Challenges for PEMS under RDE Regulations

Dr David Booker, Sensors Inc.

CECERT PEMS Conference March, 2016

ClearSkies News

sensors

March 2016 Edition

The New European RDE Program Expected to add Particle Number in 2016

On October 28, 2015, the European Commission's (EC) Member States agreed to more robust testing of passenger car emissions in Europe. Beginning September 1, 2017, these will include new Real Driving Emissions (RDE) analysis which will be used in conjunction with the new WLTC test cycle to determine whether new model cars are allowed to be sold in the EU. Moreover, in the next few years, it is very likely that additional work packages will be added to augment the current RDE testing requirements. These may include the introduction of RDE particle number (PN), cold start and in-service conformity testing / limits.

To support the RDE PN program, the EC Joint Research Centre recently completed an inter-laboratory PN measurement campaign involving eight European laboratories, using both Condensation Particle Counters (CPC) and Diffusion Charger on Portable Emissions Measurement Systems (PEMS) with a golden vehicle (Figure 1) and a reference Particle Measurement Program (PMP Regulation 49 and 83) compliant PN device.

The results, to be published later this year, are expected to confirm their suitability and performance for their inclusion into the RDE regulation (Figure 2). The corresponding EC technical expert group charged with drafting the regulation has reached general agreement on most of the pertinent areas.

Figure 1

Gasoline GDI Vehicle, WLTP CYCLE

SEMTECH CPN #/cm3

AVL 489 p/ccm

Integrated Results

17% descrepancy

Newsletter Archive (PDF)

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March 201

Introduction

- Background to the EU Legal Process
- State of the Play with the RDE Program
- Challenges for PEMS
  - Gaseous
  - PN

Comitology in the EU

Comitology in the EU references a process by which the EU law is modified or adjusted and takes place within "comitology committees" that assist in the making, adoption, and implementation of EU laws. Broadly speaking, before it can implement an EU legal act, the Commission must consult, for the detailed implementing measures it proposes, a committee where every EU country is represented. For example, the Technical Committee Motor Vehicles (TCMV) committee. In addition "Expert Groups" are formed to develop the scope, legal text and "tools" (eg EMROAD / CLEAR).

Regulation (*EC*) 715/2007

Five Key Reasons behind Comitology

RDE - TCMV 2015

On 19th May 2015, the 1st package (testing procedures) and on 28 October 2015, (conformity factors) the TCMV voted / passed the implementing measures to introduce Real Driving Emission (RDE) tests for emissions from light duty vehicles, under the framework of Regulation (EC) No 715/2007.1 with a clear majority 28 EU Member States (only the Netherlands opposed the 2nd package).

Conformity Factor 2.1 (2017) > 1.5 (2020)

$$NTE_{pollutant} = CF_{pollutant} \; x \; \text{EURO-6,}$$

	Commission proposal		TCMV opinion	
	Timetable	Conformity Factor	Timetable	Conformity Factor
First stage	1 Sept. 2017 (new models) 1 Sept. 2018 (new vehicles)	1.6 (128 mg/km)	1 Sept. 2017 (new models) 1 Sept. 2019 (new vehicles)	2.1 (168 mg/km)
Second stage	1 Jan. 2019 (new models) 1 Jan. 2020 (new vehicles)	1.2 (96 mg/km)	1 Jan. 2020 (new models) 1 Jan. 2021 (new vehicles)	1.5 (120 mg/km)

?

Client Earth, 2015

ACEA Proposed CF of 1.7!

What Happened in the EP

businessGreen

News In-depth Opinion Energy Policy Manag...

Politics

EU accused of watering down diesel emissions limits

Madeleine Cuff
29 October 2015

EU experts support doubling of legal limit of nitrogen oxide emissions allowed under Euro VI, as MEPs approve new air pollution targets

The European Union attracted both praise and criticism from green groups yesterday, after passing legislation for new 2030 air quality limits while simultaneously taking steps to relax legal limits for diesel car emissions.

A technical meeting of transport officials from member states yesterday passed a proposal from the European Commission to set weaker nitrogen oxide emissions for diesel cars undergoing "real world" driving emissions tests (RDE).

RELATED ARTICLES

...opean Parliament backs diesel ...hat will allow cars to exceed ...pollution limits

...ds sales of thousands ..., as industry begins

...any lobbied ...ests,

The panel decided to back draft regulations that allow diesel cars to emit twice the official 80mg per km limit agreed under Euro VI from 2017, to help carmakers prepare for transition to the new RDE tests, which begin the same year.

In addition, the new tests will not apply to all new cars until after 201... and from 2021 new cars will permanently be allowed to emit 50 pe... cent more NOx than the original Euro VI limit.

The change in the draft regulation follows the **Volkswagen emissions scandal**, which saw the German...

The European Parliament has the power to oppose the implementing measures adopted by the Commission, if they exceed the implementing powers granted by the EU legislature or are not compatible with the aim or the content of the Euro 6 Regulation.

...ackground notes | Weekly agenda | Plenary sessions

Environment MEPs oppose relaxing diesel car emission test limits

ENVI Press release - Environment − 14-12-2015 - 20:27

A draft decision to raise diesel car emission limits for nitrogen oxides (NOx) by up to 110%, along with the introduction of the long-awaited Real Driving Emissions (RDE) test procedure, is neither explained nor justified, and would undermine the enforcement of existing EU standards, said Environment Committee MEPs, in a resolution, voted on Monday, which objects to the draft. Parliament has a right to veto the proposal.

40 Votes For, 9 Against, 13 absentions

...w RDE procedure is designed to allow for a more realistic testi... ...rforming the test on the road. The curre... ...e exploited by carmak...

After TCMV voted in October 2015 the Opposition Stated to gain momentum.

The EP Vote

2nd February 2016
For: 323
Against: 317

Most of the Socialist EU Parliamentarians wanted to reject the Commissions Proposal. If they had succeeded the EC would have had 3 choices:

- Go back to TCMV (unlikely)
- Legally challenge the EP (very unlikely), or
- Implement the regulation in Euro VII

All could have resulted in a 3-5 year delay!

Centre-right EU parliamentarians sided with the European Commission and narrowly pushed back an attempt by their leftist and liberal colleagues who wanted to force the Executive to come up with a different law on diesel car emissions.

The Commission proposed to **temporarily raise diesel car emission limits** by up to 110% as part of a package to introduce the **Real Driving Emissions (RDE)** test procedure. The leftist Members objected, arguing that the plans to relax the limits would weaken the enforcement of existing EU standards.

The camp that opposed the Commission's move. made up by the Socialists, Greens/EFA, radical-left GUE-NGL and most of the liberal ALDE Members gathered only 317 votes, which is 6 votes less than those rallied by the EPP and ECR groups who backed the Executive's initiative. Interestingly, the 3 MEPs coming from President Juncker's Christian Social Party of Luxembourg sided with the left, against their EPP group line (and against the Commission's proposal).

On the other hand, nationalist MEPs from the far-right group of Marine Le Pen and the UKIP members backed Commission's proposal.

Most of the Socialist EU Parliamentarians wanted to reject the Commission's proposal. However, the group was split, with nearly 30 MEPs, mainly from the Czech and Spanish delegations, abstaining, while the Polish, Slovakian and the majority of Romanian Members even voting against. The Liberal group was also divided, with the majority in favour of the objection, while 20 ALDE Members from the Czech, German, Spanish, and French delegations opposed. The Greens and the Radical-left MEPs were all in favour of vetoing the Commission proposal.

EC Major Concessions:

- European Commission agreed to review the Conformity Factors on an annual basis. Any revisions would be enforceable 4 years later
  - Expert Group (First meeting Feb 2016)
- European Commissioner speech to Parliament states that aim is to have cars designed to meet a CF of 1.0 by 2023

What's Next

European Commission

2nd package: Completes gaseous RDE

- Dates and application of NTE (Not-To-Exceed) limits
  - NTE = EURO6 x CF x TF
- Conformity Factors (CF) (not yet approved)
  - NOx Step 1 (2017/8+1): 2.1 → optimization with software existing Euro 6
  - NOx Step 2 (2019/20): 1.5 → Air Quality legislation (Development of hardware might be necessary)
- Transfer Function (TF)
  - Factor that depends on the probability of having specific road conditions
- Error analysis (measurement equipment, trip variations)
- Complementary Dynamic Boundary Conditions
  - Acceleration x speed
  - Relative positive acceleration
  - Positive elevation gain

Joint Research Centre

74

3rd Package: Complete PN RDE

- PN-PEMS procedure and error analysis (Oct 2015)
- Use of PN-PEMS or Random Cycle (Nov 2015)
- Conformity Factors (CF) (Dec 2015)
  - PN Step 1 (2017/8) → Instrument measurement uncertainty + maturity
  - PN Step 2 (2019/20) → Best available technology (+instrument uncertainty)

3rd Package: Cold start (?)

4th Package: In-Service Compliance

- Administrative rules (March 2016)
- Technical rules (Oct 2016)

ANNEX

to the

Commission Regulation

amending Regulation (EC) No 692/2008 as regards emissions from light passenger and commercial vehicles (Euro 6)

Permissible tolerances

Parameter [Unit]	Permissible tolerance
CO [mg/km]	± 150 mg/km or 15% of the laboratory reference, whichever is larger
CO_2 [g/km]	± 10 g/km or 10% of the laboratory reference, whichever is larger
NO_x [mg/km]	± 15 mg/km or 15% of the laboratory reference, whichever is larger

Permissible analyser drift over a PEMS test

Pollutant	Zero response drift	Span response drift [(1)]
CO_2	≤2000 ppm per test	≤2% of reading or ≤2000 ppm per test, whichever is larger
CO	≤75 ppm per test	≤2% of reading or ≤75 ppm, per test, whichever is larger
NO_2	≤5 ppm per test	≤2% of reading or ≤5 ppm per test, whichever is larger
NO/NO_X	≤5 ppm per test	≤2% or reading or ≤5 ppm per test, whichever is larger

