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Update on the UN-ECE GRPE Particle Measurement Programme – Spring 2009

Delivering Value Through Innovation & Technology

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Background to PMP

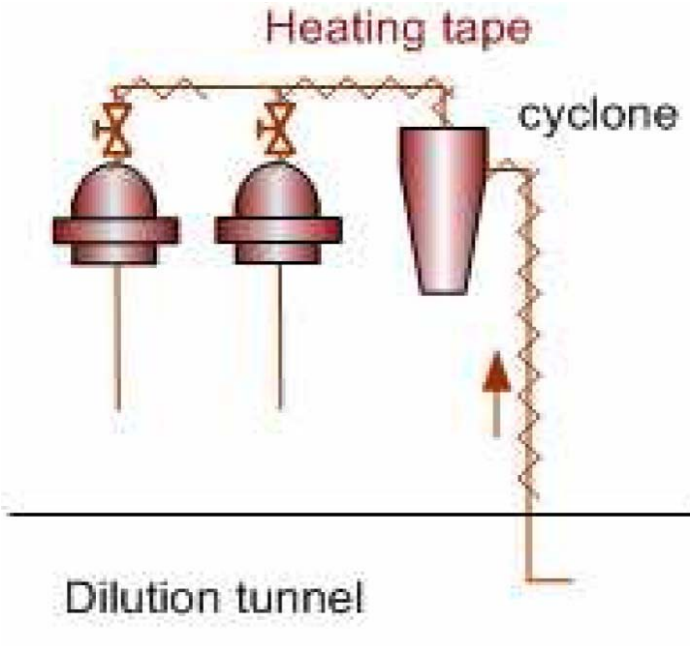
- Inter-governmental research programme under the auspices of UNECE GRPE to develop new vehicle exhaust particle measurement procedures for regulatory use
- Set up due to health concerns over nanoparticles…
- …and concerns over the ability of the current particulate mass measurement method to enable the forced adoption of technologies which effectively control their emissions
- Mandate was to develop techniques to replace or complement the particulate mass measurement method
  - must be applicable to Light Duty Vehicle & Heavy Duty Engine type approval testing

PMP Phases

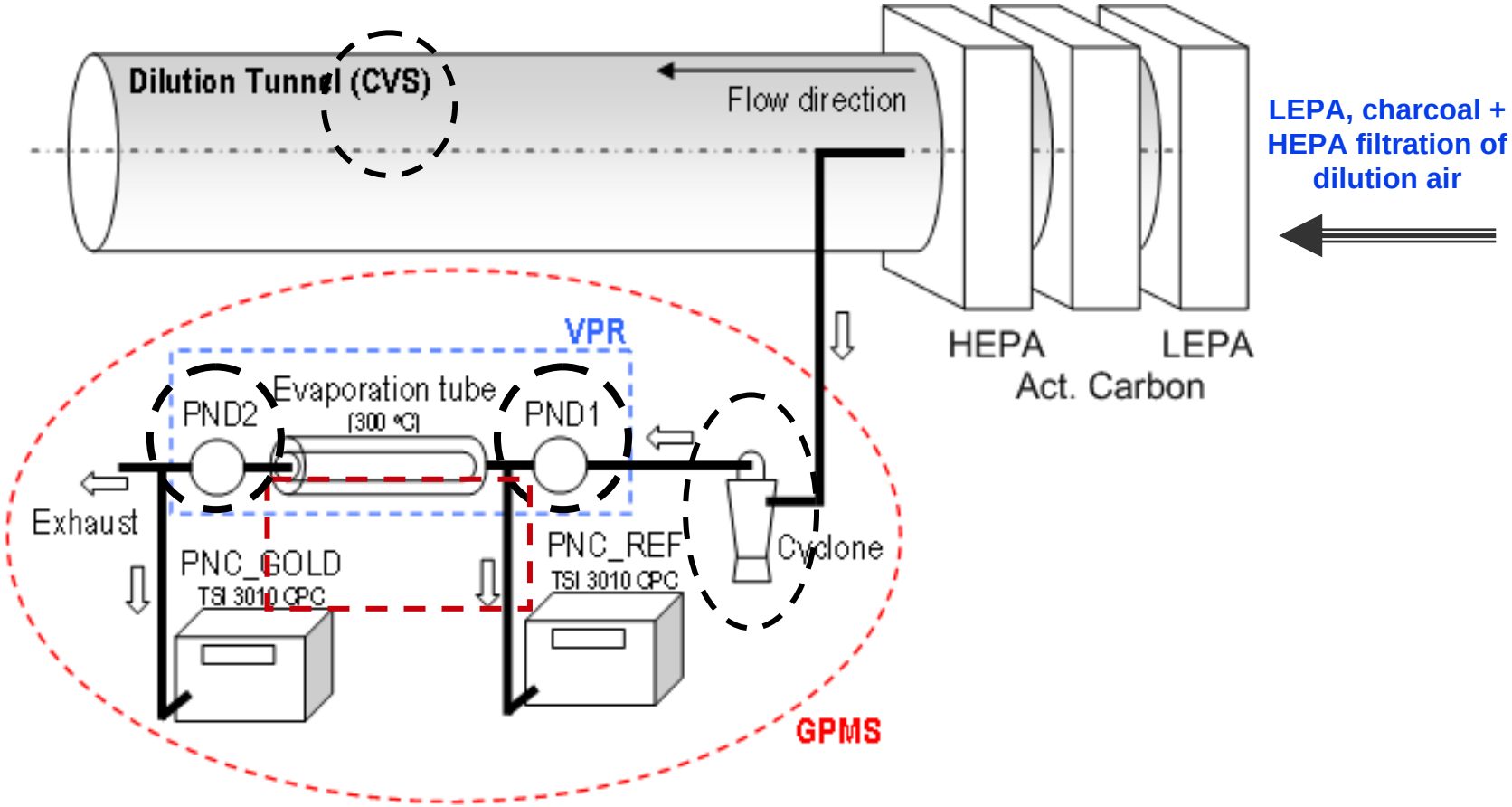
- Phase I (2001-2) developed protocols for examining different candidate measurement systems.
- Phase II (2002-3) evaluated a range of measurement techniques and sample conditioning systems.
- Phase III (2004-) validating the recommended measurement techniques via inter laboratory test programmes.
- Validation for light duty testing completed in 2006 and reported in 2007.
  - Number and Mass limits proposed for Euro 5+ using PMP Procedures
  - 6 x 10^{11}/km & 4.5mg/km
- Heavy-duty PMP Programme commenced in 2008, following development of test protocol and employing measurement approaches developed in the light-duty work

