

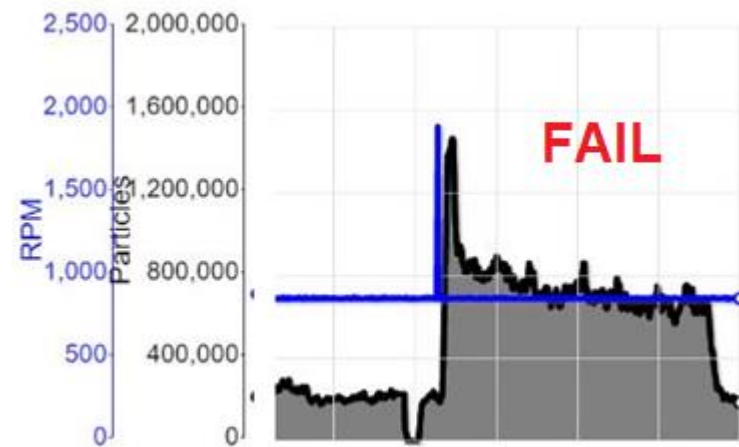
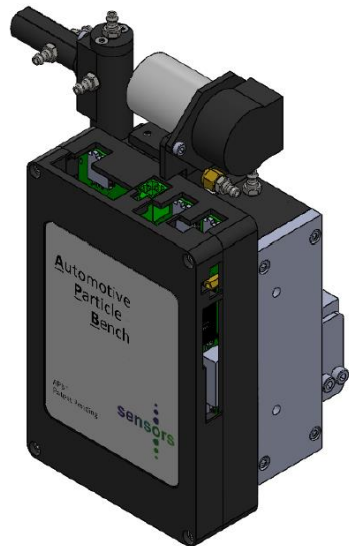
# Performance and Operational Demands for a low-cost Particle Number Measurements for Periodic Technical Inspection

Cambridge Particle Meeting, 15<sup>th</sup> June 2018

Dr David R Booker, Oliver Franken<sup>2</sup>, Michael Heuser<sup>2</sup>

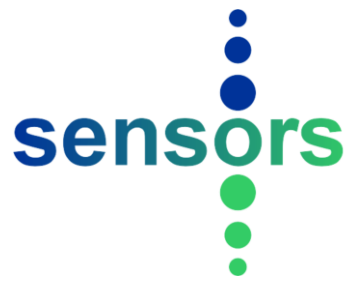
Sensors Inc., Sensors GmbH<sup>2</sup>

Automotive Particle Bench



Automotive Particle Analyzer



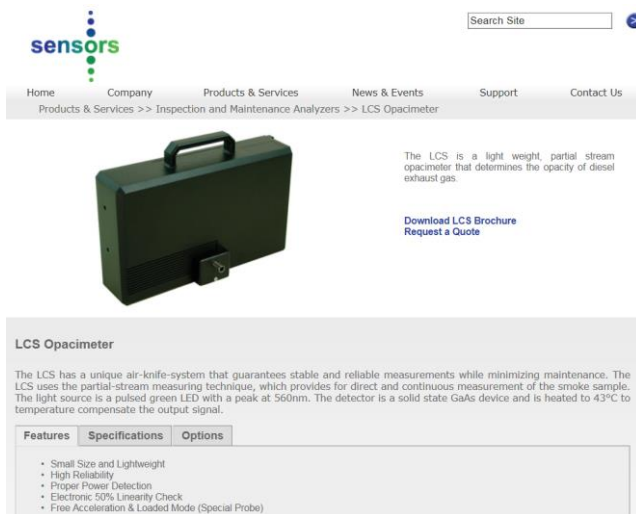


# Periodic Technical Inspection

Current PTI test procedures (based on opacity), as specified in UNECE Regulation 24 and UNECE Regulation 83 are **NO LONGER** suitable for detecting relevant levels of **malfunctioning** or **tampering** in modern vehicles with advanced emission control systems.

