

# **ECM's miniPEMS and ~~microPEMs~~** **Systems and Components**

**QBFs**



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# For 34 years, ECM has built Instruments that use Ceramic Sensors to Measure Exhaust Emissions

- AFR/Lambda/O<sub>2</sub>
- EGR (O<sub>2</sub> in intake)
- NOx/O<sub>2</sub>/CO<sub>2</sub>
- CO/CO<sub>2</sub>
- NH<sub>3</sub>
- PM/PN
- Fast Temperature



ECM has control modules for all ceramic exhaust sensors with better features, accuracy, speed-of-response, range, and diagnostics than OEM modules. Most importantly, ECM modules allow for exhaust sensor calibration which ECM can perform on a plug-and-play, rotating sensor calibration basis.

# Lambda Meter Product Line



In use for over 30 years in >90% of GM, Ford, and Chrysler dynamometers

# Pre-OEM and OEM Sensor Control Modules



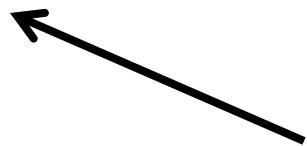
ex. NGK Spark Plug TC-6110 UEGO/Linear O<sub>2</sub> Module (ECM Product).

Tens of thousands of Pre-OEM and OEM modules distributed.

ECM has an incredible amount of in-use experience with ceramic sensors in on-road, off-road, stationary, and industrial applications.

# **ECM Measurement Modules\***

(CAN-based components of miniPEMS systems)



The “ethernet” for cars and trucks.  
A communications bus and protocol  
that allows you to easily connect  
measurement modules in a daisy-  
chain manner to build a miniPEMS.

\*you can buy these

# ECM

# Exhaust Measurement Solutions

AFR, Lambda, EGR, O<sub>2</sub>



NO<sub>x</sub>

CO<sub>2</sub>, CO

NH<sub>3</sub>



Dual-Channel  
Dashboard Display

## Particulate Matter



4x Temp

10x GPI

R<sub>h</sub>, T, P

Fast Temperature  
Measurements



# GPS and OBD (vehicle datastream)



WAAS-Enabled GPS



Data Bus Monitoring for  
Cars, Light-Duty Trucks, and  
Heavy-Duty Trucks

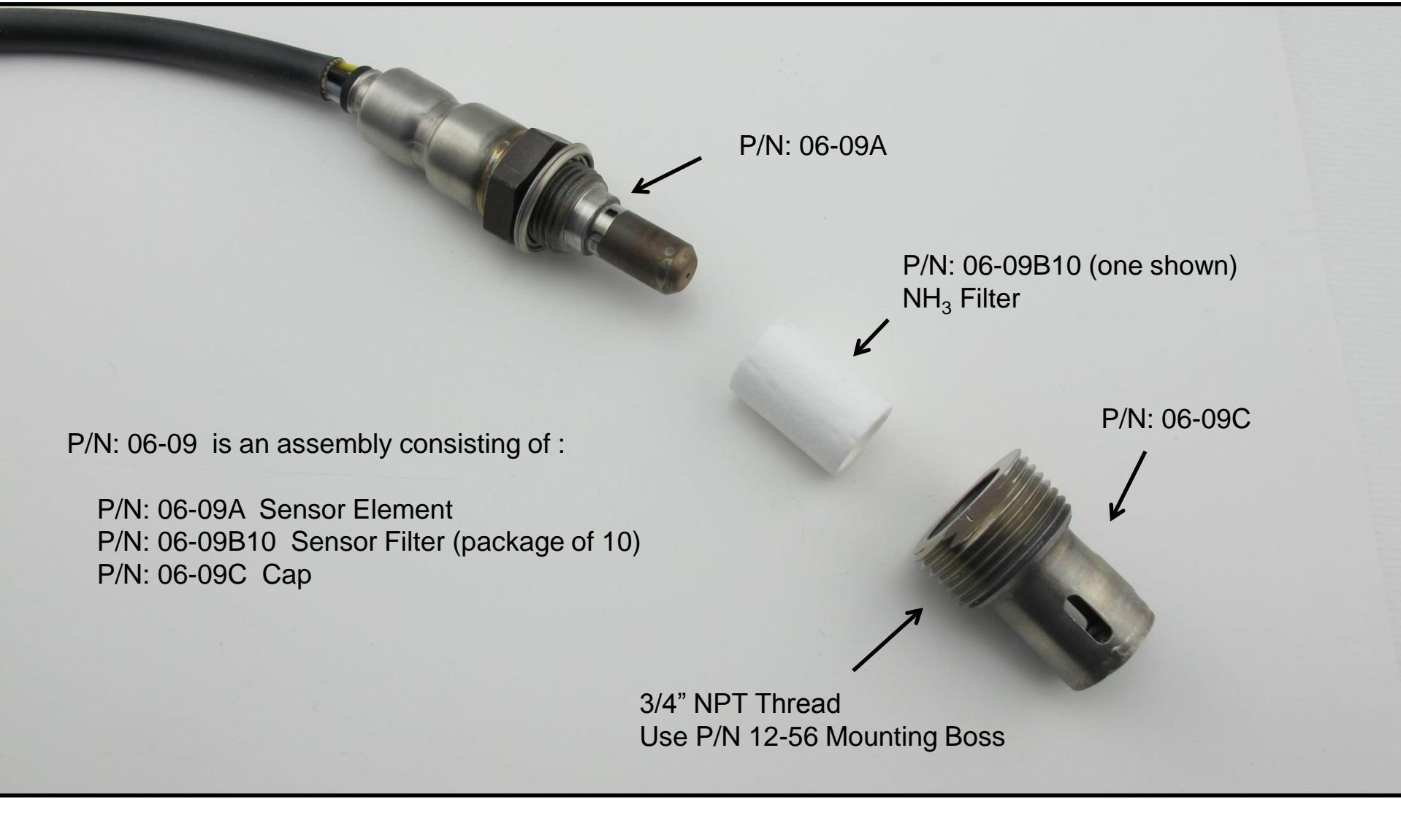
**Easily build Sophisticated Measurement Systems  
(CAN-based. Just daisy-chain the modules together.)**

This cable contains the power and CAN bus communication.



