Equipment Miniaturization & Big Data: Meeting Global Emissions Monitoring Challenges

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PEMS State-of-the-Art:

1065 Compliant PEMS provide a stable regulatory platform, but are limited:

- *Originally developed to satisfy the 1999 USEPA HDD Consent Decree*

PEMS State-of-the-Art:

§1065.915 "PEMS instruments"

June 2005 - 40 CFR 86 Part 1065

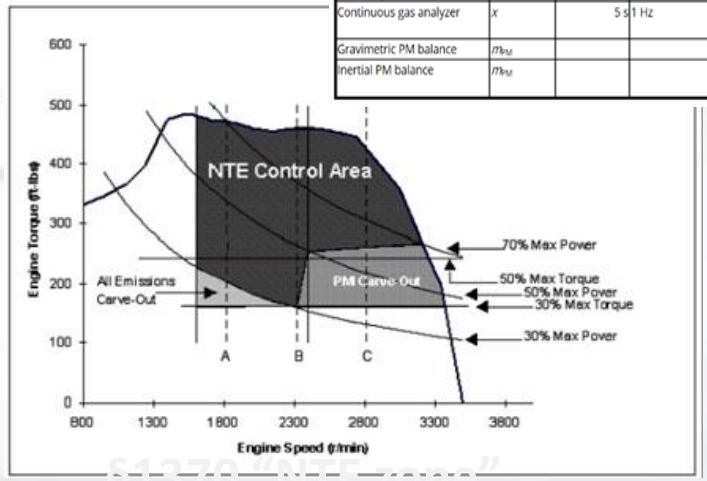
- *1999 Consent Decree 1.0 billion USD fine paved the way*
- *No 1065 "approval/certification process*
- *Method-centric*

TABLE 1 OF §1065.915—RECOMMENDED MINIMUM PEMS MEASUREMENT INSTRUMENT PERFORMANCE

Measurement	Measured quantity symbol	Rise time, t_{10-90}, and fall time, t_{90-10}	Recording update frequency	Accuracy[1]	Repeatability[1]	Noise[1]
Engine speed transducer	f_n	1 s	1 Hz means	5% of pt. or 1% of max	2% of pt. or 1% of max	0.5% of max.
Engine torque estimator, BSFC (This is a signal from an engine's ECM)	T or BSFC	1 s	1 Hz means	8% of pt. or 5% of max	2% of pt. or 1% of max	1% of max.
General pressure transducer (not a part of another instrument)	p	5 s	1 Hz	5% of pt. or 5% of max	2% of pt. or 0.5% of max	1% of max.
Atmospheric pressure meter	p_{atmos}	50 s	0.1 Hz	250 Pa	200 Pa	100 Pa.
General temperature sensor (not a part of another instrument)	T	5 s	1 Hz	1% of pt. K or 5 K	0.5% of pt. K or 2 K	0.5% of max 0.5 K.
General dewpoint sensor	T_{dew}	50 s	0.1 Hz	3 K	1 K	1 K.
Exhaust flow meter	rf	1 s	1 Hz means	5% of pt. or 3% of max	2% of pt	2% of max.
Dilution air, inlet air, exhaust, and sample flow meters	rf	1 s	1 Hz means	2.5% of pt. or 1.5% of max	1.25% of pt. or 0.75% of max	1% of max.
Continuous gas analyzer	x	5 s	1 Hz	4% of pt. or 4% of meas	2% of pt. or 2% of meas	1% of max.
Gravimetric PM balance	m_{PM}			See §1065.790	0.5 µg	
Inertial PM balance	m_{PM}			4% of pt. or 4% of meas	2% of pt. or 2% of meas	1% of max.

2007 – 40 CFR 86 Part 1370

- *"Not To Exceed" Zone standards*
- *Created by EPA and Caterpillar, Cummins, Detroit Diesel, Mack, Renault Vehicles Industriels, and Volvo Truck Corp*
- *Penalties are assessed if the NTE Zone is exceeded*



NOTE: 1065 equipment and on-road "NTE" devised for Heavy Duty Diesel (HDD) manufacturers

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PEMS State-of-the-Art:

1065 Compliant PEMS provide a stable regulatory platform, but are limited:

- *Originally developed to satisfy the 1999 USEPA HDD Consent Decree*
- *1065 Compliance PEMS traditionally based on laboratory equipment*
  1) Significant power requirements
  2) More complex; sensitivity
  3) Size – limits vehicle testing and data collection
  4) Cost – acquisition and upkeep
  5) Training requirements