PMP Light-duty Recommendations – Improved Particulate Mass Measurement

- Improved dilution air filters
- Cyclone (2.5µm to 10µm cut-point)
- Sample to be held at 47°C +/- 5°C for >0.2s
- Filter face velocity controlled
  - (50cm/s to 100cm/s)
- Pallflex TX40 filters with no backup
  - One filter for whole emissions cycle
- Weighing
  - Static charge neutralisation
  - Buoyancy correction



PMP Light-duty Recommendations – Solid Particle Number Count



- A method employing a condensation nucleus counter, but using sample pre-conditioning to eliminate the most volatile particles which may contribute significantly to variability
- The method defines the particle measured

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PMP Inter-laboratory Correlation Exercises for Heavy Duty Engines (ILCE_HD)

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ILCE_HD Objectives

- Evaluate measurement systems developed for light-duty programme in heavy-duty testing context
- Demonstrate repeatability between nominally identical systems within single laboratories
- Demonstrate reproducibility of the same systems used at different laboratories
- Demonstrate inter-lab reproducibility between commercially available PMP compliant systems from a variety of manufacturers
- Evaluate the draft test protocols and measurement methods to assist in their development

ILCE_HD Timing and Participants

- ILCE_HD comprises two programmes:
  - Validation exercise (VE)
    - similar to the light-duty validation exercise
  - Round-robin (RR)
    - typical industry round-robin
- Five laboratories have committed to the VE_HD (which is restricted to 5 laboratories in Europe)
- Twelve laboratories in the Round-Robin
  - permits participation from labs Worldwide.
- JRC, UTAC and Ricardo are participating in both exercises

Test Laboratories and Timeline

Date	Validation Exercise	Round Robin
Jan – Feb 2008	JRC	
Mar-Apr 2008	AVL-MTC	
May – Jun 2008	JRC	
Jul – Sept 2008		RWTUEV
Oct – Nov 2008		Ricardo
Dec 2008 – Jan 2009	Ricardo	NTSEL
Feb – Mar 2009		NTSEL
Feb - April 2009	UTAC	
April – June 2009	EMPA	JARI
July – Sept 2009	JRC	NIER (Korea)
Oct – Nov 2009		Volvo
Dec 2009 – Jan 2010		JRC
Feb – Mar 2010		UTAC
Apr – May 2010		TNO
Jun – Aug 2010		VTT
Sep – Oct 2010		Scania
Nov – Dec 2010		Environment Canada
Jan – Feb 2010		Daimler

ILCE_HD Testing & Differences Between VE and RR

- Similarities and Differences Between VE and RR

PMP HD Validation Exercise (PMP_VE_HD)	PMP HD Round Robin Exercise (PMP_RR_HD)
Golden Engine (VE-E1: Euro III + DPF, Iveco Cursor 8)	Round Robin Engine (RR-E2: Euro III + DPF, Mercedes OM501)
2 x Golden Particle Measurement Systems	Labs' own Particle Measurement Systems
Golden Engineer and Written Guide	Written Guide only
Fuel and lubricant from single batches	Fuel of defined spec, same lube fill in all labs
Full and partial flow used in parallel	Full and partial flow in initial 3 labs, then partial flow alone permitted
European labs only	European, Asian and N. American Labs
Aims to investigate issues with measurement approaches	Uses repeatability as metric for assessing system
Reproducibility intended to demonstrate stability of dual systems	Reproducibility intended to demonstrate similarity of different systems

