UPDATE ON THE PMP PROGRAMME SUMMER 2005

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ABSTRACT

Within the UN-ECE forum, the Governments of France, Germany, Japan, the Netherlands, Sweden, Switzerland plus the United Kingdom as Chairman, agreed to a collaborative programme aimed at developing measurement systems by which ultrafine particles could be controlled in a regulatory framework. The eventual outcome would be a system, or systems, that would replace or complement the existing gravimetric method of particulate filter mass measurement. The Particle Measurement Programme (PMP) workgroup developed a tri-phased approach to complete this work.

In PMP Phase 1, measurement systems addressing particle properties including mass, number, active surface and chemistry were evaluated along with dilution methods, sample conditioning and cost and logistical aspects. Phase 2 subjected the best performing systems to more rigorous evaluations, and as an outcome recommended two measurement systems:

- A gravimetric method based broadly upon that proposed for the US for 2007 type approvals. This offers significant improvements in repeatability compared to the current European filter method
- A particle number method using a Condensation Particle Counter and sample pre-conditioning to eliminate the volatile particles which may contribute significantly to variability. This system proved to be robust to different engines and exhaust chemistries and in Phase 2 showed better repeatability than the modified gravimetric method on two heavy-duty Diesel engines.

In PMP Phase 3: the inter-laboratory correlation exercise managed by JRC, a repeated set of measurements is underway across several European laboratories, with a 'Golden Particle Number Measurement System', and a 'Golden Vehicle' transported from laboratory to laboratory. The 'Golden Vehicle' is a Euro IV compliant, DPF equipped Diesel vehicle, other vehicle types: conventional Diesel, DISI and MPI gasoline are also being tested. Strict calibration and validation exercises are included to ensure the optimal performance of the Golden Measurement System and determine the real requirements for these exercises in a regulatory environment. A modified particulate mass measurement system is also being evaluated. Preliminary results show that the number method is approximately 20 times more sensitive than the revised mass method. Both methods appear capable of enabling discrimination between Diesel vehicles equipped with particle filters and those without, but mass methods may be uncertain due to volatile artifacts.

NEDC solid particle number emissions levels from DPF equipped Diesels are in the region of 10^{11}/km, with conventional Diesels' emissions a factor of ~500 times higher.

Particle number measurements made from non-DPF equipped Euro IV Diesels (≥5 tests) show repeatability levels typically in the range 1% to 3% compared with 4% to 8% with the revised PMP mass method.

High temperature operation, and thermal regenerations show increased emissions of both solid and volatile particles.

The next phase of work will be the heavy-duty inter-laboratory correlation exercise. This will start at the beginning of 2006, and will include the evaluation of PMP mass and number methodologies on a Golden Engine. Measurements will be made from both full and partial flow dilution systems simultaneously.

UNECE GRPE

Particle Measurement Programme

Update and Report on First Results: Light-duty Inter-laboratory Correlation Exercise

9th ETH-Conference on Combustion Generated Nanoparticles

15th –17th August 2005

J. Andersson (Ricardo Consulting Engineers, UK)
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Inter-laboratory Correlation Exercises
Summary

- Light-duty Exercise prioritised
- Commenced late summer 2004
- 9 labs participating (11 repetitions)
- Project managed by DG JRC (Ispra, Italy)
- Golden Engineer funded by DfT (UK)
- Completion of light-duty phase Winter 2005
- Heavy-duty programme planned for Early 2006

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Overview of light-duty inter-laboratory exercise

- Repeated measurements at several laboratories (with JRC bookends)
- Travelling ‘Golden Engineer’ + two of JRC staff to ensure best and reproducible testing practice
- Very low PM ‘Golden Vehicle’ at all labs
  Repeatability/Reproducibility
- Test ‘Golden Measurement System’ for particle numbers
- Test modified mass measurement system
- Test additional vehicles of various types
- Test of alternative systems for particle numbers

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Outline of Presentation

- Vehicles tested
- Mass results
- Number results
- Regeneration effects
- Preliminary conclusions

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Revised Timetable (PART A)

No	Address:	PMP testing weeks:
1	**JRC,** **Ispra, Italy**	9 to 17 November
2	AVL MTC Sweden	29 November-3 Dec 04
	AEA Technology, UK	*Calibration of Golden Measurement System*
3	Ricardo Consulting Engineers UK	1-8 February 05
4	RWTÜV Essen, Germany	1-8 March 05
5	Lab of Applied Thermodynamics (LAT) Greece	6-20 April 05
6	**JRC,** **Ispra, Italy**	10-31 May 05
	AEA Technology, UK	*Calibration of Golden Measurement System (during transfer of car to Japan)*
	INTERIM REPORT	*June- Transfer to Japan*

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Revised Timetable (PART B)

7	NTSEL, Japan	July 05
8	National Motor Vehicle Emission Research Laboratory, Korea	September 05
		End September 05 – *Transfer to Europe*
9	Shell Global Solutions UK	?
10	UTAC France	Week 41-42 or 45-46
	AEA Technology, UK	*Calibration of Golden Measurement System*
11	**JRC,** **Ispra, Italy**	November 05
	FINAL REPORT	*December 05*

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Vehicles tested

- PEUGEOT 407 HDi FAP 2000 cc (in all labs)
- BMW 525d catalysed DPF equipped, 2500 cc