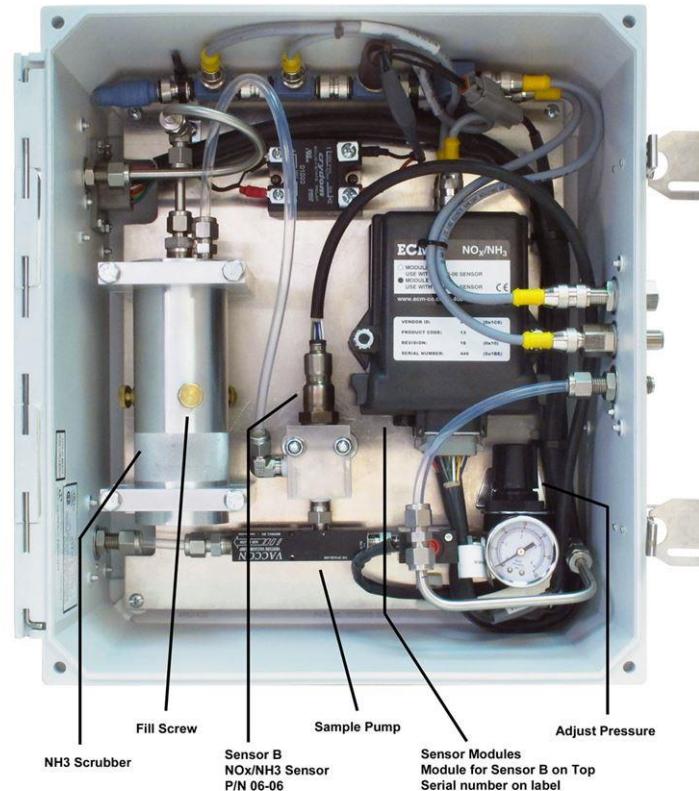
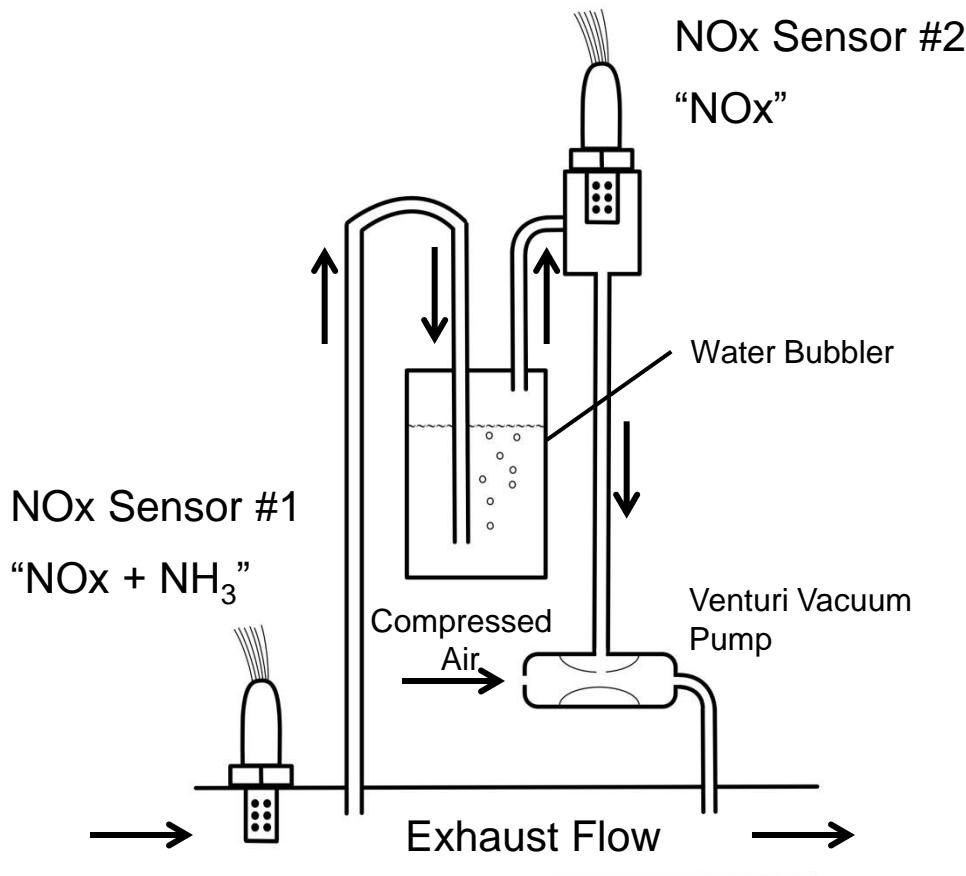
# **ECM NOx, Type F Sensor**

**(NH<sub>3</sub> Insensitive, Use with NOxCANf Controller)**



# Using Two NOx Sensors to Measure NH<sub>3</sub> and NOx in Spark Ignition Engines

$$\text{NH}_3 = (\text{NOx} + \text{NH}_3)_{\text{sensor1}} - \text{NOx}_{\text{sensor2}}$$



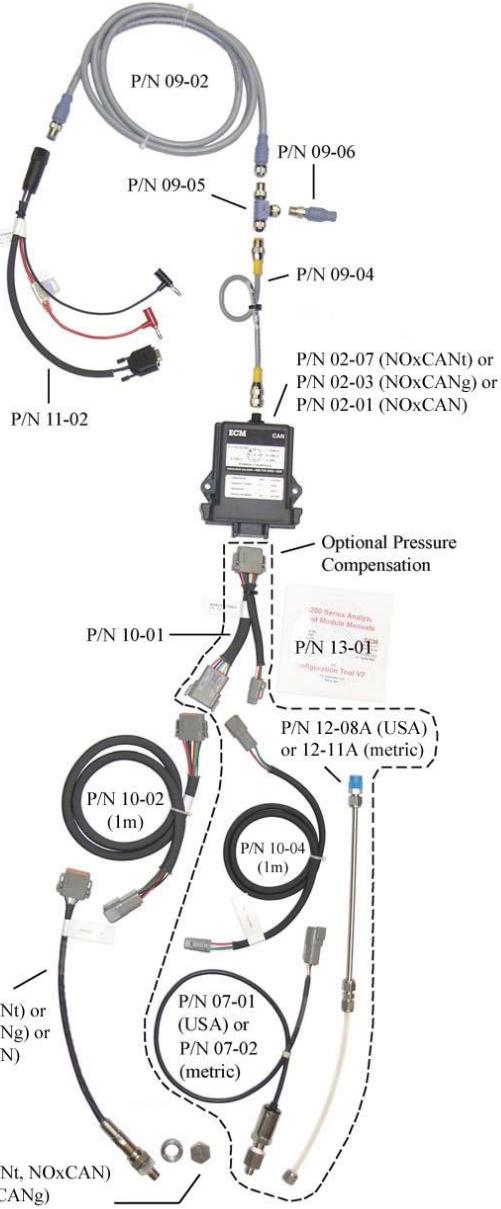
Inside of ECM NOx/NH<sub>3</sub>  
Model 5240

