Update on sub-23nm exhaust particle number emissions using the DownToTen sampling and measurement systems

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Sub-23nm PN vehicle technology effects using the DTT system

- **Introduction**
- The DTT measurement systems
- Simultaneous measurements using lab and PEPS systems
- Round up of PN measurements using the lab-based system in DTT
- Concluding remarks
- Further work

Introduction

- “DownToTen” (DTT) project is one of three EU H2020 funded projects developing robust **p**ortable **e**xhaust **p**article **s**ampling system (PEPS) methodologies that will enhance the regulatory approach for particle number (PN) emissions including the sub-23 nm region
  - New regulation for “PN_{10}” seems highly likely, in the next 3-5 years
- Initial direction of the H2020 projects, was to assess latest generations of direct injection gasoline and diesel engines under real world conditions
  - but the projects must now consider all technologies in the post-Euro 6 “technology neutrality” context
- DTT has developed a sub-23 nm PN sampling and measurement approach, and is now testing lab-based and PEPS prototypes in parallel
- This study presents results from those lab and PEPS systems running together
- But the focus of our results is on the assessment of the presence and magnitude of <23nm emissions from a large number of tests performed by various partners within DTT
  - with lab-based systems

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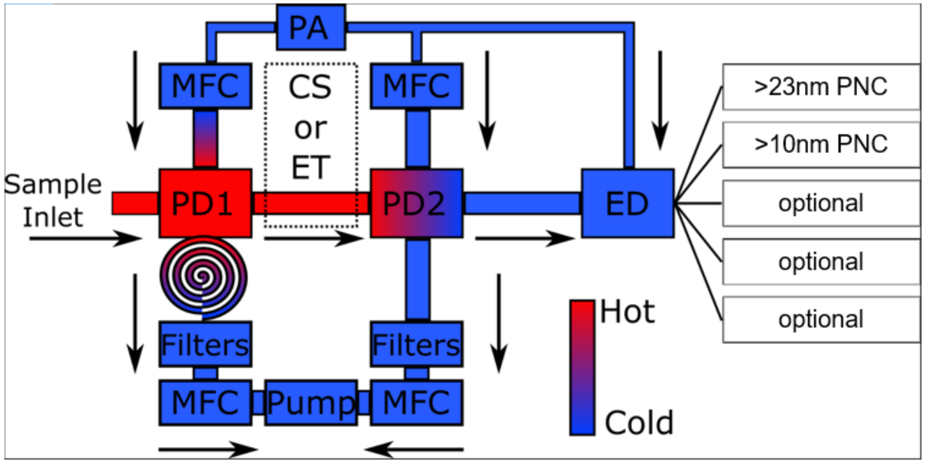
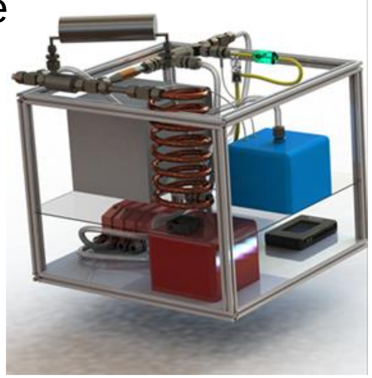
DTT Measurement Systems

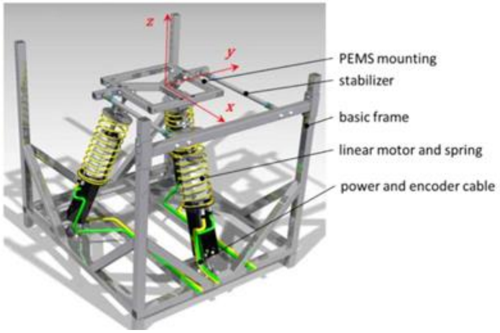
- The DTT lab measurement system consists of two porous tube diluters (PD1, PD2) and a third, optional dilution stage for sampling high particle number concentrations. This additional dilution is supplied by an ejector diluter (ED).
- Between the two PD either an evaporation tube (ET) or catalytic stripper (CS) can be placed
- The DTT PEPS simplifies dilution and is reduced in size, weight and power consumption