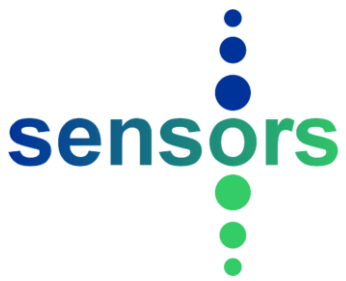
## Sensors' Smoke Meter

To date 35,000+ Devices sold



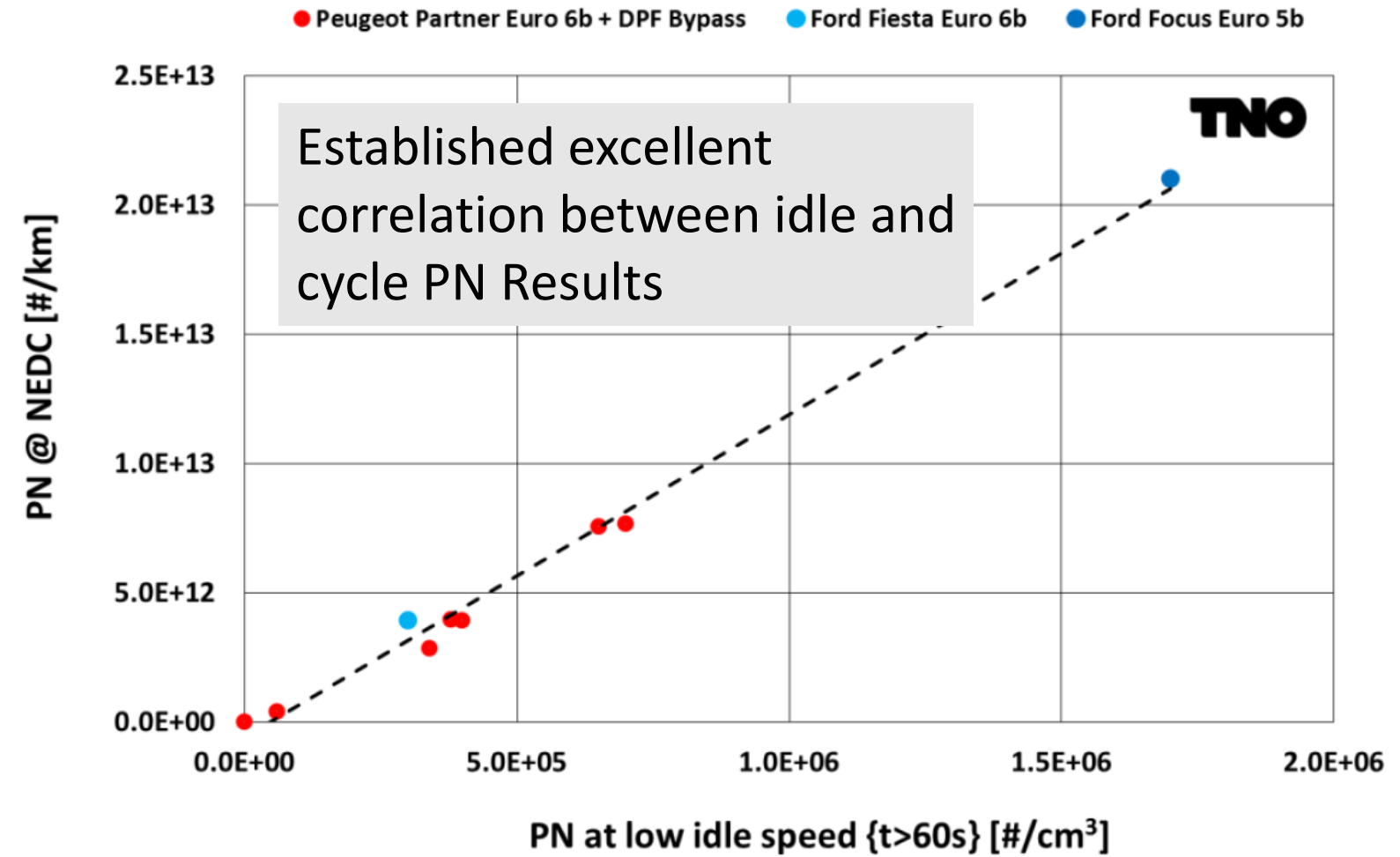
## Particle Number PTI Analyzer

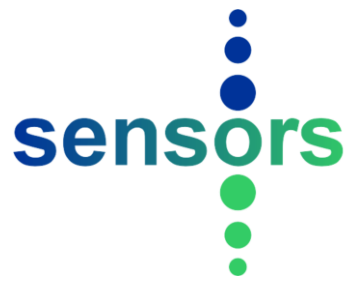




# TNO studies

TNO report | TNO 2017 R10530 | 1.0 | 1 May 2017  
TNO report | TNO 2016 R10735v2 | 10 October 2016





# The German PTI Program Starting on 01/01/2021

## 35,000 Garages

Heft 19 – 2017

852

Nr. 158 – **Änderung der Richtlinie für die Durchführung der Untersuchung der Abgase von Kraftfahrzeugen nach Nummer 6.8.2 der Anlage VIIIa Straßenverkehrs-Zulassungs-Ordnung (StVZO) (AU- Richtlinie)**  
 – **Muster eines Nachweises über die Durchführung der AU nach Anlage VIII StVZO**

2.

„1.2.

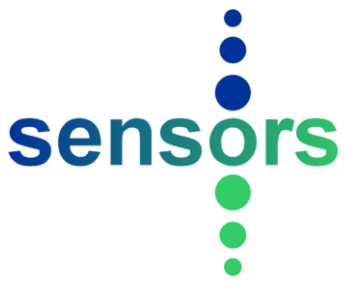
The goal of changing this directive is to the implementation of a mandatory exhaust measurement of all vehicles which are subject to periodical emission inspection. By this the possibility of a 2-stage process for the periodical emission inspection of vehicles with OBD is canceled.  
 Independent of the OBD inspection result the measurement of the exhaust emissions is now also mandatory for vehicles which have an OBD available.  
 .....

Bonn, den 20. September 2017  
 LA 27/7355.2/2

Zur Weiterentwicklung der Abgasuntersuchung wird die AU-Richtlinie geändert. Diese Änderungen werden nachstehend im Benehmen mit den zuständigen obersten Landesbehörden bekannt gegeben und sind ab dem 01.01.2018 anzuwenden.

