Application of the "PMP Protocol" to NRMM

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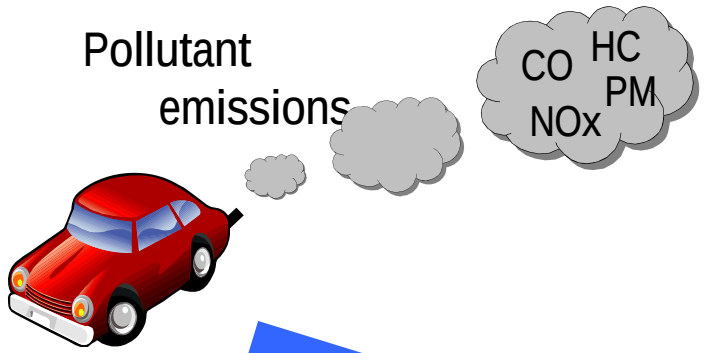
PMP Background
Health Concerns over Nano-Particles

- *The Clean Air for Europe (CAFE) Programme has forecast the likely levels of air pollution given present policies for the period 2000-2020.*

- *Despite the improvements in pollutant emissions, health impacts from air pollution across the EU are still projected to be considerable in 2020.*

- *For particulate matter, it is estimated that in 2020 some 2.5 million life years will be lost in the EU-25. This is equivalent to about 272,000 premature deaths.*

Emission Standards for Light Duty Vehicles Type Approval



EURO 1, 1992

EURO 2, 1996

EURO 3, 2000

EURO 4, 2005

EURO 5 PM ⬇

EURO 6 NOx ⬇

Emission standards have been already reduced by more than 90%
The CAFE programme called for further emission reduction

Emission Standards for Heavy Duty Vehicles
Type Approval

Pollutant emissions

CO HC PM NOx

EURO I, 1992

EURO II, 1995

EURO III, 2000

EURO IV 2005

EURO V 2008

EURO VI

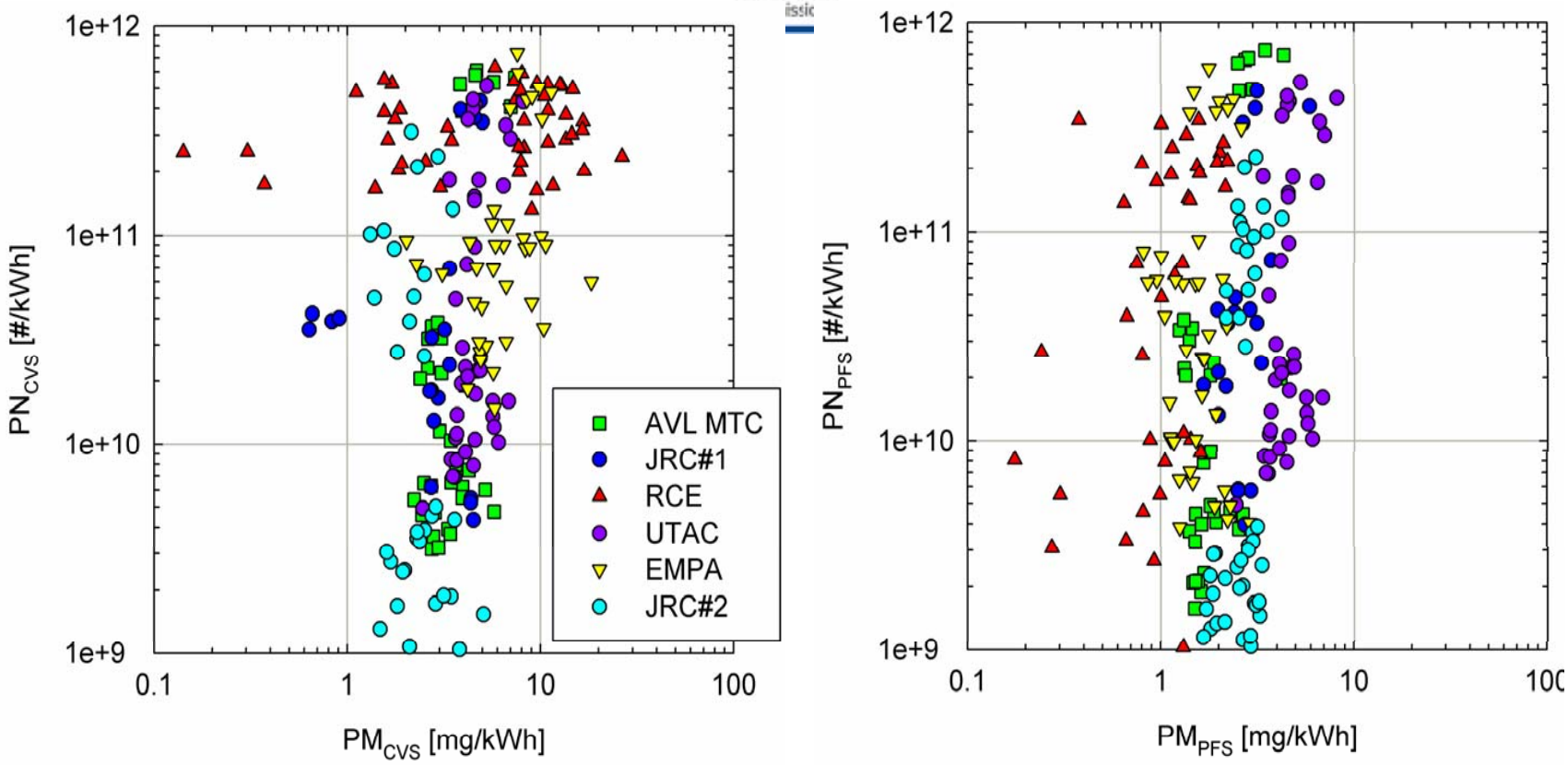
Regulating Particles from Diesel Vehicles