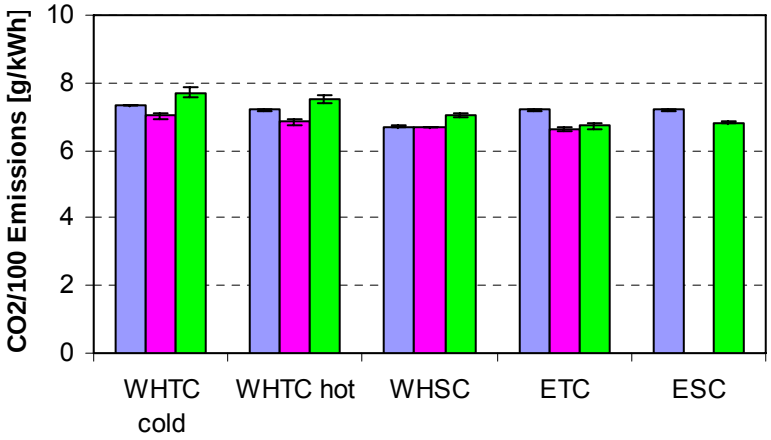
- Alternative systems welcomed in the VE

- Test Matrix addresses replicate European and World Cycles
  - Same tests for both VE and RR
- ≥8 repeats of each cycle
- Protocol includes standardised DPF fill and validation exercises for particle measurement systems

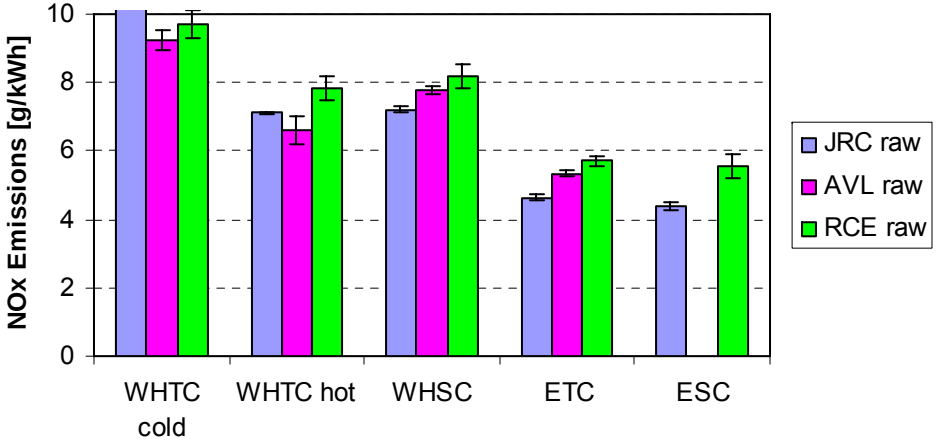
Previous lab	Day 0	Days 1-7	Day 8
	oil change	IFV	IFV
	2h ESC Mode 10	cold WHTC	cold WHTC
	3 x ETC	10 minute soak	10 minute soak
		hot WHTC	hot WHTC
		10 minutes at WHSC mode 9	10 minutes at WHSC mode 9
		WHSC	WHSC
		CP	CP
		ETC	ETC
		CP	CP
		ESC	ESC
*2 hours at ESC Mode 10	Precon	Precon	*2 hours at ESC Mode 10

ESC - European Steady State Cycle for emissions measurement [30 min]
ETC - European Transient Cycle for emissions measurement [30 min]
WHTC - World Harmonised Steady State Cycle for emissions measurement [30 min]
WHTC - World Harmonised Transient Cycle for emissions measurement [30 min]
IFV - Instrument Functional Verification
CP - Continuity Protocol
Precon - 15 miuntes ESC mode 10, 30 minutes ESC mode 7
* DPF regeneration only required if oil change and conditioning not performed

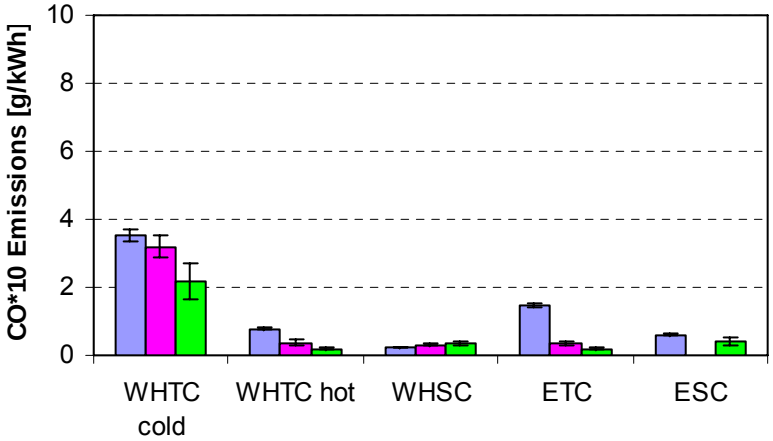
Initial Results #1: 3 Labs – Gases and PM within expected reproducibility limits