**As a further step the implementation of a particle number measurement for vehicles with compression ignition is scheduled.** The enforcement of these measures will be implemented step by step due to the required preparation work to be conducted.

NUMMER SIND.

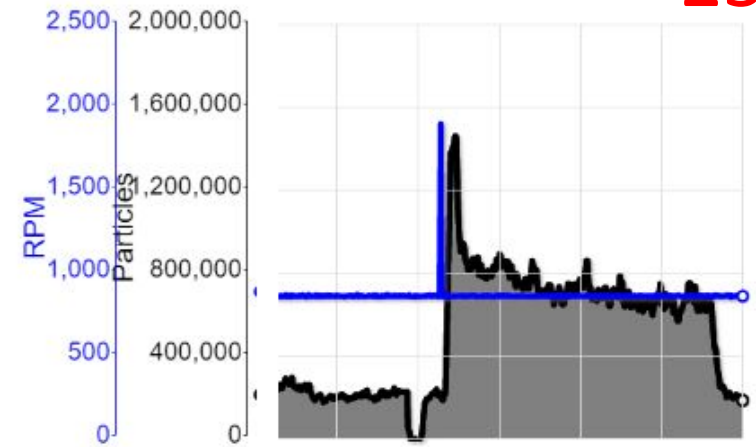


# PTI Testing – Example Observations



**FAILED PTI**  
**250,000 #/cm3 Limit**

## IDLE TEST PROCEDURE



### Test Sequence

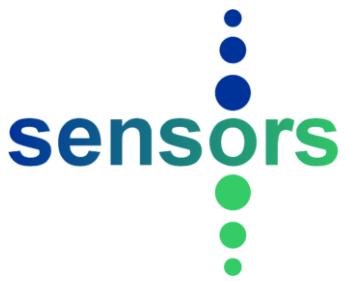
- (1) Snap Acceleration
- (2) Wait for PN to Stabilise
- (2) Measure 3 x 1 Minute Averages

Average PN Levels  
 7.3E+05-7.0E+05-6.6E+05

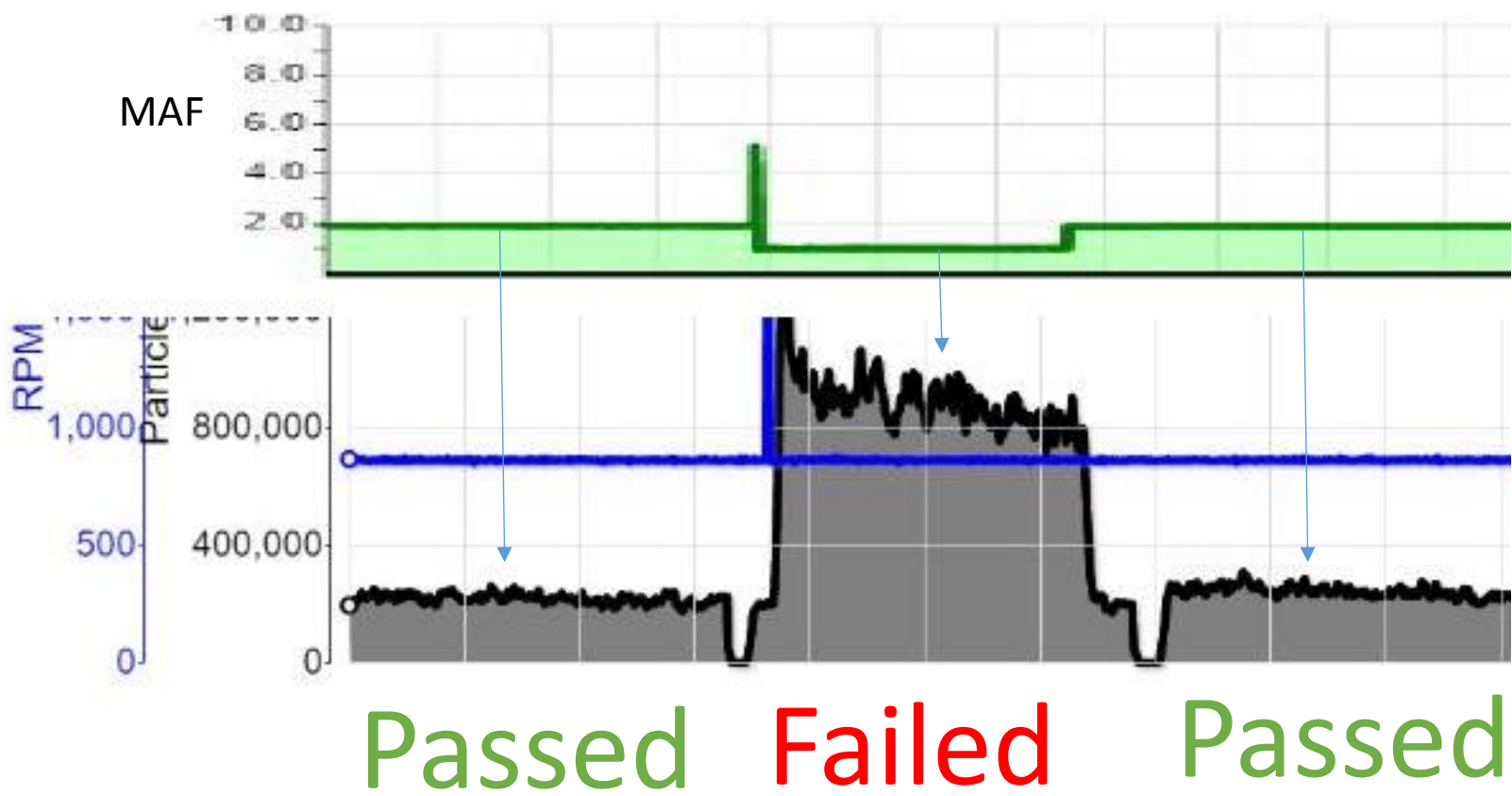
**Pass/Fail Threshold Assumed to be at 250,000 #/cm3**