DPF DIESEL

- Audi A2, TDi, EURO-4, Oxicat, 1500 cc
- Honda Accord i-CTDi, EURO-4, Oxicat/deNOx, 2200 cc
- VW, GOLF TDi, non-DPF, Oxicat, 1800 cc

DIESEL

- Mitsubishi, Carisma, GDI, TWC/deNOx 1800 cc
- VW, GOLF FSI, TWC/deNOx 1600 cc

DISI

- FIAT, Idea, MPI, EURO-4, TWC, 1400cc

MPI

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Mass systems tested

- Pallflex TX40 mandated; single batch for all tests
- Inertial protection of filter (2.5µm to 10µm cut-point cyclone)
- No back-up filter
- Single filter for entire NEDC for DPF equipped vehicles
- Modified filter holders for even deposition of material
- Lab modified systems with external heating tapes and mantles (most labs)
  - Sample passes through zone held at 47°C +/- 5°C for >0.2s
  - Temperatures recorded
- HORIBA HFU-4770 (Heated Particulate Filter Module) (2 labs)
  - Heated enclosure containing cyclone, transfer tubing and filter holders
    - Controlled to 47°C +/- 5°C, residence time >0.2s

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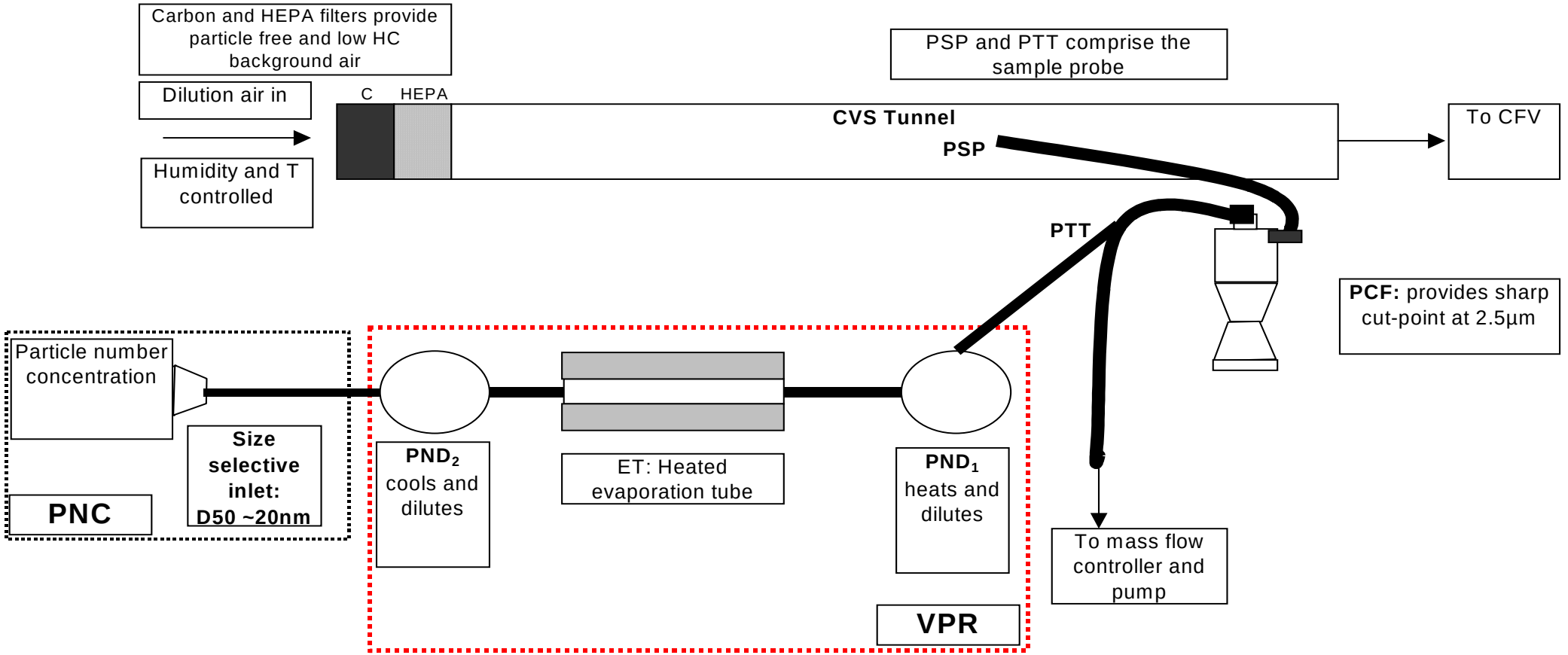
Particle Number System



- A particle number method employing a condensation nucleus counter (CNC), but using sample pre-conditioning to eliminate the most volatile particles which may contribute significantly to variability.

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Alternative number systems tested

- Dual Ejector dilutor-TSI CPC 3010 lab modified (1 lab)
- DEKATI FPS (modified) -GRIMM modified CPC 5.403 (3 labs)
- DEKATI FPS (modified) -TSI CPC 3010 lab modified (1 lab)
- HORIBA Solid particle counting system (to be tested)

- No results will be shown from the alternative systems today.