# ECM Particulate Sensor (PM, PN)



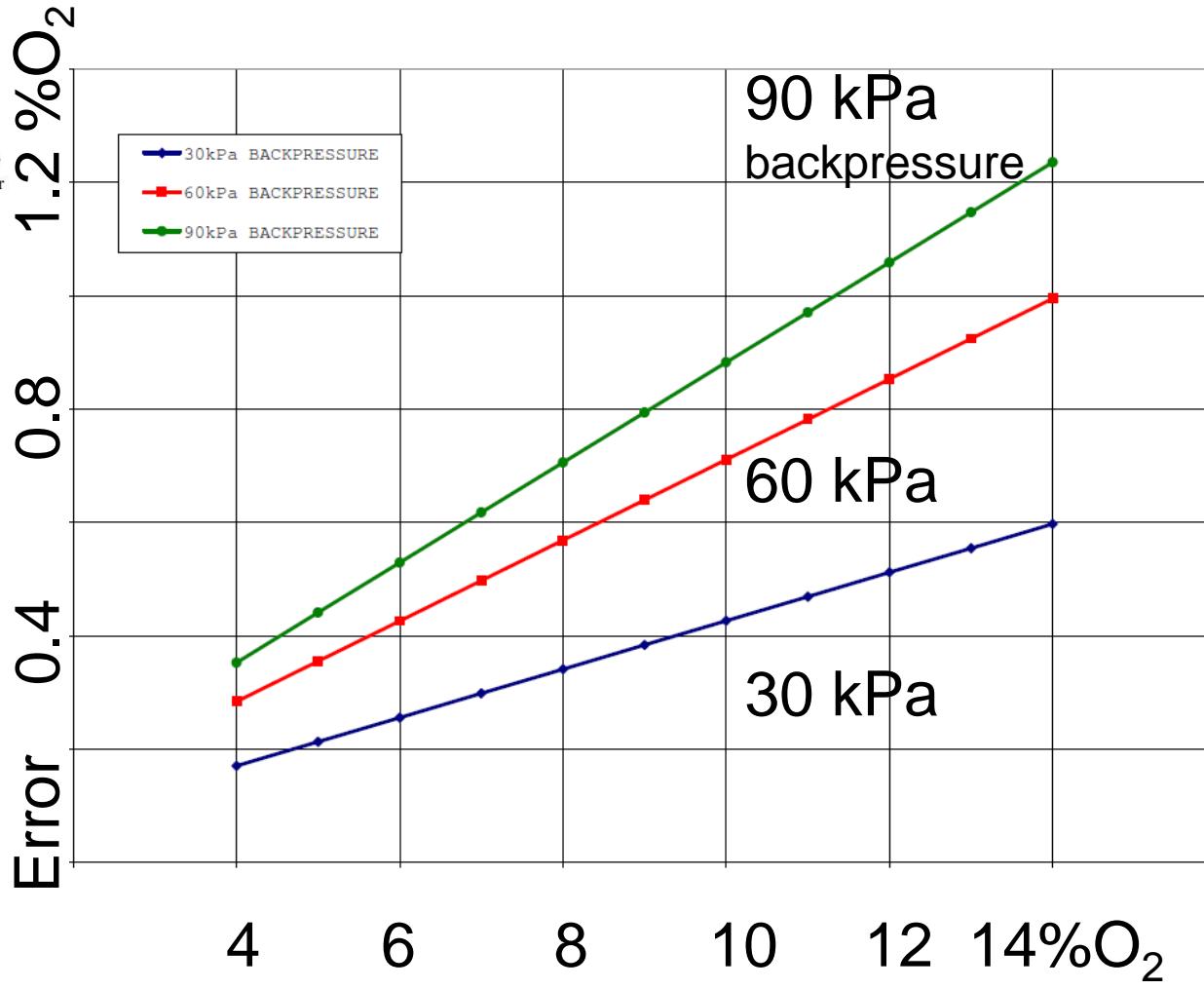
Can be disassembled for cleaning!  
In fact, that's how you recalibrate it.