LAB



PEPS





DTT shaker system (TUG) for robustness testing

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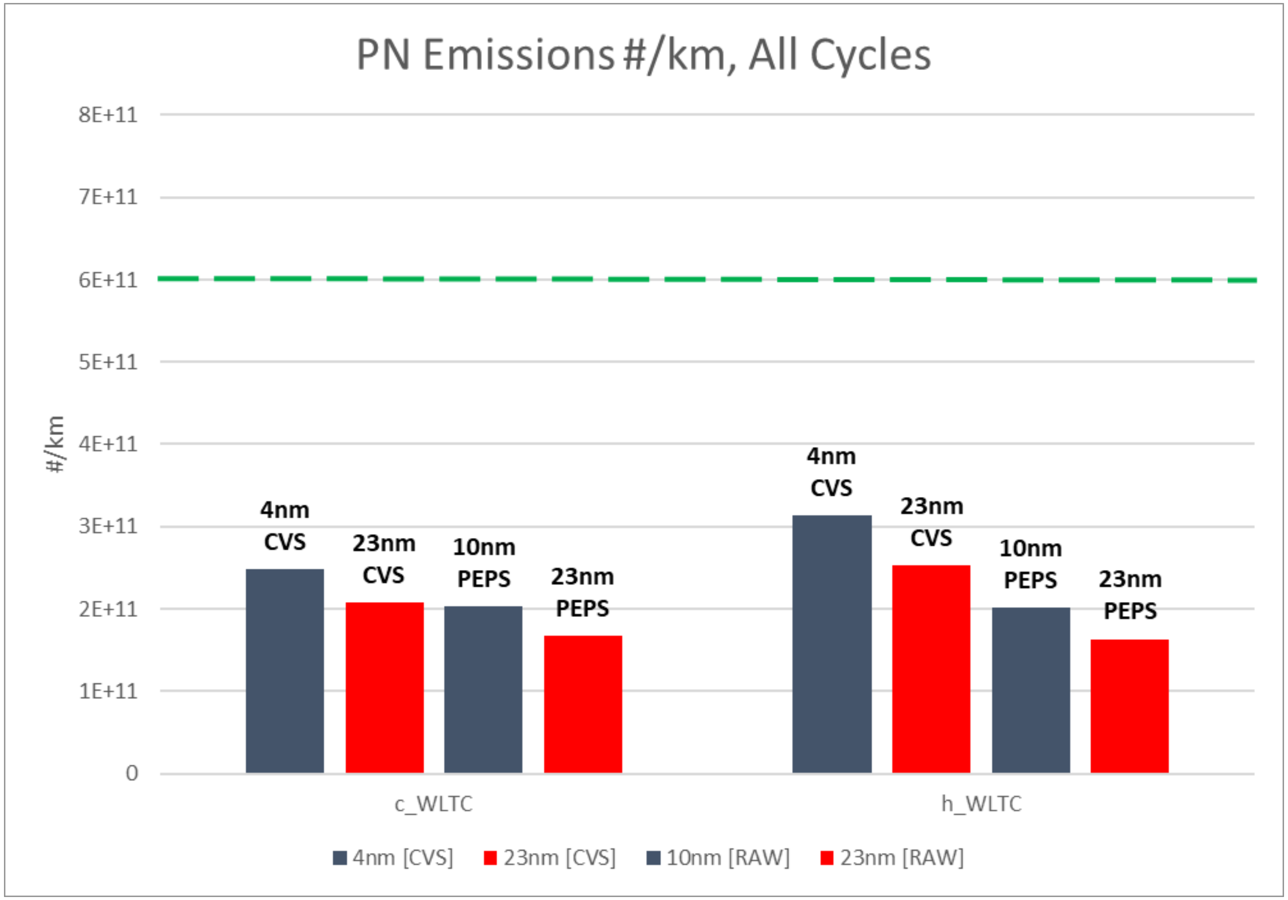
DTT lab and PEPS systems in parallel (PHEV with GPF)



- GDI PHEV with GPF (Euro 6d-temp)
- Broadly similar PN emissions between lab system and PEPS
  - Dilution corrected only
  - Calibration approach to be determined
- GPF effective in the <23nm region
  - GPF equipped vehicle shows low levels of >4nm PN (CVS) and >10nm PN (PEPS)