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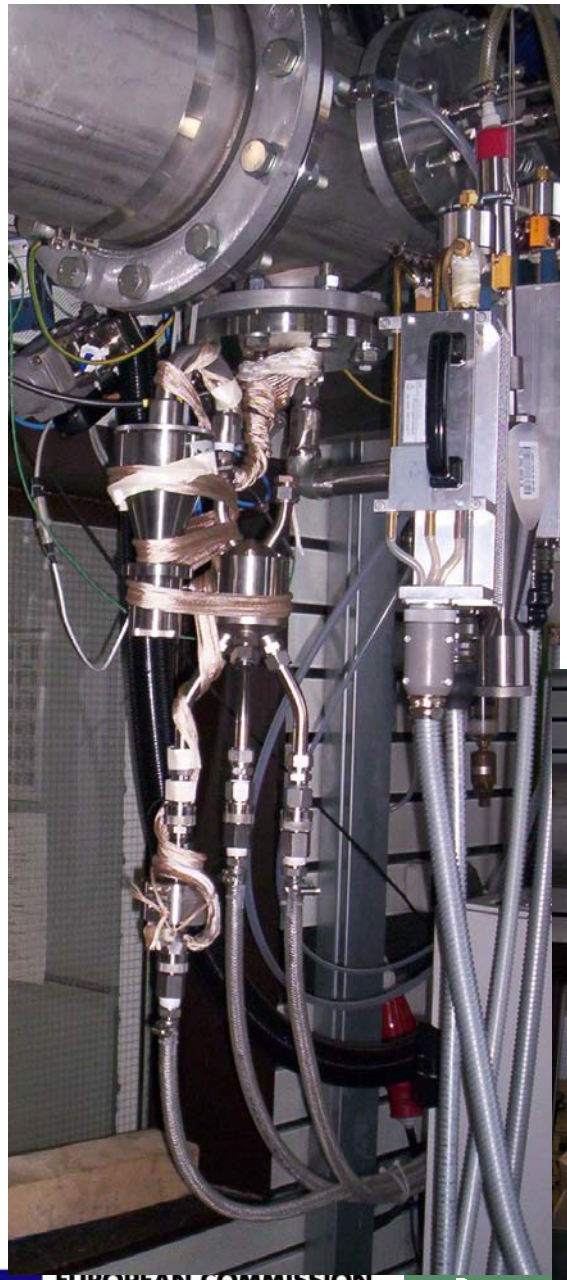