NDUV NOX (NO +NO2)Error Question - 5+5 or 10ppm
CLD NOX <5ppm

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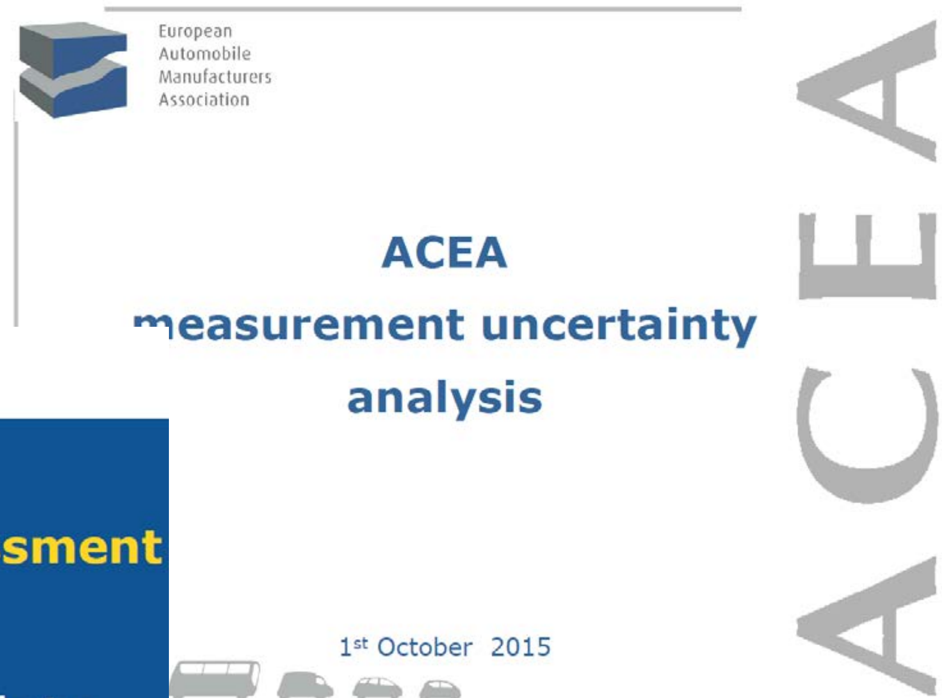
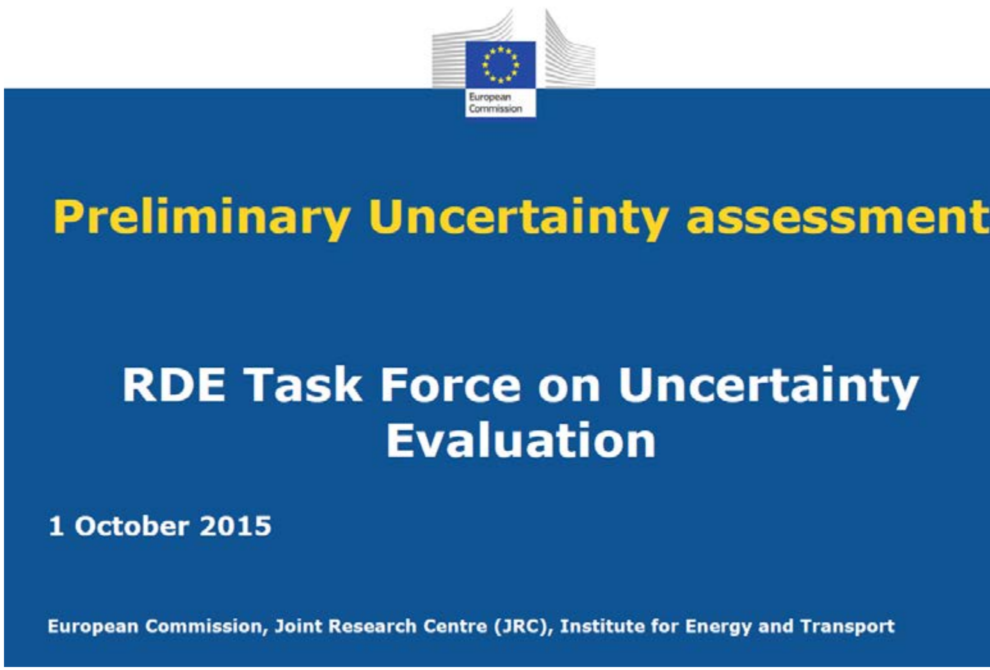
PEMS Measurement Uncertainty

ACEA and JRC Analysis for Gaseous Measurements ONLY to date.

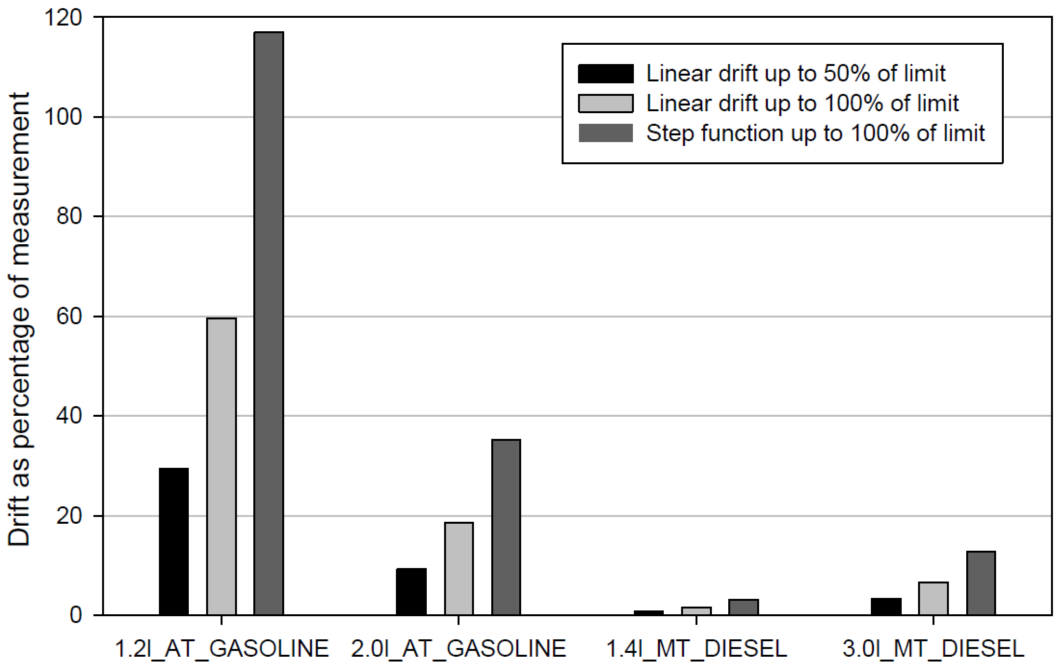




Drift (No drift Correction Allowed)

Analyzer drift

European Commission



Case-Scenario (NOx)

		1.4l Diesel (EU5)	3l Diesel (EU6)
Measured Value:	mg/km	848,3	423,8
Emission Limit	mg/km	180	80
Absolute Drift	mg/km	6,7	14
Absolute Drift	mg/km	13,4	28
Absolute Drift	mg/km	26	54,3
Considering Diesel Limit		8%	18%
		17%	35%
		33%	68%
Since Drift is technology and limit independent			
Considering Gasoline Limit		11%	23%
		22%	47%
		43%	91%

➔ 1 StdDev approx. up to 80% of limit for large engines.

10-60mg/km (depending on Engine)

Source: JRC

Time Alignment

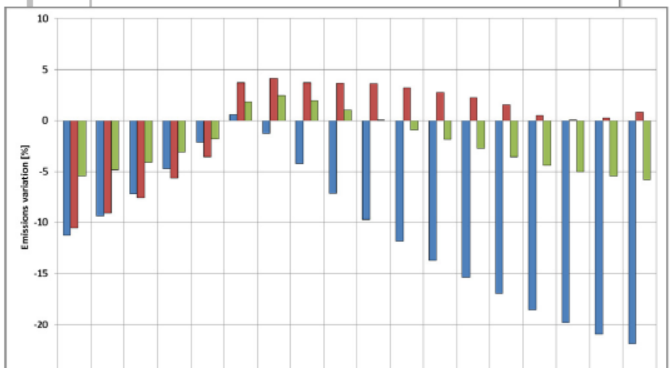
Time Alignment (only NOx)

Real Time Alignment Experience (ACEA-Member, Gasoline)	-2s	-1s	0s	+1s	+2s	Max. relative Error
Test 1	-6,0%	-3,5%	0,0%	3,0%	4,3%	**4,3%**
Test 2	-11,3%	-3,3%	0,0%	0,3%	0,2%	**0,3%**
Test 3	8,3%	5,6%	0,0%	-6,1%	-12,2%	**8,3%**

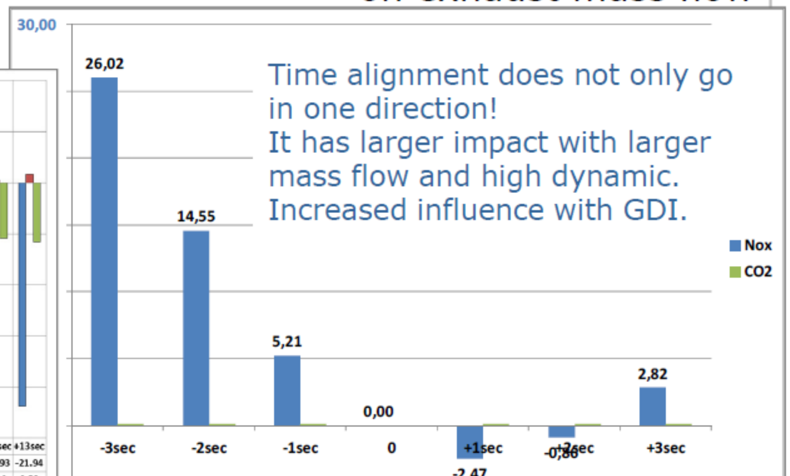
Within the reasonable range of +/-2s
➔ 1 StdDev. 10-15%

8-12 mg/km*
*mg/km depending on exhaust mass flow

Example (Source: JRC)
Was the „drafted method" applied correctly?