One of the main objectives of Euro 5/6 was to force the adoption of the best available technology (i.e. DPF) to reduce particulate emissions

- **Concerns over capability of current PM measurement to force technology which effectively controls these emissions**
- *Advanced technology emissions levels approaching limits of detection on current PM measurement*

Development and validation of new measurement techniques *for PM AND PN*:

UN-ECE Particle Measurement Programme (PMP)



- ***PM does not correlate with PN.***
- ***PN method much more sensitive****. PN levels vary over three orders of magnitude while PM by less than 1 order of magnitude for clean systems.*

PMP Mandate

- *Development of new techniques to replace or complement particulate mass measurement for Light & Heavy Duty type approval*

  - ***Simple and robust procedure*** suitable also for conformity of production testing
  - ***Good repeatability and reproducibility***
  - ***Limited investments*** in terms of measuring equipment

- *To provide data on the performance of different technologies, including DPF equipped vehicles, according to the new measurement procedures in order to set reasonable particulate emission limits*

LD PMP Phases I (2001) & II (2003)

Investigation of:

Sampling & Conditioning Systems

- Constant Volume Sampling (+ secondary dilution)
- CVS + thermodenuder or thermodiluter
- Rotary dilution
- Raw exhaust

Measurement Techniques

- Gravimetric (modified US 2007)
- Filter + chemical analysis
- TEOM
- Laser Induced Incandescence
- QCM
- Photoacoustic absorption
- Coulometric
- Photoelectric charging
- Light extinction
- Laser Light Scattering
- Differential Mobility Spectrometer
- Optical counter (CPC)
- Electrical Mobility
- ELPI
- Diffusion battery
- Diffusion charger

Phase I & II: Conclusions

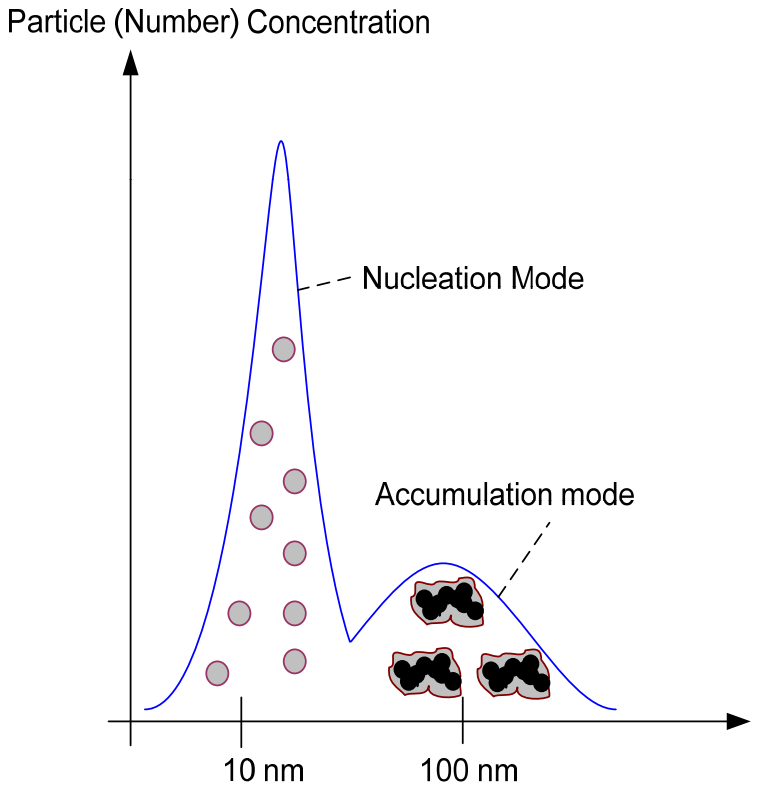
1. ***Improved Particulate Mass Measurement***
   - Dilute exhaust sampling with HEPA & HC filtered dilution air
   - Cyclone pre-classifier
   - Improved sample temperature control 47 +/-5°C
   - Deletion of back-up filter

