CHALLENGES IN AND APPROACHES FOR CONDUCTING HEAVY-DUTY TRUCK ACTIVITY DATA COLLECTION PROGRAMS

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Overall

- Background
- Understanding of Equipment
- Understanding the Data Gathering Issues
- Understanding Data Streams
- Possible Solutions
- Data Sets Examples

Background and Rationale for Data Collection Programs

- **Modeling Heavy-duty Vehicles (HDVs)** requires a better understanding of their population, activity, maintenance and emissions
  - Understanding activity is a critical component of characterizing overall emissions
    - HDVs with advanced technologies (i.e., electric vehicles and hybrids) can have different operational patterns than their conventional counterparts;
    - Need to understand the performance of modern emission control equipment under "real world" operational (usage) patterns; and
    - Need to understand "real world" durability and failure rates of emission control components

Types of Vehicles & Networks

On-Road MD and HD Trucks

- SAE J1939 (Most HDVs and Large NRE engines (e.g. construction))
  - More than 14.000 parameters (SPNs) within approximately 2000 parameter groups available for acquisition (open)
  - Wide variety of control and operational information available (historic usage patterns)
- SAE J1962 / J1979
  - Some MD and HD trucks utilize light-duty OBD style systems, per manufacturer's discretion
  - Different information may be available

Note: Various Fuel Types (both CI and SI), Engine Types, Emission Control Components, Powertrains (Hybrids and conventional), Operational Usage, and Model Year Determine Relevant Information to Collect

Considerations When Designing Test Programs

- Study objectives will dictate type of equipment to be used and parameters to be collected:
  - "Long-duration" of second-by-second activity data collection requires on-board memory, and may require cellular communication; or
  - **"Quick snapshot"** of in-use faults with diagnostic messages (DMs) and/or other vehicle/engine use data fields

Types of Data Logging Equipment

Computer Based Systems

Stand Alone Devices

- Laptops, scanning software, other similar equipment suitable for snapshots
- Smaller, unobtrusive devices may be used for longer duration continuous data collection programs
- Onboard storage, batch, or real-time transmission to transfer continuous data.
- Remote monitoring of data to ensure logger is functioning appropriately

Note: There are other devices that can also do some or all of these functions not listed here

Possible Tools for Gathering Data

Equipment		HEMData Logger	Silverscan	DieselLaptop	HEMData Streamer
Equipment Cost		$600 - $1000	$150 pigtail costs	$500 pigtail costs	$500 plus iPAD cost
Subscription Cost		$0	$1800 per year per computer	$2300 per year per computer	$0
Data Method		Plug in w/o computer wireless; stand alone or cellular	Dependent on computer	Dependent on computer	Dependent on computer; Wireless
CAN1/CAN2		Yes	Only CAN1	Only CAN1	Yes (new Version)
Memory		4GB, internal	None	None	None
J1939/J1979		Yes with pigtails & older J1708	Yes with pigtails	Yes with pigtails	Yes with pigtails
Time to Acquire ECM Data		< 2 minutes	< 5 minutes	< 5 minutes	< 2 minutes
Data File		Process against database, CSV	Get PDF, XML, TXT	Get PDF, TXT	Process against database, CSV

Logging Protocols

- J1979/J1939/J1708/Others OEM Protocols
- CAN Baud Rate (250K, 500K, other)
  - Some loggers/computers have “fixed” baud rate (need to know its setting)
    - <u>Can trip “Fault Codes” if using wrong baud rate</u>
  - Autobaud rate detection capability (better)
- ECM can have two CAN channels broadcasting data on two different protocols
  - **Need to record on both (CAN1 and CAN2)**
- Not all ECM or OEM connectors the same & follow standard protocols
  - **Might need to make “pigtail” converters to data logger**
  - **Might need a “pigtail” to capture all data streams**

J1979 using J1962 connector - multiple baud rates

J1939 green – 500K but can also be 250K

J1939 black – 250K

Selecting and Preparing Data Logging Equipment

- EPA has developed different data gathering protocols for different HDV usages
  - Historic Data on Vehicle (A Vehicle's "Medical History")
    - Developed configuration file to "screen" data fields including DMs (open and requested) in under 1-2 minutes
    - Per-trip or static data could include vehicle information, diagnostic data, fault codes, and overall vehicle operations (e.g. Total miles, total idle time, etc.)
  - Logging Live Data on a Vehicle's Operations Parameters (Presently, gathering ~350 parameters)
    - Developed general data gathering of all fields at 1 Hz rate and DMs (open and requested)
    - Over 14,000 parameters defined by J1939. (Operational, Emission controls, and trip activity data (load, RPM, speed, etc.)