	-5sec	-4sec	-3sec	-2sec	-1sec	+1sec	+2sec	+3sec	+4ec	+5sec	+6sec	+7sec	+8sec	+9sec	+10sec	+11sec	+12sec	+13sec
NOx	-11.25	-9.35	-7.20	-4.73	-2.15	0.58	-1.24	-4.22	-7.19	-9.71	-11.84	-13.72	-15.40	-17.00	-18.53	-19.80	-20.93	-21.94
CO	-10.55	-9.08	-7.57	-5.65	-3.59	3.74	4.10	3.73	3.68	3.64	3.22	2.72	2.28	1.53	0.48	0.03	0.24	0.82
CO2	-5.42	-4.85	-4.10	-3.11	-1.81	1.84	2.49	1.96	1.04	0.04	-0.94	-1.85	-2.71	-3.57	-4.39	-4.99	-5.42	-5.82



Real Time Alignment Experience (Source: ACEA-Member)

Exhaust Flow Measurement

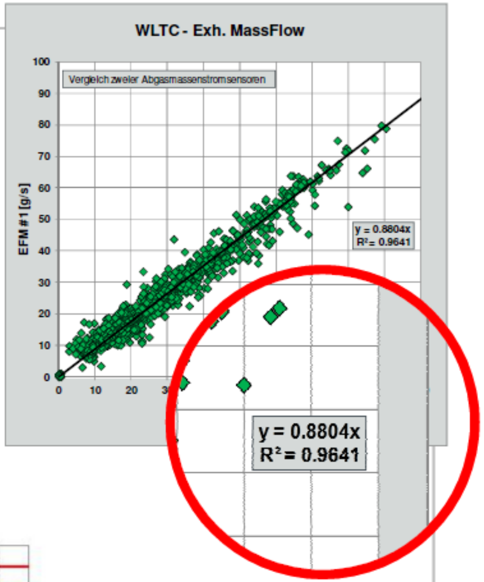
Mass Flow Measurement

ACEA measurement uncertainty analysis

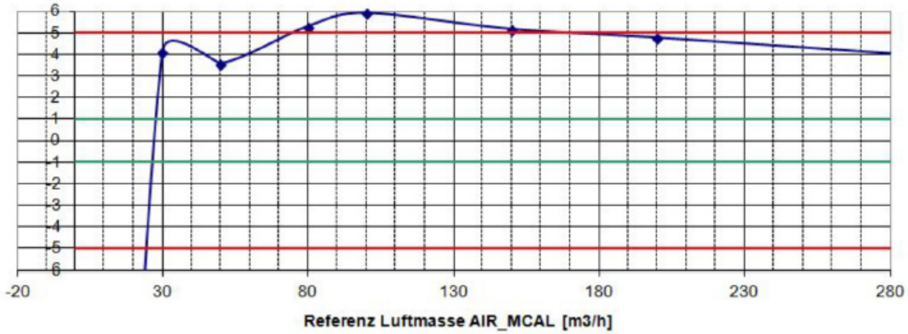
Observed Errors within reasonable range:
➔ 1 StdDev. 10-15% 8-12 mg/km

Also observed: >70% of tests overestimation of CVS-mass flow

EFM vs. EFM (Audi)



mg/km depending on exhaust mass flow



Example:
Checked Exhaust-Flow-Meter right after Manufacturer's Calibration
(Provided by Partner of ACEA-Member)

Other Errors

Unaccounted Errors

ACEA measurement uncertainty analysis

- **Pressure compensation of equipment**
- **Additional Weight / Aerodynamics / CO2-Contribution**
- **Measuring Differences between 2 different PEMS**
- **Natural Humidity Influence (not corrected)**
- **Cross-Sensitivity NOx/CO, NOx/CO2**
- **Difference T90-Responses of Systems**

8-12 mg/km

Estimation
1 StdDev. 10-15%

Although humidity influence will not be corrected, it has to be taken into account for CF-definition as a measurement uncertainty.

CF ACEA (1.7), EC 1.6 (2017) > 1.2 (2020). Current Regulation 2.1 > 1.5

(1) Measurement uncertainty in detail

European Commission

Compounding PEMS measurement errors

Exhaust mass flow rate [kg/s]: 4% overall uncertainty of instantaneous measurements
- Considering only measurements with exhaust flow meters and disregarding requirements for air and fuel flow rate
- Assuming that linearity and accuracy on the one hand and precision and noise on the other hand are equivalent to each other; the parameter with the lowest uncertainty (i.e, 2% and 1% respectively) determined the permissible uncertainty margin
- Assuming that precision and noise are implicitly verified when determining linearity and accuracy

Component concentration [ppm]: 8% overall uncertainty of instantaneous measurements
- Assuming that linearity and accuracy on the one hand and precision and noise on the other hand are equivalent to each other; the parameter with the lowest uncertainty (i.e, 1% respectively) determined the permissible uncertainty margin
- Assuming that precision and noise are implicitly verified when determining linearity and accuracy
- Assuming an over-all uncertainty of 2% related to the item 'additional requirements'
- Assuming a maximum of 1% uncertainty related to leakage
- Assuming that the drift requirements for the actual on-road test are relevant; it is permissible to zero the analyzer prior to verifying the span drift; the drift-related uncertainty is analyzer dependent but may amount to 4% uncertainty

u values: small and potentially negligible

Component mass emissions [g/s]: 9% overall uncertainty
- Disregarding errors from misalignment of signals

Vehicle speed [km/h]: 4%

Instantaneous distance-specific emissions [g/km]: 10% overall uncertainty
- Disregarding errors from misalignment of signals and analyzer drift

Summary

	Error margin (1 std. Dev) (%)	Total Mass (mg/km)
on lab (1)	19	15
on lab (2)	60	50
on lab (3)	25 to 40	20 to 30
a	20 to 80	10 to 60
	10 to 15	8 to 10
	10 to 15	8 to 10
	4	
	10 to 15	8 to 10
	%	mg/km
	33	23
	60	43
	86	64

ING: $\Delta P = \sqrt{(\Delta a)^2 + (\Delta b)^2}$

CF min	1,3
CF average value	1,6
CF max	1,9
ACEA proposal	1,7

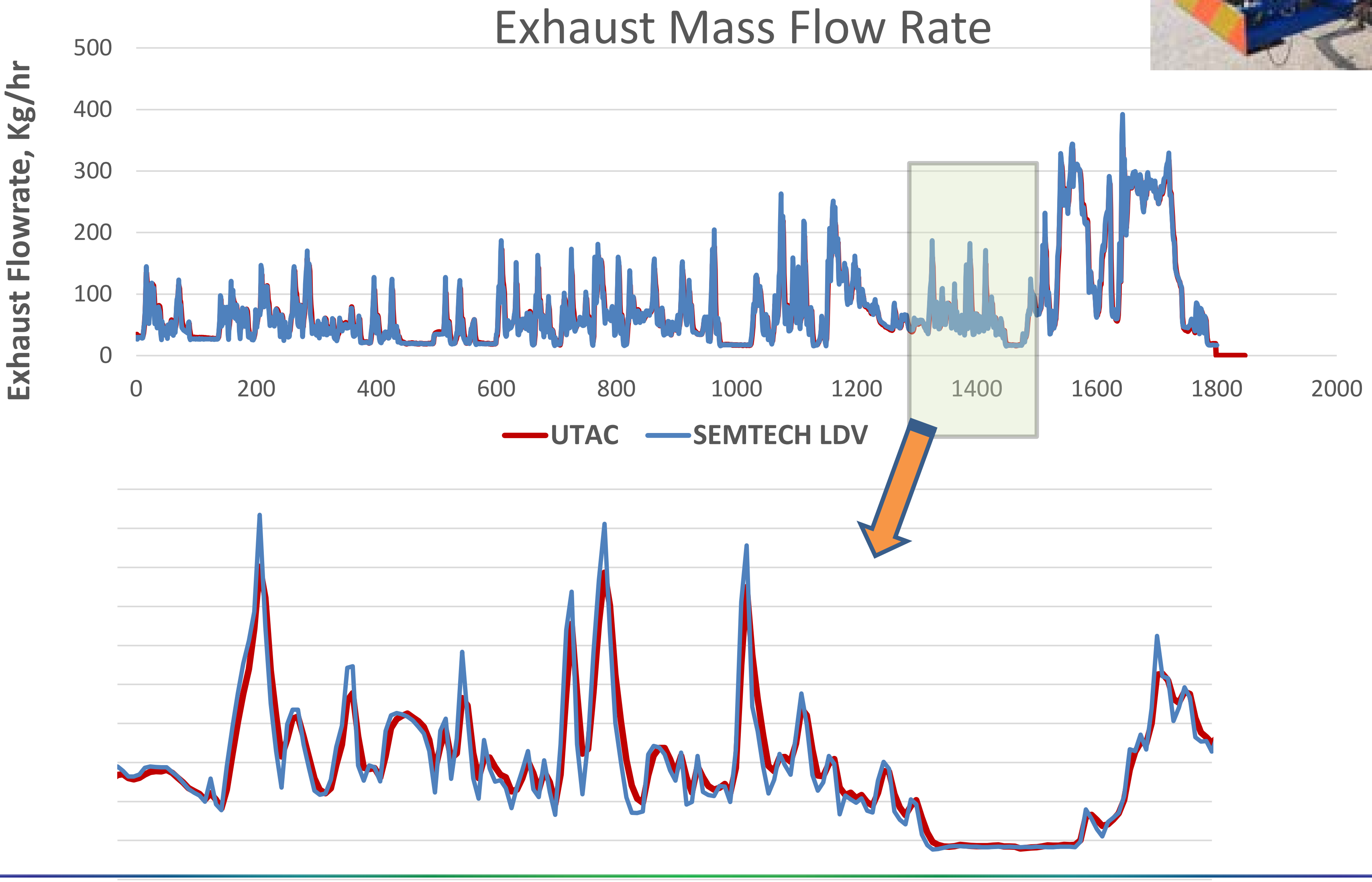
(1) Allowed tolerance during validation@ WLTC // (2, 3) @ other cycles