2. ***Solid Particle Number Count***
   - Dilute exhaust sampling with HEPA & HC filtered dilution air
   - Cyclone Pre-classifier
   - Sample thermal conditioning: heated dilution, evaporation tube, dilution
   - Condensation Particle Counter with 50% cut point at 23 nm

ONLY SOLID PARTICLES >23 nm ARE MEASURED

PMP procedure focuses on solid particles with a diameter >23 nm

- *Accumulation mode very stable and not depending on sampling conditions*
- *Nuclei mode too sensitive to sampling conditions – too high variability*



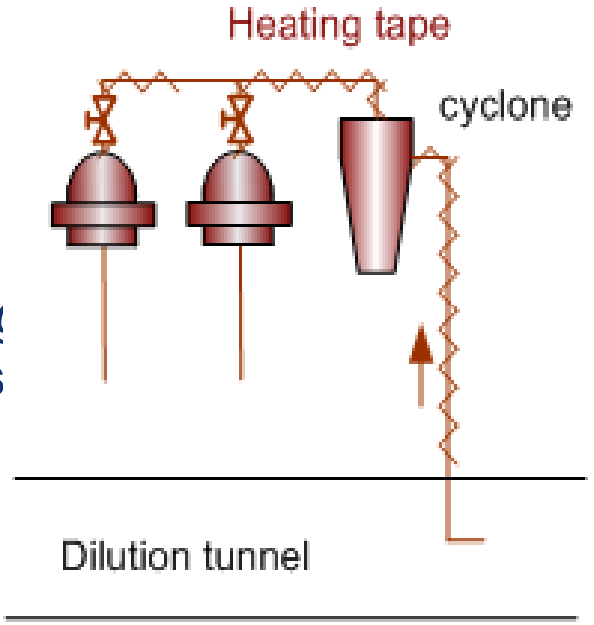
PMP Phase III - Validation

Objectives

- **To assess repeatability and lab to lab reproducibility of proposed PM & PN techniques**
- **To assess comparability of available PN measurement systems**
- **To assess performance levels of different engine / vehicle technologies**

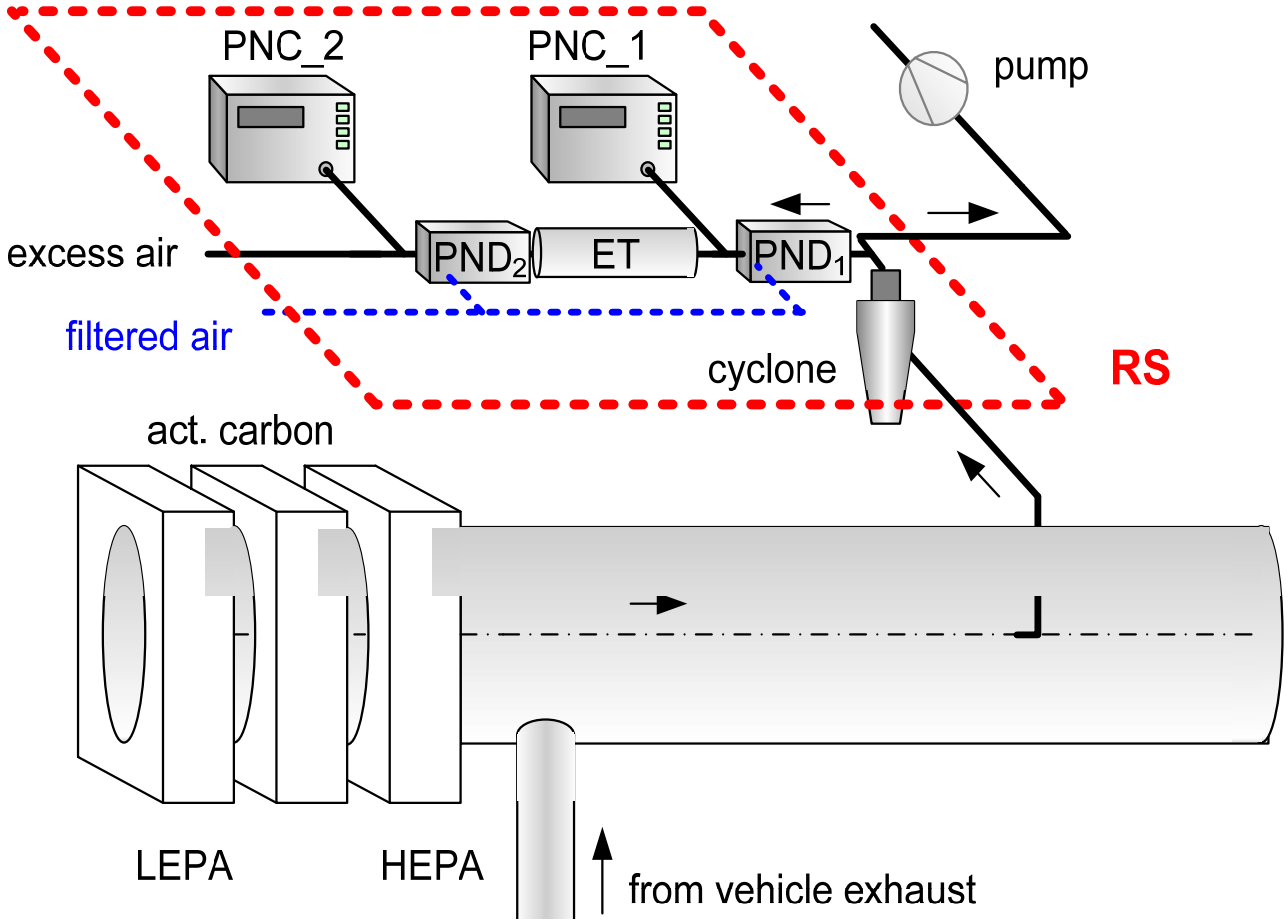
Separate Light & Heavy Duty Validation Exercises