Sample of Parameters – Class 8 HDVs

MY	Vehicle OEM	Engine Manufacturer	# of Parameters
2009	Kenworth T660	Cummins ISC	446
	Kenworth T680	Cummins ISX 15L	437
	Kenworth T680	PAXCCAR MX 14L	299
	Freightliner	Cummins ISL	492
	Freightliner	Cummins ISL	555
	International	Transtar 8600	302
	International	Prostar	318
	Volvo	Cummins ISX	330
	Volvo 670	Volvo D13	CAN1 - 34, CAN 2 - 329
	Volvo 670	Cummins ISX	342

Broadcasting varying list of parameters for different vehicle configurations

Note: Data Stream is split between two CAN channels

Data Stream Structure - SAE J1939

CAN ID

- **PGN**
- **SA**
  0 - 255

DTC Data

- **Lamp Status**
  PL, AWL, RSL, MIL
- **SPN**
  0 – 524, 487
- **FMI**
  0 – 31
- **OC**
  0 – 127

Engine #1
Engine #2
Exhaust Emission Controller
DPF/SCR Controller

PL – Protect Lamp
AWL – Amber Warning Lamp
RSL – Red Stop Lamp
MIL – Malfunction Indicator Lamp

Specific Signal Field:
e.g. NOx sensor, engine load

How did the signal field fail?

How many times has the failure happened?

PGN = Parameter group number
SPN = Suspect parameter number

FMI = Fault Monitor Identifier
OC = Occurrence Count

Many DMs – Diagnostic Messages

Importance	DM#	PGN #	Description
High	DM1	65226	**DM1 – Active Diagnostic Trouble Codes (DTCs) (Open)**
Medium	DM2		**DM2 – Previously Active DTCs (Request)**
	DM3	65228	DM3 – Diagnostic Data Clear/Reset for Previously Active DTCs (Request)
Medium	DM6	65231	**DM6 - Emission-Related Pending DTCs (Request)**
	DM11		DM11 – Diagnostic Data Clear/Reset for Active DTCs (Request)
High	DM12	65236	**DM12 – Emission Related Active DTCs (Request)**
Medium	DM23	64949	**DM23 – Emission Related Previously Active DTCs (Request)**
	DM24	64950	DM24 – SPN Support (Request)
	DM25	64951	DM25 – Expanded Freeze Frame (Request)
Medium	DM27	64898	**DM27 – All Pending DTCs (Request)**
High	DM28	64896	**DM28 – Permanent DTCs (Request)**
High	DM32	41472	**DM32 – Regulated Exhaust Emission Level Exceedance (Request)**
	DM41	64863	DTCs – A, Pending (Request)
	DM56		DM56 – Model year & Certification Engine Family (Request)

PGN/SPN Example

- PGN – Parameter Group Number
- SPN – Suspect parameter Numbers
- PGNs can be made up of one to multiple SPNs
- PGN-61444
  - SPN 899, Engine Torque mode (bit)
  - SPN 4154, Actual Engine - percent torque(frictional) (%)
  - SPN 512, Driver's Demand Engine – percent torque (%)
  - SPN 513, Actual Engine - percent torque (%)
  - SPN 190, Engine Speed (rpm)
  - SPN 1483, Source Address of controlling device for engine control (SA)
  - SPN 1675, Engine Starter mode (bit)
  - SPN 2432, Engine Demand – percent torque (%)

Possible Data Fields Acquired for Analysis

- Vehicle Report
  - – Meta Data – VIN, MY, Manufacturer MY, etc
  - – Engine Software #
- DMs Report
  - – PGN/SPN with FMI, OC, etc.
  - – Fault Indicator Lamps
  - – Identifying Possible Maintenance/Tampering Issues
- Usage Patterns (MOVES)
  - Total Mileage, Total Idle Time, Total Time, Total Fuel Used, etc.