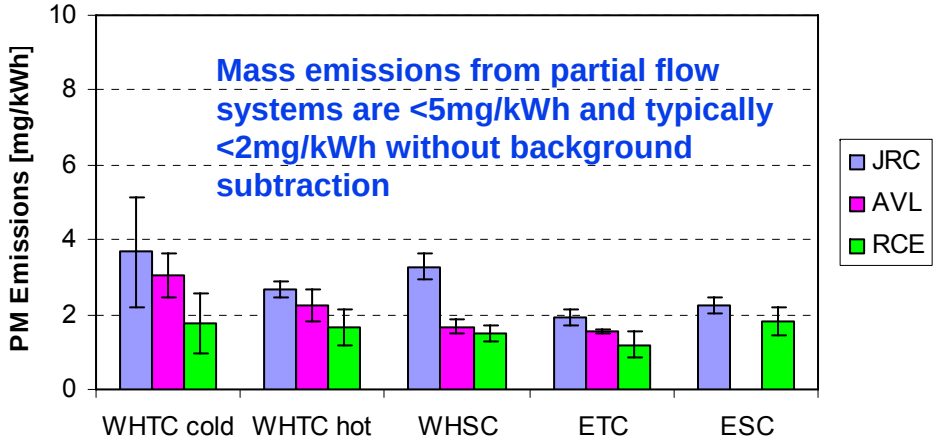
CO_2 emissions



NOx emissions

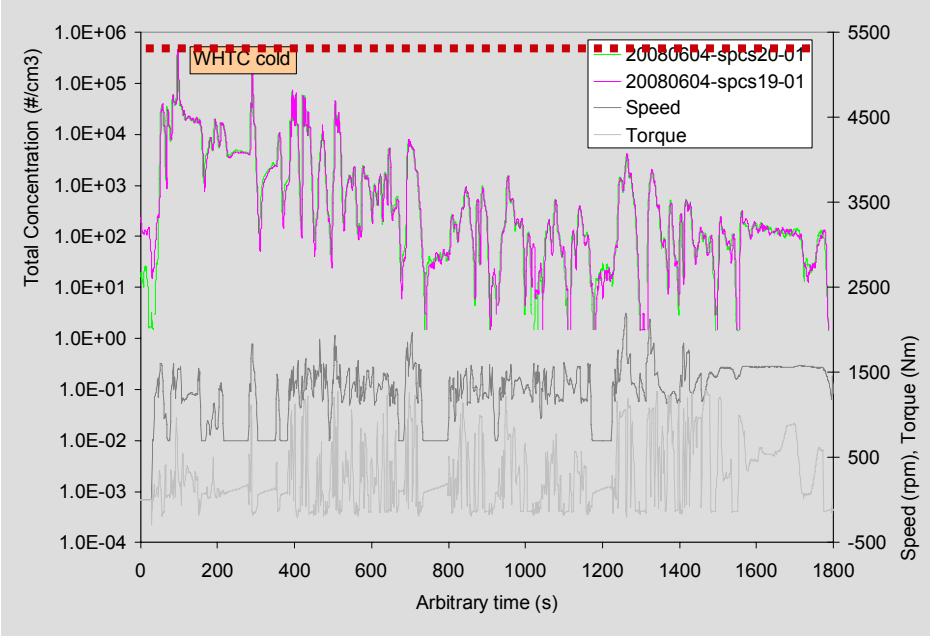


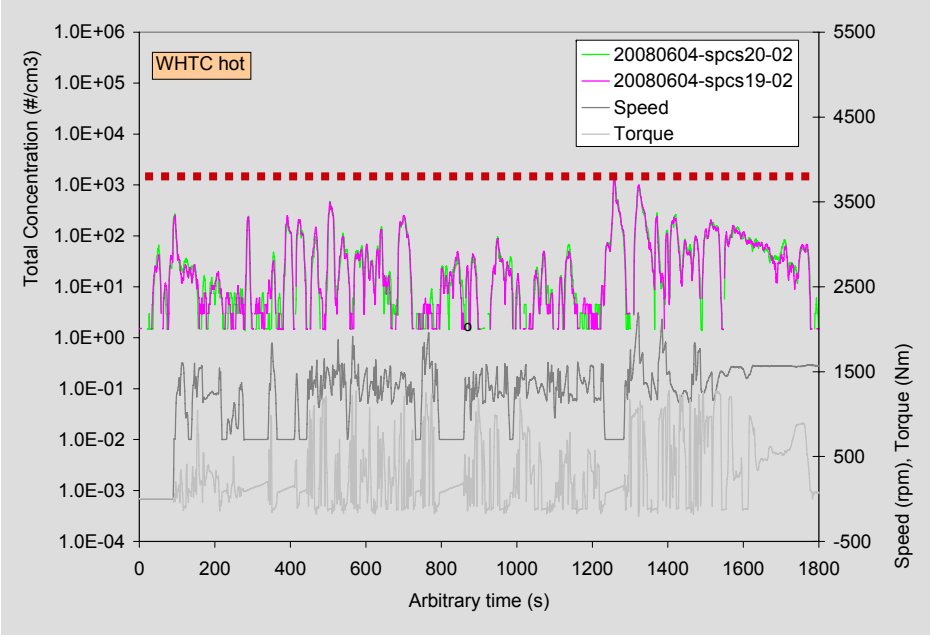
CO emissions



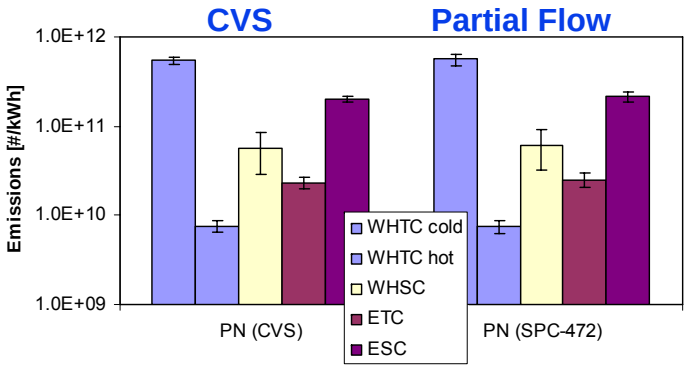
Initial Results #2: Testing at JRC – Particle Number

- Transient particle production from the WHTC shows high levels of particles under cold start, much lower from hot start. This is consistent with observations from light-duty vehicles' testing