Experimental set up: Modified Mass Method

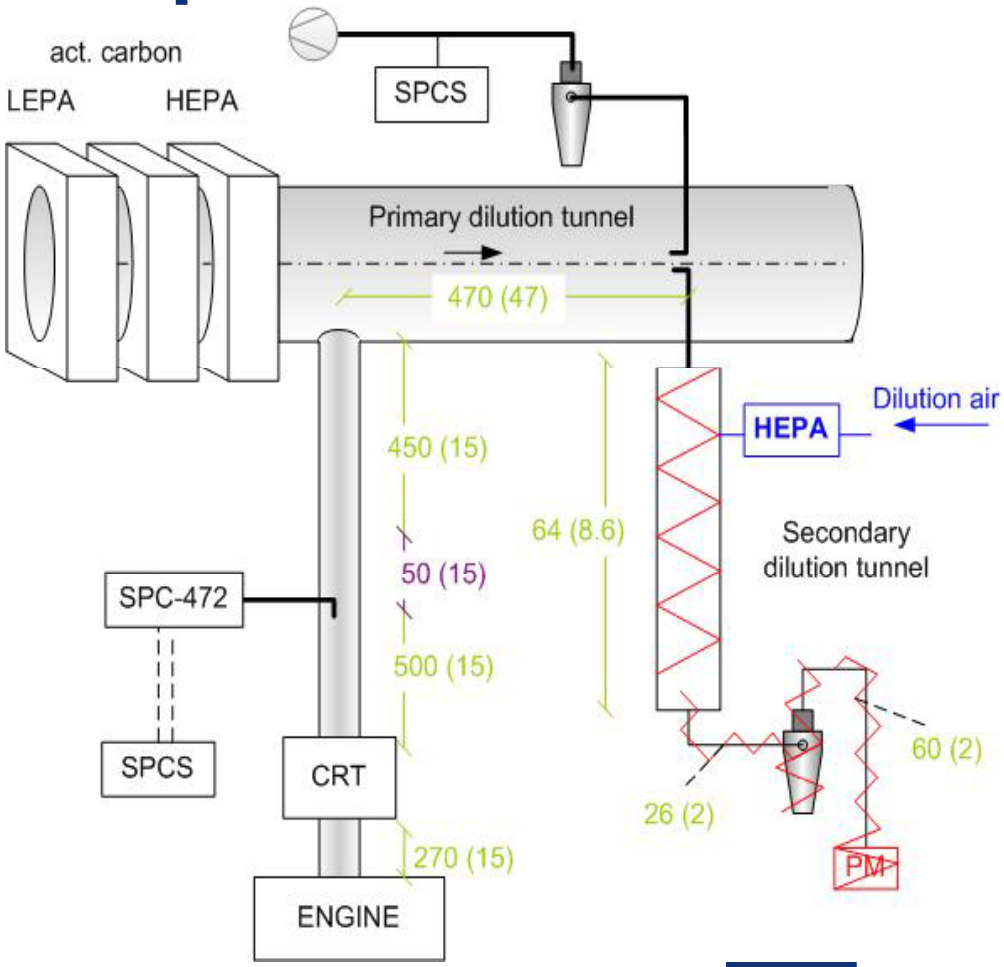


- *Cyclone (2.5µm to 10µm cut-point)*
- *Lab modified systems with external heating*
  - **Zone held at 47°C + / - 5°C for >0.2s**
  - **Temperatures recorded**
- *Filter face velocity (50cm/s to 80cm/s)*
- *Pallflex TX40 mandated; single batch for all tests*
  - **No back-up filter**
  - **Single filter for entire NEDC for DPF equipped and gasoline vehicles**
  - **Urban and extra-urban phase with separate filters for conventional Diesels**