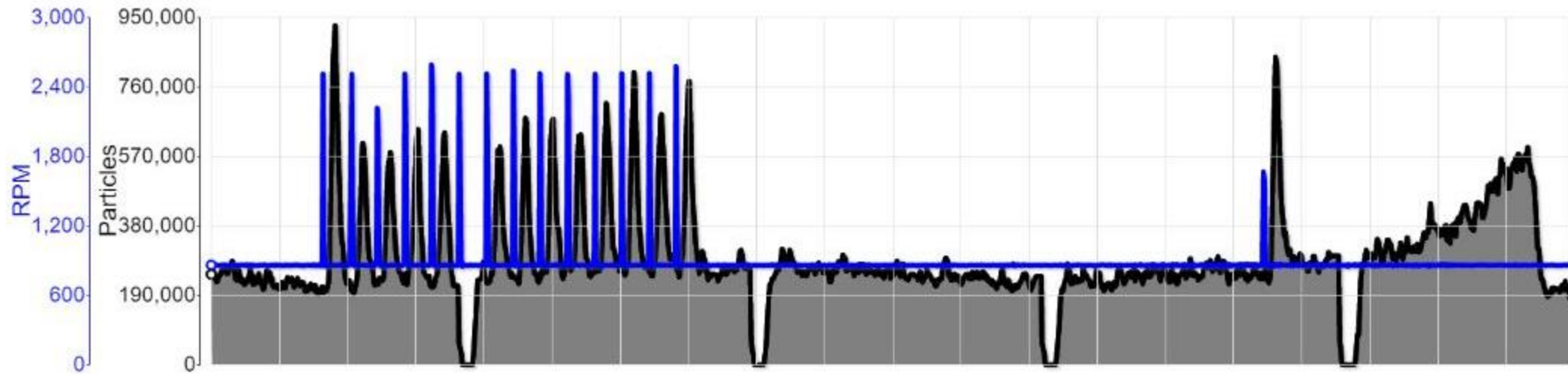
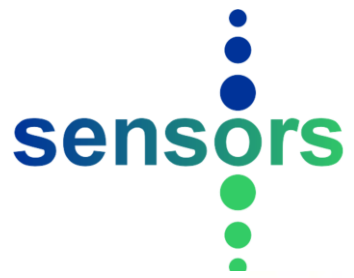
**WIFI Connection TO PC**