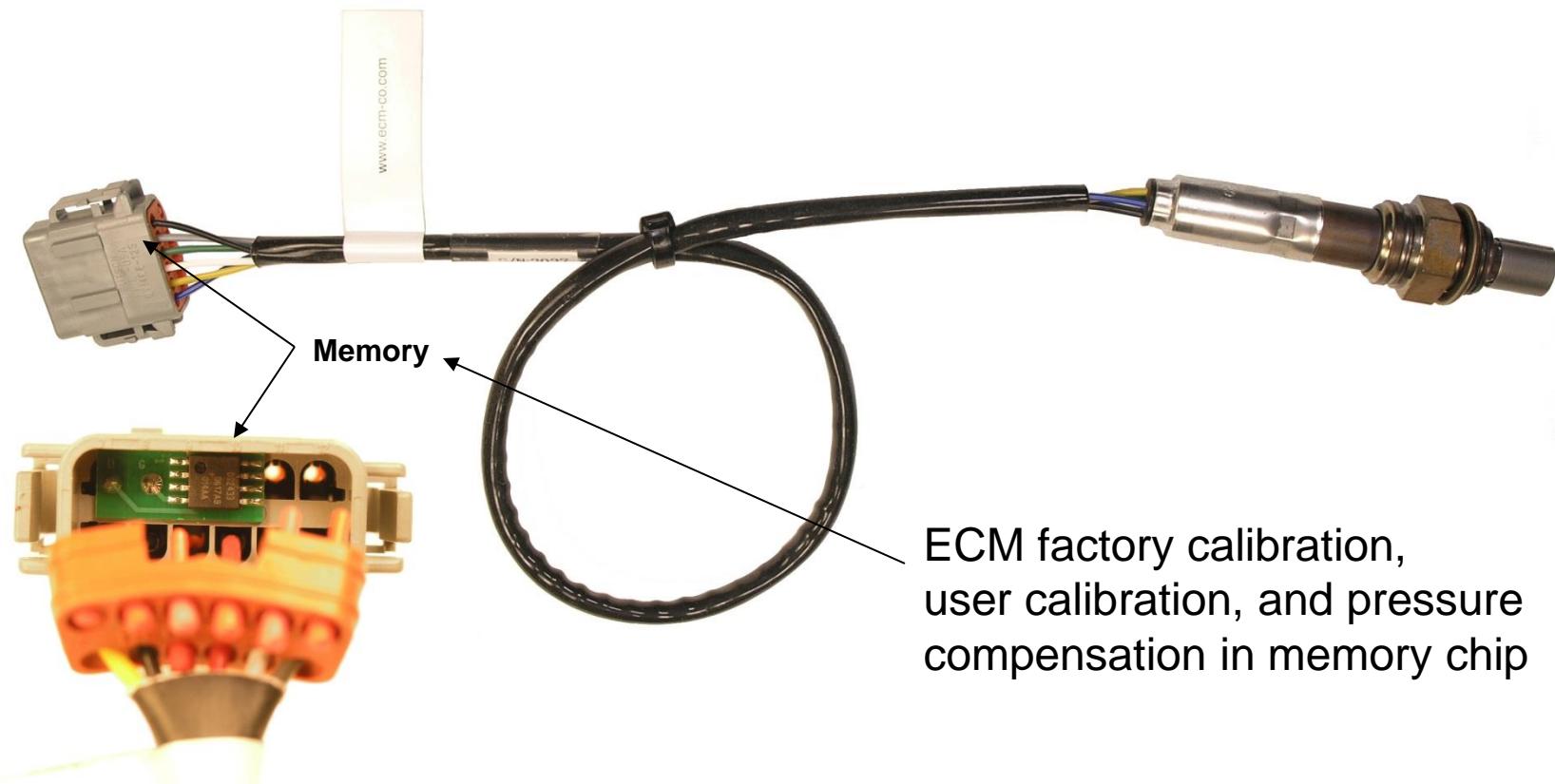


# ECM Does Pressure Compensation

(Ceramic Sensors have a Pressure Sensitivity)



# All ECM Sensors have Calibration Chip in the Sensor



- Memory chip allows calibration to be offloaded from the operator and performed in a central location (ex. ECM). Swap in a new sensor and continue testing.
- Rotating sensor recalibration (send to ECM and get before and after calibration data)



# ECM Calibration Solutions for Field Calibration



TO ECM

Report No. FE-EC-99001

Nov. 29, 1999

# Other Sensors

↑  
1999!!!

Fact:

For almost any exhaust gas component, there exists a low-cost ceramic exhaust sensor that can measure that component (ex. HC).

Unfortunately, many of them are hidden in laboratories waiting for an OEM order of 250,000 units.

[REDACTED] HC Sensor Technical Report

CONFIDENTIAL

*Shoji*  
prepared by : Sh

*Ryuji*  
checked by : Ry

*Takafumi*  
approved by : Ta

PRODUCT DEVELOPMENT DEPT.  
R & D CENTER  
[REDACTED]

# **EPA's miniPEMS**

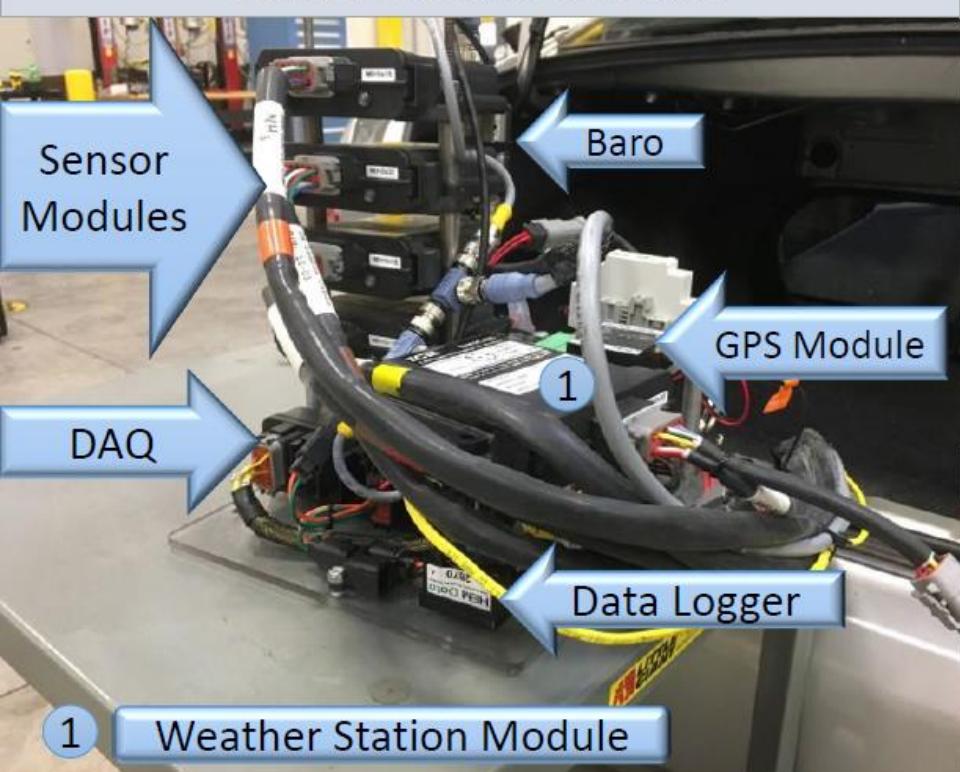
(built with ECM's measurement modules)



# Challenges in Developing and Advancing Mini-PEMS

## Measurement Setup – Sensors, Modules and DAQ\*

Sensor Modules and DAQ



2.5" LDV Tailpipe Adapter



- NOxT
- NOxF\*\*
- CO2
- NH3
- Mass Flow
- Exhaust T.

\* Complete list of components provide in Appendix A

\*\* Additional pictures of NOxF sensor in Appendix B

# Challenges in Developing and Advancing Mini-PEMS

## Future Development – Robust Packaging

Development Design



Prototype Design



Next generation prototype  
expected to be smaller

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

# **ECM miniPEMS\***

Assemblies of: Ceramic Sensor Emissions Modules

- + GPS
- + OBD (vehicle datastream)
- + Logging

\* you can buy these too

# ECM miniPEMS 1 (Motorcycles)

300mm x  
250mm x  
200mm



GPS  
Data  
OBD



Up to 4 Modules  
• Lambda, O<sub>2</sub>  
• NOx  
• NH<sub>3</sub>  
• CO, CO<sub>2</sub>  
• Exh T  
• Baro  
• V, I, DC, Freq  
• Etc