Experimental: 'Golden' Particle Number Measurement System (LDV PMP)



HD PMP Measurement setup

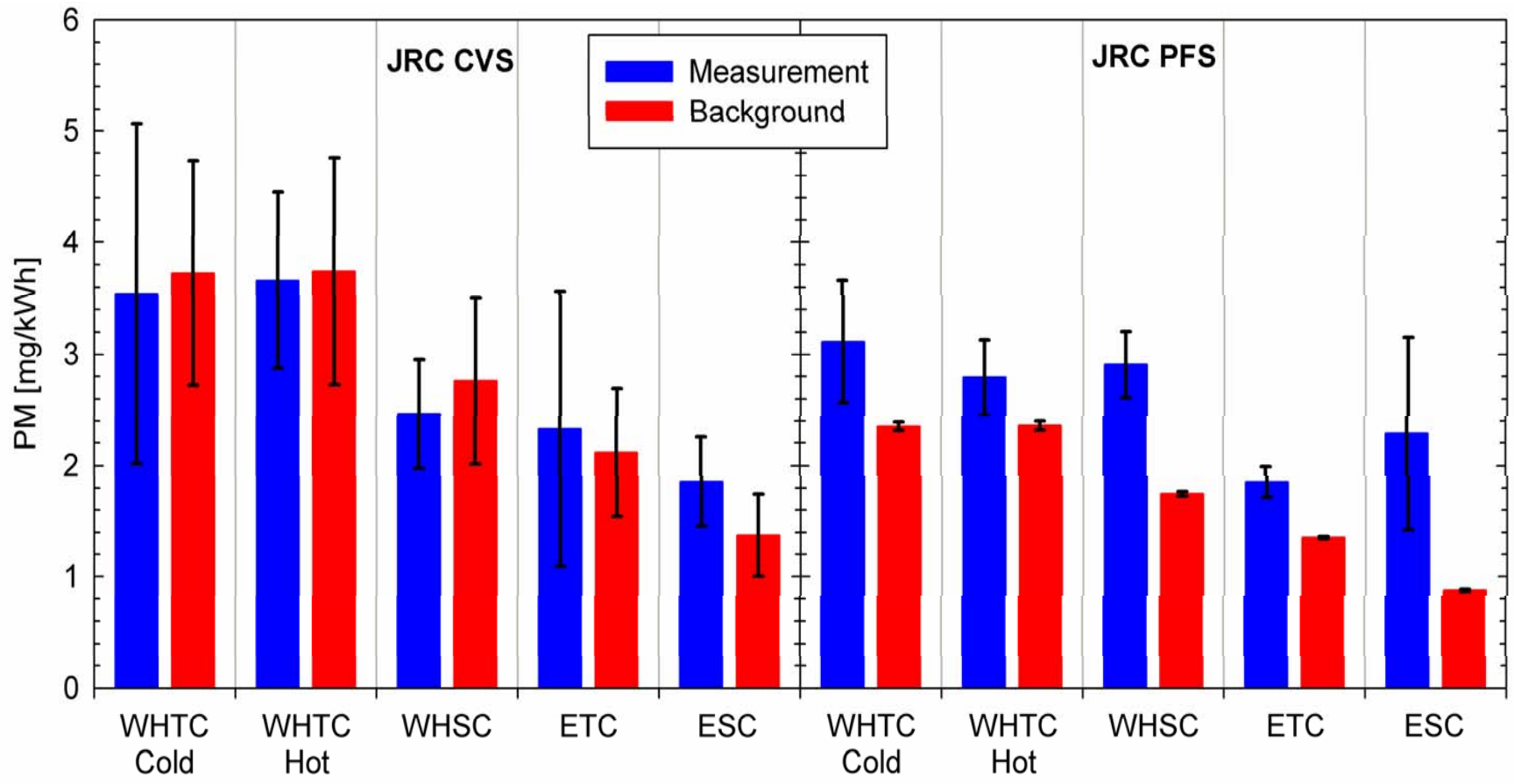


- *Two Golden Particle Measurement Systems (Horiba's SPCS). One at CVS and one at the Partial Flow System.*

- *Additional instrumentation:*
  - **VPR systems**
    - APC
    - Nanomet
    - Dual Ejector & Evaporating Tube
    - Thermodenuder
  - **TSI's SMPS**
  - **EEPS**
  - **Soot Sensor**
  - **DMM**

