AECC/Concawe 2016 GPF RDE PN Test Programme: PN Measurement Above and Below 23nm

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21st ETH-Conference on Combustion Generated Nanoparticles
June 19th - 22nd, 2017, ETH Zurich, Switzerland

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Introduction

- The introduction of Real Driving Emissions (RDE) and the inclusion of a Particle Number (PN) limit for direct injection gasoline (GDI) vehicles has accelerated the development of Gasoline Particle Filters (GPF)
  - GPFs are expected to appear on mass-market production vehicles during 2017
- As part of a larger programme exploring exhaust emissions under RDE, a 1.4 litre Euro 6b stoichiometric lambda 1 GDI was tested in standard build, and when retrofitted with a catalysed-GPF
- Particle number measurements were made of >23nm "$PN_{\uparrow 23}$" and >7nm "$PN_{\uparrow 7}$" size ranges to explore emissions levels and filtration impacts under a range of operating conditions

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PN-related Objectives

- To measure PN emissions from Real Driving Emissions (RDE) tests transposed to a chassis dynamometer and evaluate impact of moving towards RDE boundary conditions, including:
  - Normal and reduced test temperatures: 23°C, 0°C, -7°C
  - Dyno load changes: ~ road load, ~25% increase, ~50% increase
- To assess the impact of a specific GPF on PN emissions
  - Including impact on PN $_{\uparrow 7}$ and PN$_{\uparrow 23}$, if different
- Extras
  - To compare magnitude of PN-PEMS and CVS-based PN emissions
  - To assess any impact of a TWC on PN reduction

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PN Systems' Sampling Configurations
2 raw systems, 2 dilute systems, >7nm system, 3 x >23nm systems

	Initial dilution	Pre-classifier	PND_1 (diluter#1)	Volatile Removal	PND_2 (diluter#2)	PNC (counter)
4: Raw PN-PEMS (prototype)	[-]	1µm	dilution 10 ambient	DOC 350°C	dilution 10 ambient	d50 23nm
3: Raw SPCS	dilution 10 ≤350°C	<10µm	dilution 10 ~190°C	Evap tube 350°C	dilution 15 < 35°C	d50 23nm
2: *Dilute* Catalytic Stripper	CVS (<30) <52°C	[-]	[-]	DOC 350°C	[-]	**d50 7nm***
1: *Dilute* SPCS	CVS (<30) <52°C	<10µm	dilution 10 ~190°C	Evap tube 350°C	dilution 15 < 35°C	d50 23nm