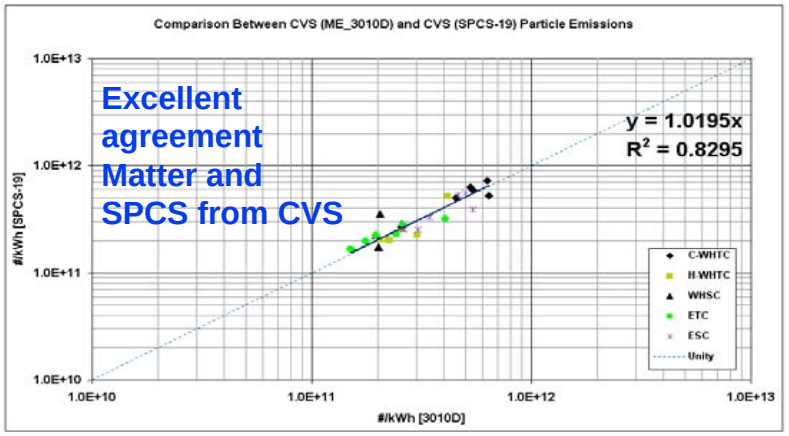


- Particles/kWh levels >5x10^{11}/kWh from cold WHTC
- 75 times lower from hot WHTC
- ETC close to hot WHTC
- Steady cycles levels are between cold and hot

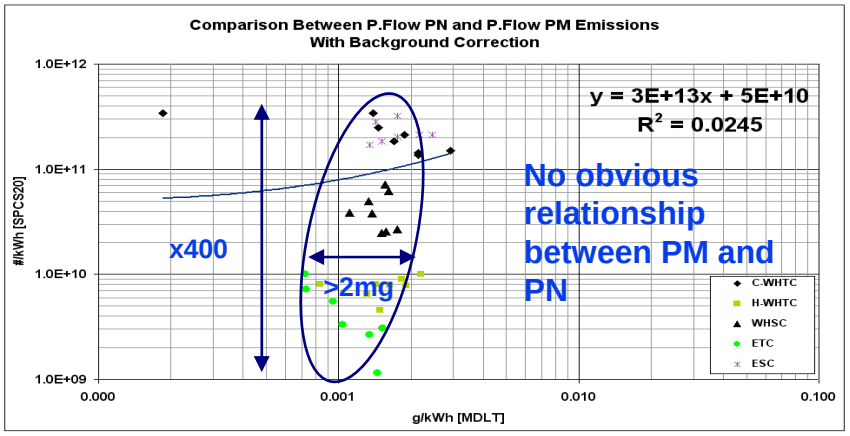


- Repeatability levels good
  - CoV 7% to 50%
  - Mean CoV <20%
- Good agreement between partial flow and CVS
- Emissions throughout cycle are above system backgrounds