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Summary of test variables

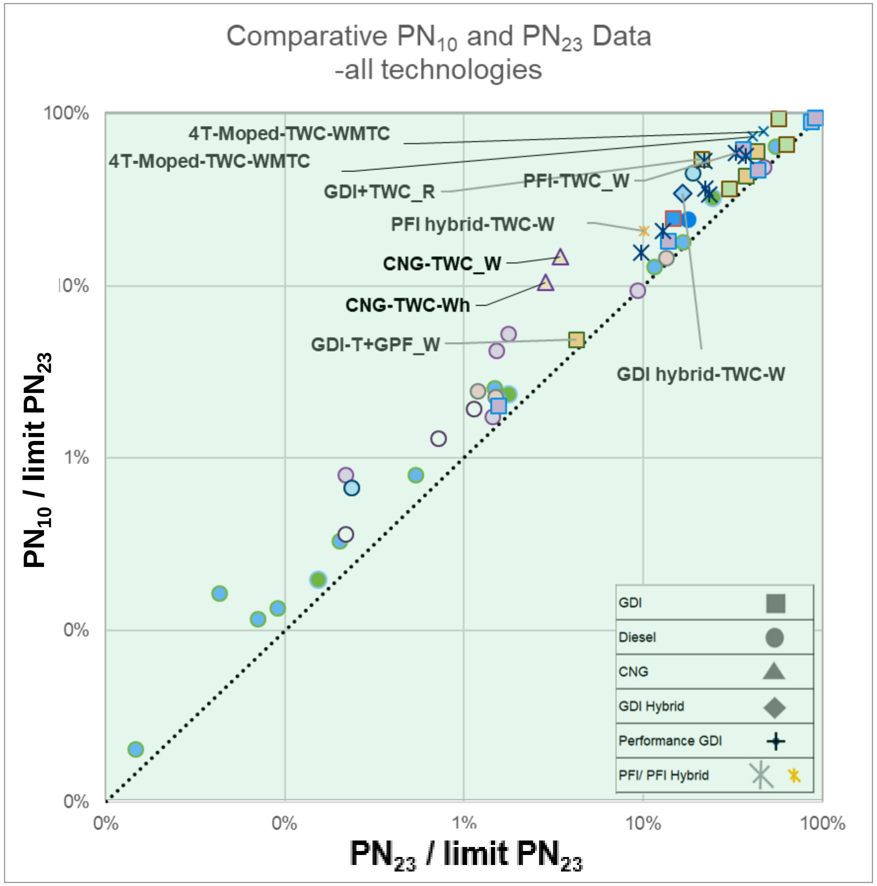
Test Sites	Technologies	Aftertreatment	Cycles	Other factors
Ricardo	Diesel	DPF	NEDC	T_{test} -7°C to 30°C
AVL	Gasoline PFI	DOC	WLTC	Hot and cold start
LAT	Gasoline GDI	LNT	JC08	DPF regeneration
JRC	GDI hybrid	SCR	US06	LNT deNOx
	PFI hybrid	SCRF	on-dyno RDE	LNT deSOx
	GDI performance	TWC	WMTC	High O_2 fuel (as R-OH)
	CNG van and PC	GPF (coated, 4W)	R47	High PN index fuel
	Moped (4T)	GPF (uncoated, 3W)	TfL (city)	Euro 4, 5, 6b, 6c
	Motorcycle (4T)	[+ all commercially available combinations of above]	Steady states	Post Euro 6c
	Gasoline dual GDI/PFI		Acceleration	SI: l<1, l=1, l>1

- Wide range of technologies, fuels, regulatory cycles, temperatures, operating conditions, aftertreatment…
- All data are shown corrected for dilution only **NOT for losses (no PCRF)**

PN_{10} v PN_{23}: regulatory regime (no PCRF)

- Most technologies compliant with $6x10^{11}$#/km for both >23nm AND >10nm ranges