Data Analysis Opportunities

- EPA acquired and analyzing a 25,000 HDV dataset that was gathered using the “medical record” method
  - Develop better understanding of “real-world” activity patterns for modeling efforts;
  - Analyzing frequency of DMs/MIL Lights/PGN/SPN/FMI/OC;
  - Any possible relationships within dataset; and
  - Develop a methodology to grade vehicle:
    - “**Green**” – looks to be functioning properly
    - “**Yellow**” – might have possible maintenance problems
    - “**Red**” – known maintenance problems

Possible Data Gathering Opportunities

- Develop pilot programs at the State level to investigate gathering HD ECM data
  - Gathering additional data during an existing State's HDV testing program.
    - Little additional time or cost to staff
    - Increased understanding and knowledge of use and maintenance patterns.
- Develop better analytical tools to understand HD ECM data
- Develop better GUI interfaces to evaluate in "real-time" HD ECM data

Many Different Controllers

Controller	Name	SPN Count	Total Vehicles
0 / 00	Engine #1	5,422,282	13,441
11 / 0B	Brakes - System Controller	995,991	
33 / 21	Body Controller	525,095	
15 / 0F	Retarder - Engine	521,326	
3 / 03	Transmission #1	410,673	3,618
49 / 31	Cab Controller - Primary	336,823	
23 / 17	Instrument Cluster #1	334,656	1,312
42 / 2A	Headway Controller	271,370	
1 / 01	Engine #2	210,029	1,114
61 / 3D	Exhaust Emission Controller	203,637	1,082
85 / 55	Diesel Particulate Filter Controller	203,597	1 – 2014 International Navistar 8600
255 / FF	proprietary	110,768	
8 / 08	Axle - Steering	83,634	
150 / 96	reserved	44,759	
58 / 3A	Passenger-Operator Climate Control #2	43,814	
240 / F0	reserved	41,537	
16 / 10	Retarder - Driveline	39,459	
17 / 11	Cruise Control	38,776	
74 / 4A	Communications Unit, Cellular	36,776	
25 / 19	Passenger-Operator Climate Control #1	36,026	
133 / 85	reserved	34,845	
37 / 25	Off Vehicle Gateway	33,793	
71 / 47	Chassis Controller #1	28,350	
62 / 3E	Vehicle Dynamic Stability Controller	26,353	
232 / E8	reserved	23,527	
160 / A0	reserved	22,582	
132 / 84	reserved	17,828	
140 / 8C	reserved	17,771	
5 / 05	Shift Console - Primary	17,568	

Expand and Look at Controller 0/00 Engine #1 Details

Note: Data from over 24, 942 vehicles with over 30 different controllers

Controller 0/ 00 – Engine #1
MY2010+ - 13,441 vehicles

SPN	SPN Name
111	Engine Coolant Level 1
3,597	ECU Power Output Supply Voltage #1
2,588	Maximum Vehicle Speed Limit 1
1,761	**** Aftertreatment 1 Diesel Exhaust Fluid Tank Volume**
3,216	**** Aftertreatment 1 SCR Intake NOx 1**
3,226	**** Aftertreatment 1 Outlet NOx 1**
1,590	Adaptive Cruise Control Mode
641	Engine Variable Geometry Turbocharger Actuator #1
97	Water In Fuel Indicator 1
1,569	Engine Protection Torque Derate
2,589	Maximum Vehicle Speed Limit 2
1,810	Longitudinal Acceleration
5,848	** Aftertreatment 1 SCR Intermediate NH3
168	Battery Potential / Power Input 1
157	** Engine Fuel 1 Injector Metering Rail 1 Pressure
96	Fuel Level 1
1,209	** Engine Exhaust Pressure 1
5,742	** Aftertreatment Diesel Particulate Filter Temperature Sensor Module
5,743	** Aftertreatment 1 SCR Temperature Sensor Module
91	Accelerator Pedal Position 1
3,556	** Aftertreatment 1 Hydrocarbon Doser 1
2,623	Accelerator Pedal #1 Channel 2
84	Wheel-Based Vehicle Speed
3,464	Engine Throttle Actuator 1 Control Command
171	Ambient Air Temperature
563	Anti-Lock Braking (ABS) Active
2,659	** Engine Exhaust Gas Recirculation 1 Mass Flow Rate
2,791	** Engine Exhaust Gas Recirculation 1 Valve 1 Control 1
609	Controller #2
3,251	** Aftertreatment 1 Diesel Particulate Filter Differential Pressure

