HORIZON 2020

Call: H2020-GV-2016-2017

Technologies for low emission light duty powertrains

Action:

"Measuring automotive exhaust particles down to 10 nanometres – DownToTen"

Project Partners

In collaboration with:

The University of California at Riverside,

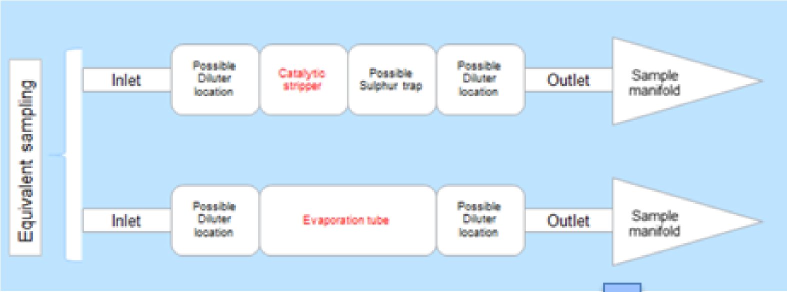
National Traffic Safety and Environmental Lab (Japan)

and

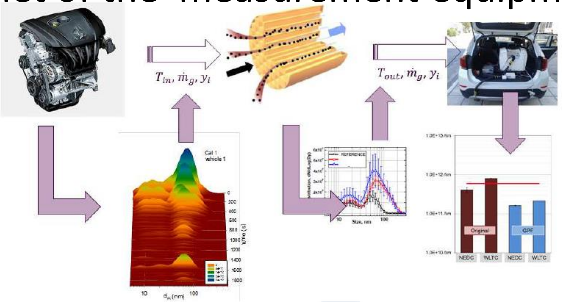
National Metrology Institute (Japan)

Concepts and approach

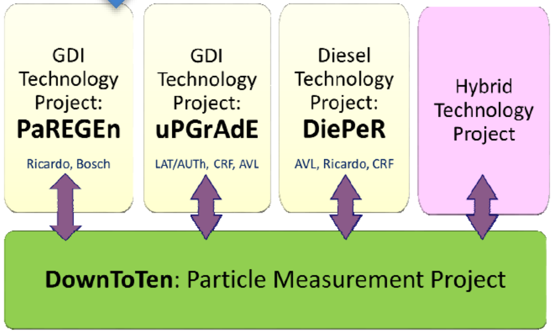
Equipment and sampling set-up (WP2 & WP3)



Modelling particle transformation (tailpipe-out to the inlet of the measurement equipment) (WP3)



Testing, including technologies that will be developed in the parallel projects (WP3 & WP4)



Synthesis and evaluation of testing results, incl. metrology (WP5)

Overview of key project results

WP	Exploitable knowledge	Exploitable product(s) or measure(s)	Sector(s) of application	Timetable for commercial use	Owner & other partners involved
[illegible]	Proposal for system to generate laboratory-grade exhaust-type of aerosol	Device and method to generate aerosol (demonstrator in month 14)	Calibration institutes, users of aerosol instruments	2020	TUT, TUM
WP2	Instrument benchmarking below 23 nm	Knowledge on instrument performance	Exhaust aerosol measurement labs	Not relevant	TUT, AVL, LAT/AUTh, RICARDO
WP3	Understanding formation, properties and characteristics of PN <23 nm	PN <23 nm definition for regulatory purposes	Standardization and regulatory bodies	2018	Entire consortium
WP3	PN <23 nm sampling configuration for laboratory testing and PEMS	Demonstrator (in month 17)	Exhaust aerosol measurement labs	2020	TUT, AVL, LAT/AUTh, RICARDO
WP3	PN <23 nm measurement configuration	Instrumentation to be proposed	Exhaust aerosol measurement labs	Not relevant	Entire consortium
WP4	DownToTen PN PEMS demonstrator unit	Device and Test protocol (demonstrator in month 22)	Exhaust aerosol measurement labs, regulatory authorities	2020	TUG, AVL, LAT/AUTh, RICARDO, TUT
WP4	Evaluation procedures for RDE particle number	Software code and method (demonstrator in month 32)	Exhaust aerosol measurement labs, regulatory authorities	2019	TUG, AVL, LAT/AUTh, RICARDO, JRC
WP5	Emission perform... of late and forthcomin... e types	Emission factors to be used in models and estimates	Air quality research, policy making	2019	LAT/AUTH, TUG, TUT, TUM
WP5	...easuring	Calibration test protocols	Standardization and regulatory bodies	2020	TUT, TUG, TUM, JRC
WP5	...processes ...on	Simulation model	Researchers, manufacturers	2021	LAT/AUTH, TUT