**The emissions levels recorded with the 7nm d50 CPC were corrected for losses in the catalytic stripper*

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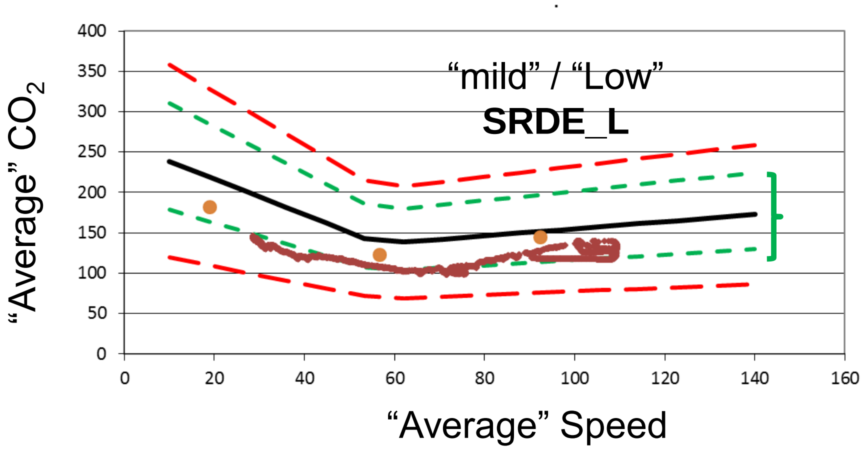
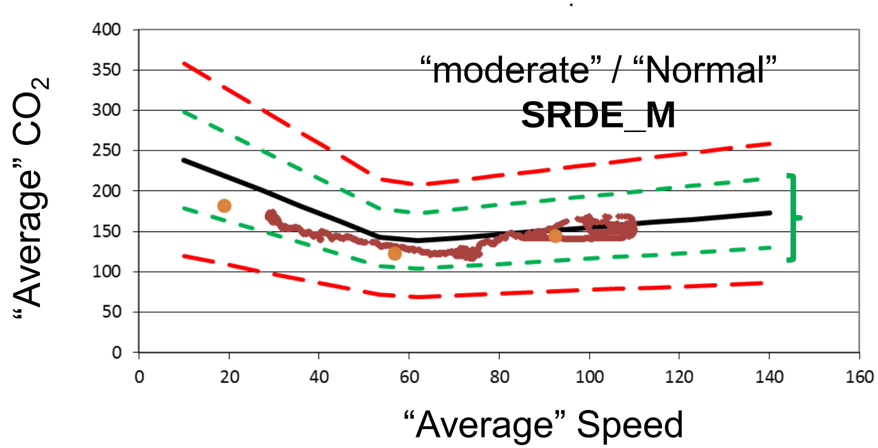
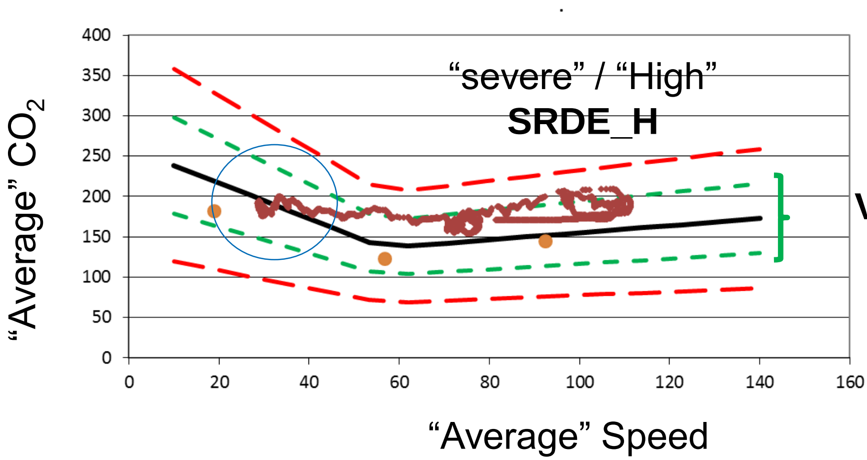
Test Cycles

- Regulatory Test Cycles at 23°C conducted at dyno load consistent with real road load
  - NEDC
  - WLTC
- Real Driving Emissions (RDE)
  - Based upon actual valid on-road drive
  - EMROAD processing of RDE using WLTC cycle conducted above
  - On road cycle then transposed to dyno, driven and reprocessed in EMROAD
    - CO_2 levels from on-road and on-dyno very close
- Real Driving Emissions (RDE) performed on dyno with increased acceleration rates
  - Nominated as SRDE (Severitized RDE)
  - Minimal increase in dyno load
    - SRDE_L at 23°C
    - SRDE_L0 at 0°C
    - SRDE_L-7 at -7°C
  - ~25% increase of dyno load
    - SRDE_M
  - ~50% increase of dyno load
    - SRDE_H [also 0°C & -7°C]
- SRDE variants tested with and without GPF

EMROAD outputs for On-dyno RDE: SRDE_L, SRDE_M, SRDE_H







Valid range for RDE data

- SRDE approach allows the valid RDE "space" to be explored within the controllable environment of the test laboratory