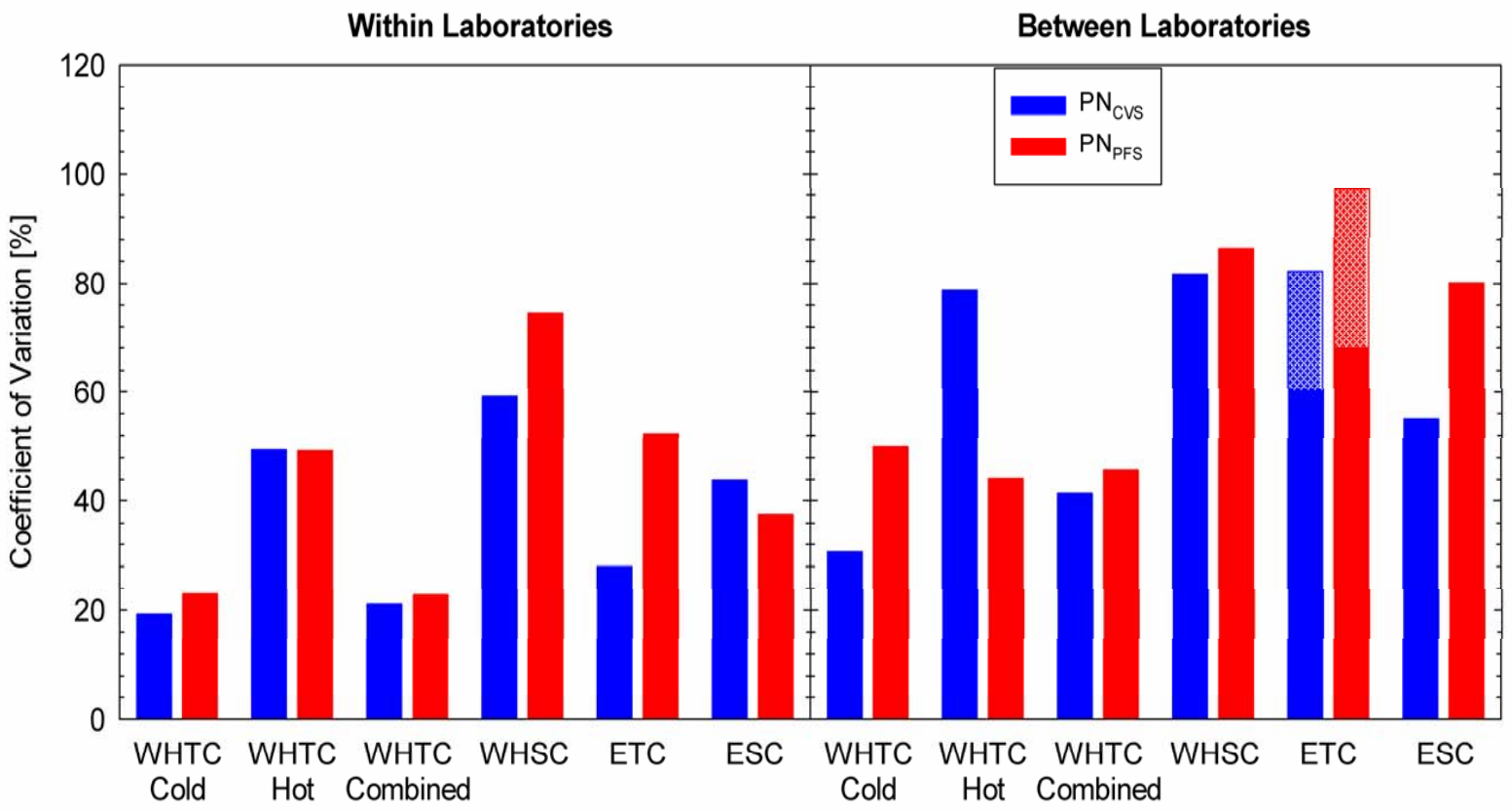
Some experimental results

Background PM



Limited background data collected at the end of the measurement campaign (3 tests from CVS – 2 tests from PFS) were found at the same levels as samples.

PN Repeatability - Reproducibility



- *Repeatability ranged between ~20% (over the high emission cold WHTC) and ~60% (over the high temperature WHSC) for both CVS and PFS after removing outliers.*
- *Reproducibility ranged between ~40% (cold WHTC) and 80% (WHSC).*

Summary

- *PM:*
  - **PM emissions were generally <6 mg/kWh.**
  - **However, background levels were equivalent to test cycle emissions levels.**
  - **The majority of PM mass is gaseous volatiles, which contribute from 10% (cold WHTC) to 99% (hot start cycles) of the total mass.**

- *Particle Number:*
  - **PN emission levels over cold WHTC were determined to be ~4×10^{11} #/kWh with both CVS and PFS systems. At these emission levels, the background effect is insignificant.**
  - **PN emission levels over hot start WHTC and ETC cycles were <2×10^{10} #/kWh. Passive regeneration occurring over the WHSC and ESC cycles could result in an increase of the emissions up to 6×10^{10} #/kWh.**