Months 1 – Month 14
Currently at Month 20

Months 7 – Month 21
Currently at Month 20

Months 16 – Month 32
Currently at Month 20

Vehicle class	Engines	Exhaust aftertreatment	Fuels	Cycles	Potential Source of the test vehicles
Passenger cars	GDI & PFI	3WC with and without GPF	Reference Petrol and biofuel admixtures	NEDC, WLTC, 3 RDE cycles; real PEMS trips	uPGrAdE, PaREGEn
	SI-Hybrid	3WC with and without GPF			A hybrid from GV-2-2016
	Diesel	SCR and/ or NSC with DPF	Reference diesel and biofuel admixtures		DiePeR
	CI-Hybrid	SCR/NSC with DPF			A hybrid from GV-2-2016
	CNG	3WC with and without GPF	Different qualities		GasON
HDV	Diesel	SCR and DPF	Reference diesel and biofuel admixtures	WHVC, standard CO2-vehicle test cycles; PEMS trips	To be decided
	CNG	Not decided yet	Different qualities		To be decided
2-wheelers	≥500ccm	3WC	Reference Petrol and biofuel admixtures	WMTC, RDE cycles, PEMS test for >500ccm	Suggestions from the German programme
	50ccm	3WC			

Progress to month 18

WP2: Survey of exhaust particles and their properties

- Two areas were identified where current knowledge and publications appear especially limited:
  a) direct composition analysis of sub-23 nm particles,
  b) the limitations and capabilities of GPFs

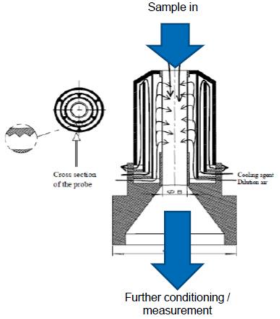
- GDI vehicles emit more PN than (DPF-equipped) diesels of the same generation

- Secondary aerosol emissions are especially relevant to gasoline vehicles – these emissions levels are generally higher than the PM emission standards for diesel and GDI vehicles

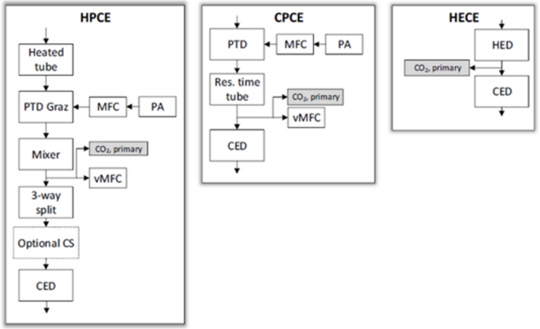
WP2: Performance of selected high temperature aerosol sampling systems - The principal system

- The principal chosen system
  - A 2-stage dilution system combining a heated porous tube-type primary dilution stage, and an ejector type secondary dilution stage
  - 2 catalytic strippers (CS) assessed
- Comparison with double ejector systems (cold and hot)
- A commercial PN-PEMS system was included for solid particle loss comparison
- In parallel, methods to define the origin and composition of the nanoparticles emitted by novel engine concepts have been explored

Porous tube dilutor



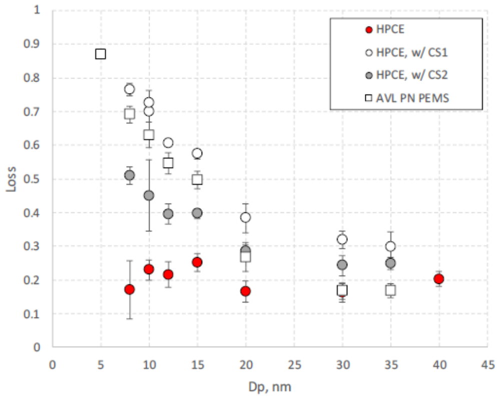
Comparison lay-out



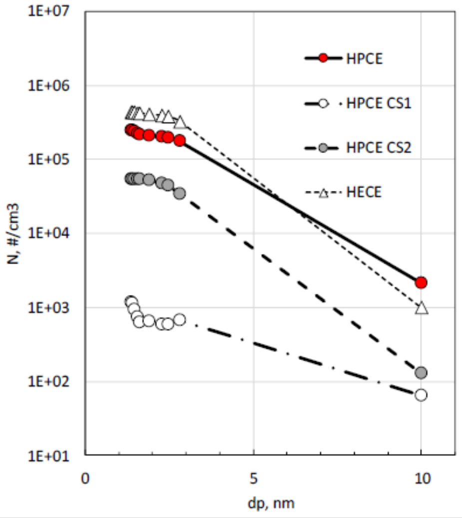
WP2: Performance of chosen high temperature aerosol sampling systems - Evaluation

- The systems facilitates solid particle measurement down to 10 nm with acceptable losses and apparent robustness against semi-volatile particle artefacts
- Highest diffusion losses were observed inside the catalytic strippers
- Thermophoresis was most substantial in the cold ejector dilution step
- No nucleation mode artefact was observed, although a sulfuric acid related nano-cluster aerosol mode was observed below 3 nm
- The system without the CS can be used for secondary aerosol emission characterization
- The use of CS was advised, at least as an option