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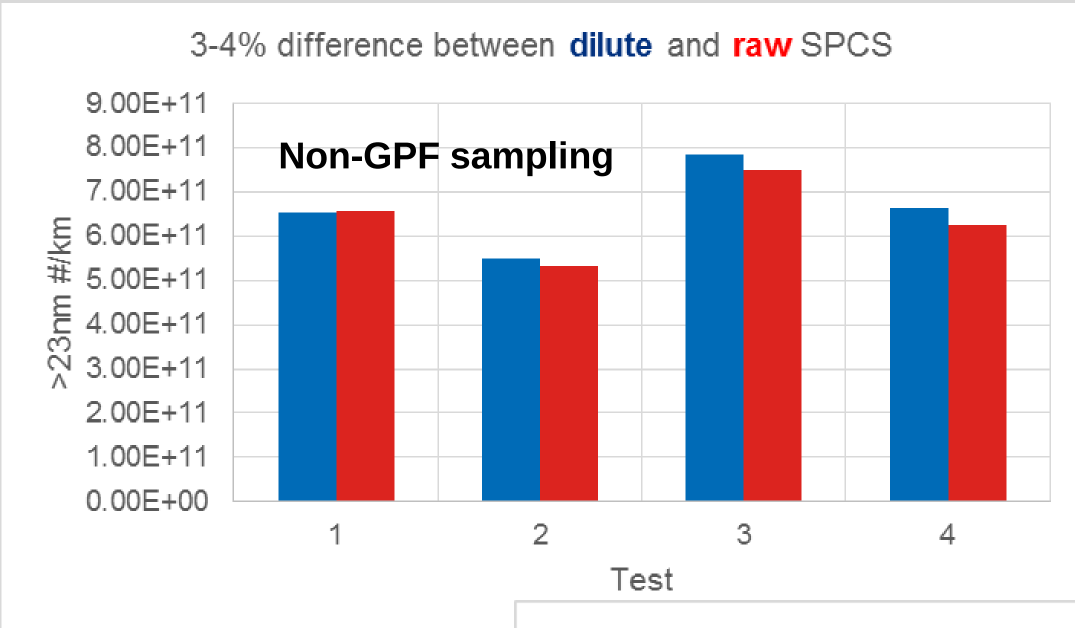
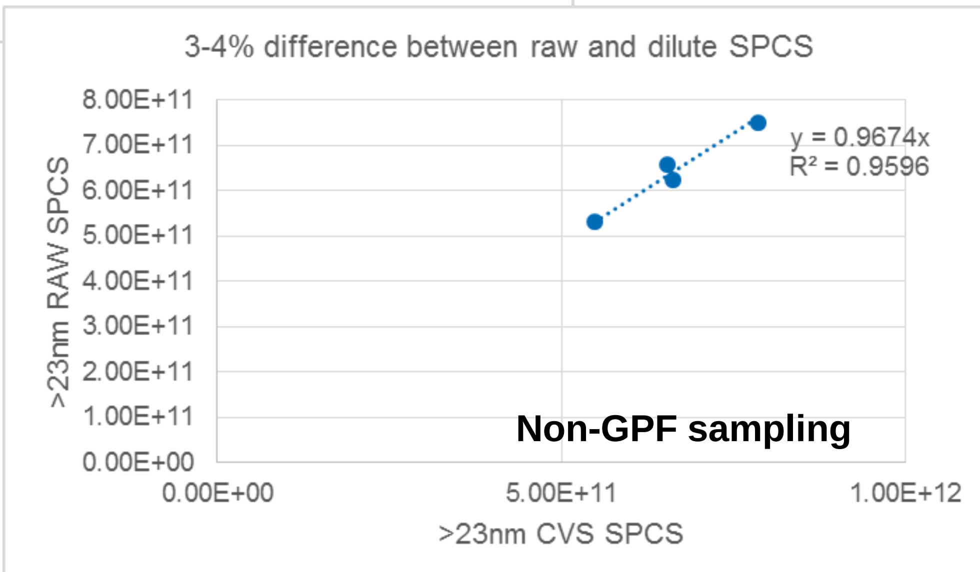
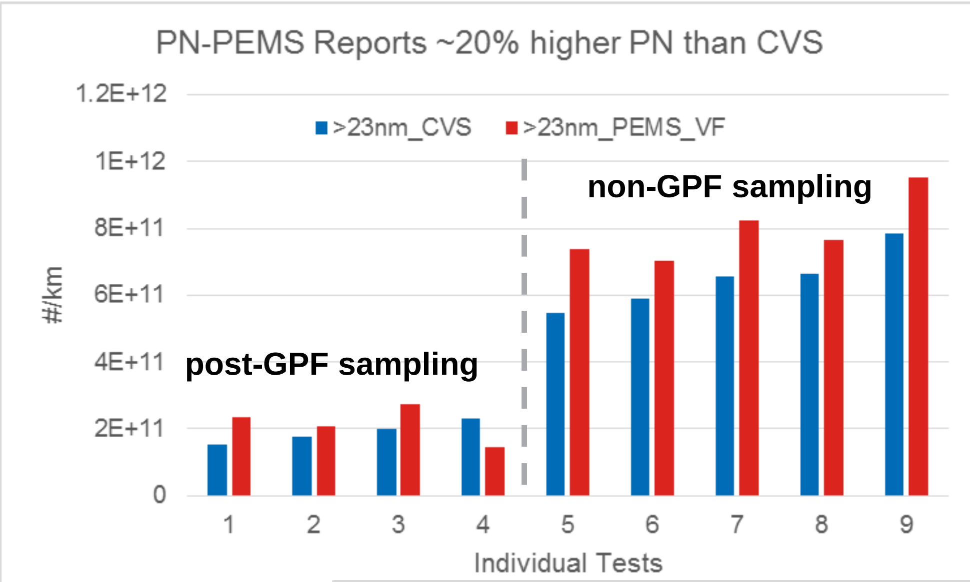
CVS (dilute) and Raw >23nm PN sampling appear sufficiently similar to be considered equivalent