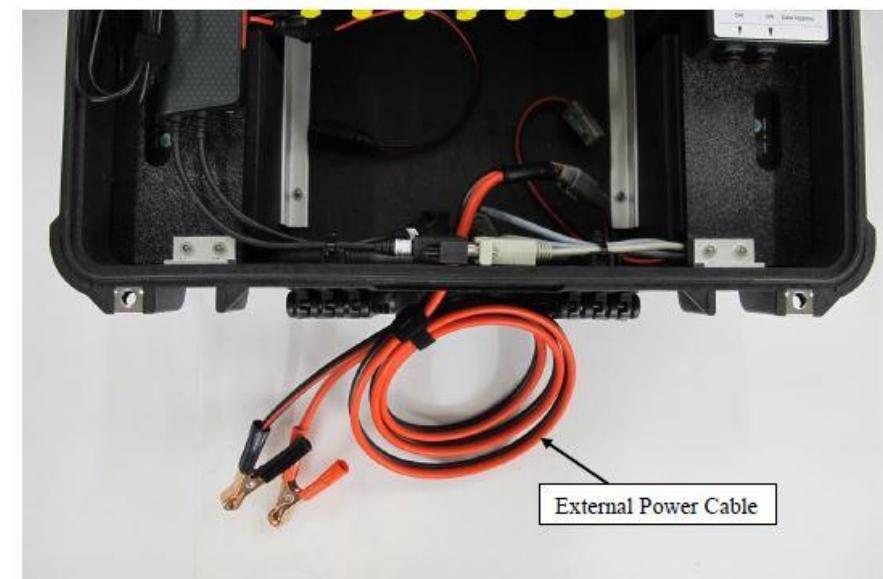
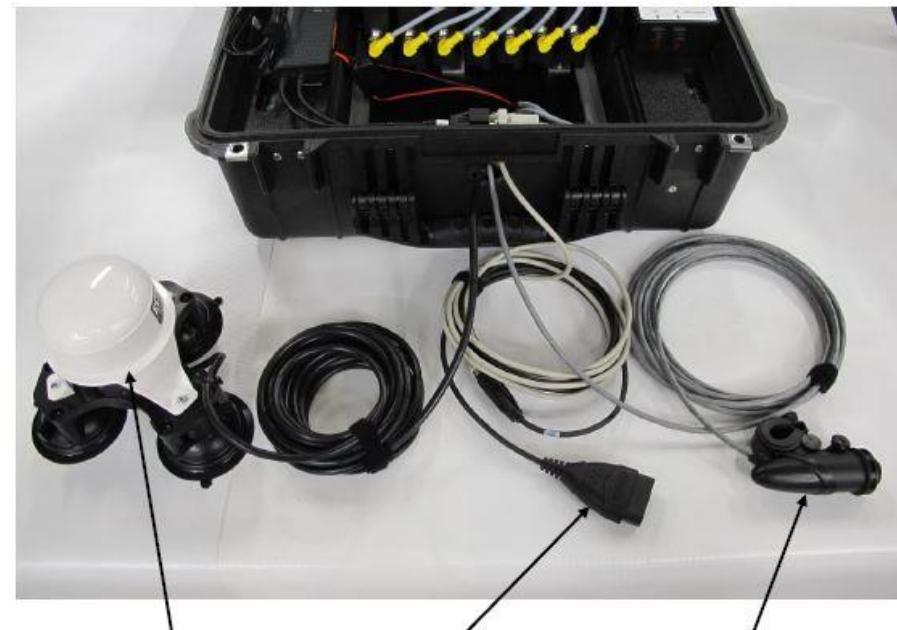
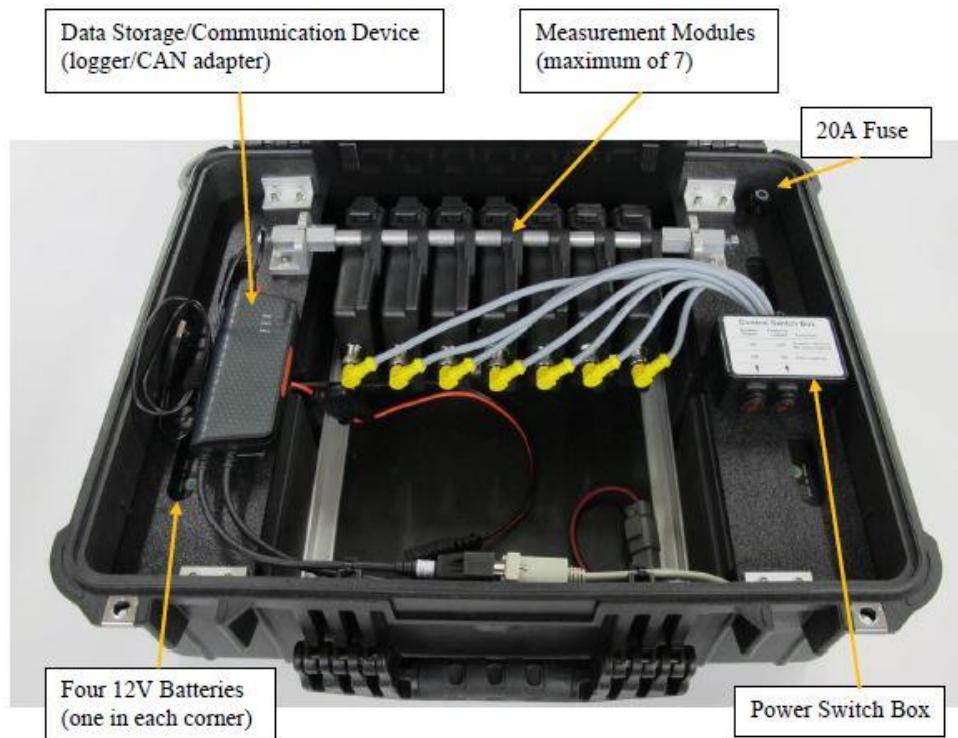
Self-Powered