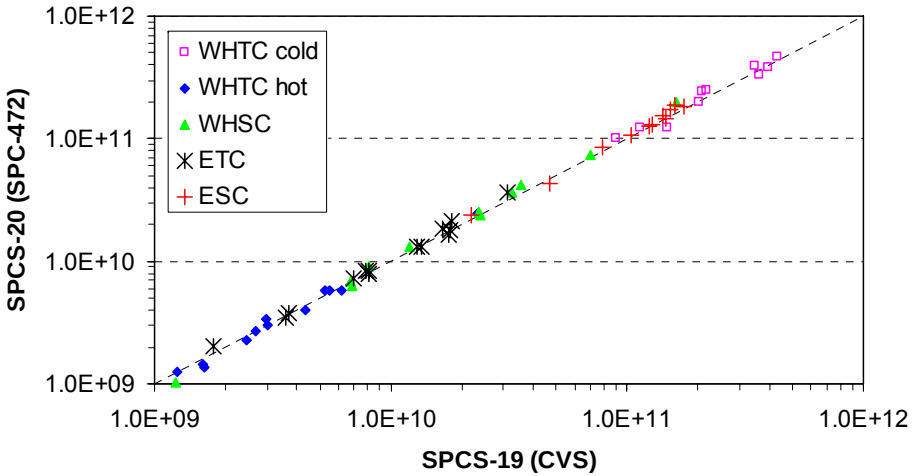
Initial Results #3: Mass is insensitive, but number has high discrimination power



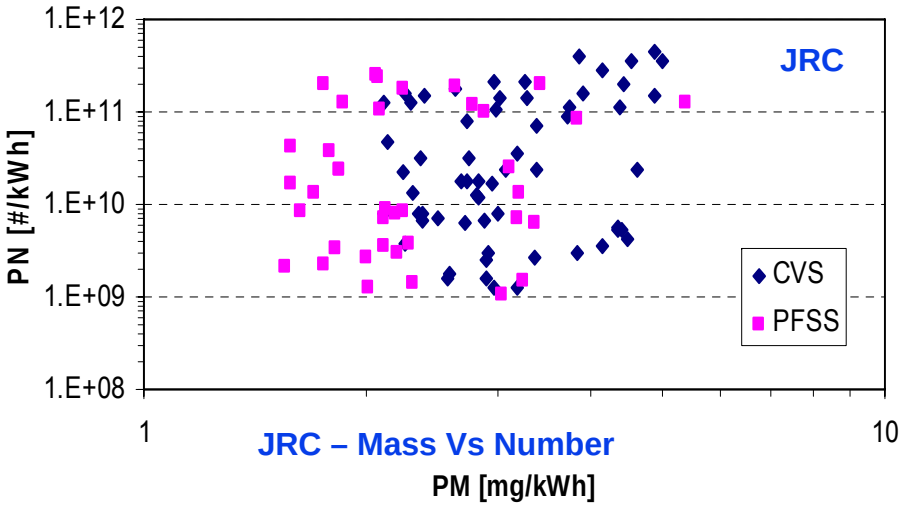
Ricardo –Matter System Vs SPCS (DF)



Ricardo – Mass Vs Number (MDLT)