Expand and Look at SPN 3216 Details

Note: Data from over 24, 942 vehicles and over 680 different SPNs

Summary on SPN 3216
Aftertreatment 1 SCR Intake Nox 1

Summary		
DM	**DM Name**	**Count**
DM01	Active Diagnostic Trouble Codes	392
DM02	Previously Active Diagnostic Trouble Codes	317
DM06	Emission-Related Pending DTCs	78
DM12	Emission-Related Active DTCs	233
DM23	Emission-Related Previously Active DTCs	200
DM27	All Pending DTCs	85
DM28	Permanent DTCs	308
FMI	**FMI Name**	**Count**
2	Erratic, Intermittent, or Incorrect	58
3	Voltage Above Normal	72
4	Voltage Below Normal	360
5	Current Below Normal	21
9	Abnormal Update Rate	291
10	Abnormal Rate of Change	338
11	Other Failure Mode	2
12	Failure	47
13	Out of Calibration	6
14	Special Instruction	2
15	High-least severe	5
16	High-moderate severity	21
17	Low-least severe	2
19	Data Error	8
20	Data Drifted High	371
21	Data Drifted Low	7
31	Condition Exists	2

Expand and Look at DM01 Details

Note: Data on 823 Vehicles

SPN 3216 – Aftertreatment 1 SCR Intake NOx 1

SPN	SPN Name	DM	FMI	FMI Name	Count	Manuf	Year	Engine	Model
3,216	Aftertreatment 1 SCR Intake NOx 1	DM01	31	Condition Exists	1	Volvo	2014	Volvo 12.8	VNL
3,216	Aftertreatment 1 SCR Intake NOx 1	DM01	31	Condition Exists	1	Volvo	2016	Volvo 12.8	VNM
3,216	Aftertreatment 1 SCR Intake NOx 1	DM01	21	Data Drifted Low	50	International	2014	Navistar 12.4	ProStar+
3,216	Aftertreatment 1 SCR Intake NOx 1	DM01	2	Erratic, Intermittent, or Incorrect	4	Volvo	2012	Volvo 12.8	VNL
3,216	Aftertreatment 1 SCR Intake NOx 1	DM01	2	Erratic, Intermittent, or Incorrect	1	International	2016	Navistar 12.4	ProStar+
3,216	Aftertreatment 1 SCR Intake NOx 1	DM01	2	Erratic, Intermittent, or Incorrect	14	International	u2016	Navistar 12.4	ProStar+
3,216	Aftertreatment 1 SCR Intake NOx 1	DM01	2	Erratic, Intermittent, or Incorrect	10	Volvo	[illegible]	[illegible]	[illegible]
3,216	Aftertreatment 1 SCR Intake NOx 1	DM01	2	Erratic, Intermittent, or Incorrect	1	International	[illegible]	[illegible]	[illegible]
3,216	Aftertreatment 1 SCR Intake NOx 1	DM01	2	Erratic, Intermittent, or Incorrect	2	International	2016	Navistar 12.4	ProStar+
3,216	Aftertreatment 1 SCR Intake NOx 1	DM01	3	Voltage Above Normal	1	Peterbilt	2015	Paccar 12.9	579
3,216	Aftertreatment 1 SCR Intake NOx 1	DM01	3	Voltage Above Normal	1	Peterbilt	2017	Paccar 12.9	579
3,216	Aftertreatment 1 SCR Intake NOx 1	DM01	3	Voltage Above Normal	126	Peterbilt	2017	Paccar 12.9	579
3,216	Aftertreatment 1 SCR Intake NOx 1	DM01	3	Voltage Above Normal	33	Peterbilt	2017	Paccar 12.9	579
3,216	Aftertreatment 1 SCR Intake NOx 1	DM01	3	Voltage Above Normal	1	Peterbilt	2016	Paccar 12.9	579
3,216	Aftertreatment 1 SCR Intake NOx 1	DM01	3	Voltage Above Normal	126	Peterbilt	2017	Paccar 12.9	579

Note: Need to understand how a particulate FMI code on a SPN relates to maintenance or emissions

Available Parameters: 24,868 vehicle MY2010+

Note: Expect a high percentage of vehicles to report key activity and maintenance values