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PEMS State-of-the-Art:

Limited PEMS capability hasn't helped; Ignorance is Expensive:

- *Volkswagen – Global fines now exceed $36 billion.*
- *Daimler –could be set for a massive fine in Germany over diesel fake data,...*
- *Fiat Chrysler - $800 million to settle lawsuits over allegations it used defeat devices in 100,000 vehicles.*
- *Mitsubishi Motors - in 2016, a fuel-economy ratings scandal damaged the Japanese automaker's brand, Nissan.*
- *Subaru – faulty data on fuel economy and emissions from final inspection tests.*
- *Honda - emitted six times the regulatory limit of NOx; some had 20 times the NOx.*
- *Renault, Nissan, Hyundai, Citroen, Fiat, Volvo and Jeep - Diesels significantly more NOx in more realistic driving conditions.*
- *Suzuki, Mazda, Yamaha – fuel economy and emissions checks on cars fell short of Japanese standards.*
- *Ford Motor Co. – the latest carmaker to reveal potential flaws in its exhaust testing systems.*
- *Volvo Group - $776 million charge related to an emission-control component in its heavy-duty trucks.*
- *Paccar's DAF Trucks unit, agreed to pay European Union regulators $3.23 billion in fines.*
- *Daimler - 1.14 billion dollar penalty.*
- *Cummins – $2.1 million penalty and recall 405 engines under a settlement agreement resolving alleged violations of the Clean Air Act.*

Don't use a sledgehammer to kill a fly, when a flyswatter is good enough...

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“mini” PEMS:

These mini/small next-gen devices are beginning to expand the understanding of in-use conditions by filling a complimentary role:

- *Micro PEMS” (uPEMS), “nano PEMS” (nPEMS), integrated PEMS” (iPEMS)*

3DATX parSYNC®

Global MRV Firefly

NGK “NCEM”

“mini” PEMS:

These mini/small next-gen devices are beginning to expand the understanding of in-use conditions by filling a complimentary role:

- *Micro PEMS” (uPEMS), “nano PEMS” (nPEMS), integrated PEMS” (iPEMS)*
- *Current usages*
  1) Pre-Certification (feedback prior to lab/1065 testing)
  2) Vehicle/Systems development (prototyping)
  3) Periodic Technical Inspection (PTI)
  4) Unique configurations (motorcycles, etc.)

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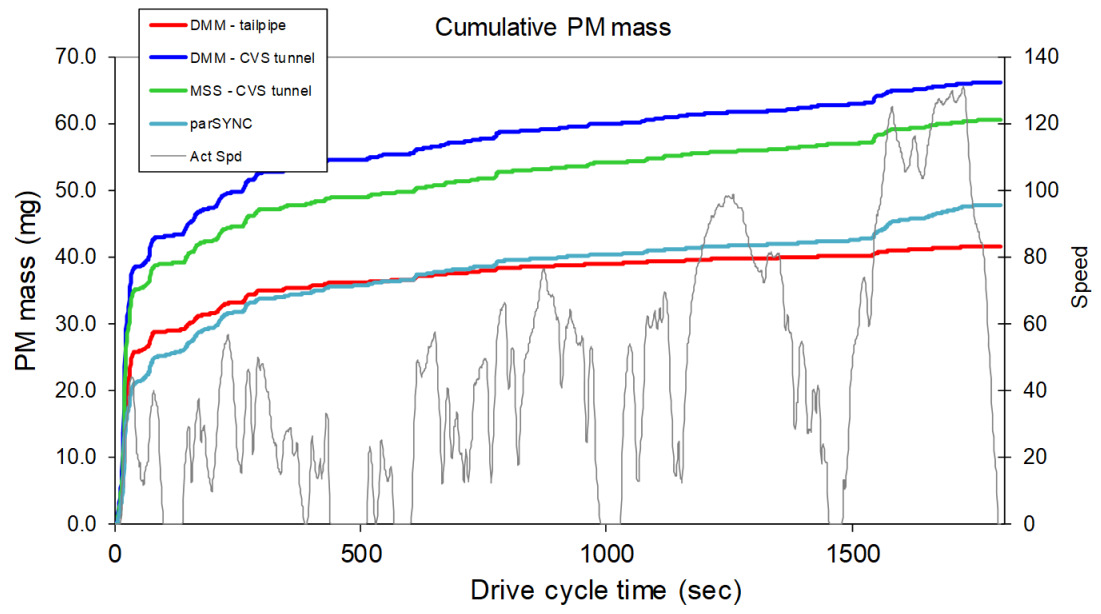
"mini" PEMS:

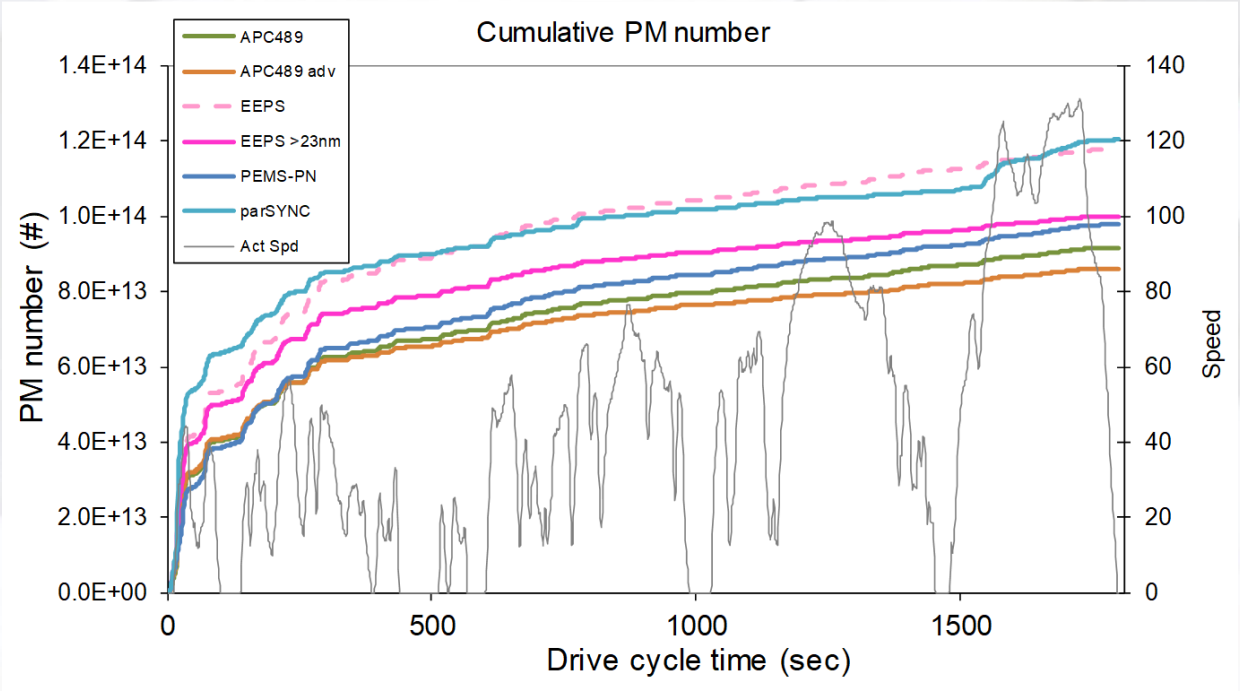
Trade-offs – when is "good enough" good enough?

Overview – PM mass
WLTP drive cycle



Note: Tailpipe DMM is unexpectedly low; should be similar to CVS MSS

Overview – solid particle number
WLTP drive cycle



parSYNC® RDE PM/PN evaluation

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Pluses and Minuses:

Regulatory PEMS vs. Mini - "non-compliant" devices

Comparison List

PEMS Type	"one-person"	Accuracy	Certification	Cost Efficiency	Large Vehicles	Small Vehicles	Airplane Travel
1065 Compliance		✔	✔		✔	✔ *	
mini/small	✔	– *			✔	✔ *	
micro/nano	✔	– *		✔	✔	✔	
integrated	✔	– *		✔	✔	✔	✔

**Dependent upon requirments and definitionss*

**Some vehicles may be precluded*

"Filling in the gaps" – the trade-offs contribute to a more complete understanding of everyday conditions

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Filling in the Gaps:

China, the EU, and the US can benefit with enhanced inventories and data-based guidance that smaller devices can provide:

- *Larger data set*
- *Faster turn-around time*
- *Increased testing throughput*

Quicker decision making and lower per-test costs =
complete information

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Opportunities:

Small and Mini iPEMS are already beginning to provide a cost-effective alternative for

- *In-use testing*
- *Enhanced (NEW) Periodic Technical Inspections (NPTI)*
- *Real Driving Emissions (RDE)*

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Opportunities: One Example

NPTI: The EU leads the way, and Germany is setting the bar:

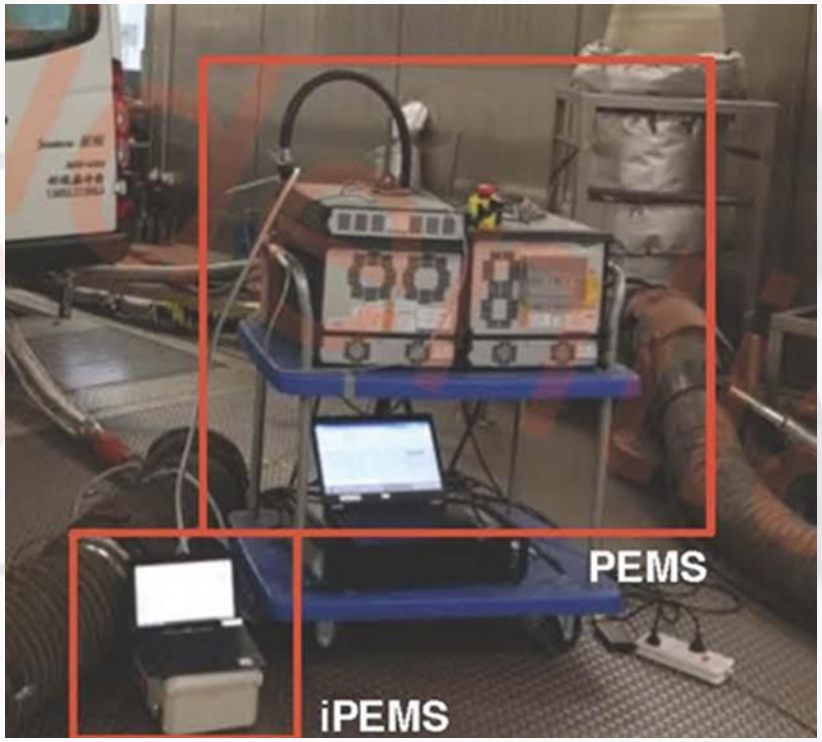
- *Particulate filters on diesel and GDI engines - increased difficulty of periodic technical inspections (PTI).*
- *Opacity/Smoke meters cannot identify particulate filter failures or tampering.*
- *10% of passenger cars equipped with diesel particulate filters (DPF) have high PN emissions (damaged/removed DPF).*
- *As of 2016, New Periodic Technical Inspection (NPTI) include particle number (PN); supported by the EU, Germany, the Netherlands, Belgium, and Switzerland. Programs are already being adopted**
- *In 2017, the German Federal Council reintroduced PTI tailpipe emission tests**
    1) Gaseous pollutants - January 2018
    2) PN measurements - no later than January 2021
    3) NPTI – applied to non-road mobile machinery (NRMM) EU Stage V emission standards
    4) Includes PN emission limits for multiple engine categories

*German publication StVZO 2017

Vision-Casting:

Continued reduction in size will contribute to

- *Built-in high-resolution vehicle sensors*
- *Drone advancements*
- *Improved Big Data – automated, "AI" decision-making, streamlined traffic systems*



"Fossil Fuels" are here for a while longer (25 – 50 years) so we must continue to improve efficiency!

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Vision-Casting:

- *Harmonized Global Standards (RDE, MOVES, etc.) and Sustainability*
- *Big Data - evaluation services*
- *Level Playing Field Development (fuels, roadways, driver education, engines, etc.)*
- *Integrated telematics (further assimilation of sensors and software into the vehicle)*
- *Carbon standard metrics (external and independent measurement tool)*

Special thanks to:

Ford Motor Company – Vehicle Emissions Research Laboratory, Research and Advanced Engineering, *Diep Vu, Joseph Szente, Matti Maricq*

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Dekra – *Thomas Ost, Technical Director*

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Any Questions?

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