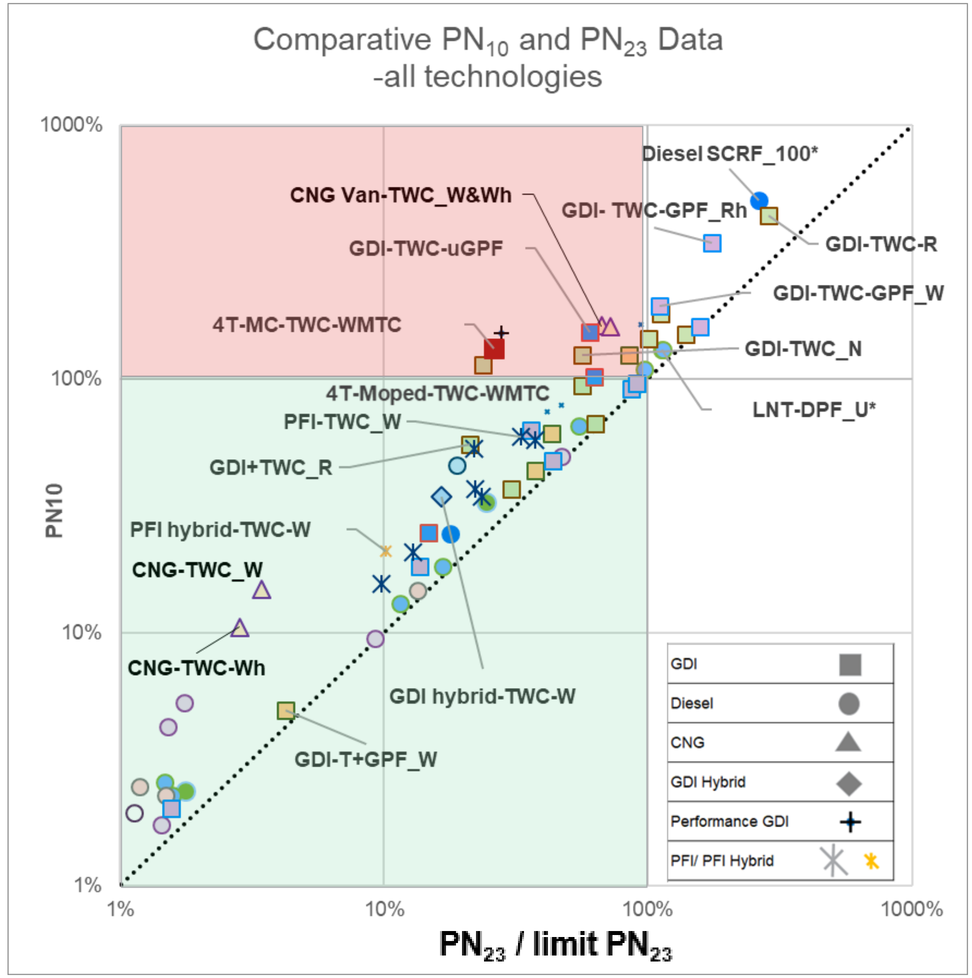
100% on either axis refers to $6x10^{11}$#/km



PN_{10}

PN_{10} v PN_{23}: outside regulatory regime (no PCRF)