**Bluetooth Connection to OBD (eg RPM, Coolant Temp and MAF)**

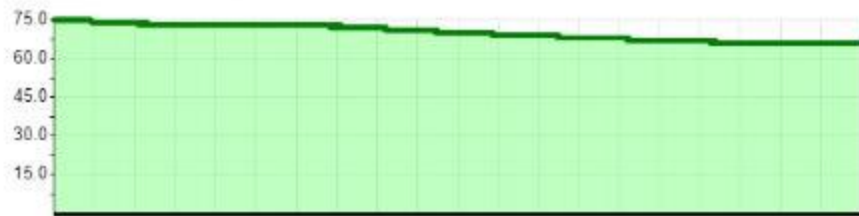


# Test Procedure still to be Defined by Member States (For example, - False Pass / Fail Risks)

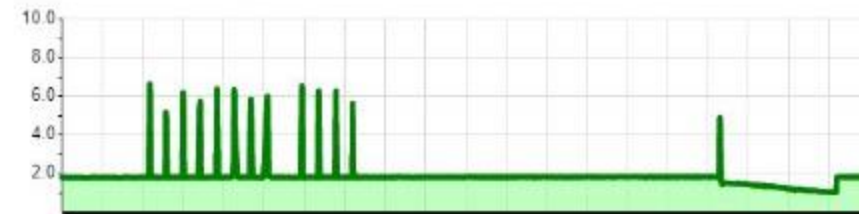


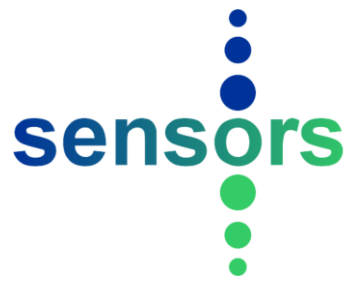


OBD Coolant Temp ▾



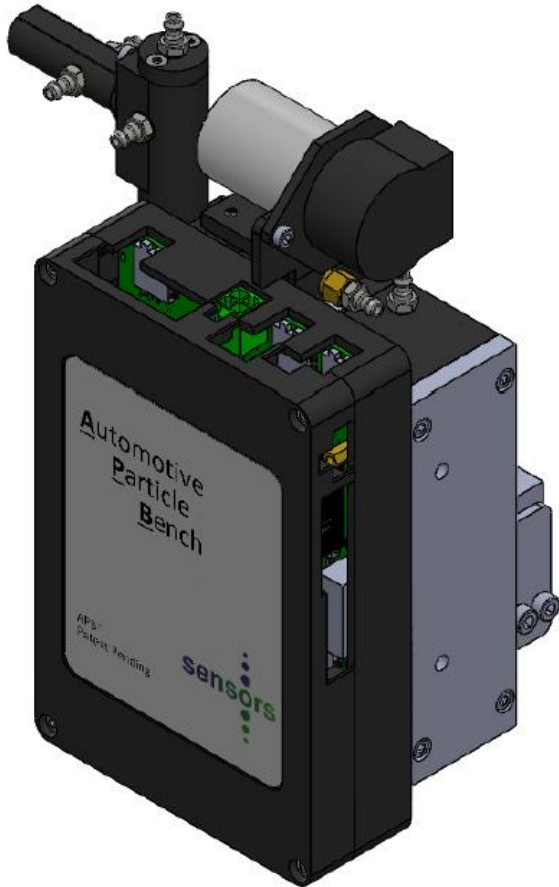
Mass Air Flow ▾





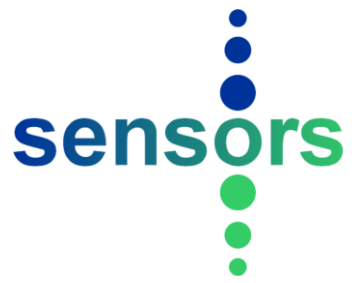
# CPC-Based Particle Number Bench and Analyzer Development

BENCH



Analyzer





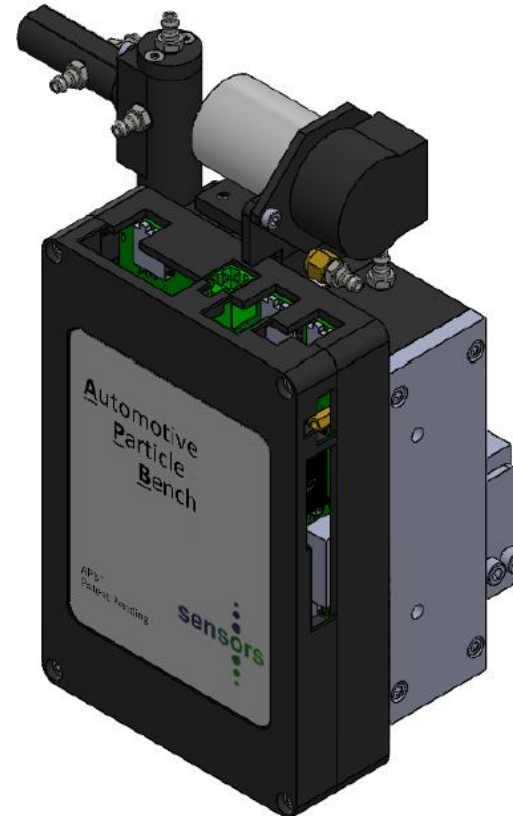
# Automotive Particle Bench

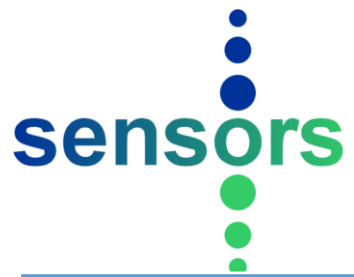
## Automotive Particle Bench (APB)

Robust Mixing CPC (PNC)  
Integrated Ejector Diluter (PND2)  
Microprocessor Controlled  
Linux Computer (wifi, Bluetooth OBD, evaluation unit)  
Low Cost, Robust for field use.

Can be calibrated to fulfil ISO 27851:2015

- Affordable (low cost in volume)
- ISO defines 12 month validity
- Simple daily checks
- intrinsically linear
- adjustable d50 (10 to 40nm)



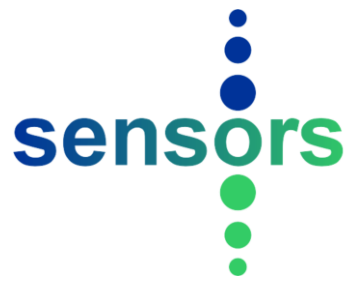


# Automotive Particle Analyzer

SPECIFICATIONS	
Operating Temperature	5 °C to 30 °C
Operating Humidity	0 to 95%
Particle Counter Technology	Mixing CPC - IPA (working Fluid)
APB Maximum Concentration APA (with additional ejector diluter)	600,000 #/cm <sup>3</sup> 6,000,000 #/cm <sup>3</sup>
Min Particle Size	d50 10-50 nm (Defaultt 23nm) Configurable using external diffusion screens
Warm Up Time	≤ 15 min @ 20°C
Zero Drift	N/A – No Drift
Resolution	0.1 #/cm <sup>3</sup>
Gas Temperature Range	0 – 650 °C
Storage Temperature	-32 °C to 55°C
APB Acoustic Noise	< 60 dBA
Accuracy	±15% absolute
Software and Coms	Web-based or Rs232
Data Acquisition Rate	1 Hz
APA Dimensions (HxWxL)	280 (394 with stand) x 457 x 127 mm 11 (15.50 with stand) x 18 x 5 in
APA Weight	16 kg (35 lbs)
APB Dimensions (HxWxL)	235 x 380 x 90 mm 9.25 x 15 x 3.5 in
APB Weight	5.6 kg (12 lbs)
APB Power Input	12 VDC (provided by AC PSU)
APB Power Consumption	< 60 W