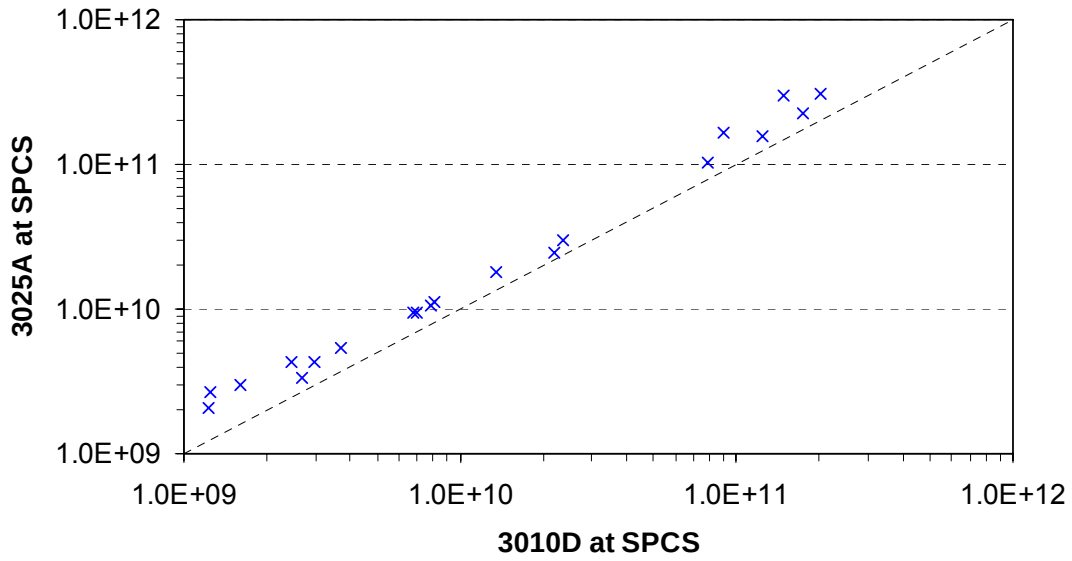
JRC –CVS v Partial Flow Number



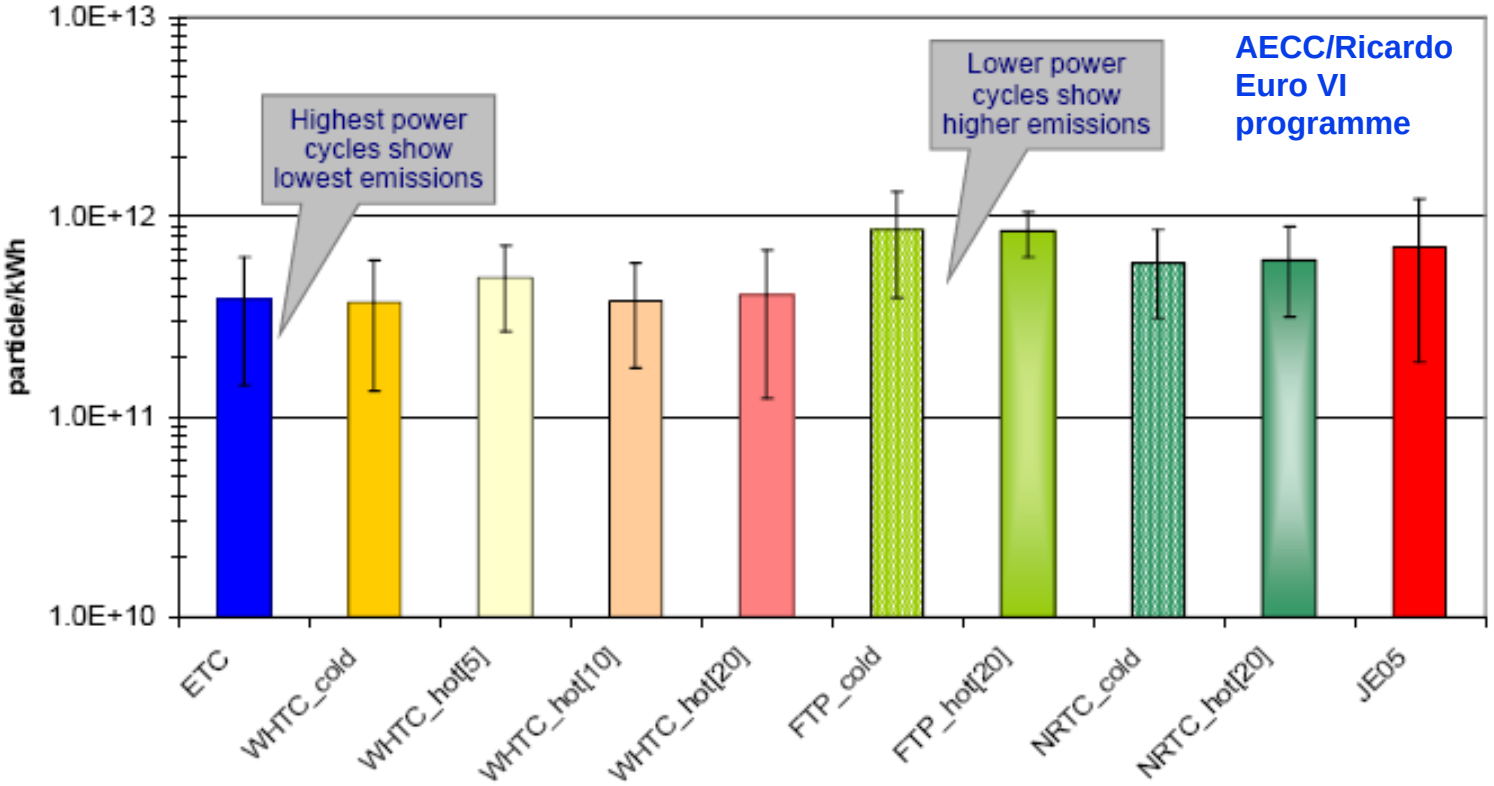
JRC – Mass Vs Number

Other Considerations: Small, solid particles

- **Kittelson, CARB data suggests solid nanoparticles may be present from some engines**
- **ILCE_HD data confirms that substantial fraction of total >3nm may be PMP solids**
  - Measuring with 3025A CPC increases particle number measured by ~60% relative to 3010D
  - Increase in numbers is consistent from many cycles and across the concentration range
  - BUT correlation between 3010D and 3025A suggests that <23nm particles behave in the same manner as >23nm particles