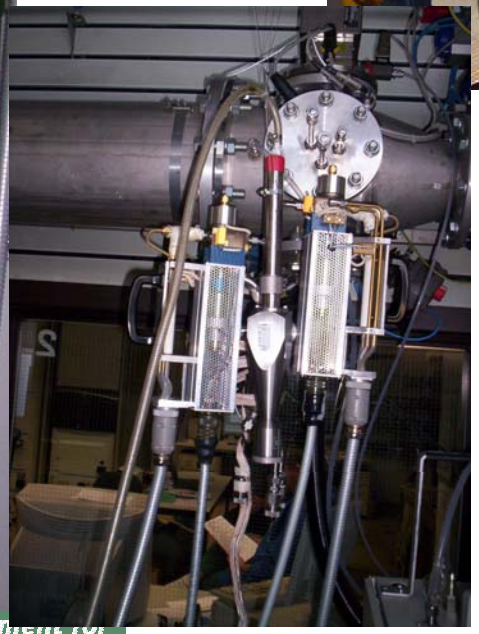

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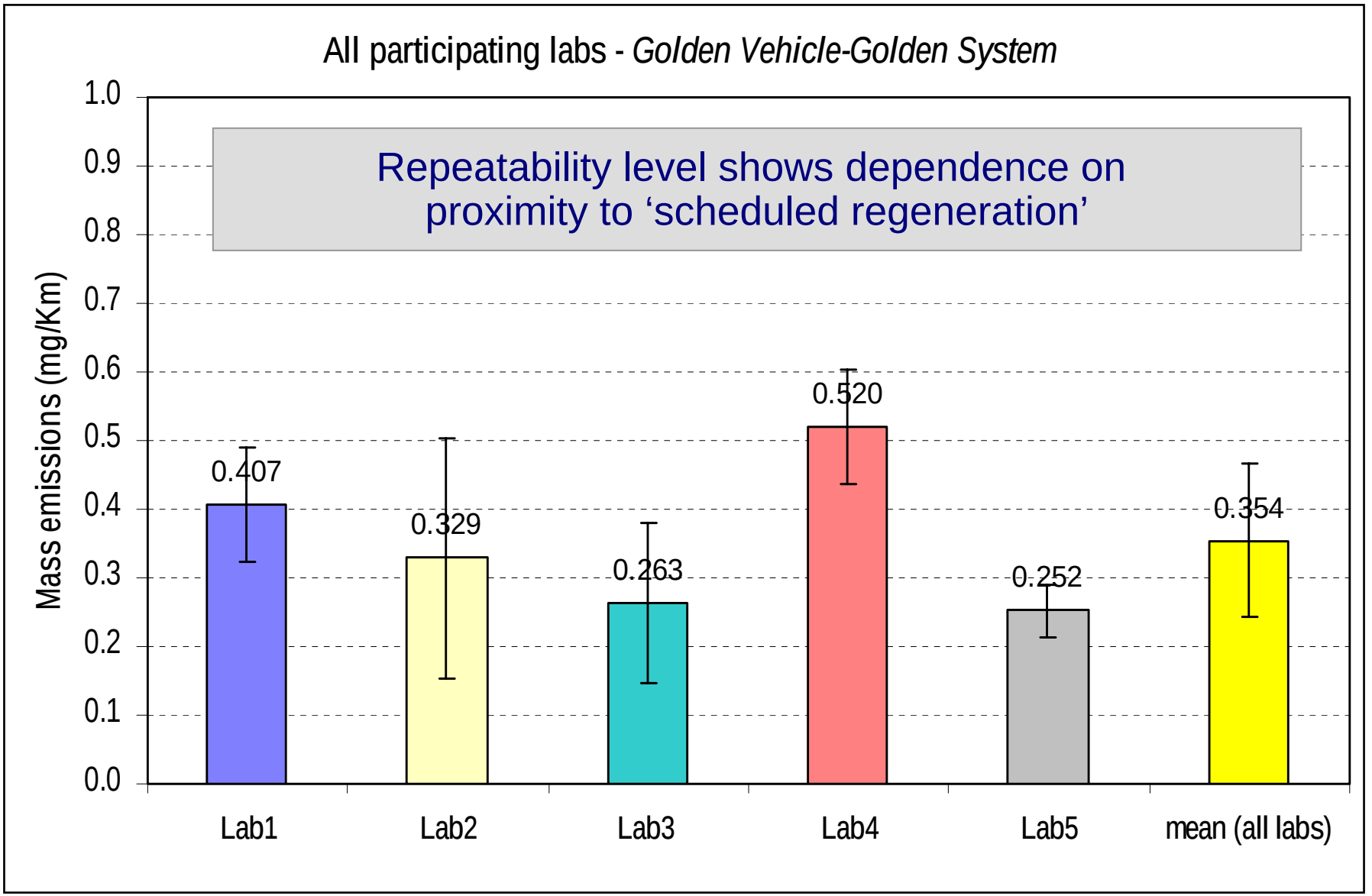
Particulate Mass Emissions From Golden Vehicle Below 1mg/km



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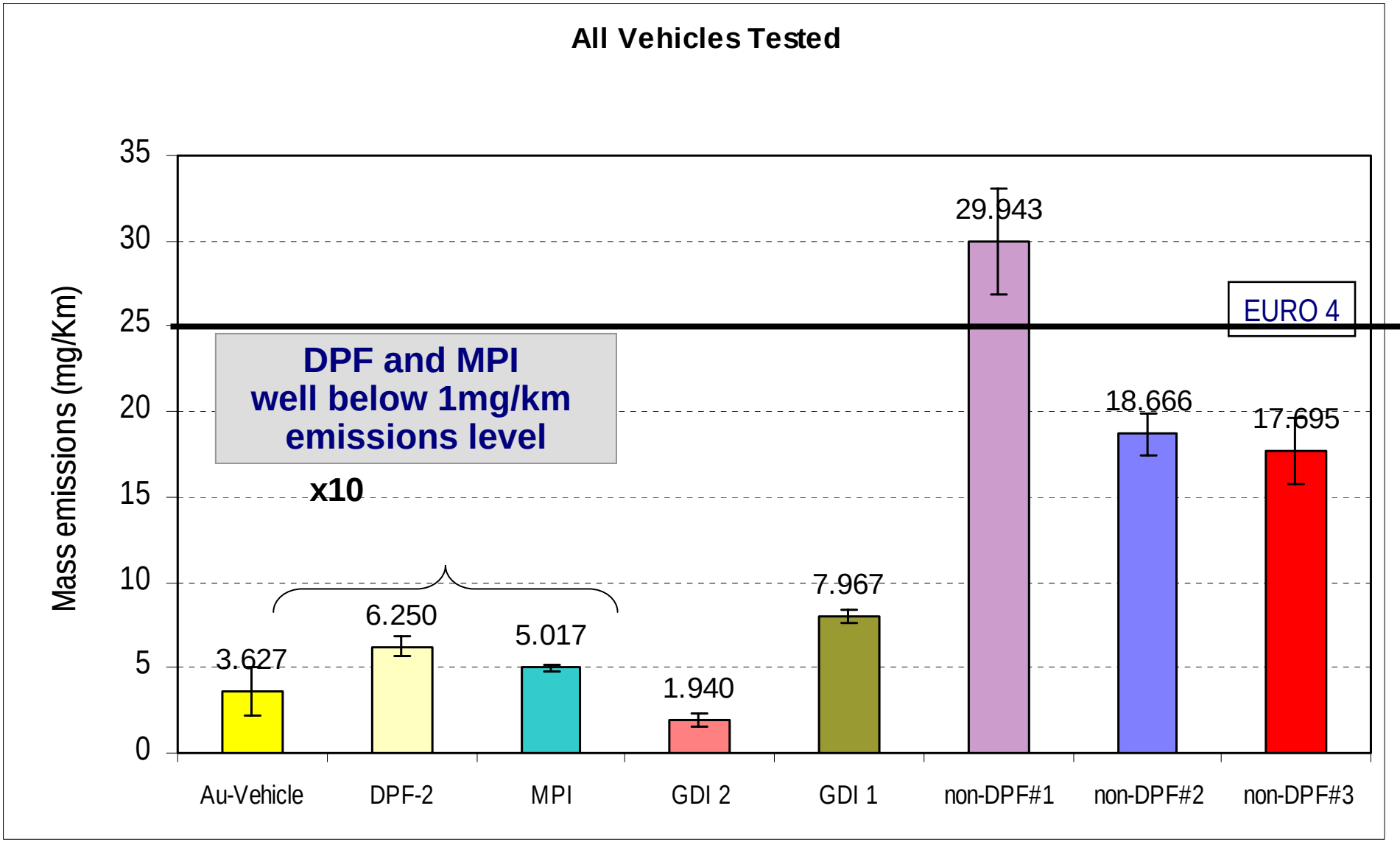
Particulate Mass Emissions (mg/km)