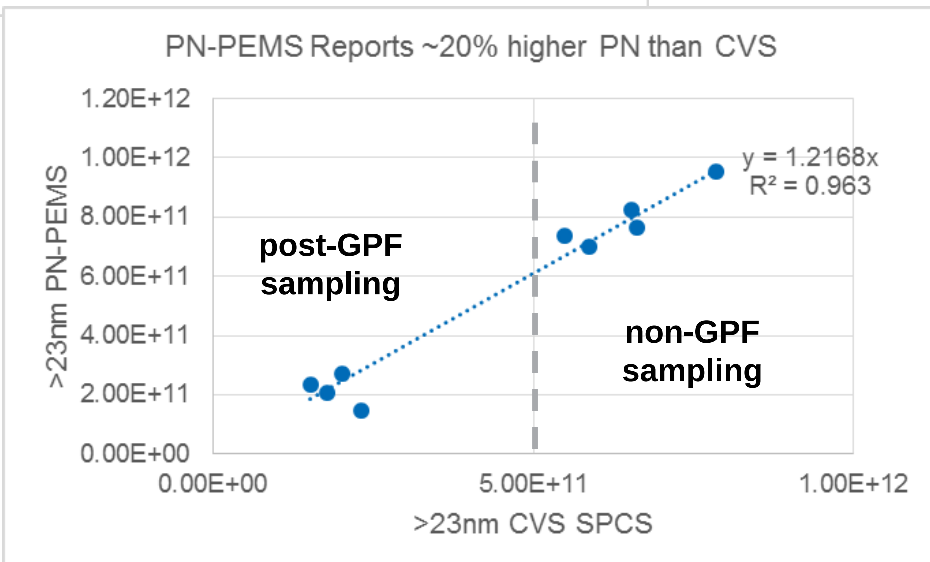




- Comparison of raw and dilute SPCS systems indicates <5% difference
- CVS levels are slightly higher
  - May indicate CVS background contribution not present in raw sample
  - Other differences exist though
    - Additional raw diluter
    - Different pre-classifier