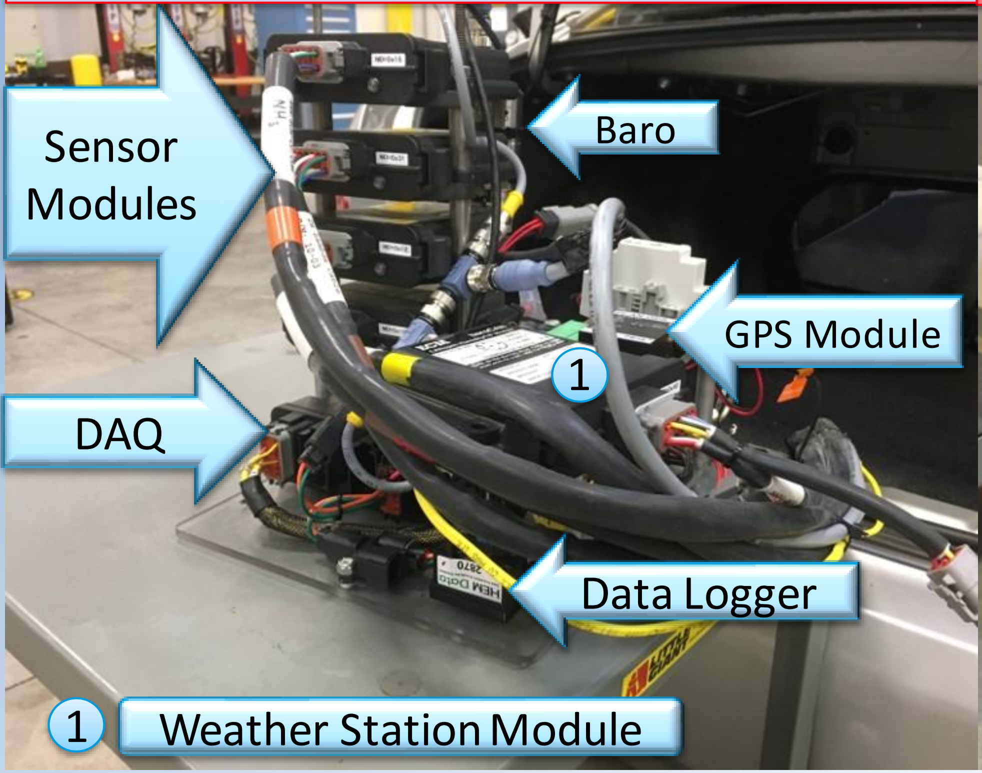
Name	Percent	Unit
Engine Speed (190)	99.9	rpm
Actual Engine - Percent Torque (513)	99.9	%
Engine Torque Mode (899)	99.8	bit
Engine Percent Load At Current Speed (92)	99.6	%
Suspect Parameter Number (1214)	99.6	binary
SPN Conversion Method (1706)	99.5	bit
Amber Warning Lamp (624)	99.5	bit
Failure Mode Identifier (1215)	99.5	binary
Red Stop Lamp (623)	99.5	bit
Occurrence Count (1216)	99.5	binary
Malfunction Indicator Lamp (1213)	99.5	bit
Source Address of Controlling Device for Engine Control (1483)	99.4	SA
Engine Fuel Rate (183)	99.3	l/h
Engine Intake Manifold #1 Pressure (102)	98.7	kPa
Engine Intake Manifold 1 Temperature (105)	98.6	C
Engine Instantaneous Fuel Economy (184)	98.6	km/L
Engine Oil Pressure (100)	98.6	kPa
Engine Coolant Temperature (110)	98.5	C
Driver's Demand Engine - Percent Torque (512)	98.3	%
Barometric Pressure (108)	98.3	kPa
Accelerator Pedal Position 1 (91)	98.2	%
Brake Switch (597)	98.1	bit
Nominal Friction - Percent Torque (514)	98	%
Wheel-Based Vehicle Speed (84)	98	kph
Parking Brake Switch (70)	97.8	bit