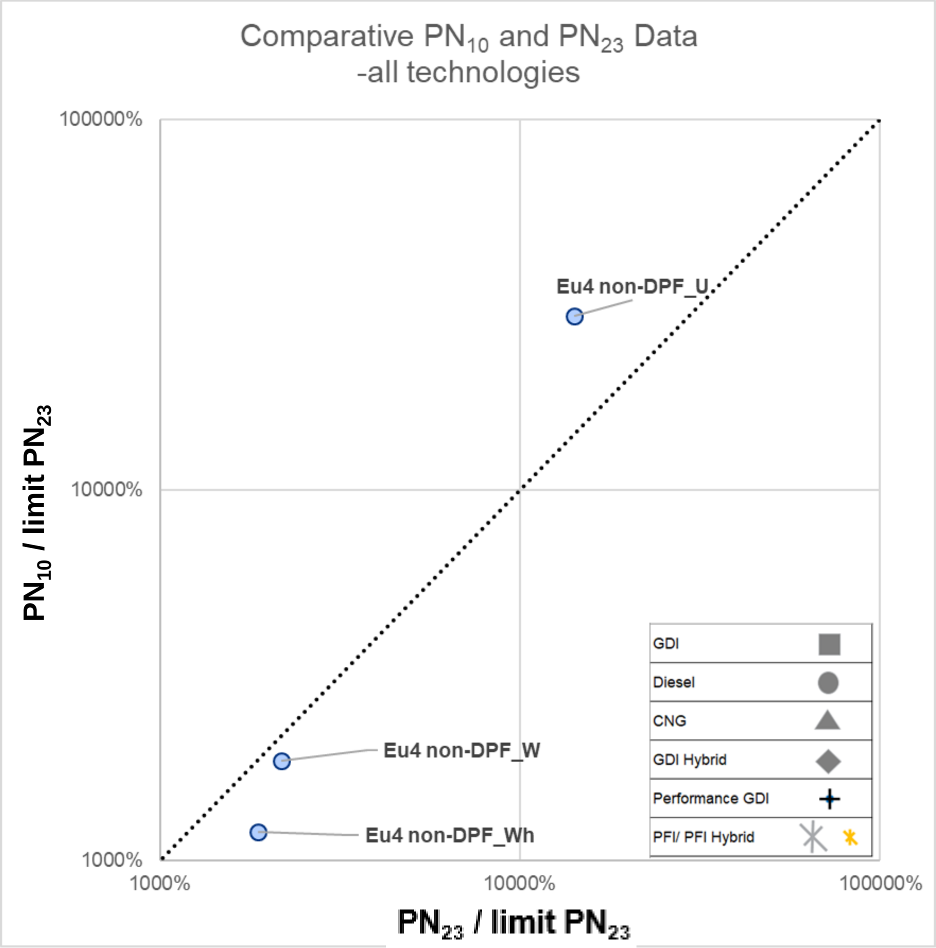
- Some technologies may have PN emissions that are compliant with the current limit value (PN_{23} range), but would exceed the regulatory threshold if PN_{10} were measured instead
  - includes
    - a 4-stroke motorcycle with a three-way catalyst on the WMTC
    - a CNG van with a TWC on WLTCs
    - a GDI with an uncoated GPF



PN_{10}

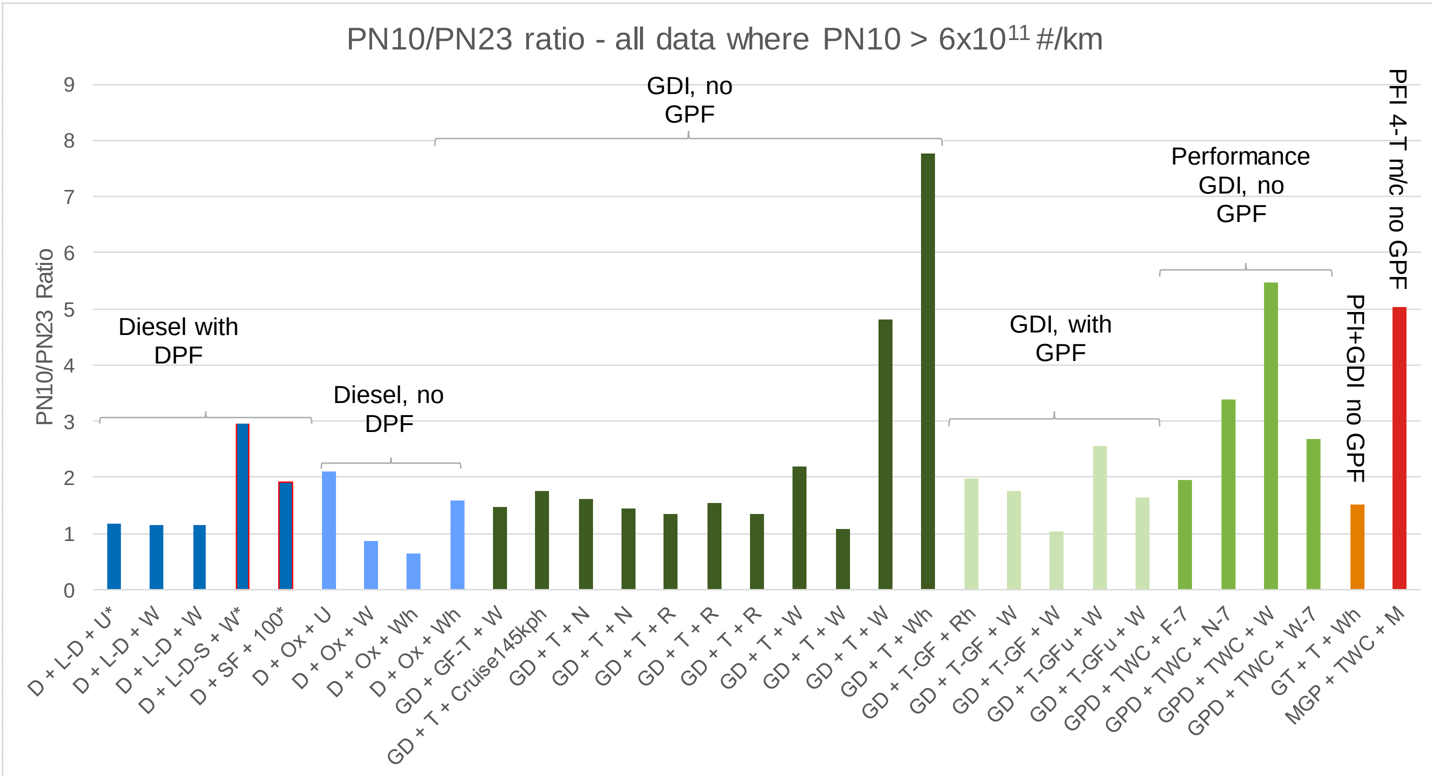
PN_{10} v PN_{23}: outside regulatory regime (no PCRF)