# ECM miniPEMS 2 (Cars, LD & HD trucks)

530mm x  
460mm x  
230mm





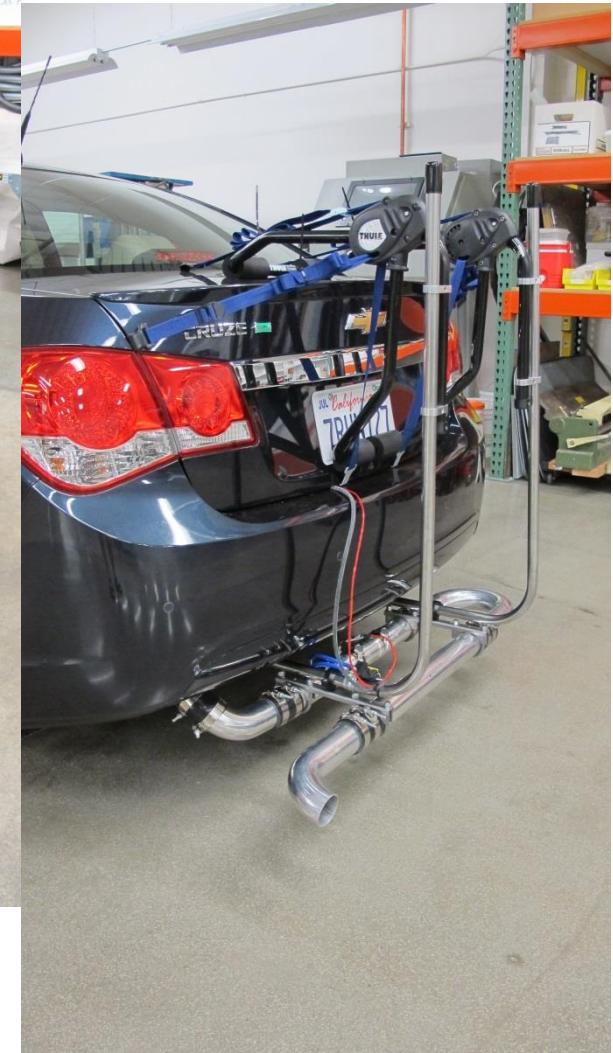
# Sensor Mounting Options



Stubby Style



1m Extended



2m Extended

# Produces Excel Files

minipems.xlsx - Microsoft Excel

File Home Insert Page Layout Formulas Data Review View Developer Load Test Team

Record Macro Use Relative References Macro Security Code Visual Basic Macros Add-Ins COM Add-Ins Insert Design Mode Run Dialog Properties View Code Source Expansion Packs Export Document Panel Modify XML Refresh Data

B1

	B	D	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH
1																															
2	Preview Chart																														
3																															
4																															
5																															
6	Date & Time (Excel forr Elapse Time (Exc NOX(ppm O2R(%)) IP2(uA) IP1(mA) VSW(V) TEMP(degC) CANopen CANopen CANopen CANopen ECM_ErrCode2 TC1(degC) TC2(degC) TC3(degC) TC4(degC) CANopen CANopen CANopen ECM_ErrCode2 Speed(m Course(d Latitude( Longitud Altitude(m	3/15/2016 20:49:01.112	0:02:03.112	8.9364	20.942	0.02553	5.99758	12.933	33.49	5	65280	129	0	0	0	28.55	11.45	0	0	5	61441	1	4	0	0	11.8782	331.135	37.4167	-121.973	-29.29	
3831	3/15/2016 20:49:01.212	0:02:03.212	8.9364	20.942	0.02553	5.99758	12.933	33.49	5	65280	129	0	0	0	28.55	11.45	0	0	5	61441	1	4	0	0	11.5202	329.428	37.4167	-121.973	-29.29		
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3844	3/15/2016 20:49:01.505	0:02:03.505	8.9364	20.942	0.02553	5.99758	12.933	33.49	5	65280	129	0	0	0	28.45	11.65	0	0	5	61441	1	4	0	0	10.6031	321.011	37.4167	-121.973	-29.02		
3845	3/15/2016 20:49:01.511	0:02:03.511	8.9364	20.942	0.02553	5.99758	12.933	33.49	5	65280	129	0	0	0	28.45	11.65	0	0	5	61441	1	4	0	0	10.6031	321.011	37.4167	-121.973	-29.02		
3846	3/15/2016 20:49:01.517	0:02:03.517	8.9364	20.942	0.02553	5.99758	12.933	33.49	5	65280	129	0	0	0	28.45	11.65	0	0	5	61441	1	4	0	0	10.6031	321.011	37.4167	-121.973	-29.02		
3847	3/15/2016 20:49:01.523	0:02:03.523	9.3426	20.942	0.02669	5.99758	12.933	33.49	5	65280	129	0	0	0	28.45	11.65	0	0	5	61441	1	4	0	0	10.4018	320.415	37.4167	-121.973	-29.02		
3848	3/15/2016 20:49:01.529	0:02:03.529	9.3426	20.942	0.02669	5.99758	12.933	33.49	5	65280	129	0	0	0	28.45	11.65	0	0	5	61441	1	4	0	0	10.4018	320.415	37.4167	-121.973	-29.02		
3849	3/15/2016 20:49:01.535	0:02:03.535	9.3426	20.942	0.02669	5.99758	12.933	33.49	5	65280	129	0	0	0	28.45	11.65	0	0	5	61441	1	4	0	0	10.4018	320.415	37.4167	-121.973	-29.02		
3850	3/15/2016 20:49:01.618	0:02:03.618	9.3426	20.942	0.02669	5.99758	12.933	33.49	5	65280	129	0	0	0	28.45	11.65	0	0	5	61441	1	4	0	0	10.4018	320.415	37.4167	-121.973	-29.02		
3851	3/15/2016 20:49:01.718	0:02:03.718	9.3426	20.942	0.02669	5.99758	12.933	33.49	5	65280	129	0	0	0	28.25	11.55	0	0	5	61441	1	4	0	0	10.2452	319.774	37.4167	-121.973	-29.02		
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3854	3/15/2016 20:49:01.858	0:02:03.858	9.3426	20.942	0.02669	5.99758	12.933	33.49	5	65280	129	0	0	0	28.25	11.55	0	0	5	61441	1	4	0	0	10.1557	314.764	37.4167	-121.973	-29.02		
3855	3/15/2016 20:49:01.918	0:02:03.918	9.3426	20.942	0.02669	5.99758	12.933	33.49	5	65280	129	0	0	0	28.25	11.55	0	0	5	61441	1	4	0	0	10.1557	314.764	37.4167	-121.973	-29.02		
3856	3/15/2016 20:49:01.991	0:02:03.991	9.3426	20.942	0.02669	5.99758	12.933	33.49	5	65280	129	0	0	0	28.25	11.55	0	0	5	61441	1	4	0	0	9.97675	311.832	37.4167	-121.973	-29.02		
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3858	3/15/2016 20:49:02.018	0:02:04.018	9.3426	20.942	0.02669	5.99758	12.933	33.49	5	65280	129	0	0	0	28.25	11.55	0	0	5	61441	1	4	0	0	9.97675	311.832	37.4167	-121.973	-29.02		
3859	3/15/2016 20:49:02.118	0:02:04.118	9.0718	20.942	0.02592	5.99758	12.933	33.49	5	65280	129	0	0	0	28.25	11.55	0	0	5	61441	1	4	0	0	9.95438	309.084	37.4167	-121.973	-29.02		
3860	3/15/2016 20:49:02.218	0:02:04.218	9.0718	20.942	0.02592	5.99758	12.933	33.49	5	65280	129	0	0	0	28.25	11.55	0	0	5	61441	1	4	0	0	9.75306	306.951	37.4167	-121.973	-29.02		
3861	3/15/2016 20:49:02.252	0:02:04.252	9.0718	20.942	0.02592	5.99758	12.933	33.49	5	65280	129	0	0	0	28.25	11.55	0	0	5	61441	1	4	0	0	10.0439	304.682	37.4167	-121.973	-29.02		
3862	3/15/2016 20:49:02.318	0:02:04.318	9.0718	20.942	0.02592	5.99758	12.933	33.49	5	65280	129	0	0	0	28.25	11.55	0	0	5	61441	1	4	0	0	10.0439	304.682	37.4167	-121.973	-29.02		
3863	3/15/2016 20:49:02.359	0:02:04.359	9.0718	20.942	0.02592	5.99758	12.933	33.49	5	65280	129	0	0	0	28.25	11.55	0	0	5	61441	1	4	0	0	9.97675	301.089	37.4167	-121.973	-29.02		
3864	3/15/2016 20:49:02.418	0:02:04.418	9.0718	20.942	0.02592	5.99758	12.933	33.49	5	65280	129	0	0	0	28.25	11.55	0	0	5	61441	1	4	0	0	9.97675	301.089	37.4167	-121.973	-29.02		
3865	3/15/2016 20:49:02.475	0:02:04.475	9.0718	20.942	0.02592	5.99758	12.933	33.49	5	65280	129	0	0	0	28.25	11.55	0	0	5	61441	1	4	0	0	9.95438	296.723	37.4167	-121.973	-29.02		
3866	3/15/2016 20:49:02.481	0:02:04.481	9.0718	20.942	0.02592	5.99758	12.933	33.49	5	65280	129	0	0	0	28.25	11.55	0	0	5	61441	1	4	0	0	9.95438	296.723	37.4167	-121.973	-29.02		
3867	3/15/2016 20:49:02.487	0:02:04.487	9.0718	20.942	0.02592	5.99758	12.933	33.49	5	65280	129	0	0	0	28.25	11.55	0	0	5	61441</											