14

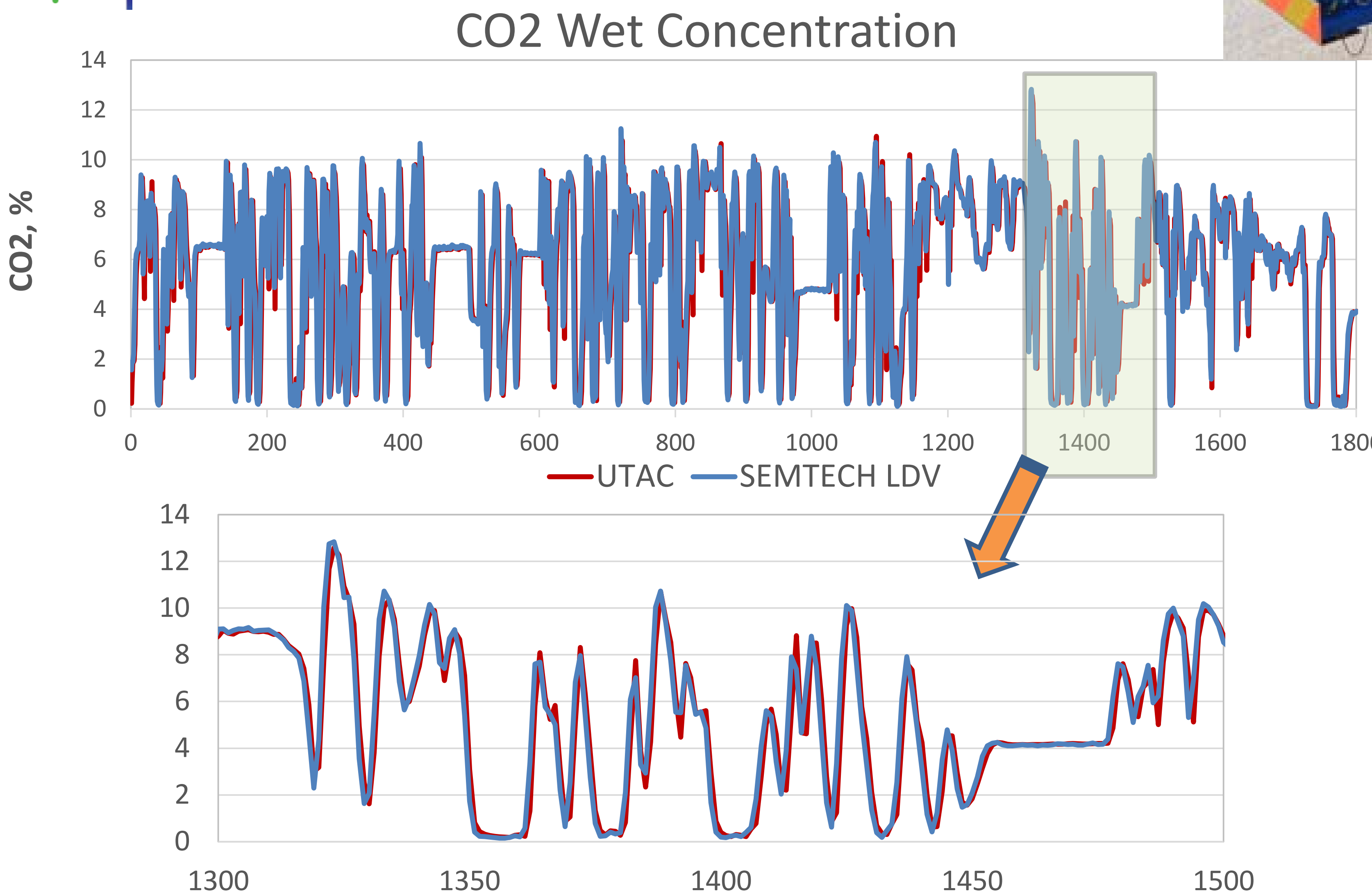
Background

- Correlation / Validation testing over WLTC "highly recommended" for Packages 1 & 2 RDE testing
  - Limits (% and Absolute) provided in proposed regulations
  - Example Correlation testing performed at UTAC on 1.6 liter diesel vehicle

Correlation to Laboratory – WLTC Cycle
1.6 liter Diesel at UTAC, 10/29/2014



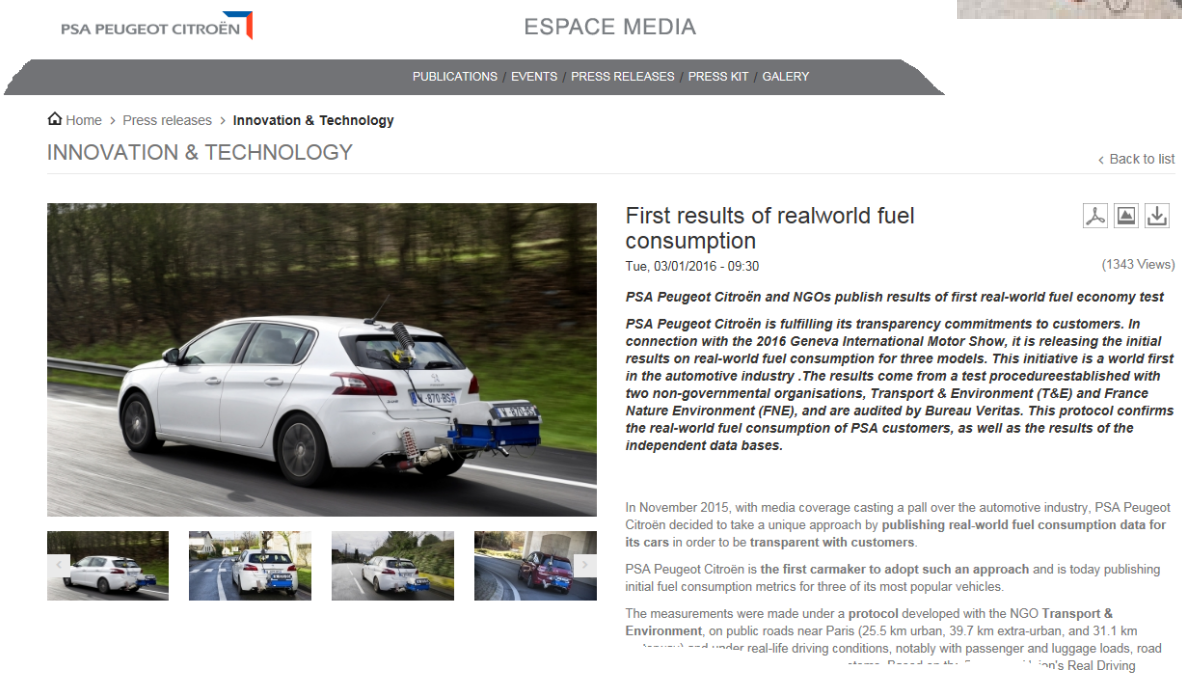
Correlation to Laboratory – WLTC Cycle
1.6 liter Diesel at UTAC, 10/29/2014



PEMS Testing – RDE, Development, Fuel Economy

Requirement: Errors <5%

A Factor of 2 better than the current RDE validation test criteria.



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First results of realworld fuel consumption

Tue, 03/01/2016 - 09:30 (1343 Views)

PSA Peugeot Citroën and NGOs publish results of first real-world fuel economy test

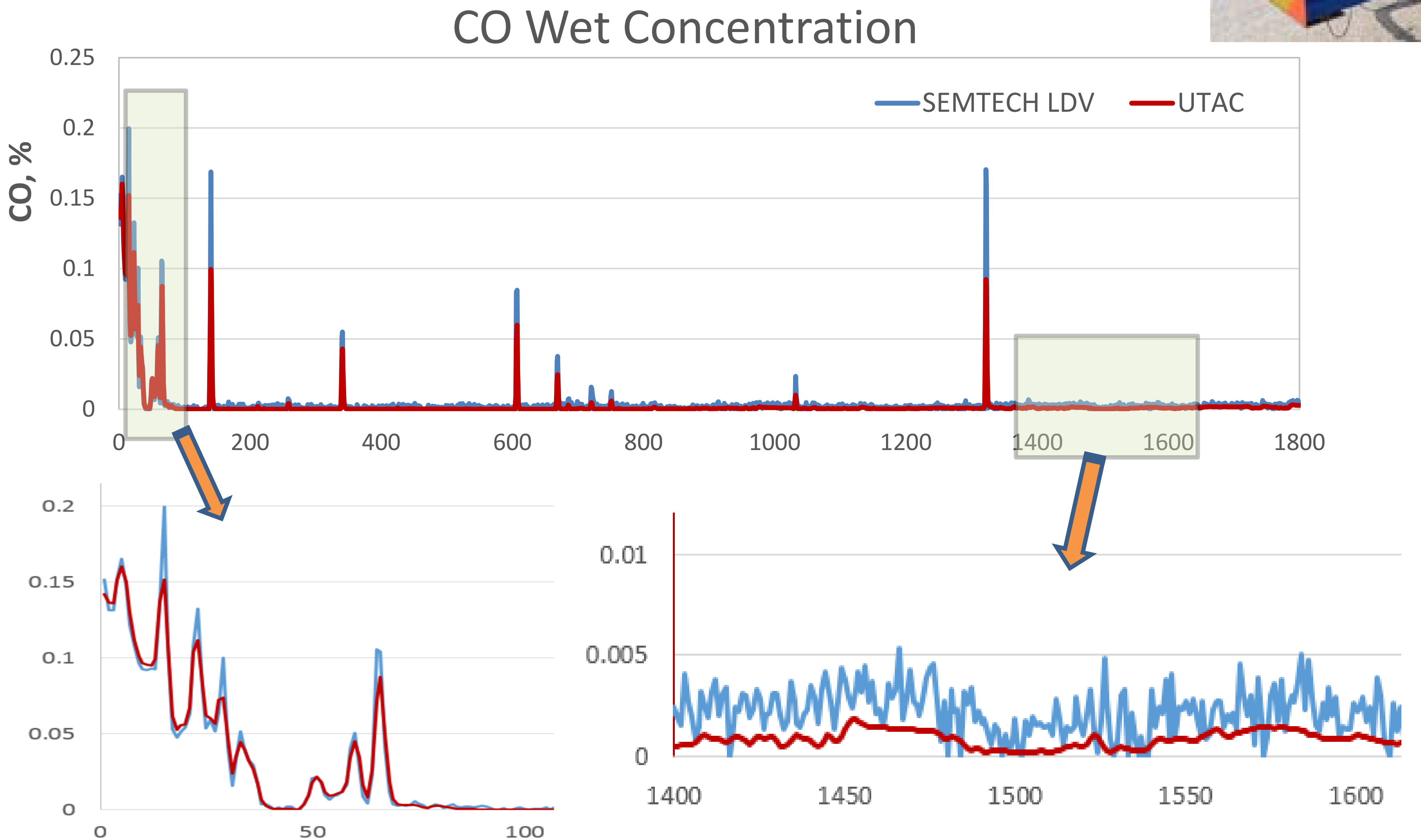
PSA Peugeot Citroën is fulfilling its transparency commitments to customers. In connection with the 2016 Geneva International Motor Show, it is releasing the initial results on real-world fuel consumption for three models. This initiative is a world first in the automotive industry .The results come from a test procedureestablished with two non-governmental organisations, Transport & Environment (T&E) and France Nature Environment (FNE), and are audited by Bureau Veritas. This protocol confirms the real-world fuel consumption of PSA customers, as well as the results of the independent data bases.

In November 2015, with media coverage casting a pall over the automotive industry, PSA Peugeot Citroën decided to take a unique approach by **publishing real-world fuel consumption data for its cars** in order to be **transparent with customers**.

PSA Peugeot Citroën is **the first carmaker to adopt such an approach** and is today publishing initial fuel consumption metrics for three of its most popular vehicles.