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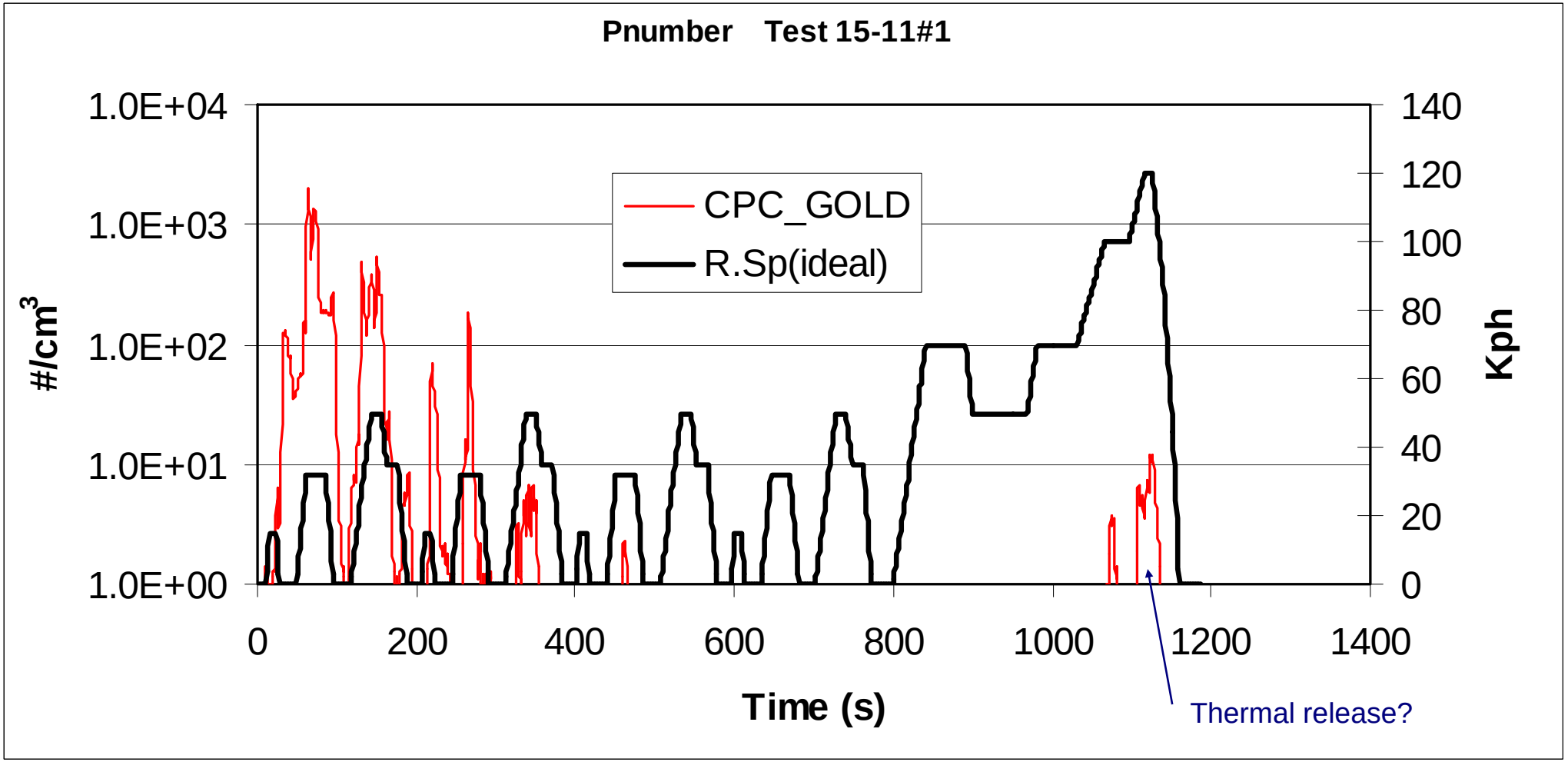
Majority of Particle Numbers Emitted During Cold-Start Testing