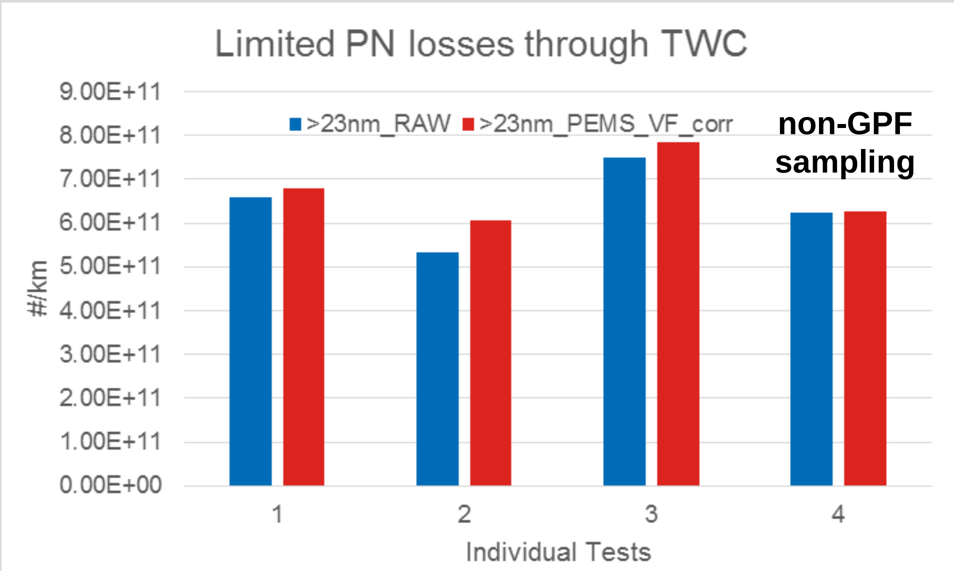
Prototype PN-PEMS system shows good correlation with CVS-based $PN_{\uparrow 23}$ system, but ~20% higher levels

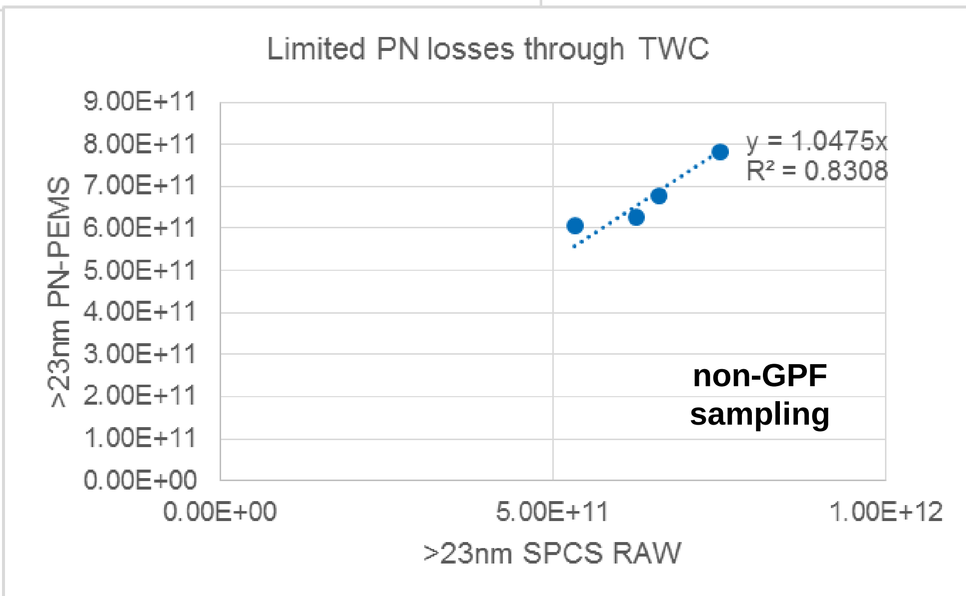




- Draft RDE regulation requires measured PEMS emissions to be ±50% of CVS levels
  - Easily achieved
- Higher PEMS-PN levels indicative of differences in:
  - Methodology for corrections of losses
  - Absolute losses (raw v dilute)
- Good linearity of relationship allows ‘correction’ of PN-PEMS data to simulate CVS levels from raw exhaust