The measurements were made under a **protocol** developed with the NGO **Transport & Environment**, on public roads near Paris (25.5 km urban, 39.7 km extra-urban, and 31.1 km ... under real-life driving conditions, notably with passenger and luggage loads, road ... 's Real Driving

Correlation to Laboratory – WLTC Cycle
1.6 liter Diesel at UTAC, 10/29/2014



Correlation to Laboratory – WLTC Cycle
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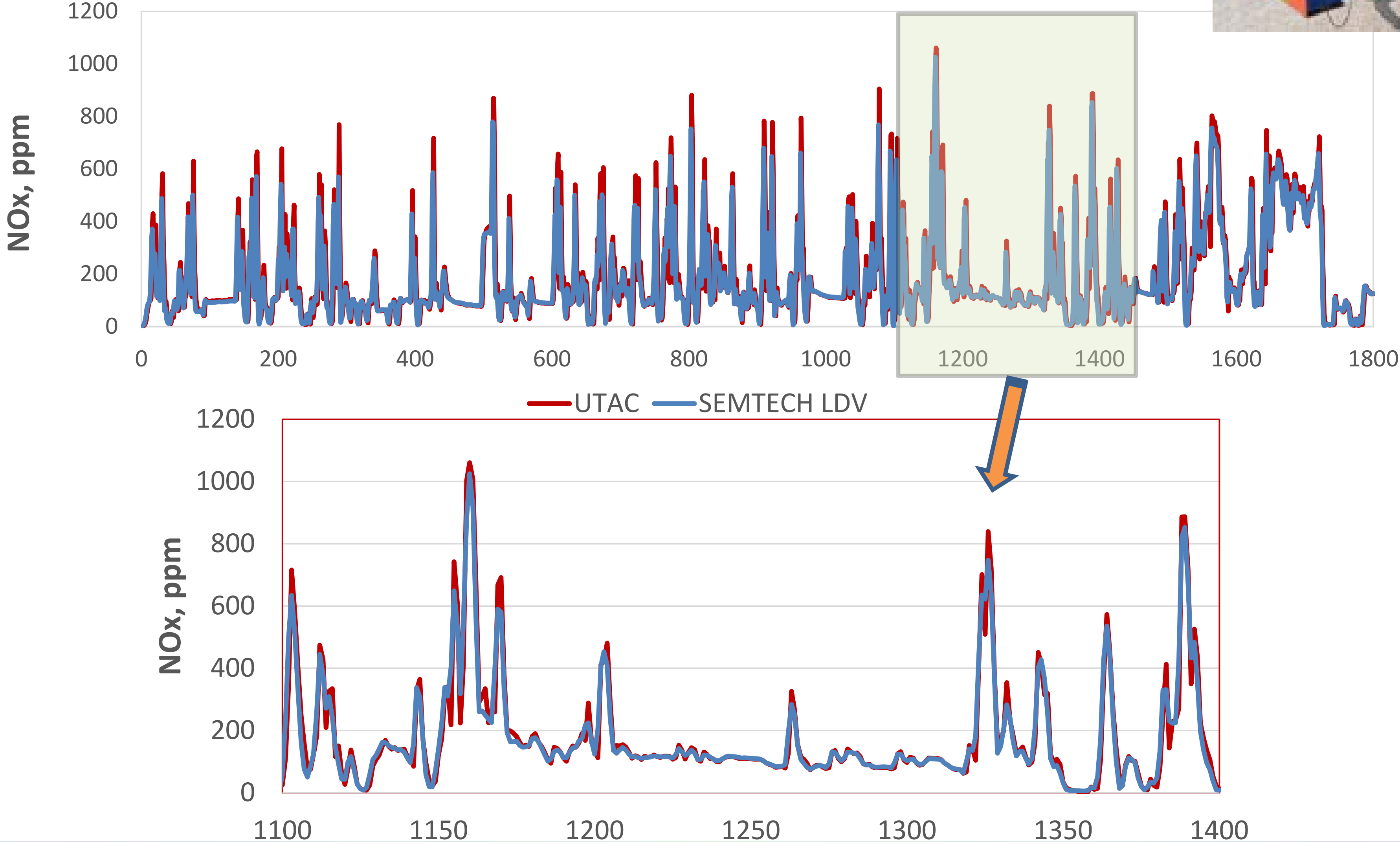

Correlation to Laboratory – WLTC Cycle
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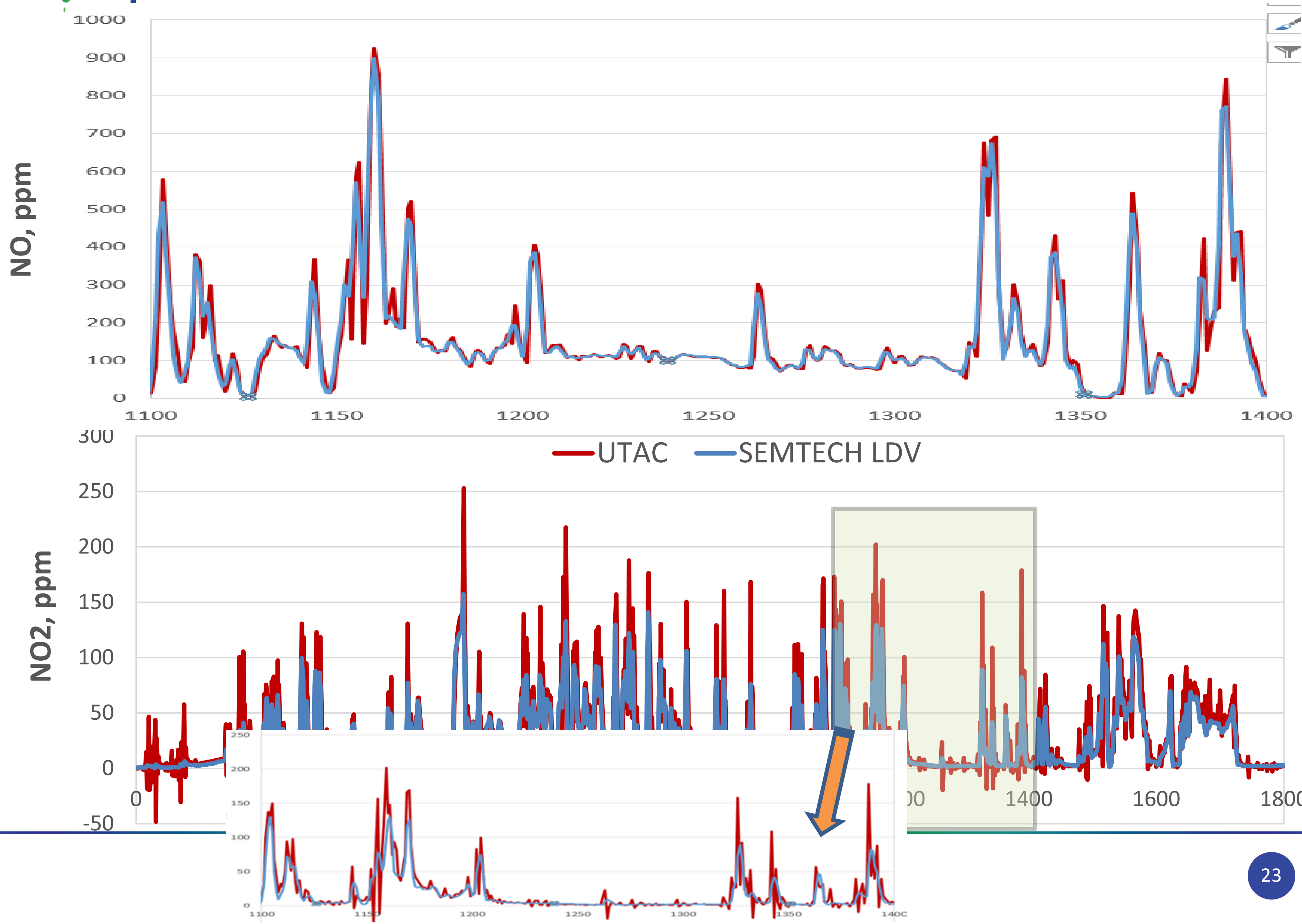
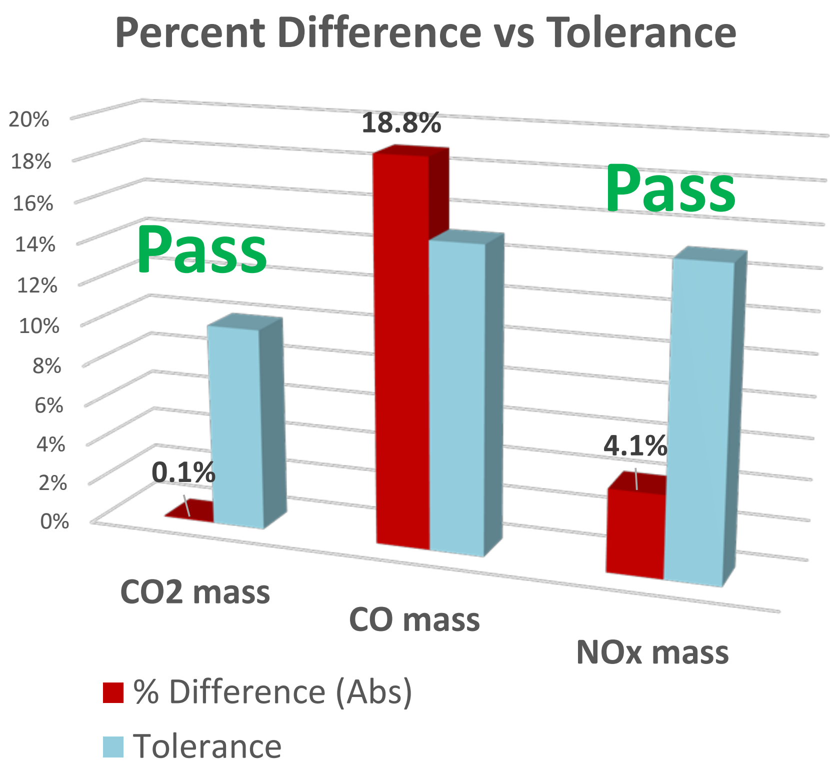
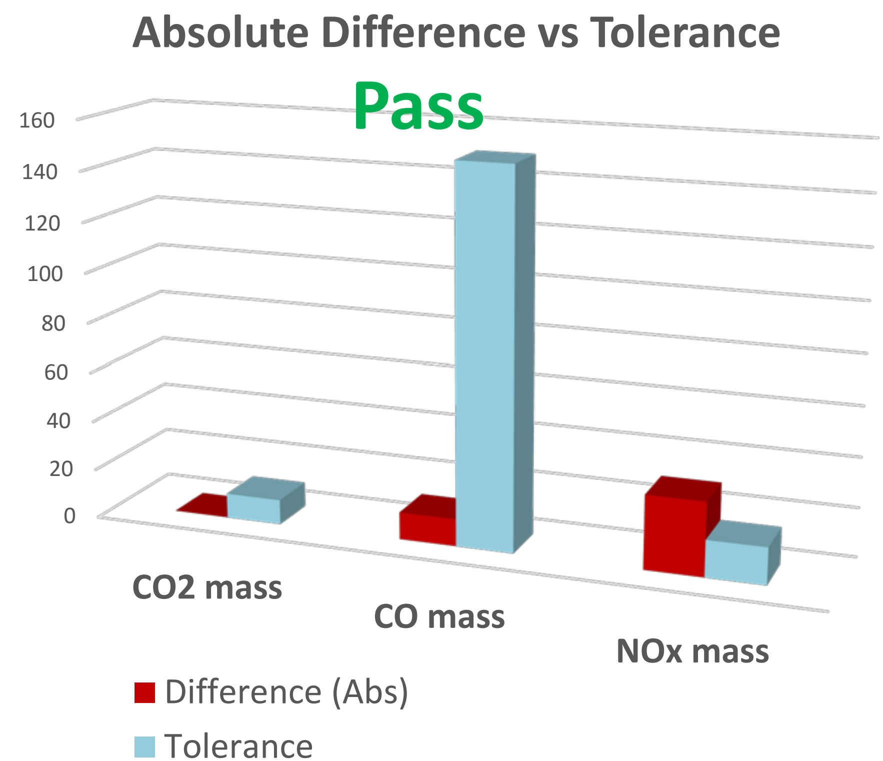