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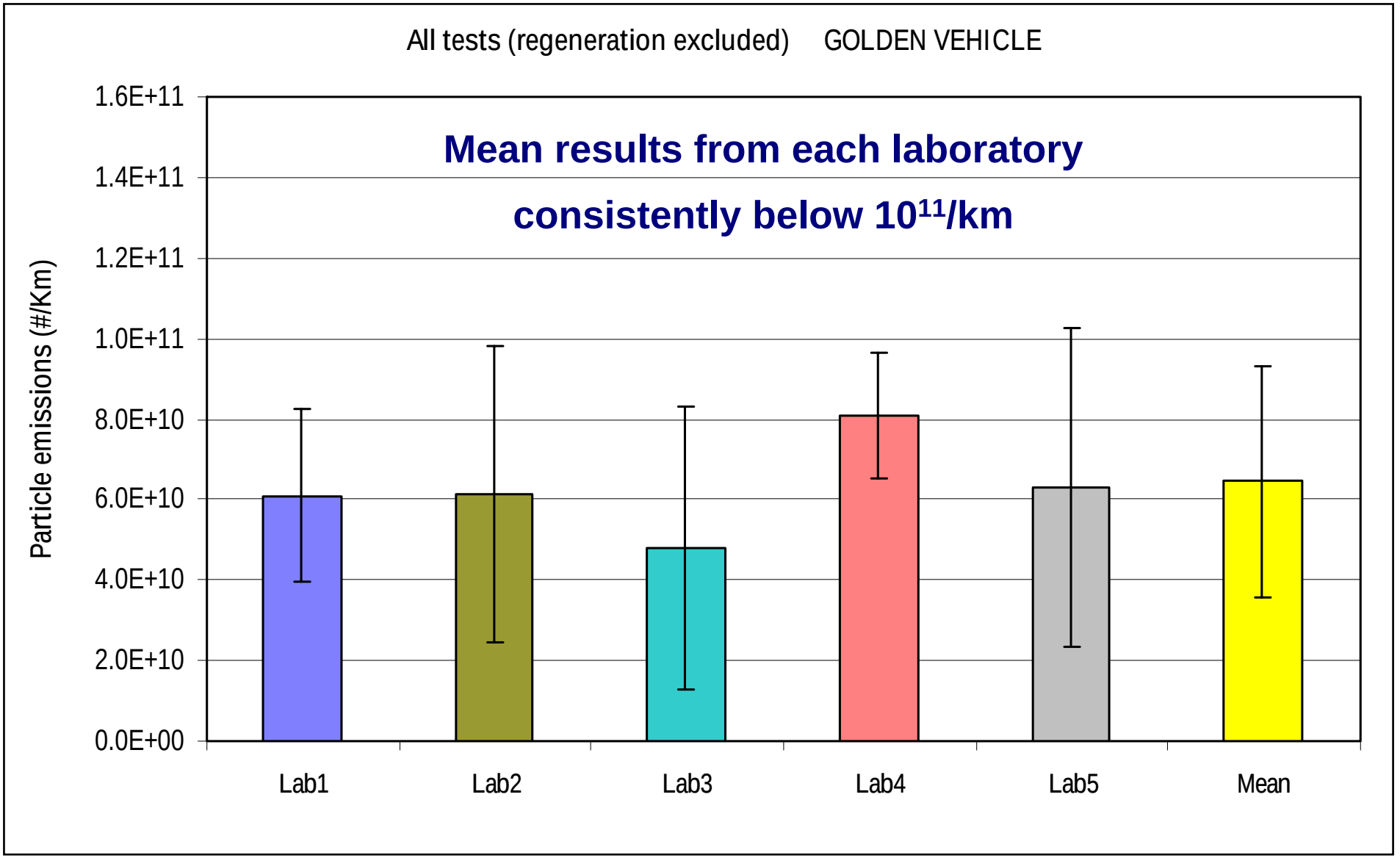
Particle Numbers from NEDC ≤ 10^{11}/km