Particle losses for HPCE diluter and for dilution system of AVL PN PEMS



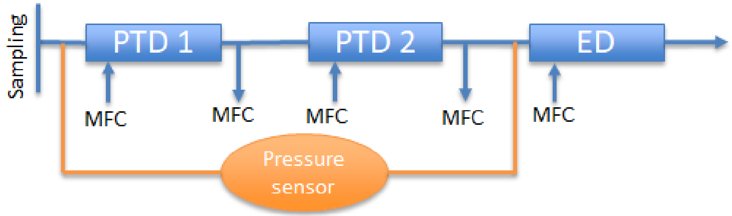
Cumulative size distributions

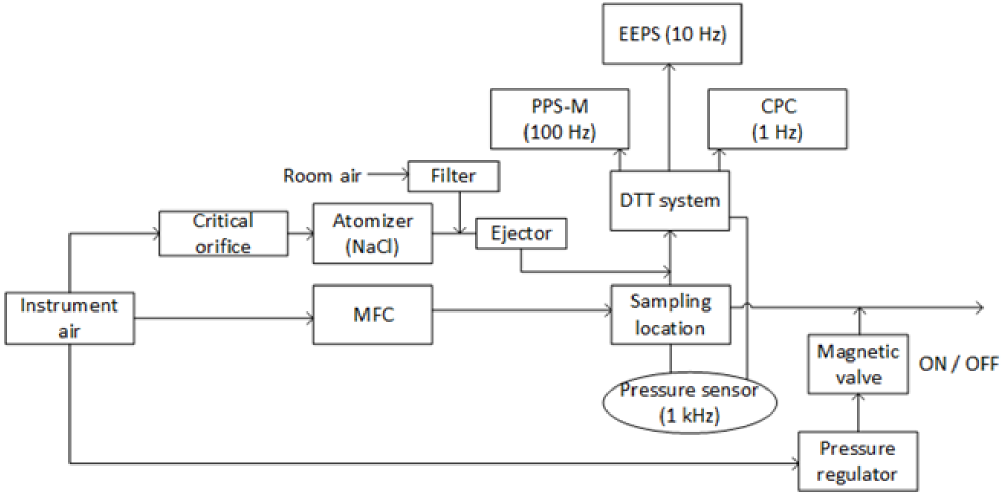


WP2: Assessment of sampling and instrumentation methods with laboratory aerosols – Effect of pressure

- Characterize the dilution performance with different inlet pressure levels for PD+PD+ED system

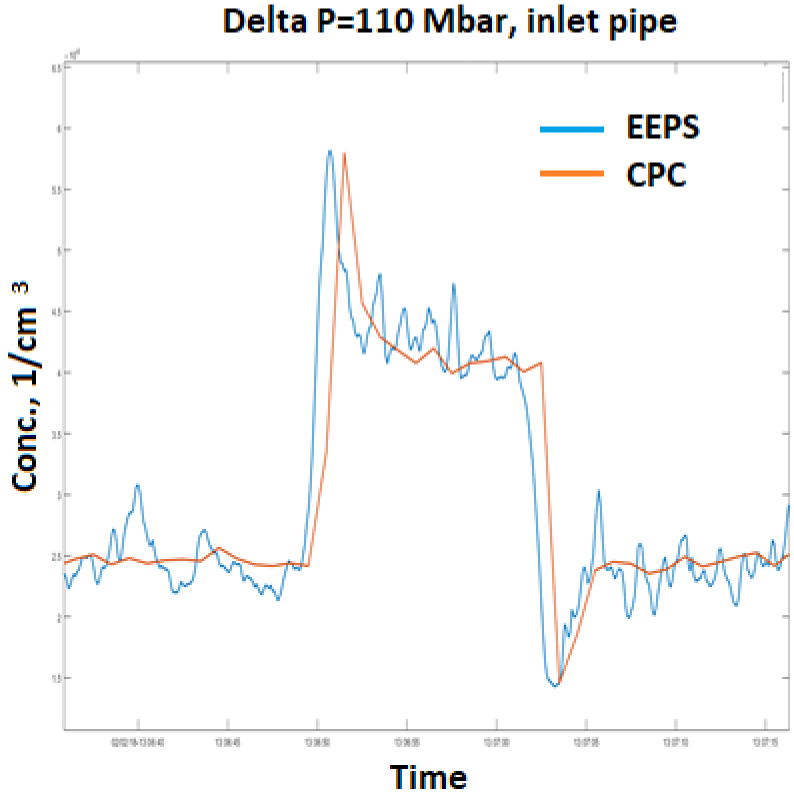
- Challenge the "2nd gen" DTT sampling system with fast changes in pressure level





WP2: Assessment of sampling and instrumentation methods with laboratory aerosols - Effect of pressure (2)

- Stepwise inlet pressure variation imposes a predictable concentration increase on CPC and EEPS during operation, mainly due to ED behavior
- Simple transfer function model is being developed for better correlation of MFC behavior
- With transient pressure changes, the different time responses of MFC and ED negatively impact DR stability



WP2: Conclusions and recommendations

Nonvolatile particle losses

- Identified loss issues with components
  - Diffusion: mostly at the CS
  - Thermophoresis: in prototype cold ED
- Possible solutions
  - Cooling dilution with porous tube (minimize thermophoresis)
  - Optimising the CS size