The Three-Way Catalyst (TWC) is not a major source of particle removal or loss



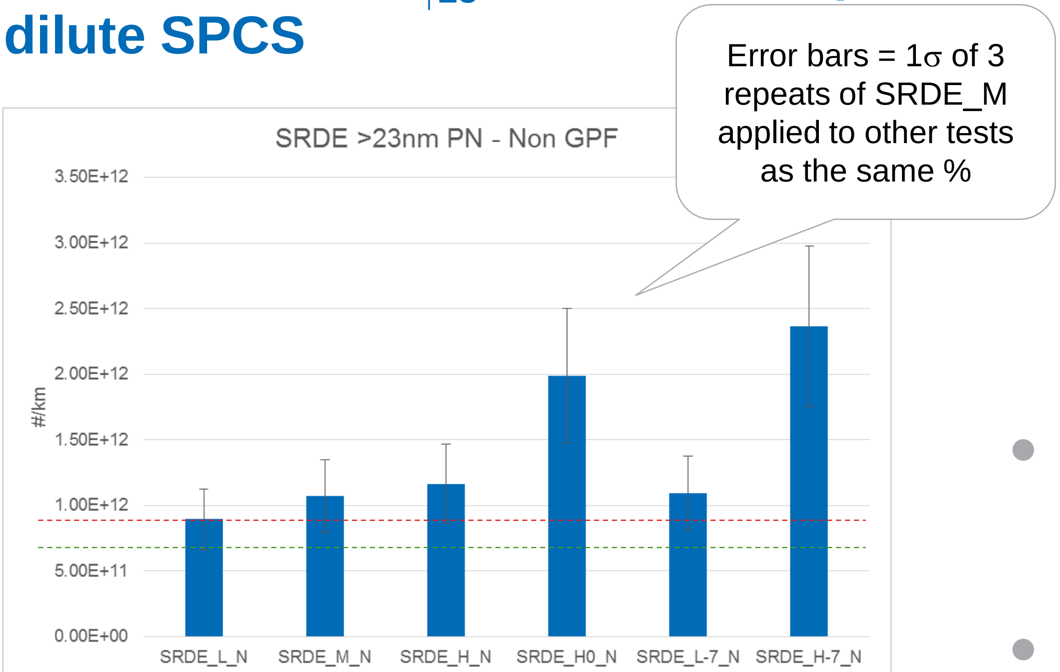


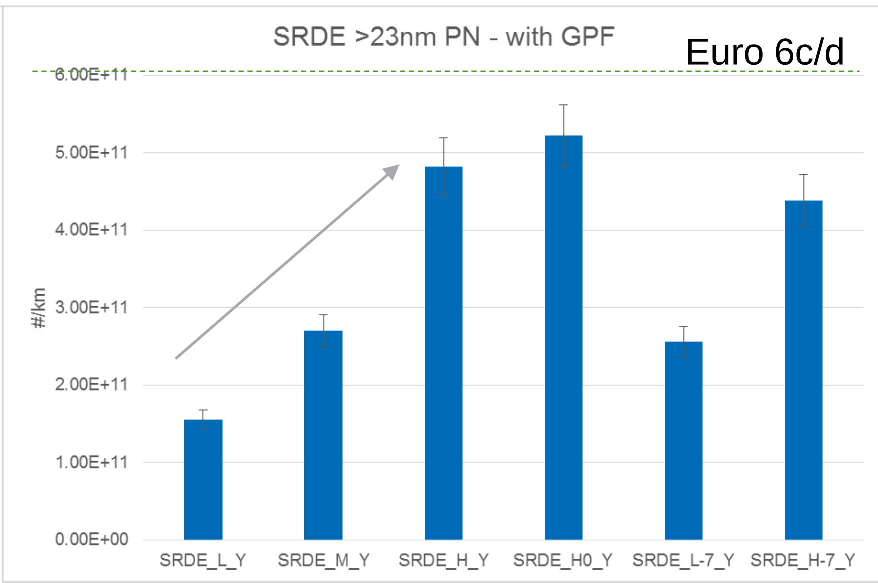
- Equating non-GPF measurements from the raw SPCS (pre-TWC) with the 'corrected' tailpipe PN-PEMS shows <5% difference
- Losses / elimination of particles in the TWC are <10%
  - With the difference between raw and dilute SPCS factored-in

0°C and -7°C SRDE $PN_{\uparrow 23}$ data, based upon CVS measurements using dilute SPCS