# In my opinion...

- Although ceramic exhaust sensors can be used to build impressive, low-cost, and robust pseudo-PEMS systems, there will never be a miniPEMS system that sells for \$10,000 that can mimic a \$450,000 AVL or Horiba PEMS.
- Even if we could make a \$10,000 PEMS, the time to install, the system calibration, and the necessity of a skilled operator keeps the number of tests that we can perform in a year below what is required for a rigorous survey of the world's vehicles.
- We're looking for needles in a haystack. We need a better way.

- I see a need for a new class of approved\* test devices and procedures to find the needles in the haystack: **QBFs**  
**QBFs** (Quick Bad-vehicle Finders) are devices that can be installed, used, and removed in under 20 minutes by a non-expert. **QBFs** focus on specific failures (ex. gNOx/kWh > limit).
- For this purpose, ceramic exhaust sensors with a centralized calibration service are well-suited.
- These are potentially \$1,000/ea devices.
- Companies are required to have independent audits of their finances to be permitted to sell securities (i.e. stocks). Can there be legislated a similar requirement for independent audits of emissions that can be performed by accountants?

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\* Approved means blessed, promoted, legislated, and funded by our government agencies. Otherwise there is little incentive for shareholders to develop devices and techniques.

**QBFs**

~~**microPEMs**~~



- Quick Bad-vehicle Finders (**QBFs**)
  - specialized field testers
    - red light/green light devices,
    - “signature analysis” devices

# **EZ-PEMS: The Euro 6 NOx Tester**

## **A gNOx/kWh Threshold Indicator**

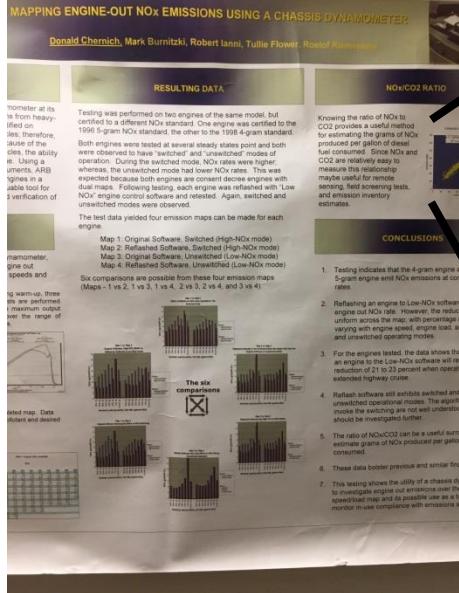
(you'll get to see it at UCR later today)



- Install one pre-calibrated sensor, drive for 10-20 minutes
- Lights indicating PASS, FAIL, and System Condition
- Self-powered via internal battery
- Optional display, OBD, and Real-time to Cloud Data Storage



# Method of Operation Based on CARB Report (that's the California Air Resources Board)



Knowing the ratio of NOx to CO2 provides a useful method for estimating the grams of NOx produced per gallon of diesel fuel consumed. Since NOx and CO2 are relatively easy to measure this relationship maybe useful for remote sensing, field screening tests, and emission inventory estimates.

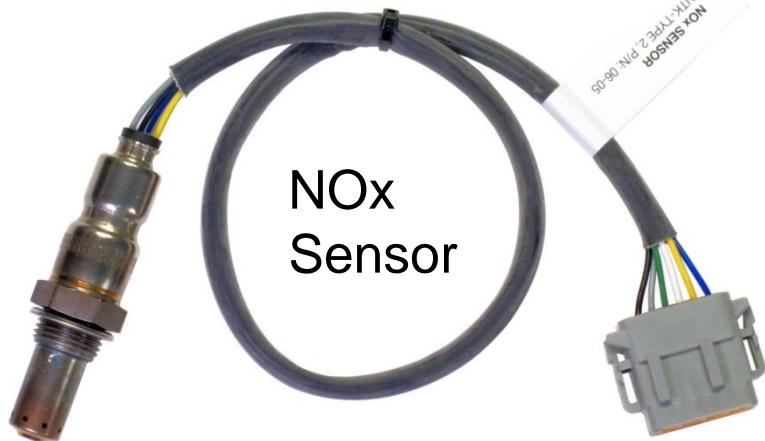
So  $(\text{NOx ppm}/\text{CO}_2 \text{ ppm})$  proportional to  $\text{gNOx/gFuel}$