Summary

- *Particle Number:*
  - **Repeatability and reproducibility levels for the CVS and PFS were similar, ranging from:**
    - ~20% and ~40%, respectively, over cold WHTC
    - ~70% and ~80%, respectively, over WHCS, due to passive regeneration related emissions.
  - **PFS systems showed lower backgrounds than CVS systems, but when the two systems had similar backgrounds, the correlation between PN emission levels was excellent.**
  - **Particle number emissions do not correlate with PM results, as the latter are almost entirely volatile material.**

CONCLUSIONS

- **The PMP succeeded in developing a new measurement technique for particle number suitable for type approval purposes**

- **The PMP has provided the technical basis for the future European emission standards**

- **Cooperation between policy makers, industry and research institutes fundamental for the development of shared and scientifically sound pieces of legislation**

Application of the PMP protocol to NRMM

Focus: diesel engines

Land-based NRMM 2005 numbers

European Commission

	Stage IV	Stage IV	Stage IV	not reg.
N0x Emissions (kt)	56-75 kW	75-130 kW	130-560	> 560
	65.5	102.5	345	600
Small Equipment (Agri)	0	0	0	0
Small Equipment (Constr)	0	0	0	0
Generator Sets	14	20	44	59
Agricultural Tractors	107	185	185	0
Agricultural Harvesters	0	2.1	80	4.9
Light Construct. Equip.	175	0	0	0
Heavy Construct. Equip.	0	71	157	21
Total NOx mass (kt)	296	278	466	85
Total (%)	24	22	37	7

	Stage IV	Stage IV	Stage IV	not reg.
PM Emissions (kt)	56-75 kW	75-130 kW	130-560	> 560
	65.5	102.5	345	600
Small Equipment (Agri)	0	0	0	0
Small Equipment (Constr)	0	0	0	0
Generator Sets	0.99	0.94	1.81	4.2
Agricultural Tractors	7.55	8.58	7.58	0
Agricultural Harvesters	0	0.10	3.27	0.4
Light Construct. Equip.	12.41	0	0	0
Heavy Construct. Equip.	0	3.16	5.86	1.40
Total PM mass (kt)	21	13	19	6.0
Total (%)	30	18	27	9