- **PND1: 10:1**
- **VPR (300C)**
- PND2: 20:1
- PNC (CPC)
- Bluetooth OBD
- Wifi GUI
- **IPA Tank for prolonged use**





# PTI Device(s) Calibration / Validation

Unlike our RDE PEMS PN  
which uses Butanol, our PTI  
PN CPC uses Iso-Propanol  
Alcohol (IPA)

CERTIFICATE OF CALIBRATION			
ISSUED BY Ricardo-AEA Ltd trading as Ricardo Energy & Environment			
DATE OF ISSUE	13/02/2018	CERTIFICATE NUMBER	PMC337
 Ricardo Energy & Environment Particle Measurement Centre Unit 2 Ludbridge Mill Reading Road, East Hendred Wantage, Oxfordshire OX12 8LN, UK		 0401	
Telephone: 01235 861343      Email: PMC.EE@Ricardo.com		Page 1 of 4 pages Approved Signatory Name: Mr. Jason Southgate Dr. Ian Marshall Signature: 	
Customer :	To: Sensors Inc	On behalf of : Sensors Europe GmbH	
Address :	Sensors, Inc. 6812 State Road, Saline, Michigan, 48176		
Instrument :	Automotive Particle Bench	Customer Client Contact:	Dr David Booker
Serial No :	K17502235	Customer address:	Sensors Europe GmbH, Feldheider Str. 60, 40699, Erkrath, Germany
Software version:	1018	Calibration date :	15 January 2018
		Calibration engineer :	Mr Jason Southgate

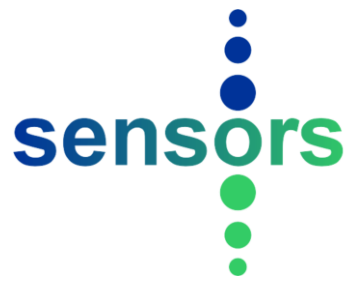
## Method:

The Particle Number Counter (PNC) was calibrated according to the principles of ISO 27891:2015 using the methods described in Ricardo Energy & Environment Procedure WI/46.02-PNC. The PNC calibration was carried out with 70 and 23nm nominal diameter carbonaceous particles. The efficiency of the Particle Number analyser (PN analyser) was determined using 100, 70, 50, 41, 30, 23 and 15 nm nominal diameter carbonaceous particles. Calibrations marked 'Not UKAS Accredited' in this certificate have been included for completeness.

### International Laboratory Accreditation Co-operation

The United Kingdom Accreditation Service (UKAS) is one of the signatories to the International Laboratory Accreditation Co-operation (ILAC) Arrangement for the mutual recognition of test reports, calibration certificates & inspection reports.

This certificate is issued in accordance with the laboratory accreditation requirements of the United Kingdom Accreditation Service. It provides traceability of measurement to the SI system of units of measurement realised at the National Physical Laboratory or other recognised national metrology institutes. This certificate may not be reproduced other than in full, except with prior written approval of the issuing laboratory.



# PTI Device(s) Calibration / Validation at Ricardo-AEA

## CERTIFICATE OF CALIBRATION

Certificate Number PMC337  
Page 2 of 4 pages

### PNC Status

#### Instrument on Test Details:

Make:	Automotive Particle Bench	Previous Calibration Certificate Ref:	New Unit
Model:	CPC_V1	Previous Calibration Date:	N/A
Serial Number:	Unknown	Previous Calibration Aerosol Used:	N/A
Firmware Version:	1052		

#### PNC Temperatures and Pressures

	Measurement		Units	Expected		Status
	As Found	As Left		Low Limit	High Limit	
Saturator Temperature	33.3	33.8	°C	31.5	33.5	OK
Condenser Temperature	15.0	14.9	°C	14.5	15.5	OK
Sample Flowrate	0.012	0.012	slpm	-	-	-

#### Mean Instrument Zero Reading:

Average particle concentration detected over 5 minute sampling period.

	Units	Expected		Status
		Low Limit	High Limit	
0.110	p/cc	0	1.0	OK

### Particle Number Counter (PNC) Detection Efficiency

#### Description of calibration method for detection efficiency

Detection efficiency of the PNC on test is calibrated by measuring its performance against a transfer standard PNC in single particle count mode. Both the instrument on test and the transfer standard PNC are challenged with a size and charged-defined particle sample of a well-controlled thermally pre-treated monodispersed soot aerosol which is size determined by a traceably verified scanning mobility particle sizer. The aerosol counting efficiency at a defined particle size, is measured over a concentration range from zero to no more than 10,000 particles cm<sup>-3</sup> in single count mode. the PNC on test detection efficiency is determined from the reciprocal of the gradient averages at the particle sizes measured (1/gradient).