Artefact formation

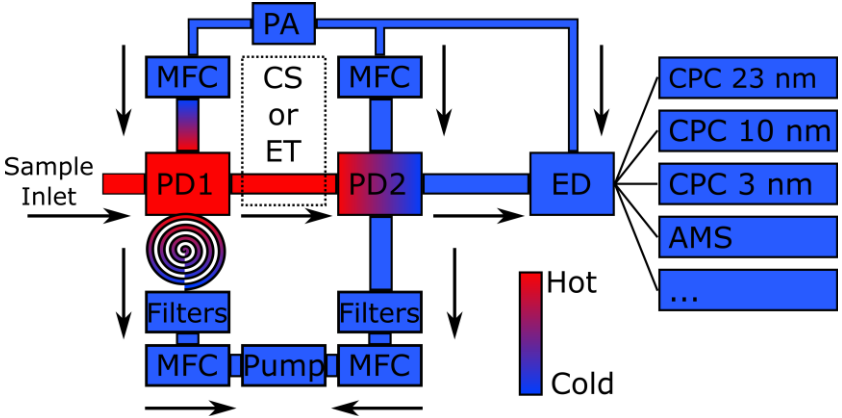
- The HPCE system appeared to be artefact free at 10 nm. However, HC content in real exhaust aerosol could cause particle growth into the measured range. The CS effectively reduced particle growth.

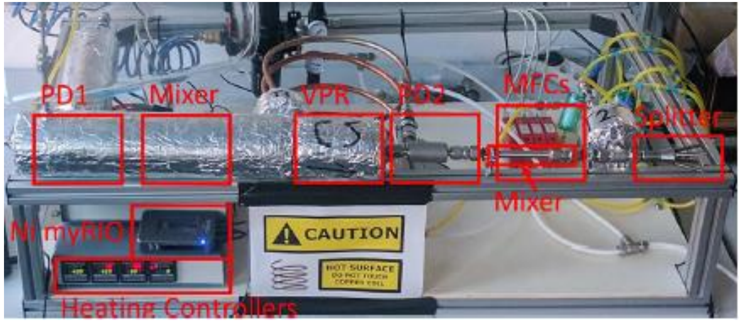
Secondary aerosol sampling

- The system can be used for secondary aerosol emission characterization by using a separate line after the first dilution stage

WP3: Equipment and sampling set-up

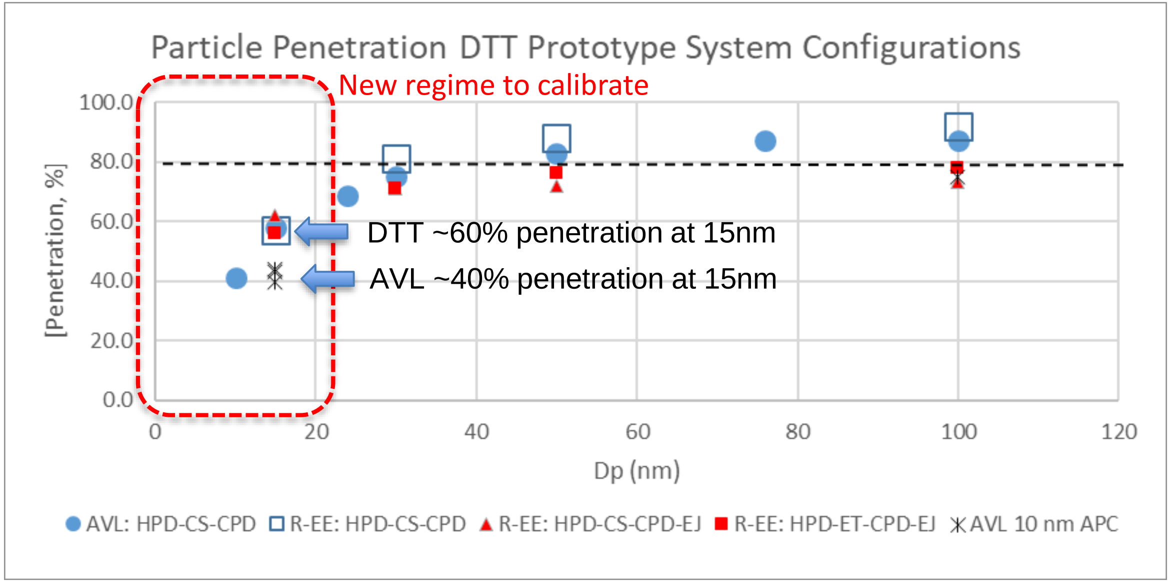
- The prototype DTT measurement system was constructed following WP2 recommendations, and comprises:
  - Two Porous Tube Dilutors (PD1, PD2)
  - A third (optional) dilution stage (ejector diluter, ED)
  - An evaporation tube (ET) or a CS that can be placed between the two PD