## Method of Operation (continued...)

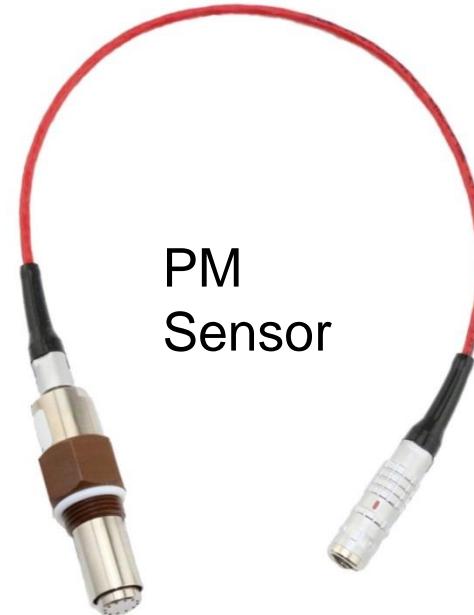
- And since HD engines typically have a BSFC of between 160-165 g/kWh during test cycles, you can modify the relationship to say:  
 $(NOx \text{ ppm}/CO_2 \text{ ppm}) \text{ proportional to } gNOx/kWh$
- Depending on the Euro (ex. Euro 6) standard and conformity factor, there is a  $gNOx/kWh$  limit.
- Our device operates by calculating an average of  $gNOx/kWh$  over a short (~4km) arbitrary test route. The instantaneous values of  $gNOx/kWh$  come from the NOx ppm and CO<sub>2</sub> ppm measurements of the NOx sensor.
- After a certain period of time, either the PASS or FAIL light activates.

\*\*\*Extensive testing in Sweden, Denmark, and Germany\*\*\*

...add another sensor and we can also do PN/kWh or gPM/kWh



NOx  
Sensor



PM  
Sensor

Gives Pass/Fail for **gNOx/kWh**  
-calibrate by sending it to us

Gives Pass/Fail for **PN/kWh** or **gPM/kWh**  
-calibrate by cleaning

\*\*\* Note that exhaust flowmeter is not required \*\*\*

...add an OBD Dongle and we can do Real-Time to Cloud  
 \*\*\* It's up and working \*\*\*



**Select Vehicle**

Vehicles

Vehicle	VIN	Trips	Number Plate	Name	Logger	Vehicle Type
354678055518984	WDD2132041A314444	21				Car

**Create Vehicle**

**Select Trip**

TRIPS

Start Time	Stop Time	Duration	Journey Length	Start Address	Stop Address	VIN	Exports	Configuration	Custom GPS Source	DTCS	Markers
4/20/2019, 9:16:49 AM	4/20/2019, 9:16:49 AM	15 min	1 km	Västra Bondegatan 1B, 271 60 Ystad, Sweden	Svarta vägen 1B, 271 60 Ystad, Sweden	WDD2132041A314444	Export as		GPS		
4/19/2019, 8:44:48 AM	4/19/2019, 11:57:58 AM	133 min	195 km	BORGÅRD 104, 305 93 Halmstad, Sweden	Svarta vägen 14, 271 60 Ystad, Sweden	WDD2132041A314444	Export as		GPS		
4/19/2019, 8:49:47 AM	4/19/2019, 2:12:02 AM	158 min	144 km	Söderleden, 431 53 Mölndal, Sweden	Eriksväg 122, 313 97 Ängel, Sweden	WDD2132041A314444	Export as		GPS		
4/18/2019, 8:49:19 AM	4/19/2019, 11:53:16 AM	17 min	13 km	Kungsbäckaleden, 428 36 Källared, Sweden	Kontrabasgatan 10, 421 50 Västra Frölunda, Sweden	WDD2132041A314444	Export as		GPS		
4/15/2019, 6:40:33 AM	4/15/2019, 8:07:19 AM	37 min	31 km	von Ullstorpsgatan 11, 411 85 Göteborg, Sweden	Bräckavägen 38, 437 42 Lindome, Sweden	WDD2132041A314444	Export as		GPS		
4/17/2019, 10:45:24 AM	4/17/2019, 11:08:04 AM	21 min	17 km	Gamla Härnösändsgatan, 428 36 Källared, Sweden	von Ulfslagsgatan 20, 415 05 Göteborg, Sweden	WDD2132041A314444	Export as		GPS		
4/17/2019, 12:33:20 PM	4/17/2019, 12:48:00 PM	9 min	1 km	Gamla Härnösändsgatan 201, 437 40 Lindome, Sweden	Bräckavägen 38, 437 42 Lindome, Sweden	WDD2132041A314444	Export as		GPS		

**View Data**

DATA

MAP

Drive Behavior: On

Graphs

NOX (CANdb)

Vehicle Speed (auto) (GPS)

SIGNALS

ERCD	NOX	RPVS	VHCM	GPS_DIR	GPS_SAT
0 bits	39.16 ppm	1560 ohms	9.25 v	113.85 deg	6
GPS_SPEED	LAT	LONG			
32.02 kph	55.43103	13.85301			

# EPA QBF Research

2020-01-0372 Published 14 Apr 2020



## Motor Vehicle Emission Control Quality Monitoring for On-Road Driving: Dynamic Signature Recognition of NO<sub>x</sub> & NH<sub>3</sub> Emissions

Xiaoguo Tang, John Kargul, and Dan McBryde US Environmental Protection Agency

2018-01-0650 Published 03 Apr 2018



## Vehicle Exhaust Emission Control-Dynamic Signature Measurement and Analysis - A Method to Detect Emission Testing Irregularities

Xiaoguo Tang, Walter Caldwell, and Dan McBryde US EPA

**A Simple Test Method to Monitor Emission Control Operating State Space (Emission Control Failure & Defeat Device Recognition)**

2016-01-2324

Published 10/17/2016

**Xiaoguo Tang and Dan McBryde**

USEPA National Vehicle Fuel/Emission Lab

**CITATION:** Tang, X. and McBryde, D., "A Simple Test Method to Monitor Emission Control Operating State Space (Emission Control Failure & Defeat Device Recognition)," SAE Technical Paper 2016-01-2324, 2016, doi:10.4271/2016-01-2324.

# Summary

1. ECM has extensive experience with ceramic exhaust sensors.
  - 34 years in the business
  - Tens of thousands of units
  - Can control all of the sensors
  - Extensive usage experience
  - Offer rotating sensor calibration service
2. Don't hold your breath for the \$10,000 AVL/Horiba-mimicking miniPEMS.
3. We have all the parts to develop low-cost **QBFs** (Quick Bad-vehicle Finders) that can be deployed in the thousands and used by non-conventional "technicians" (ex. accountants from Accenture).

Once we've identified the bad vehicles, further investigation with a real PEMS can be justified.

4. Without the USEPA and CARB actively working on and supporting QBFs, with the goal to certifying their use for legitimate and legislated applications, nothing is going to happen.
5. I see too many underfunded and understaffed projects being worked on to clean the same air. It's time we worked together and got something deployed. Otherwise, we have a “Gilligan’s Island” situation where we are pretending to get off the island but in reality, we’re just playing around.

