
- Data Being Analyzed
  - 5.8 years of data (January 1, 2009 to December 31, 2015)
  - Over 10 million vehicles representing over 40 million valid records

Vehicle Specific Power (VSP)

VSP is defined as the instantaneous power per unit mass of the vehicle

$$VSP = \frac{\frac{d}{dt}(KE + PE) + F_{rolling} v + F_{aero} \left(v^2\right) v}{m}$$

$$VSP_{LDV} = v\left\{1.1a + g\left(\frac{r}{100}\right) + 0.132\right\} + 0.000302v^3$$

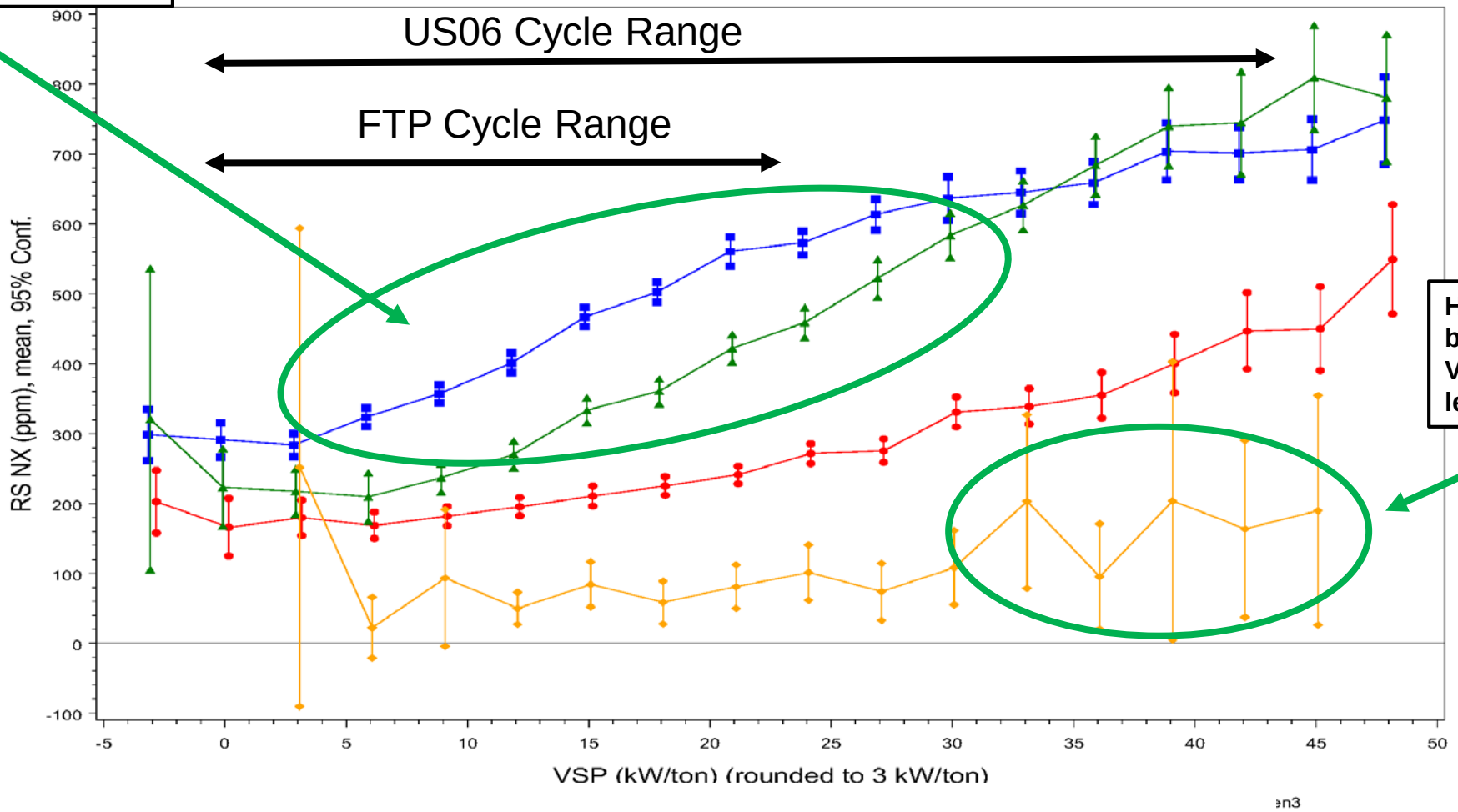
VSP = Vehicle Specific Power (kw/ton), *LDV* = for typical light duty vehicle
a = vehicle acceleration (m/s^2)
g = acceleration of gravity (9.81 m/s^2)
r = road grade (%)
v = vehicle speed (m/s)

Data Analyzed Methodology

- Methods Used:
  - VIN Decoded: MY, Make, Model, Engine Size, and Fuel Type
  - Reclassified vehicles into MOVES (Car/Truck Regulatory Classes)
  - Applied vehicle speed and acceleration through the RSD unit
  - Applied grade slope for each Colorado's RSD test site
  - Applied average NOx (ppm) concentration for each measurement
- Analyzed by NOx concentration (ppm) vs VSP (kW/ton)
  - Also analyzed by NOx g/kgfuel vs VSP(kW/ton) – same results
- Limited to new MY vehicles (MY2009 – MY2015)
- Limited data to minimum 10 different vehicles with 25 valid RSD NOx measurements

Accuracy of RSD NOx Emissions by VSP

Low error because of large datasets within VSP bins (95% confidence levels)



Higher measurement error because of less data at higher VSP bins (95% confidence levels)