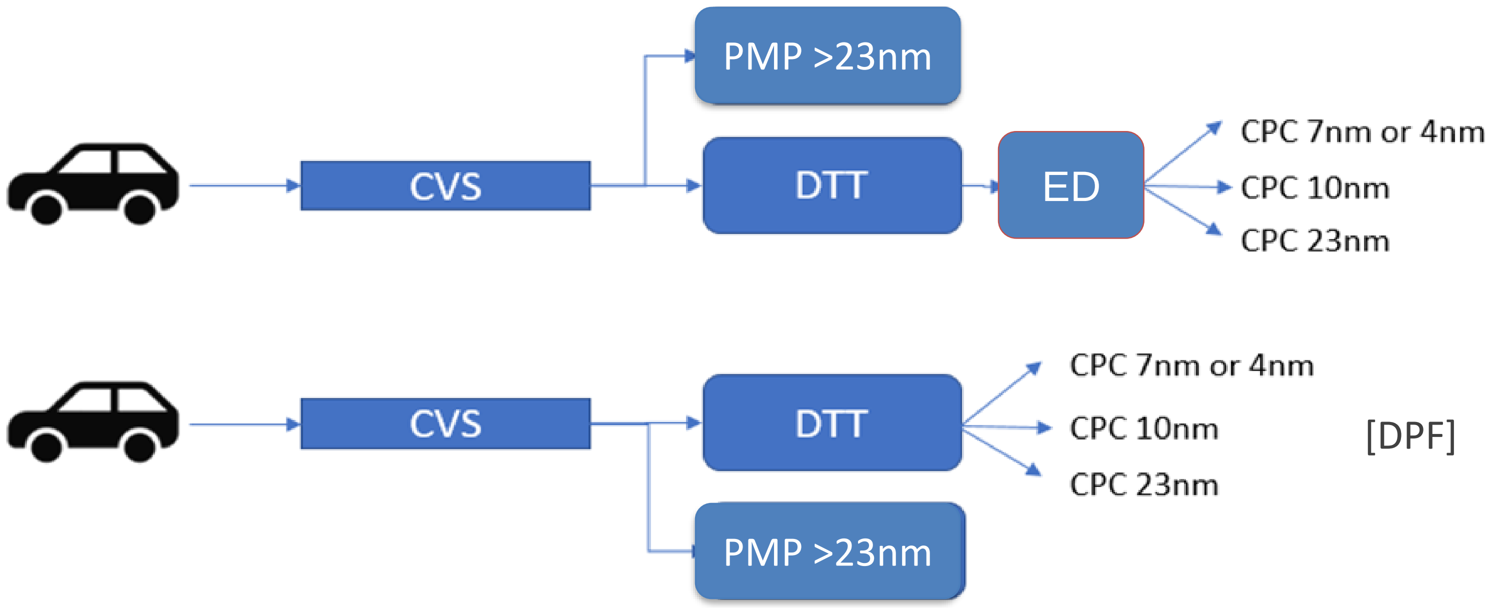
WP3: Equipment and sampling set-up – Evaluation of losses

- The penetration performance of the DTT prototype system when equipped with a CS as VPR is not appreciably different to that seen when an ET-based VPR is used
- The benefits of the CS in eliminating potential volatile artefacts justify its selection in preference to ET, and prioritization in this study



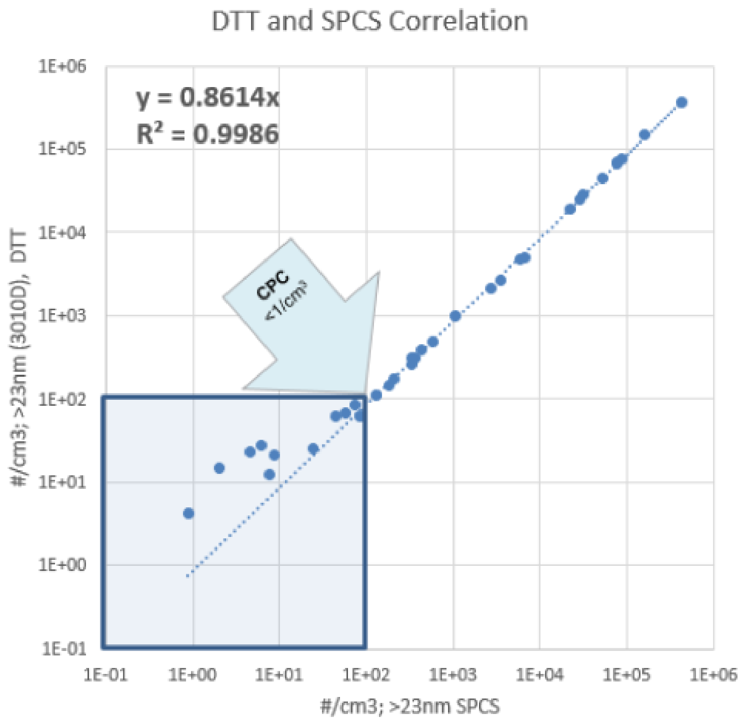
The 20% of baseline losses are attributed to thermophoretic losses