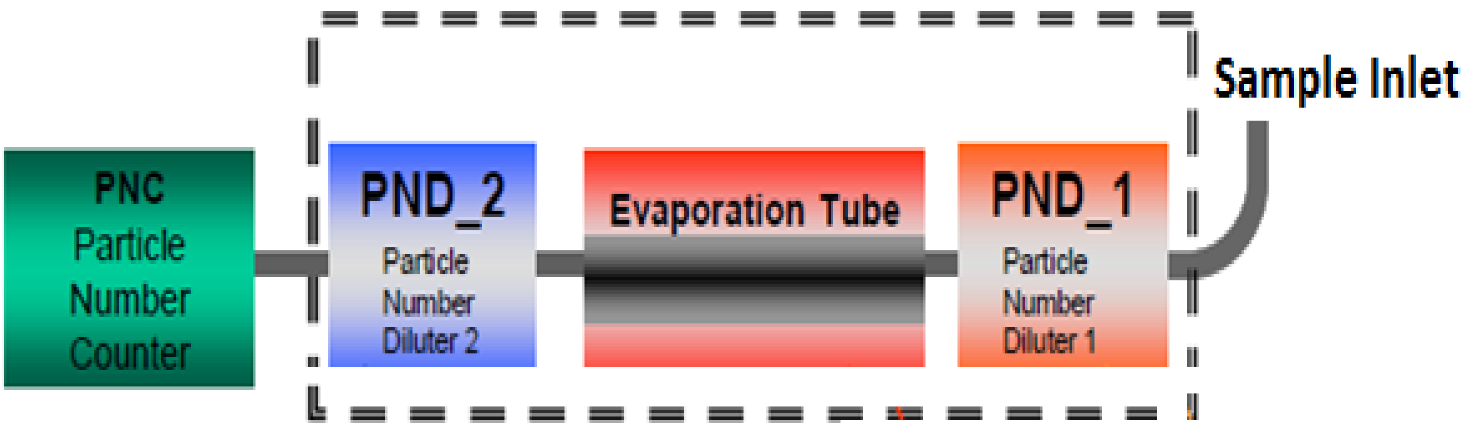
Correlation Evaluation: PEMs vs CVS Bag





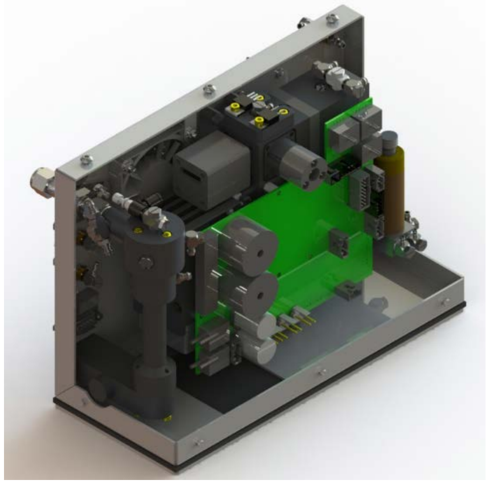
All gases pass requirements. Low CO levels result in higher %error, but well within the .15 g/km absolute tolerance.

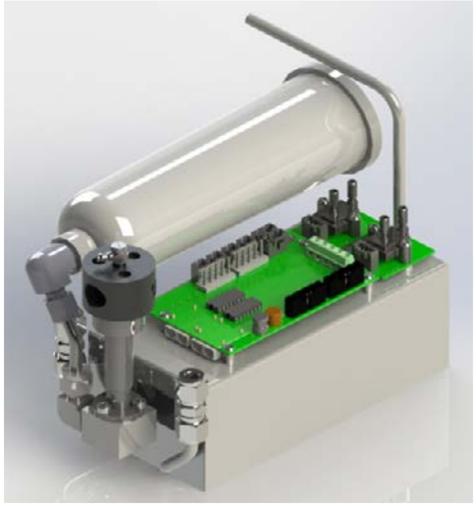
SEMTECH CPN compliant to the PMP Standard - UNECE Reg. 83

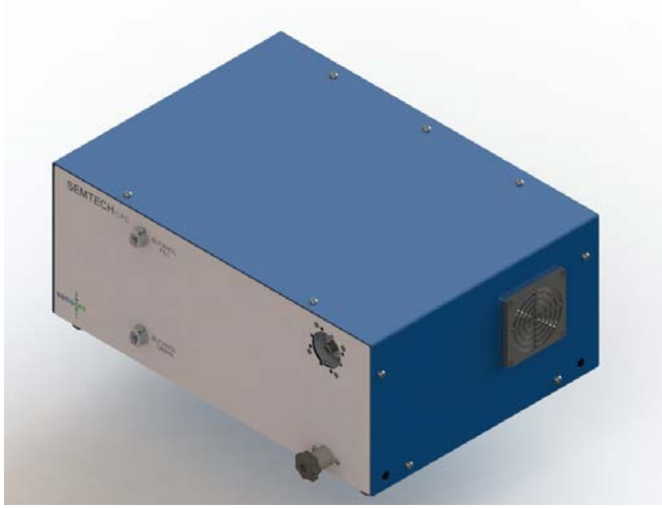


Volatile Particle Remover

SENSORS CPC Module







Ref. Technology (Tail-pipe to CVS)

European Commission

PMP-TP vs PMP-CVS

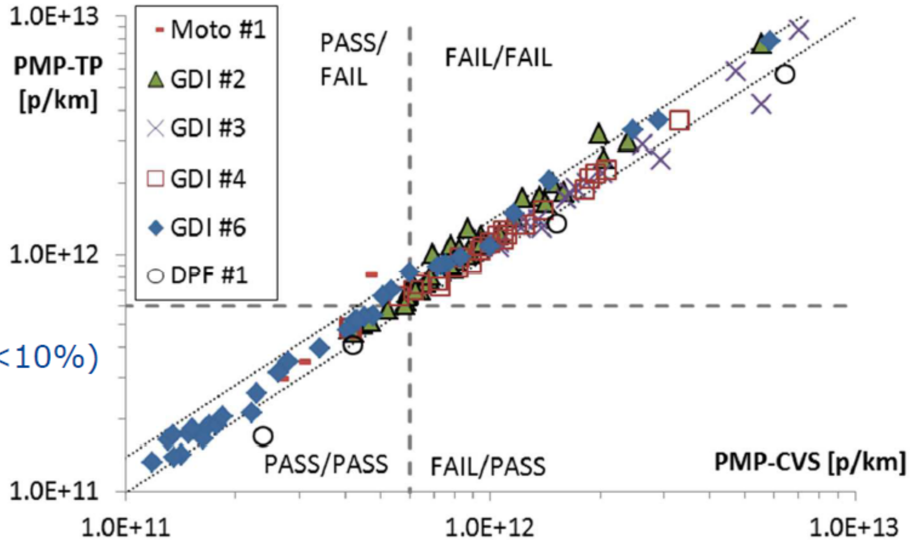
Results within

0.95 - 1.40

Reasons:

-Time alignment (<10%)
-Exhaust flow accuracy (<10%)

-Thermophoretic losses+
-Diffusion losses (<5%)
-Agglomeration (<15%)



Giechaskiel et al. (2015) JRC report 27451

Joint Research Centre

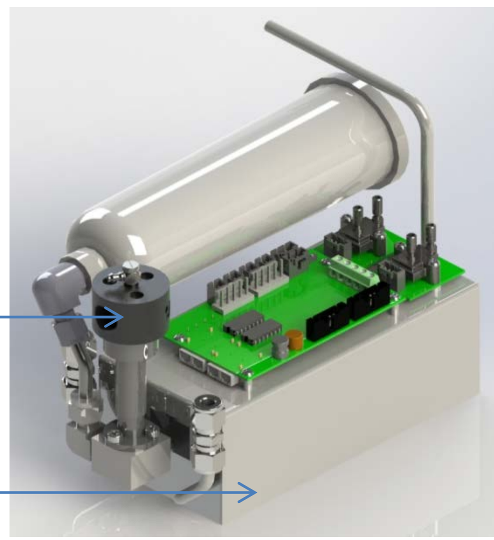
49

VPR-Catalyst

- Catalyst from Catalytic Instruments
  - PMP Specifications ✓
  - 67% penetration at 10 nm ✓

PND1 Heated Dilution
10-20:1

Heated Catalyst
300 °C



°Catalytic Instruments
hot technologies • clean solutions

CERTIFICATE OF CONFORMANCE

MODEL: 030CC00 catalytic core

SERIAL NUMBER: 030CC00-20130018

Catalytic Instruments herby certifies that the above referenced core conforms to the original manufacturer's specifications. The device performance has been tested and verified using the equipment, metrics, and methods described below.

Picture - Feasibility study on the extension of the Real Driving Emissions (RDE) procedure to Particle Number (PN), JRC 2014

TEST EQUIPMENT USED: TSI 3080 L SMPS, HORIBA MEXA 584 L

Flowrate: 3 L/min

Heater setpoint: n/a

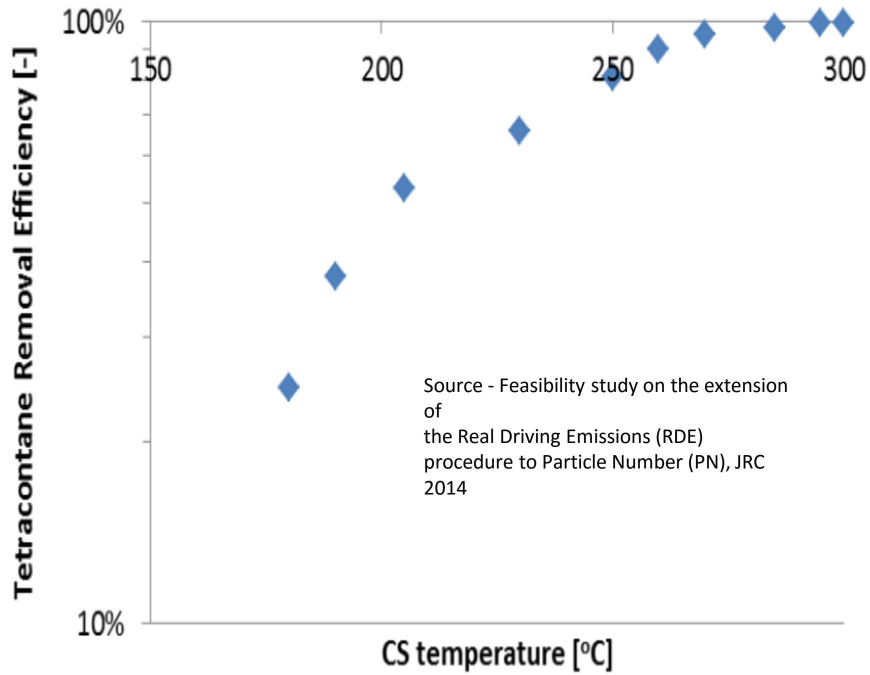
Propane oxidation: >99%

Solid particle penetration: 66% **Size:** 10nm

Penetration measured at room temperature

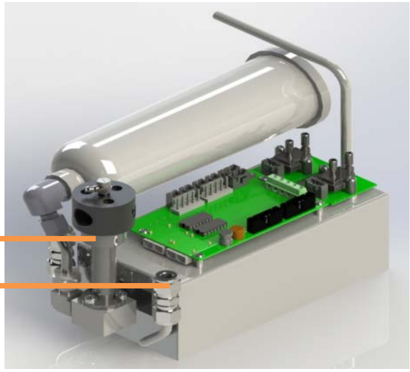
VPR-Catalyst – Experimental Verification