**Range of Calibration** Up to 10 000 cm<sup>-3</sup> (Calibration Determined for Stated Calibration Range to Convert Measured PNC Concentration to the Reference concentration)

## CERTIFICATE OF CALIBRATION

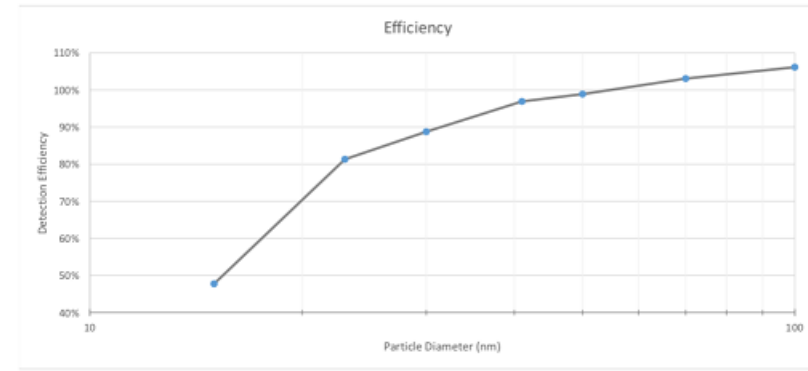
Certificate Number PMC337  
Page 3 of 4 pages

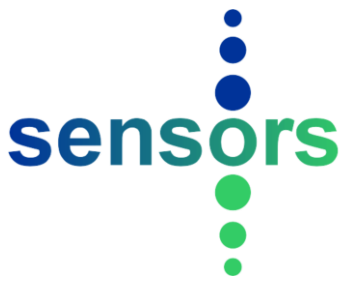
### PNC Linearity Check

Particle counting efficiency against d <sub>50</sub> =10 nm transfer standard				
Diameter (nm)	Efficiency	$ x_{min} (a-1)+a_0 $ ≤5% max	Standard Error of Estimate (SEE) ≤10% max	Correlation coefficient
70	103.1%	2.24%	4.74%	0.983
23	81.3%	0.80%	2.68%	0.992

### PNC Detection Efficiency

Component 1, PNC	
Particle size (nm)	Efficiency
15	48%
23	81%
30	89%
41	97%
50	99%
70	103%
100	106%





# Can a simplified field-based calibration be implemented for CPC PTI Devices?

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- Why CPC Technology
  - Well-designed CPC's are Intrinsically Linear
  - Particle size dependency "above cut-point" essentially zero
  - *De facto* standard in vehicle homologation (Test Cell and RDE PN Measurements)
  - Swiss PTI Program – a success story using TSI NPET (CPC)
  - Performance is predictable, reliable and deterioration factors are very low and well-established
  - Calibration methodology established ISO 27891:2015
  - Can meet the price criteria for PTI

## **YES – Metrology Data already Exists**

- For example - System Flow checks with tracer gas
- For example - CPC Span by co-location with a reference CPC device

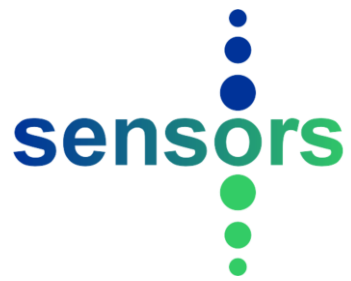
# National Metrology Institute's Ready for Particle Number

- Currently only a small handful of organizations are NMI accredited for the calibration of particle number counters.

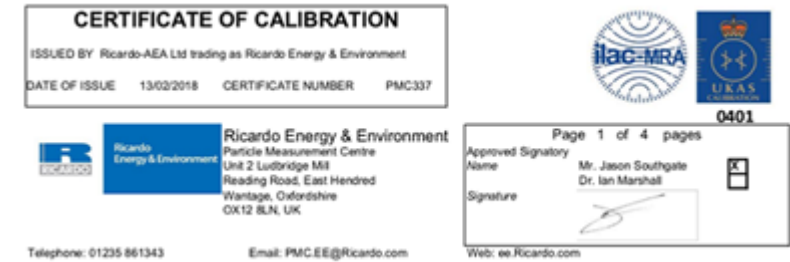
- Swiss Institute of Metrology (METAS, Swiss)
- Ricardo-AEA, UK (UKAS, ilac-MRA - NPL, UK)
- National Metrology Institute of Japan (NMIJ)



- For the German PTI Program, the PTB (Federal German Metrology Institute) will be responsible for “approving and checking” the PTI devices