Engine Reference Torque (544)	97	Nm
Engine Speed At Point 5 (531)	97	rpm
Engine Percent Torque At Point 4 (542)	97	%
Engine Speed At Point 4 (530)	97	rpm
Engine Maximum Momentary Override Speed. Point 7 (533)	97	rpm
Diesel Particulate Filter Active Regeneration Inhibited Due to Inhibit Switch (3703)	97	bit
Aftertreatment Diesel Particulate Filter Active Regeneration Status (3700)	96.9	bit
Total Vehicle Distance (High Resolution) (917)	96.9	m
Engine Coolant Level 1 (111)	96.7	%
Accelerator Pedal 1 Low Idle Switch (558)	96.5	bit
Diesel Particulate Filter Lamp Command (3697)	96.3	bit
Exhaust System High Temperature Lamp Command (3698)	96.3	bit
Fan Drive State (977)	95.8	bit
Fuel Level 1 (96)	95.3	%
Protect Lamp (987)	95.3	bit
Engine Total Fuel Used (250)	95.3	l
Battery Potential / Power Input (168)	95.2	V
Engine Demand Percent Torque (2432)	94.6	%
Engine Trip Fuel (182)	94.2	l
ABS/EBS Amber Warning Signal (Powered Vehicle) (1438)	94.1	bit
Front Axle Speed (904)	94	kph
Anti-Lock Braking (ABS) Active (563)	93.9	bit
Relative Speed; Front Axle. Left Wheel (905)	93.9	kph
Aftertreatment 1 Diesel Exhaust Fluid Tank Volume (1761)	93.8	%
Relative Speed; Front Axle. Right Wheel (906)	93.8	kph
Relative Speed; Rear Axle #1. Right Wheel (908)	93.7	kph
Engine Total Revolutions (249)	93.7	r
Relative Speed; Rear Axle #1. Left Wheel (907)	93.6	kph
Aftertreatment Diesel Exhaust Fluid Tank Low Level Indicator (5245)	93.4	bit