- Only non-DPF diesels have shown emissions $>10^{13}$#/km
  - No independent <23nm mode present



PN_{10}

PN_{10} v PN_{23}: outside regulatory regime (no PCRF)

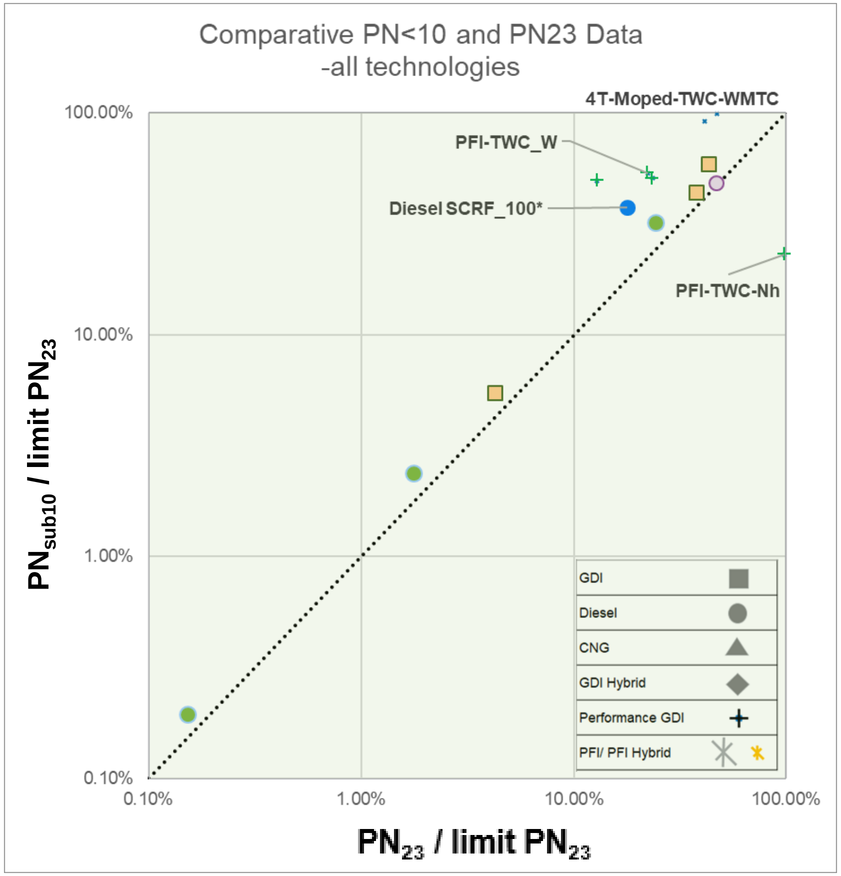


- Whole emissions cycle data, where PN10 > $6x10^{11}$#/km
  - PN_{10} always <10x PN_{23} levels, generally <5x
  - With DPF and GPF always <3x, even during tests featuring DPF regeneration