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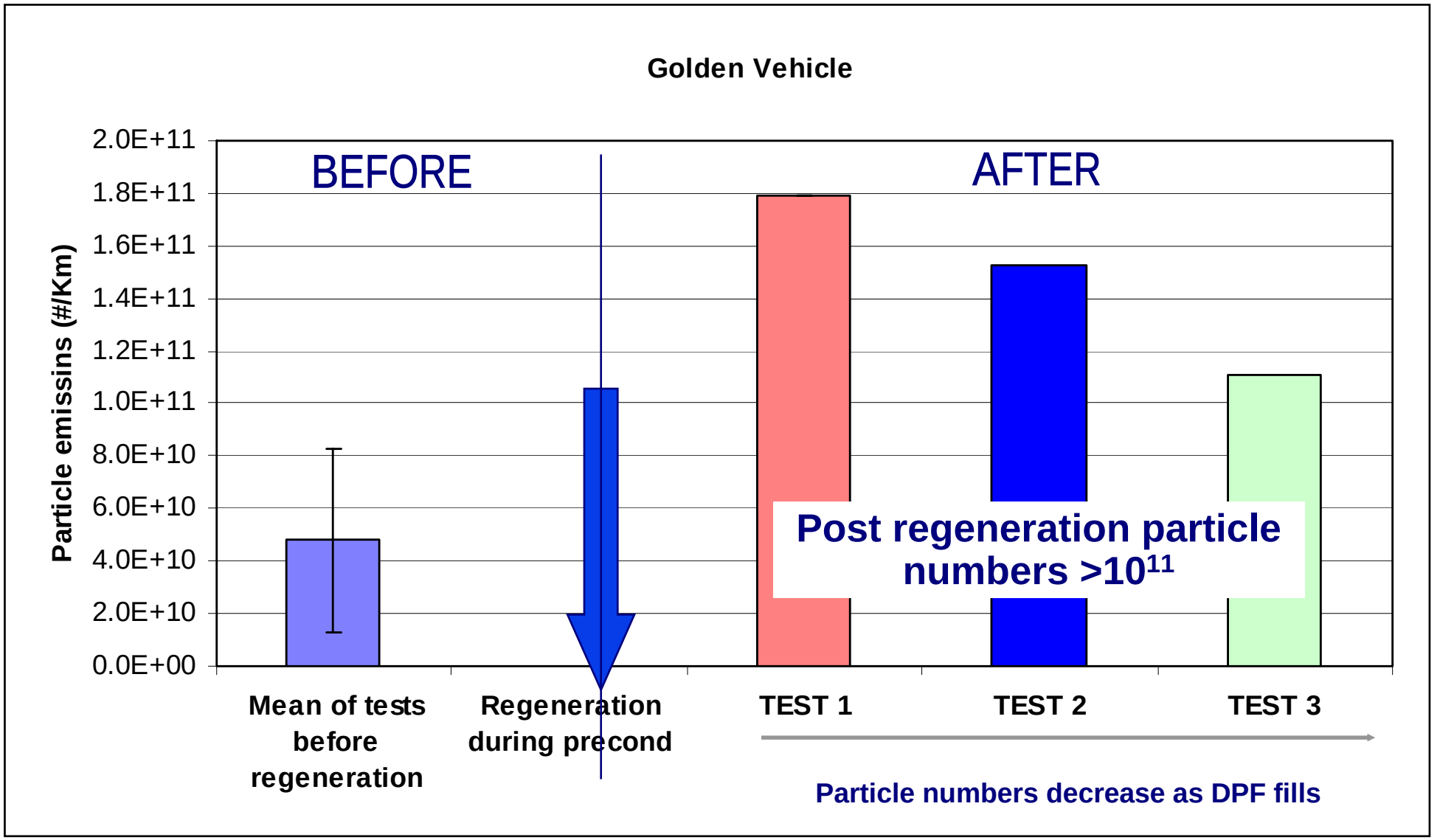
DPF fill state influences particle numbers – and repeatability!



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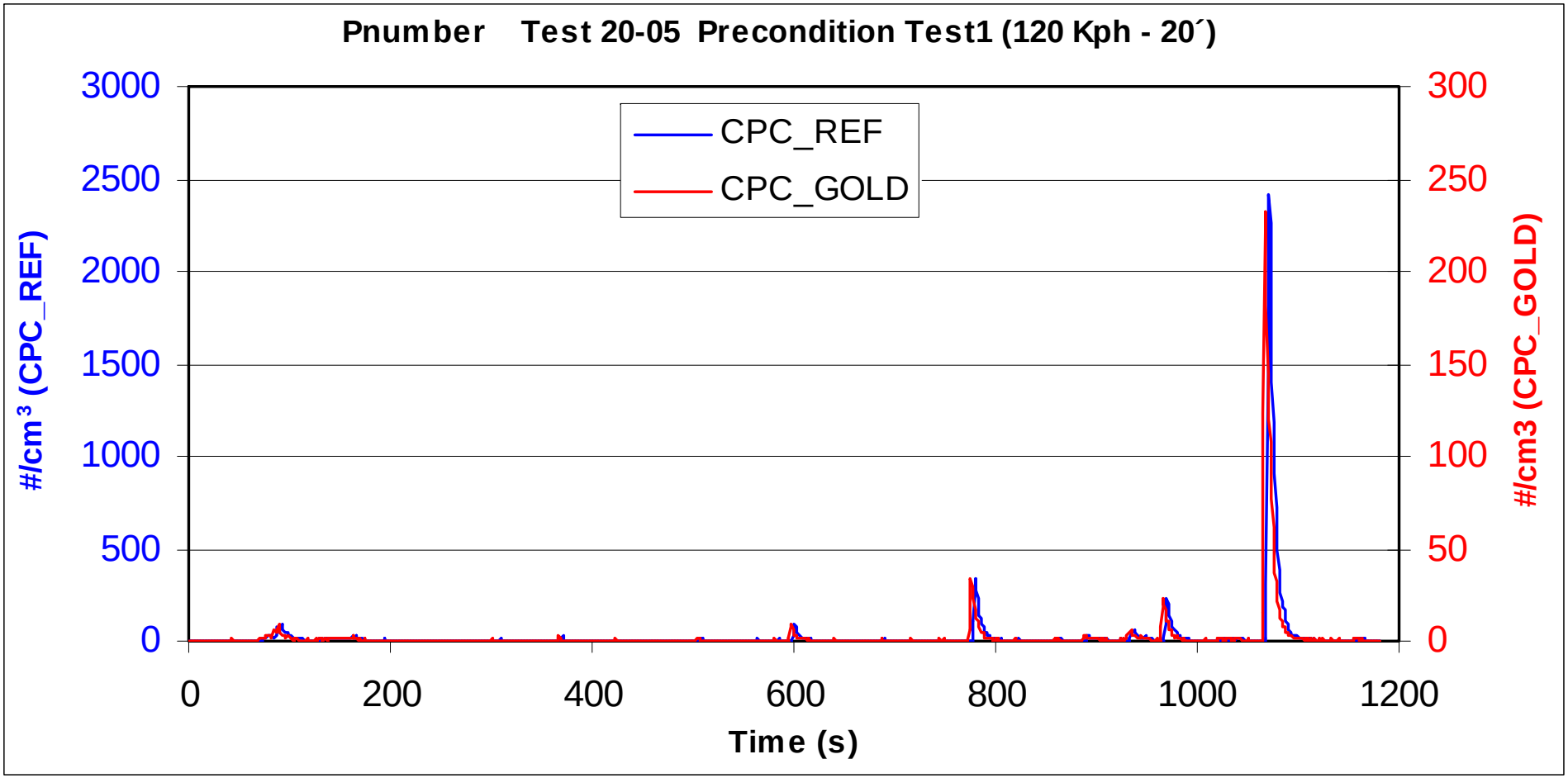
High temperature preconditioning (20 minutes @ 120kph) liberates some solid particles