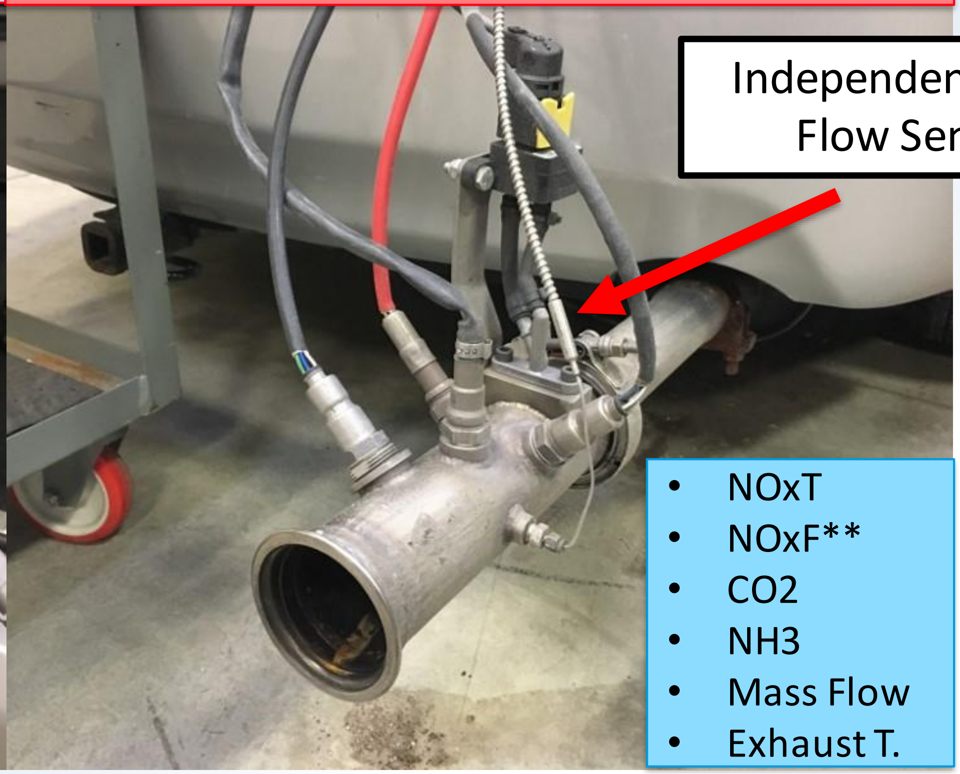
EPA's Mini-PEMS Version

Measurement Setup – Sensors, Modules and DAQ*

Sensor Modules and DAQ



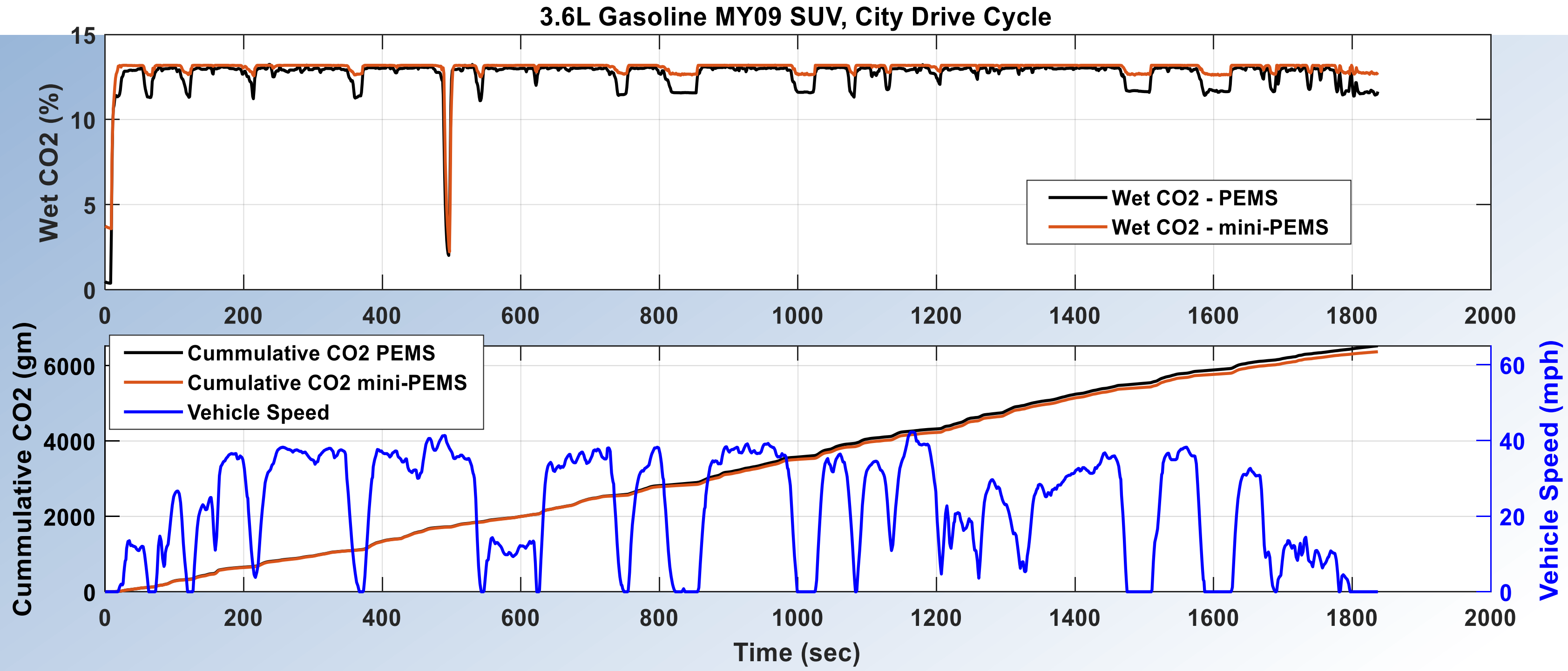
2.5" LDV Tailpipe Adapter



* Complete list of components provide in Appendix A

** Additional pictures of NOxF sensor in Appendix B

Validation – Fuel Economy – 3.6L Gasoline SUV



Measurement	CO2 Mass (gms/mile)
PEMS	577.8
Mini-PEMS	563.8
Percent Error	-2.4 %

Measurement	Fuel Economy (MPG)
PEMS	15.36
Mini-PEMS	15.80
Percent Error	2.9 %

Challenges in Developing and Advancing Mini-PEMS

Future Development – Robust Packaging

Development Design

Prototype Design

Design Includes: Control Modules, DAQ, Data Logger, Battery (8 hours) and Barometric Pressure
Dimensions: W21”xH8.5”xD16”
Weight: approx. 25 lbs

Next generation prototype expected to be smaller

CRADA & Equipment Loans

- CRADA – Cooperative Research and Development Agreements
  - EPA partnerships to conduct research (activity & emissions) on light-duty and heavy-duty vehicles plus nonroad equipment
    - State of Colorado's Department of Public Health & Environment;
    - Texas Transportation Institute (TTI);
    - University of California, Riverside, College of Engineering Center for Environmental Research and Technology (CE-CERT); and
    - State of New Jersey
  - Equipment Loans (EPA has many equipment loans agreements)
    - PEMS (Emission & Activity)
    - PAMS (Data Loggers)

Contact

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