WP3: Typical sampling set-up



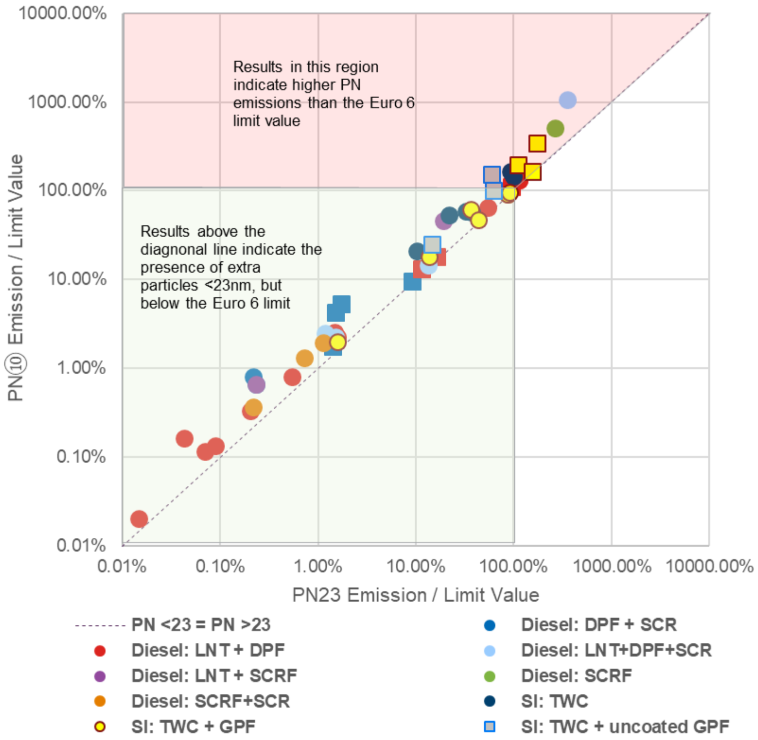
WP3: Equipment and sampling set-up – Correlation with Horiba SPCS

- Excellent linear agreement between the DTT system and Horiba 2000SPCS above 1#/cm^3 across a wide concentration range (four orders of magnitude)
  - There are larger differences below this point, due to differences in dilution ratio and background particle levels in the two systems
- At >1#/cm^3, the DTT system reports ~14% lower than the commercial system
  - NOTE: data used are corrected for dilution factors, but no PCRF correction is applied to data from either system



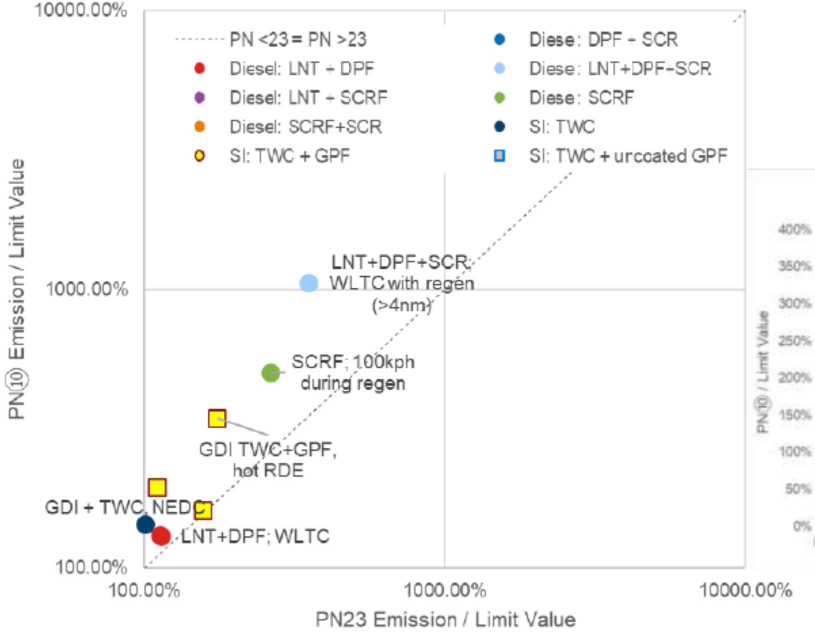
WP3: Equipment and sampling set-up – Non-volatile PN emissions from Standard Emissions Cycles

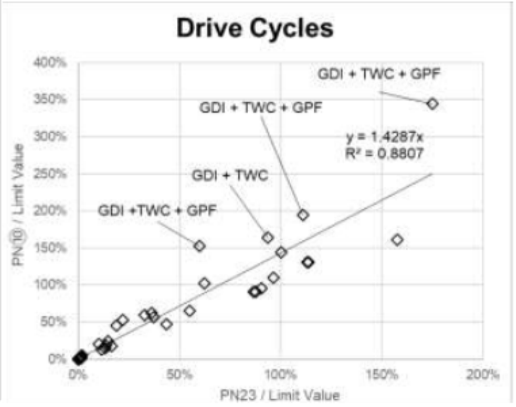
- All chassis dyno: includes US Cycles, Japan cycles, NEDC, WLTC, moderate RDE and some cruises
  - ✓ Plus some fuel and climatic variations
- PN⑩ represents measurements with a particle counter that has a 50% counting efficiency at 7 or 10nm
- PN23 represents the current PN
- Majority of tests show both PN⑩ and PN23 to be below the current European PN limit value
- ***A few results demonstrate emissions levels of PN⑩up to ~10x the current limit value, with these tests also exceeding the limit value for the PN23 range***