- Catalyst from Catalytic Instruments
  - PMP Specifications
  - 67% penetration at 10 nm

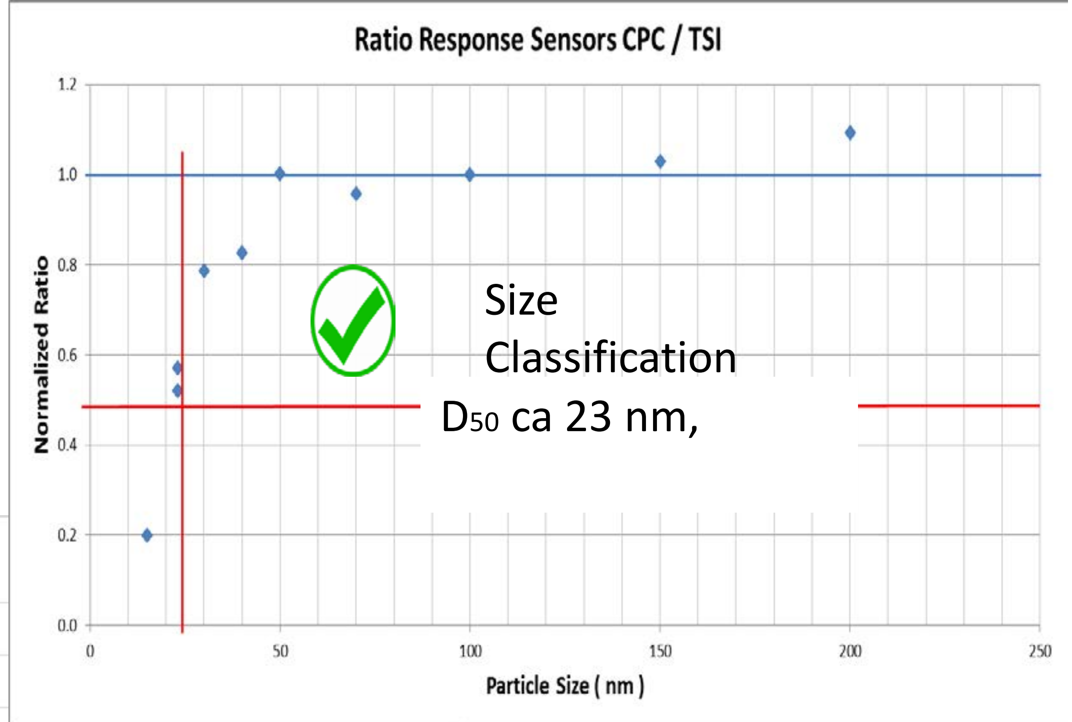


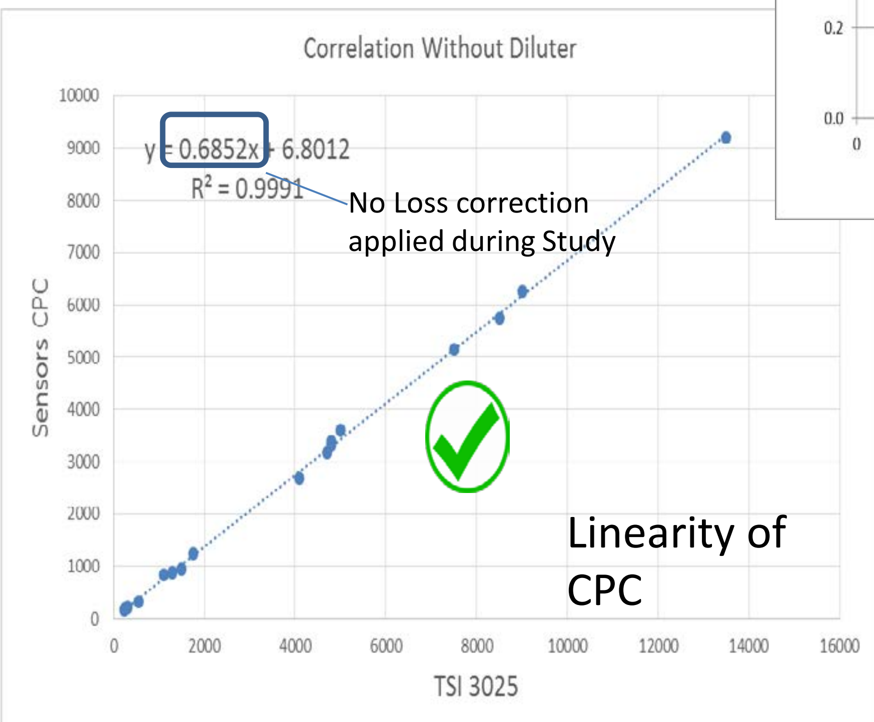
Stage 1 Heated Dilution
10-20:1

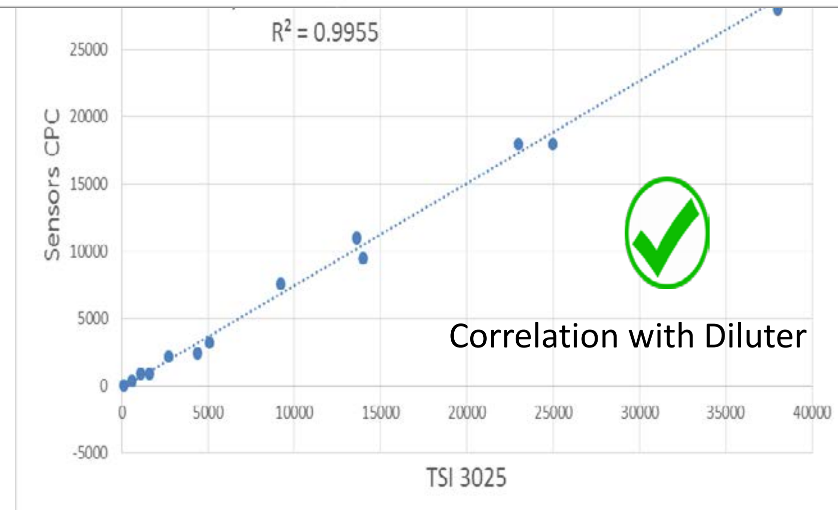
Heated Catalyst
300 °C



Aerosol Laboratory Evaluation





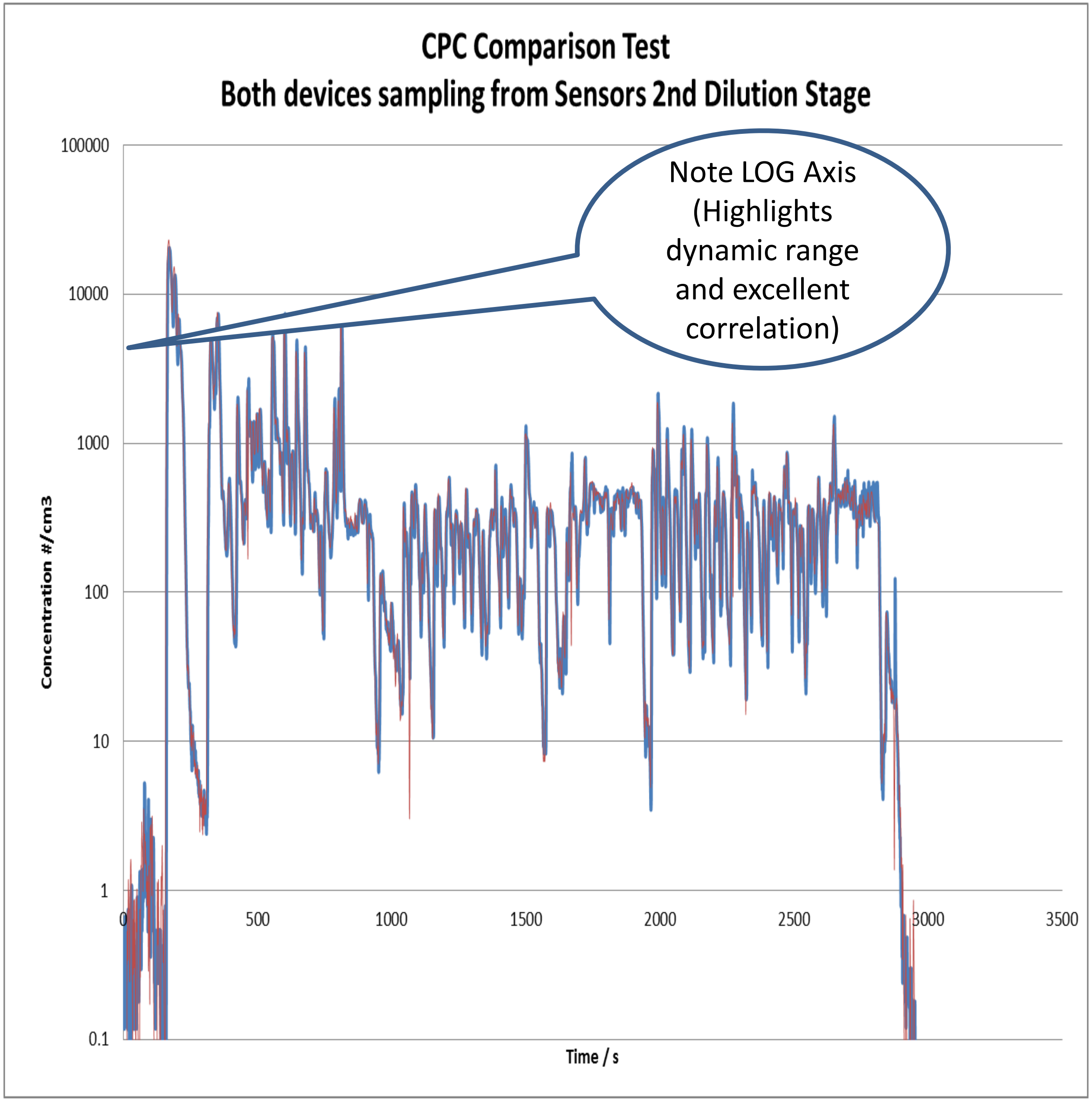


SEMTECH CPN vs TSI SPC

Data obtained at JRC ISPRA

CPC Evaluation:

Exhaust of CPN module measured simultaneously by TSI CPC and Sensors CPC during chassis dyno testing

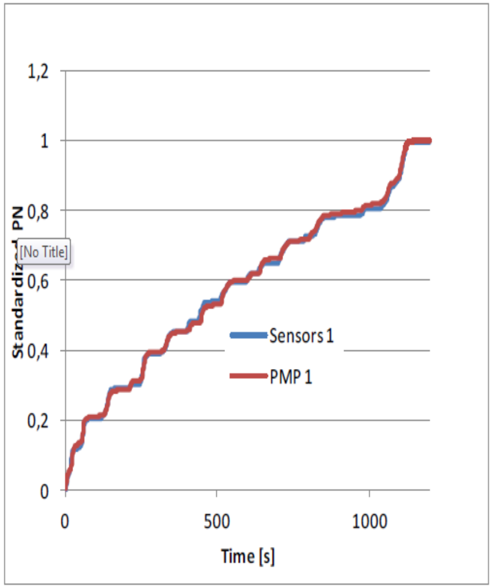


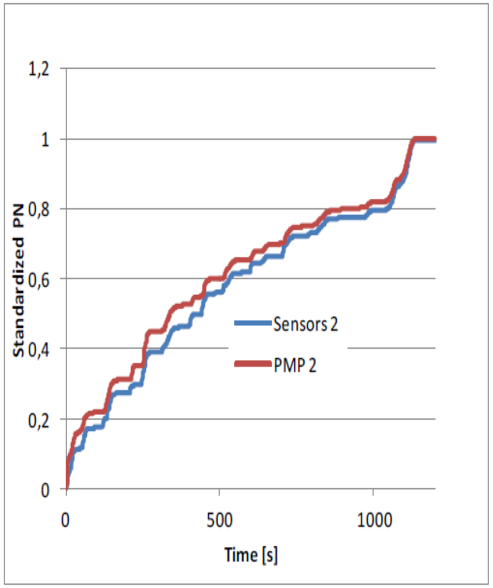
Test Cell Comparison
SEMTECH CPN and Horiba PMP

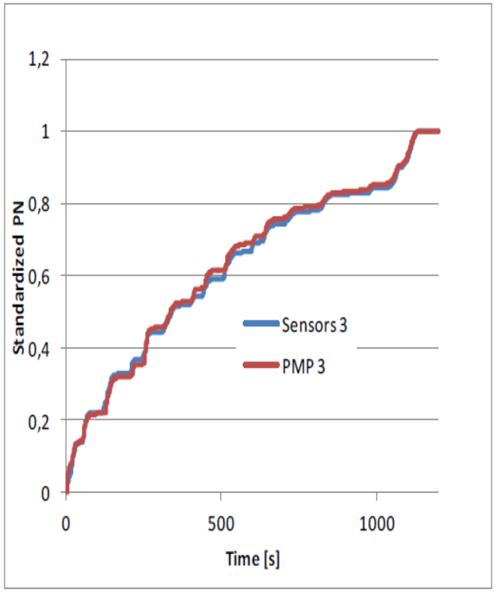
Data Supplied by
..Source Confidential......

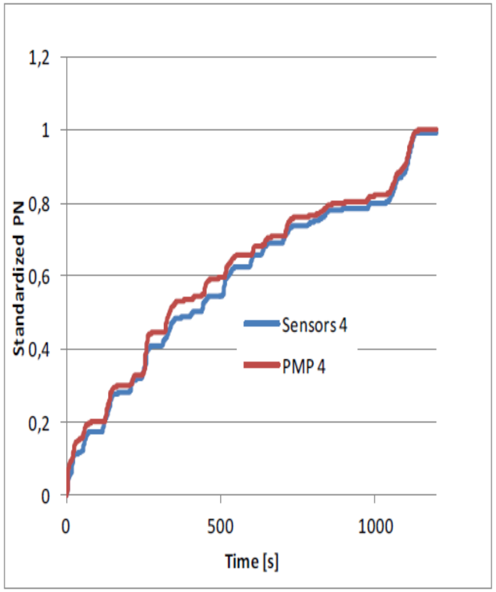
The charts are normalized

Cycle averages within 20% to reference PMP







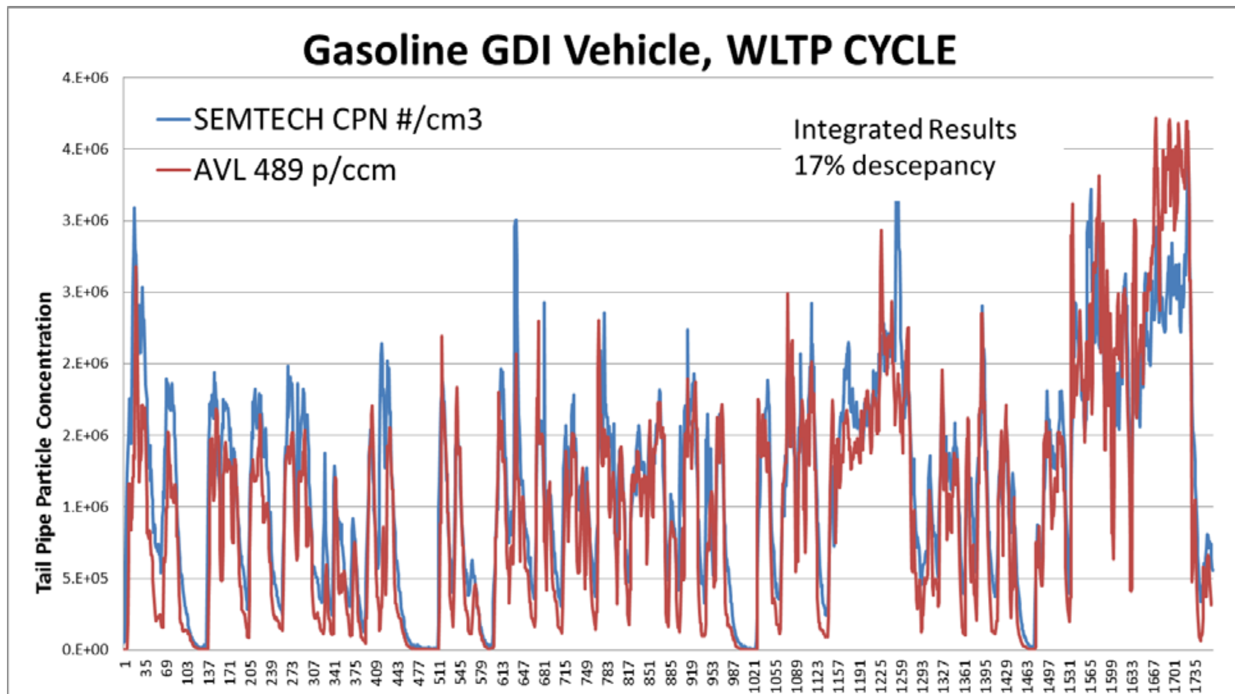


sensors

Test Cell Comparison
SEMTECH CPN and AVL 489 PMP

Data Supplied by **JRC**
Dr.Francesco Riccobono

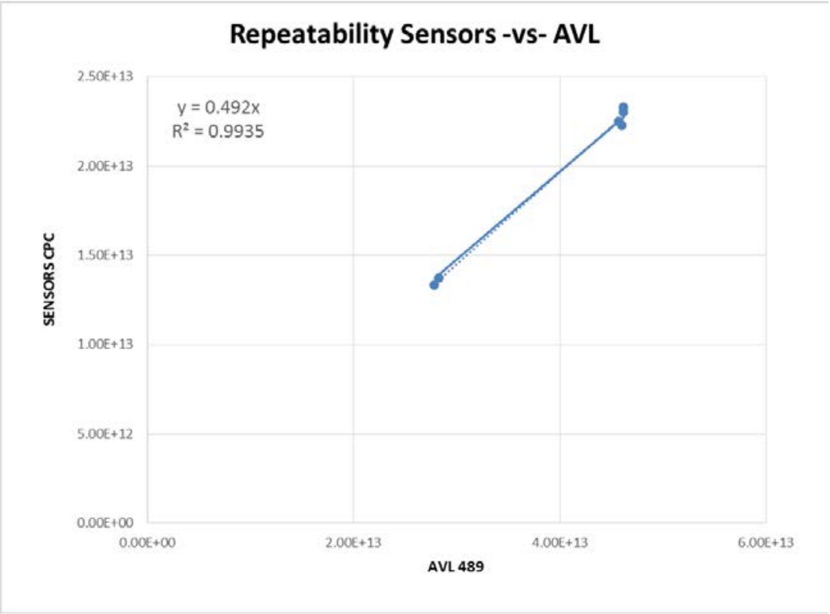
Cycle averages within <20% to reference PMP

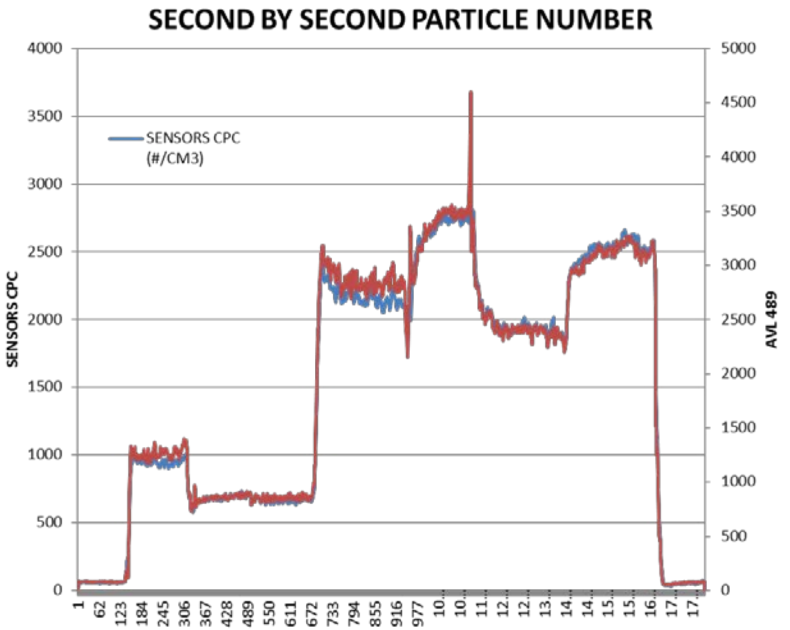


Heavy Duty Test Cell Comparison
SEMTECH CPN and AVL 489 PMP

Data Supplied by **Cummins**
Dr. Shirish Shimpi

Demonstrated excellent Linearity and repeatability





sensors

Thank You For Your Attention