CF=1.5

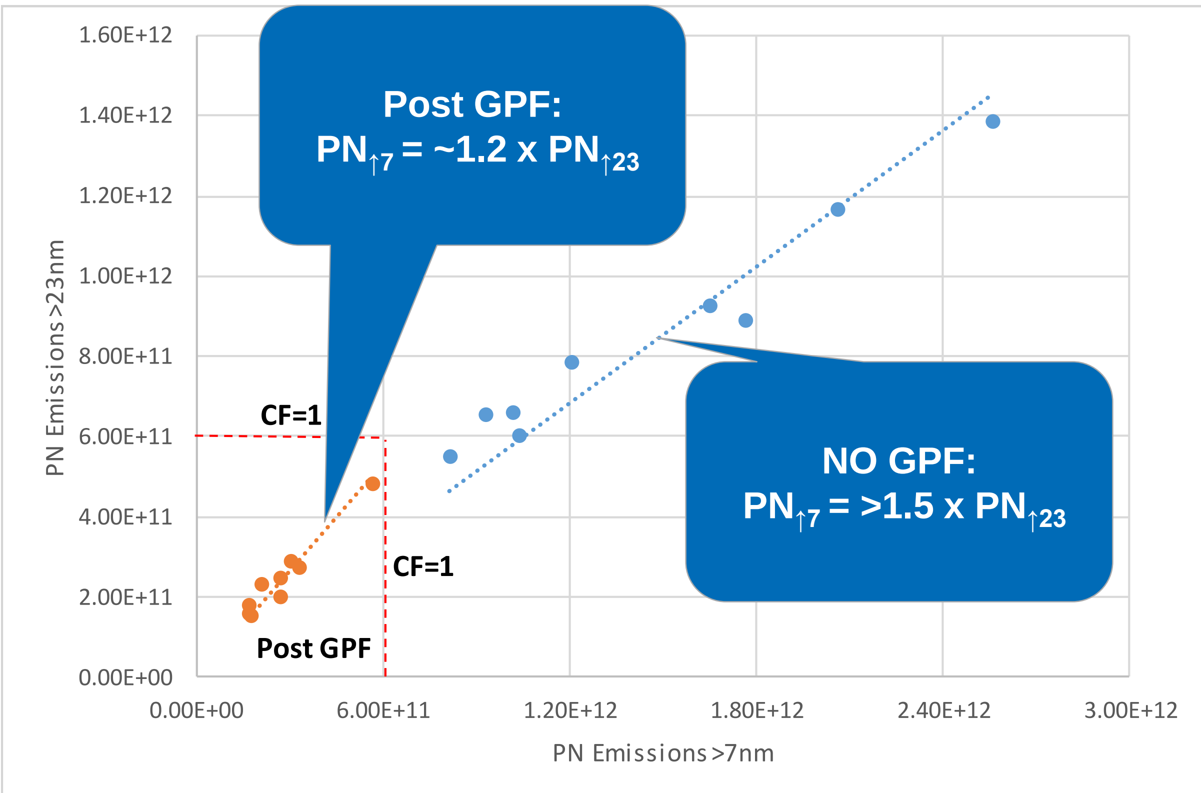
Euro 6c/d





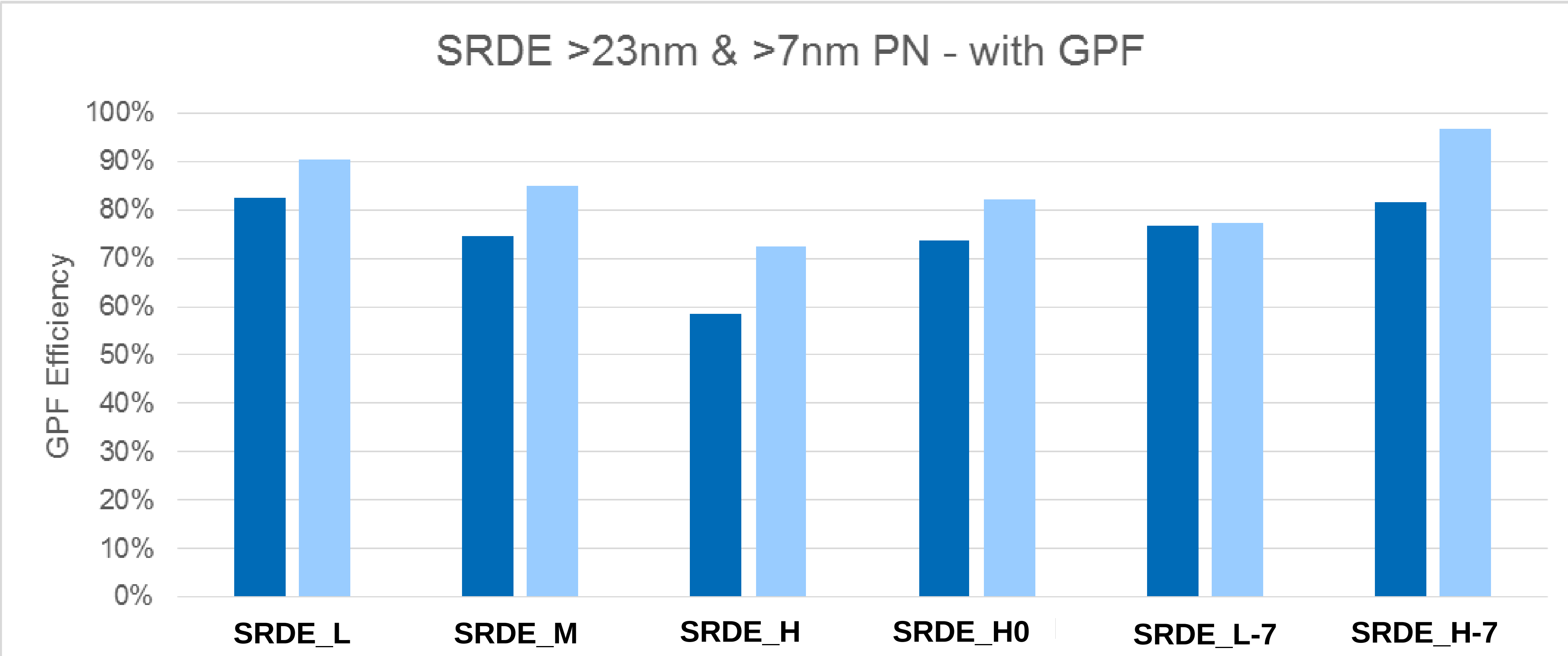
- $PN_{\uparrow 23}$ levels rise as cold-start temperature reduces
  - Larger rise 23°C to 0°C than from 0°C to -7°C
- Post-GPF PN levels rise by ~80% with each step from SRDE_L to SRDE_M to SRDE_H
- Engine-out PN levels from all conditions equal to, or in excess of CF=1.5
- Post-GPF $PN_{\uparrow 23}$ levels below CF=1 from all SRDE

Relationship between total $PN_{\uparrow 7}$ and total $PN_{\uparrow 23}$ changes when specific GPF is applied



- CVS-based measurements of $PN_{\uparrow 7}$ and $PN_{\uparrow 23}$ show that all post-GPF tests' emissions were below the Euro 6c limit
  - NEDC, WLTC and SRDE_L,M &H testing
- When a GPF is applied, the differential between the number of particles >7nm and the number of particles >23nm is minimised
- The GPF appears to preferentially trap the smallest particles
  - Diffusion collection mechanism dominates

GPF efficiencies for >23nm particles range from ~60% to ~80%, but are exceeded by >7nm efficiencies (70% to >90%)



- Observed increase in filtration efficiency between >7nm and >23nm ranges indicates larger increase for 7nm to 23nm range in isolation (>95%)

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Conclusions

- The addition of a GPF enabled the regulatory limit value for GDI vehicles ($6x10^{11}$#/km) to be achieved, for $PN_{\uparrow 23}$, from standard chassis dyno cycles and very demanding RDE conditions, including high load and low temperature tests
- Increases in engine-out PN of >50% were seen when extending the measurement range from d50=23nm down to ~7nm, but with a GPF in place this differential dropped to ~20%
  - The GPF tested appears especially efficient for <23nm PM
- CVS (dilute) and Raw $PN_{\uparrow 23}$ lab-based PN sampling (the latter currently being considered as an option for certification testing) appear sufficiently similar to be considered equivalent in the configurations used at Ricardo
- >23nm PN-PEMS particle number emissions proved to be ~20% higher than CVS-based levels, due to lower sampling losses
  - but agreement is well within the ±50% range permitted for regulatory correlation

Acknowledgements

- Thanks to:
  - AECC members
  - Concawe members
  - Staff at Ricardo
    - Simon de Vries
    - Carl Jemma

Any questions?