Total PM:
~ 70 kt

PM > 56 kW
84% = 59 kt

Railcars & Locomotives 2005 numbers

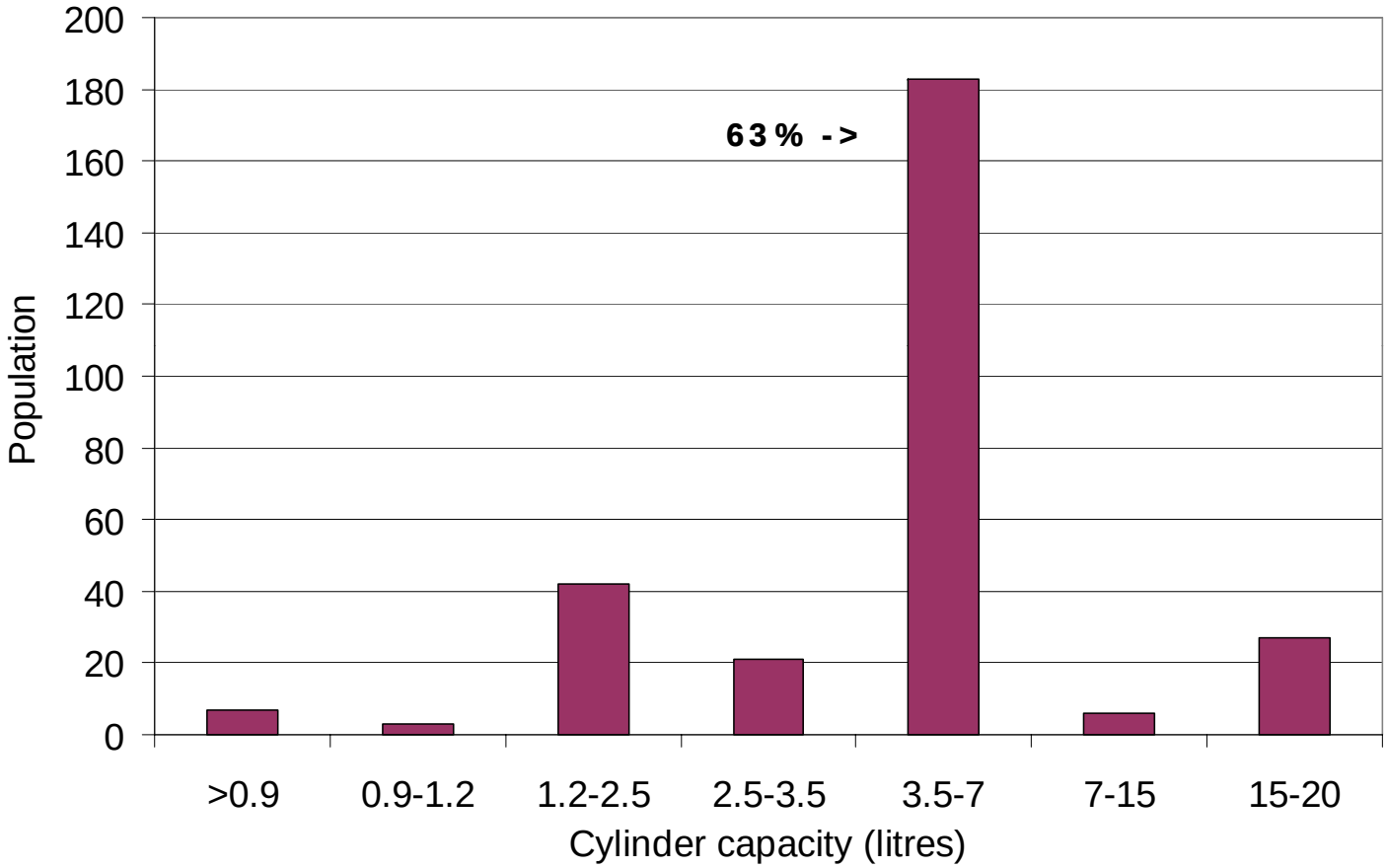
26.000 engines

Scenario1	year	PM (kt)	N0x (kt)	fuel (kt)
Railcar	<1990	2.5	65	1058
	>1990	0.7	37	1150
Main Loco	<1990	4.6	210	3139
	>1990	0.5	37	703
Shunting	<1990	1.9	42	775
	>1990	0.2	10	187
	Total	10.5	401	7012

Scenario2	year	PM (kt)	N0x (kt)	fuel (kt)
Railcar	<1990	0.5	12	202
	>1990	0.1	7	219
Main Loco	<1990	0.9	42	620
	>1990	0.1	7	139
Shunting	<1990	0.4	10	181
	>1990	0.1	2	44
	Total	2.1	80	1404

Inland Waterway Vessels 2005 numbers

~ 80 new engines/year



Inland waterway propulsion engine power distribution
Installed from 2002 to mid 2005

Total PM Emissions similar to rail sector

Considerations

⇒ **Careful consideration of :**

- **Size of the specific sector (sales numbers, road engine derivate?)**
- **Engine specifics (power band, engine specific emission levels, total emissions contribution)**
- **Total cost for test facility modifications**
- **Extra cost per engine type approval**

The petrol side of NRMM: small spark ignited engines

Small SI engines 2005 estimates

Machinery specific HC + NOx emissions

engine type	limits HC+NOx EU stage I	limits HC+NOx EU stage II	typical emission for EU I engines	typical emission for EU II engines	Load factor	environmental load HC+NOx in 2005 [to]	environmental load HC+NOx in 2015 [to]	2-stroke 2005	2-stroke trend 2010
chainsaws hobby	247	50	140	50	0.5	6.440	2.300	100	100
chainsaws professional	166	72	120	72	0.85	20.853	12.512	100	100
trimmers hobby	247	50	170	50	0.5	2.896	852	80	50
trimmers professional	166	72	120	72	0.5	2.453	1.472	90	70
others hobby	247	50	170	50	0.5	1.690	497	70	50
others professional	166	72	145	72	0.5	2.223	1.104	90	50
lawn mowers hobby	16.1	16.1	15	15	0.5	5.431	5.431	< 20	0
lawn mowers professional	16.1	16.1	15	15	0.5	67	67	< 20	0
riding mowers hobby	13.4	12.1	12	10	0.4	3.162	2.635	~ 0	0
riding mowers professional	13.4	12.1	12	10	0.4	2.999	2.499	~ 0	0
TOTAL						**48.214**	**29.368**		

	2005	2015
PM (t)	892	543
PM = 1,85% von HC+Nox		
PM = 2% HC		
2stroke HC = 98% HC+Nox		
Solid PM fraction = 5% of total		
PM (t)	**45**	**27**

~ 5 mio. Engines / year

Small SI Engines Conclusions 2007

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PMP setup: high costs for small industry

Difficult to measure and dilute small exhaust flow without acting on engine (change performance)

Difficulty with high liquid (oil) content

High variability of 2-stroke PM measurements

Need of certified fuels, oils

Certification time increase from 0.5 to ~ 2 days

PM control through HC emissions as cheap option

Oil/fuel mixture reduction: 50:1 possible for almost all applications, otherwise 25:1 for special construction machinery (dusty environment)

Thank you for your attention!