WP3: Equipment and sampling set-up – The ''Exceedance Zone''

- DPF regenerations show highest PN emissions in both PN23 and PN⑩ ranges
  - ✓ 10-23nm fraction increases more than >23nm range, but can be dealt with by Ki factor approach
- GDI, even with GPF, can exceed the current limit value, but not substantially
- A few non-regenerating LNT-equipped diesel results also found to be slightly above the limit
- On average, PN⑩ is ~40% higher than PN23





Remember: no PCRF with either system

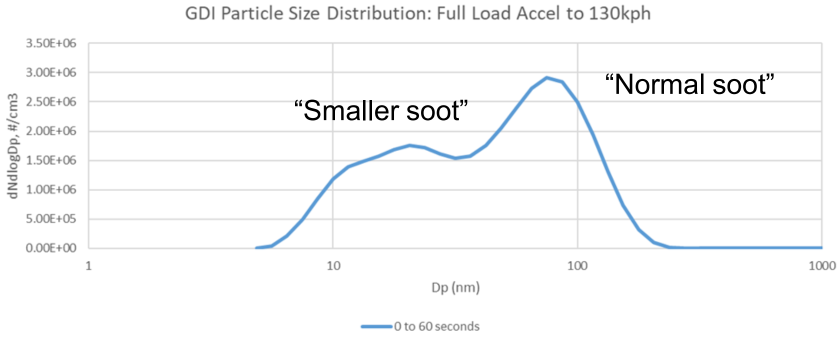
WP3: Testing measurement systems with challenging internal combustion engine aerosols

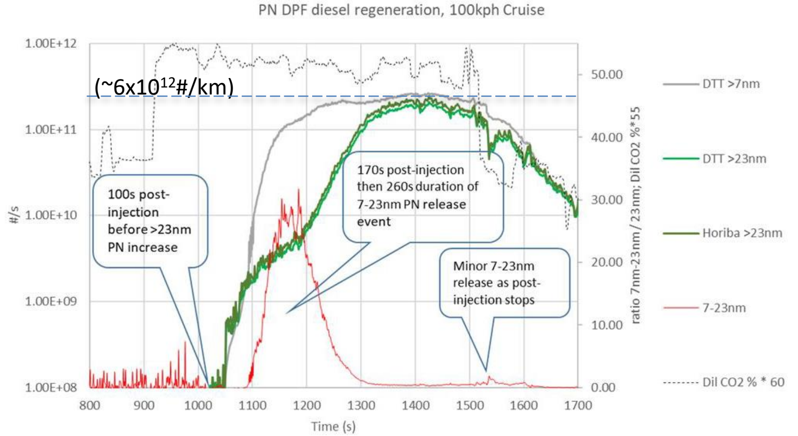
- The most demanding real-exhaust test aerosols are being actively generated, and used to both:
  - Test the DTT system
  - Search for sampling and measurement artefacts
- A number of light-duty vehicles/engines with different technologies are employed:
  - Stoichiometric GDI and 4WC for GDI,
  - Diesel DOC, DPF, LNT and SCR
  - Gas LPG & CNG

WP3: Equipment and sampling set-up
– Where do we generate solid <23nm particles?

- Hard accelerations may produce an additional mode of non-volatile particles in the sub-23nm range alongside a conventional soot (accumulation) mode

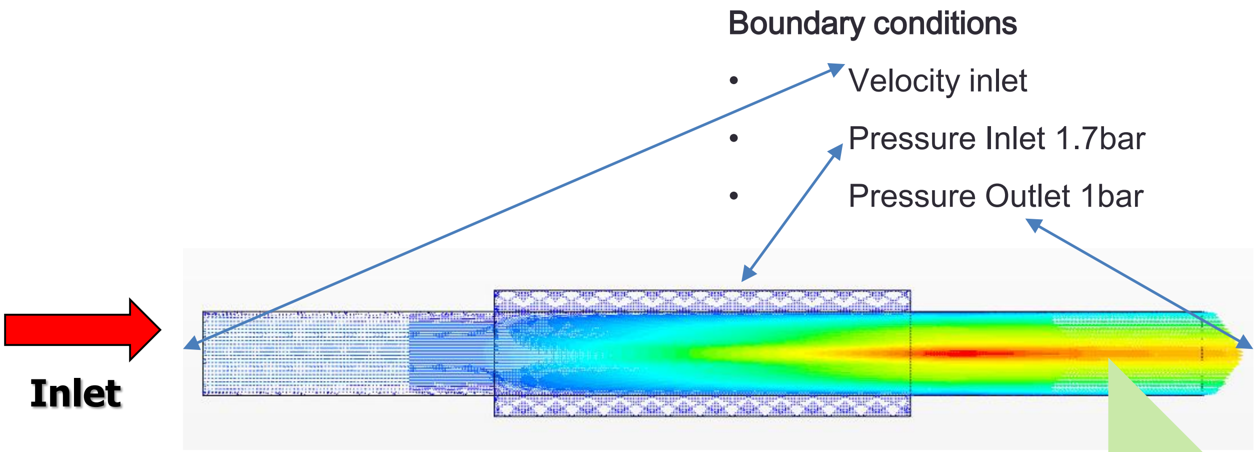
- There is a major <23nm particle production event that takes place a few minutes after diesel post-injection starts. This leads to emissions of <23nm particles at levels 10 to 100x times those seen in the >23nm range for a period of 2-3 minutes
- These particles are mostly <10nm, and the levels of particles emitted above 7nm, along with the short duration of the event, are not high enough to influence a pass or fail result at the Euro 6c PN limit, once the Ki factor is included