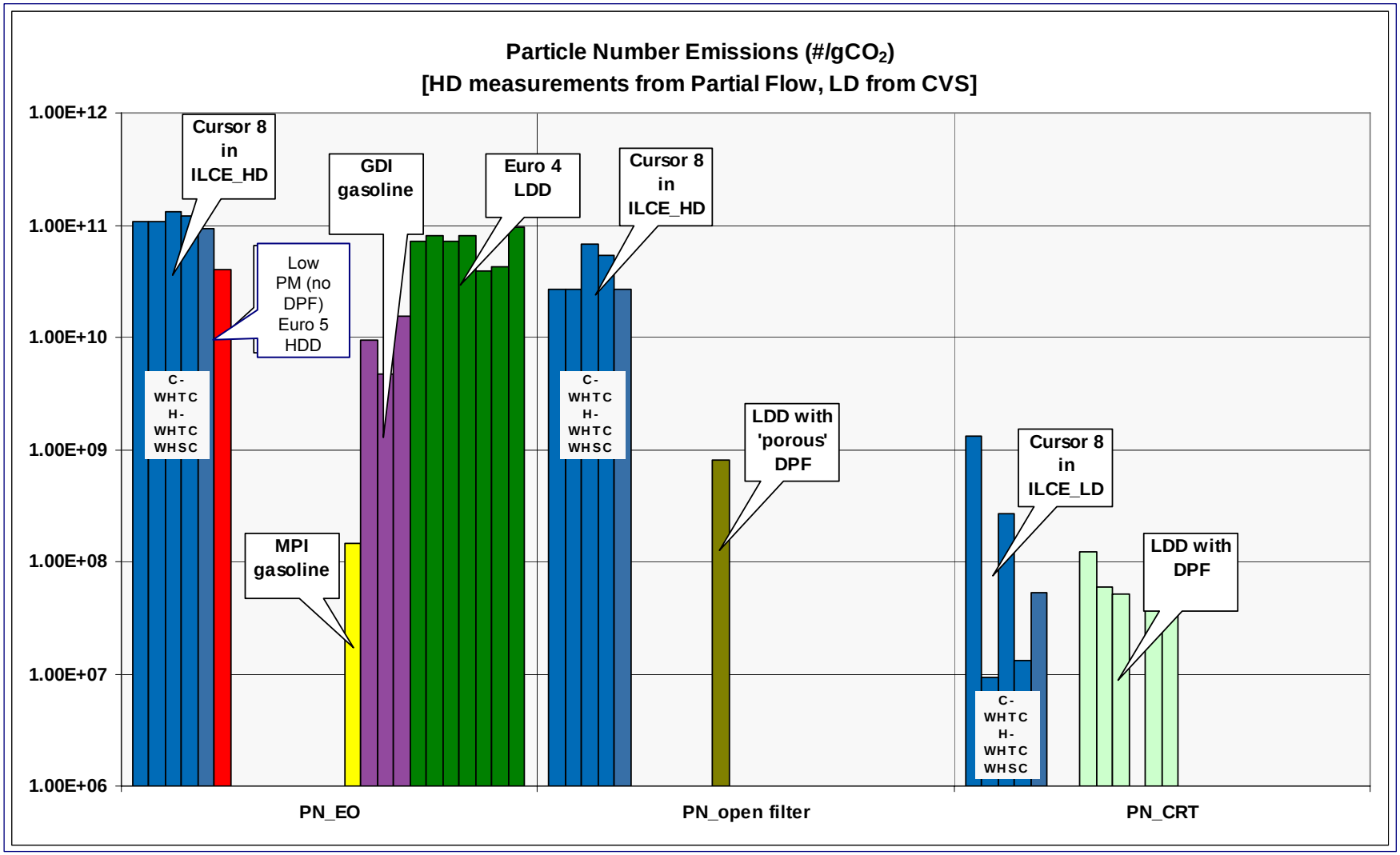


Other Considerations: Is it just the cycle power that discriminates emissions between cycles?



- DPF may normalise emitted concentrations independent of engine operation (at stable fill)
  - Characteristic of the DPF, not the engine?
- Only discriminator may be the power of the cycle (#/h similar, #/kWh different)
- Has implications for similar engines/DPFs used in different global markets
- Thermal release particles might end up the differentiator, penalising highly rated engines with lower CO_2

Other Considerations: Is PN per g/CO_2 a better way to compare?



Next Steps

- Compile interim VE results including Alternative Systems for Review in March 09
- Analyse data and prepare reports for PMP WG
- Further VE testing to complete later in 2009
- Consideration of on-going RR testing (to complete late 2010)
- Final data analysis and reporting
- On-going revision of draft regulatory document (R49)
  - Consideration of implications of differences between light and heavy-duty measurement system results
- Submission to GRPE and WP29 of proposals to incorporate new measurement procedures in R49
- EC consideration in Brussels of revised R49 procedures as part of Euro VI requirements