PN_{10}

PN_{sub10} v PN_{23}: regulatory regime (no PCRF)

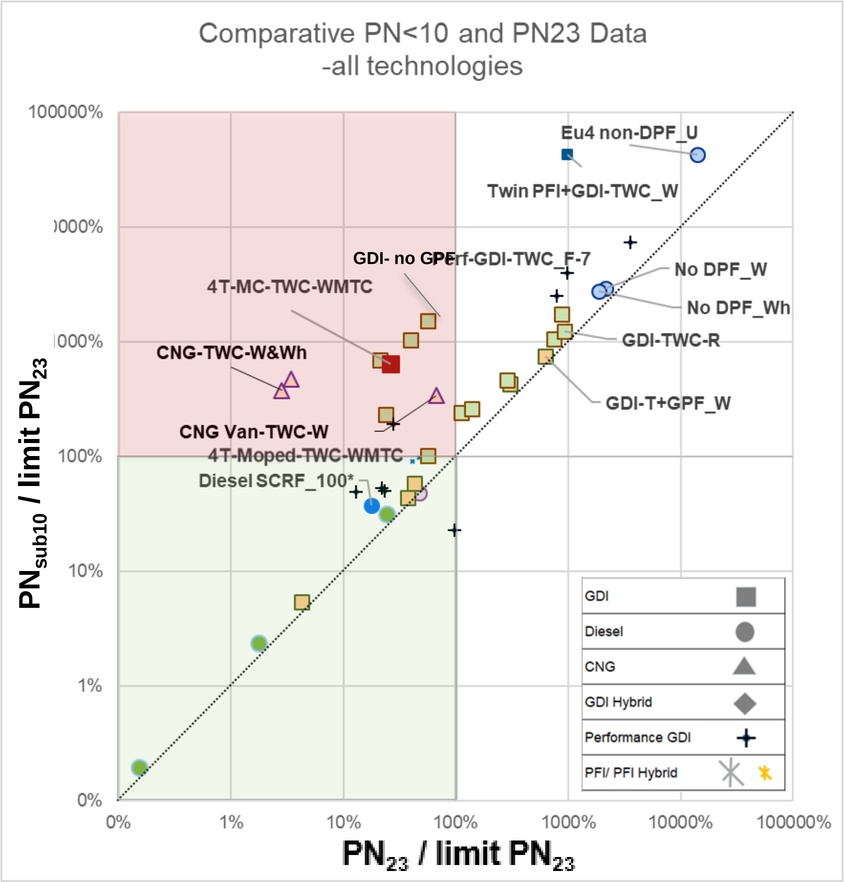
- Sub-10nm PN data (2.5nm, 4nm, 7nm d50 data included)
- Contains conventional vehicles that dominate the fleet
  - PFI vehicles with TWC, DPF equipped diesels