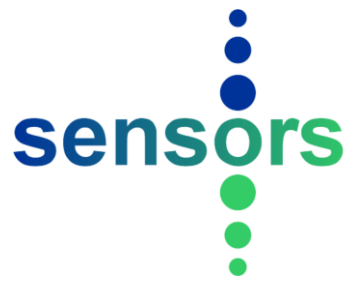


# Example – Ricardo-AEA Uncertainty Budget



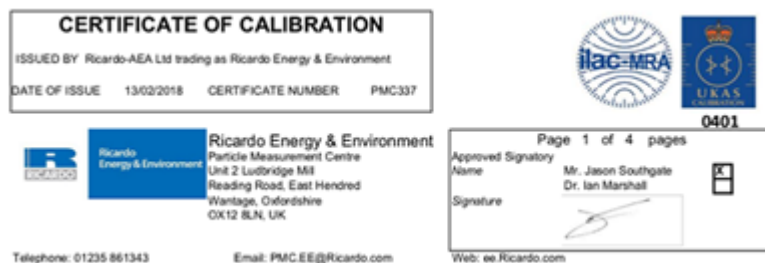
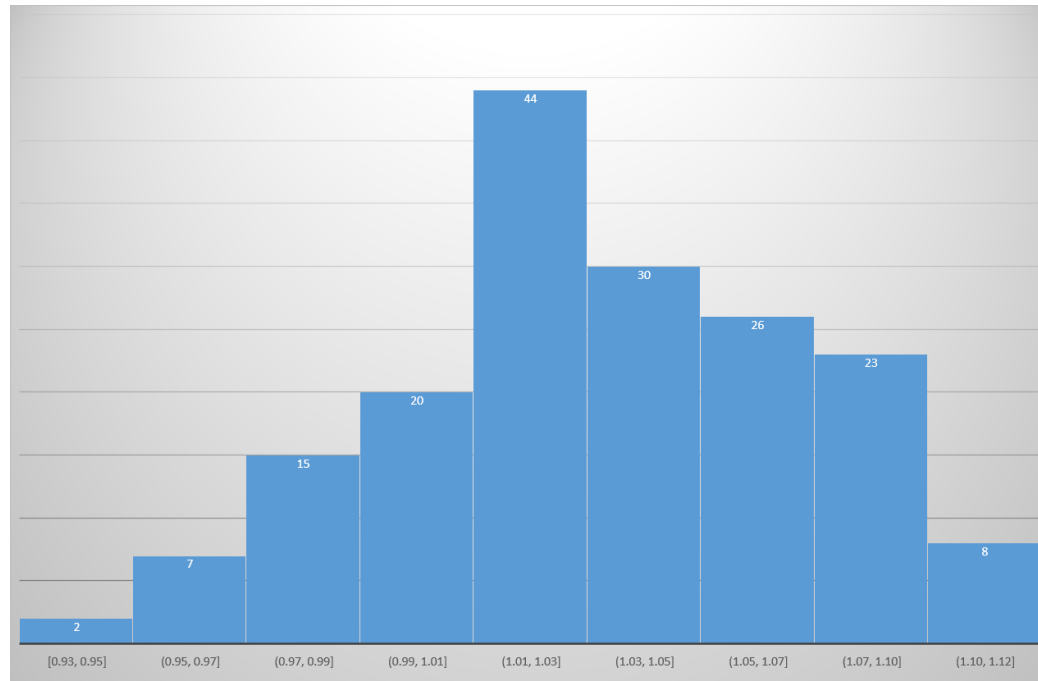
- Reference CPC
  - Inlet flow rate repeatability
  - Year on year drift at each diameter of interest (NMI calibration coefficients, 7 % expanded relative uncertainty (k=2, 95 % confidence))
- Splitter bias (assessed according to ISO27891)
- Flow meter
  - Uncertainty from calibration certificate (ISO17025 accredited)
  - Year on year drift
  - Repeatability in use
- Electrostatic Classifier
  - Year on year drift at each diameter of interest (NMI validation)
- Dilution factor
  - Method repeatability at maximum and minimum dilution conditions

***7.6 % expanded relative uncertainty (k = 2, 95 % confidence)***

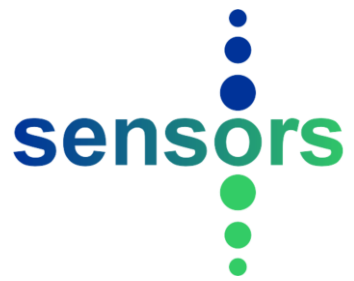


# CPC Technology - Stability Over Time

- Population of **47 individual CPCs**
- Multiple calibrations over a **7 year period** with mini-CAST generated, thermally conditioned particles
- Total of **175 separate calibrations**
- Includes the effects of service, repair, cleaning, wick changes, etc.
- ISO 17025 accredited calibration method
- 7.6 % expanded relative uncertainty (k = 2)
- **Population coefficient of variation 4 %**

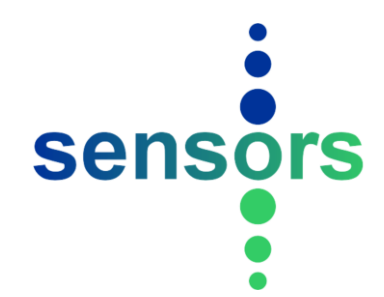






## Conclusions

- CPC Technology Suitable for PTI
  - Initial market concern was PRICE would be too high compared to alternative technologies (eg DCs).
  - Multiple suppliers with CPC technology expected to participate / sell in the EU member state PTI programs.
- Calibration and Stability over prolonged period very important
- Calibration Metrology / ISO Standard mature
- Harmonisation to Vehicle Type Approval



**THANK YOU**