WP3: Evaluation of sampling conditions and measurement set-up - Raw vs Dilute Particle Sampling Modelling

- Modal aerosol dynamics model (first version has been developed and is currently validated)
- Current CFD investigation focused on PTD -unsteady simulation

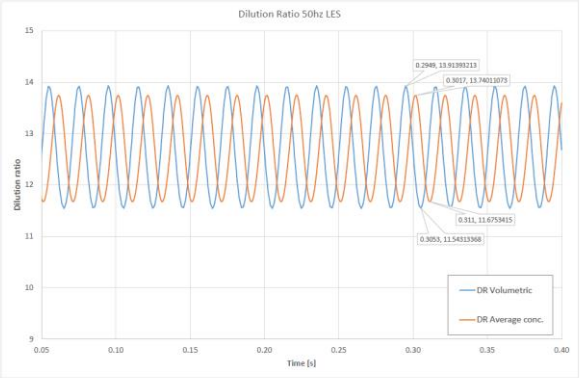


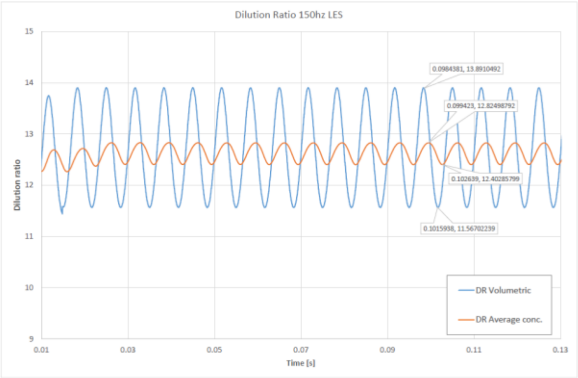
Baseline model evaluation and Shear Stress Transport (SST) turbulence model implementation
- SST model implementation in steady state model
- SST model in unsteady state

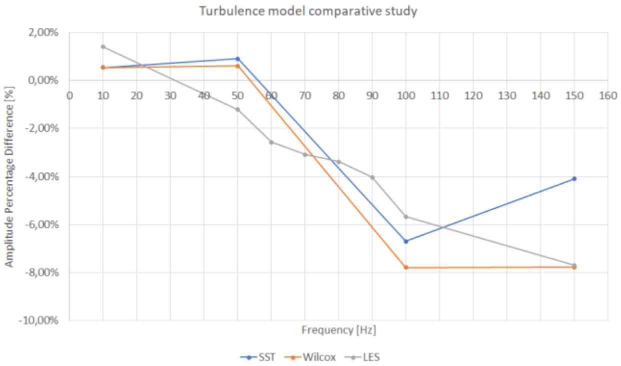
Implementation of Wilcox turbulence model in Baseline
- Wilcox model evaluation steady state
- Wilcox mode in unsteady state

Implementation of Large Eddy Simulation (LES) in Baseline
- LES evaluation steady state
- LES in unsteady state

WP3: Evaluation of sampling conditions and measurement set-up - Dilution ratio analysis







- Air flow rate is constant due to high porous media resistance
  - Agreement with the baseline model prediction
- Volumetric DR fluctuates with same amplitude as inlet velocity - amplitude independent of frequency
- Concentration-based DR amplitude reduces as frequency increases
- Further work is underway investigating the effects of the second porous tube and ejector diluters

WP3: Findings up to now and next steps

- The DTT system has a 23nm response that is highly correlated with production systems
- Measurements of a range of vehicle technologies, aftertreatment, fuels and regulatory emissions cycles show:
  - That even when extending the size range down to 10nm, or just below, most non-volatile particle emissions remain below the certification limit, even though measured levels increase by ~40% on average
  - Some technologies / aftertreatment can produce levels above the limit value, but increases are relatively small: mainly SI (with and without GPF), Diesel with LNT
- Some isolated 'periodic' events can produce dramatic increases in non-volatile <23nm PM, but even these do not appear to have a large influence on regulatory compliance
- It is not yet certain that an increase in the regulatory size range will deliver any benefit
- Functional aspects
  - Develop the prototype from the lab into the real-world raw-exhaust environment
- Technologies not yet rigorously explored in CVS
  - Gas engines, extreme fuels, climatic effects
- Shift to PEMS based system / raw exhaust in CVS facility and test cells
  - Focus on 'extreme sources' from current work
  - Validation of measurement approach / evolution
- Coupling aerosol model with CFD
- Continue the parallel workstream looking at semi-volatile and secondary particles

WP4: Development of test protocols and performance of testing campaign

- WP4 started at month 16 of the project (January 2018) and the work proceeds as planned

Any questions ?