PN_{sub10}

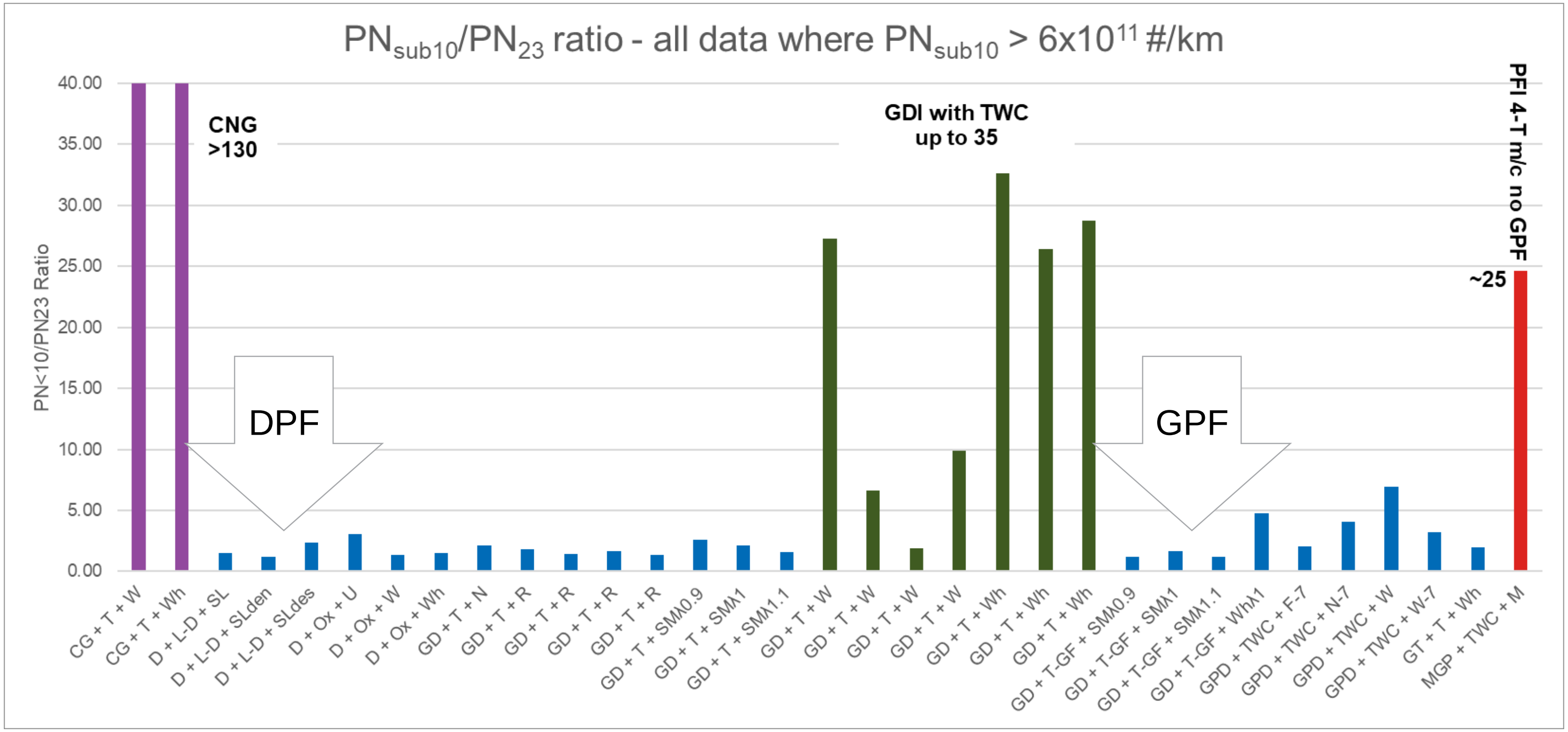
PN_{sub10} v PN_{23}: outside regulatory regime (no PCRF)

- Sub-10nm PN data (2.5nm, 4nm, 7nm d50 data included)
  - Higher emitters reflect those for PN_{10}
  - Some (PFI!) technologies would uniquely meet the limit for PN_{23} and PN_{10}, but fail at PN_{sub10}
    - Performance motorcycle and CNG applications



PN_{sub10}

PN_{sub10} v PN_{23}: outside regulatory regime (no PCRF)



- Whole emissions cycle data, where PN_{sub10} > $6x10^{11}$#/km
  - No excessive PN increases in <10nm region when DPF and GPF are present
  - High PN emissions observed with some PFI and CNG applications, without particle filters!
    - (over 100x >23nm levels for CNG)

PN_{sub10}

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Concluding remarks

- Most vehicles do not exhibit substantially elevated <23nm PN emissions, but evidence is emerging of elevated <23nm PN emissions in some cases
  - Ironically, these seem to be from technologies that are currently excluded from any kind of PN control…
    - Performance motorcycles and light-duty CNG passenger cars
    - Both would currently be considered niche
- Data are from full-flow dilution systems, and there is still a possibility there is an influence of sampling artefacts related to CVS and/or transfer system, and these should be investigated
- If these PN are real, and future regulation demands technology harmonisation (all technologies, same limits), how to control applications with high emissions below 10nm, but low emissions above 10nm, without imposing damagingly stringent limits on other technologies?

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Further work

- Functional aspects
  - Vibration testing of the PEPS on shaker rig
- Parallel raw and dilute sampling
  - Focus on 'extreme sources' identified in previous work during raw exhaust testing
  - Investigate/eliminate potential artefacts
- Calibration and correction for losses
- Understanding formation pathways and chemistry of nanoparticles
- Continue the parallel workstream looking at semi-volatile and secondary particles