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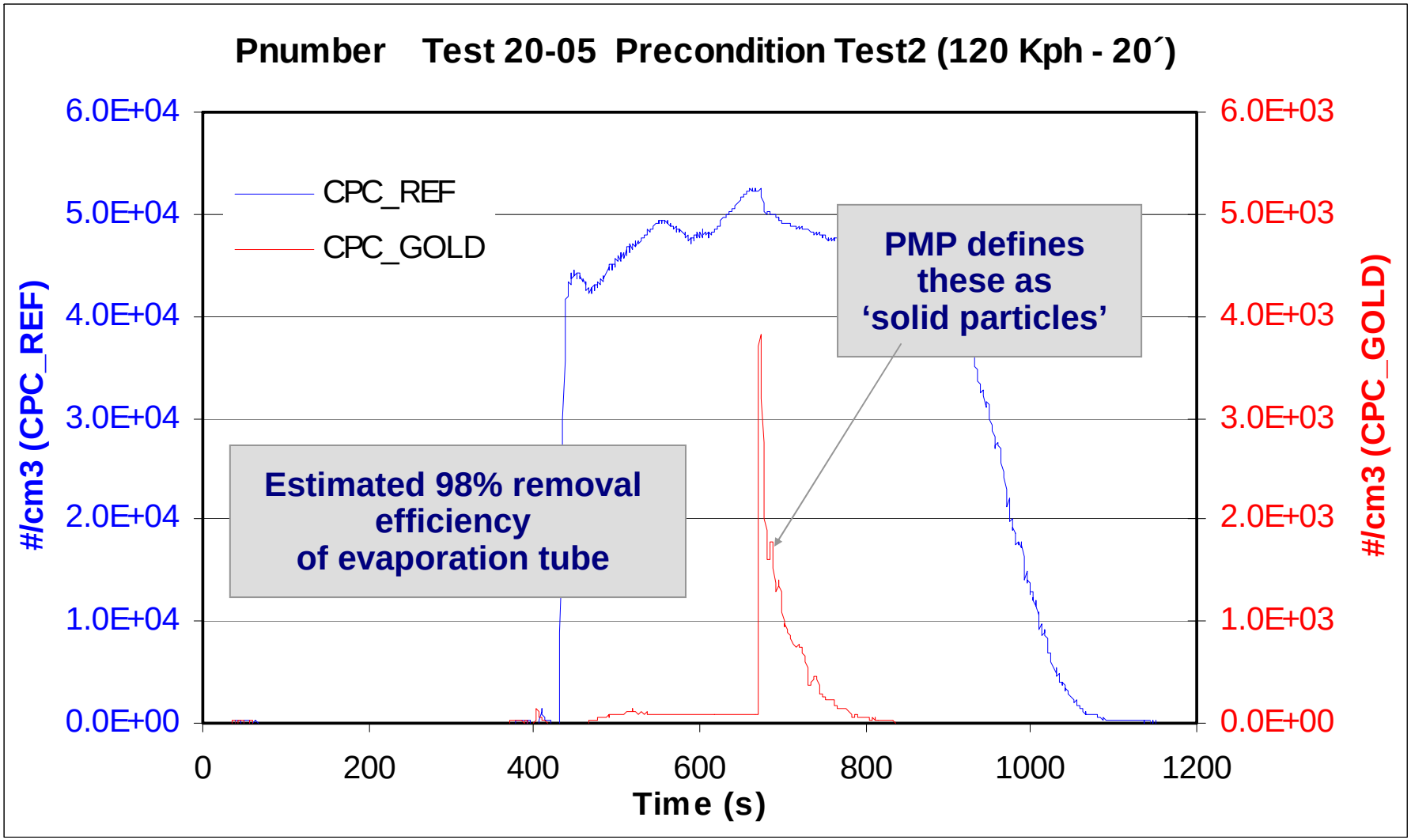
Regeneration liberates solid and volatile particles (Scheduled regeneration during 20 minutes @ 120kph, engine throttled, oxygen restricted)



Low oxygen levels may lead to poor oxidation and breakthrough of carbon during regeneration

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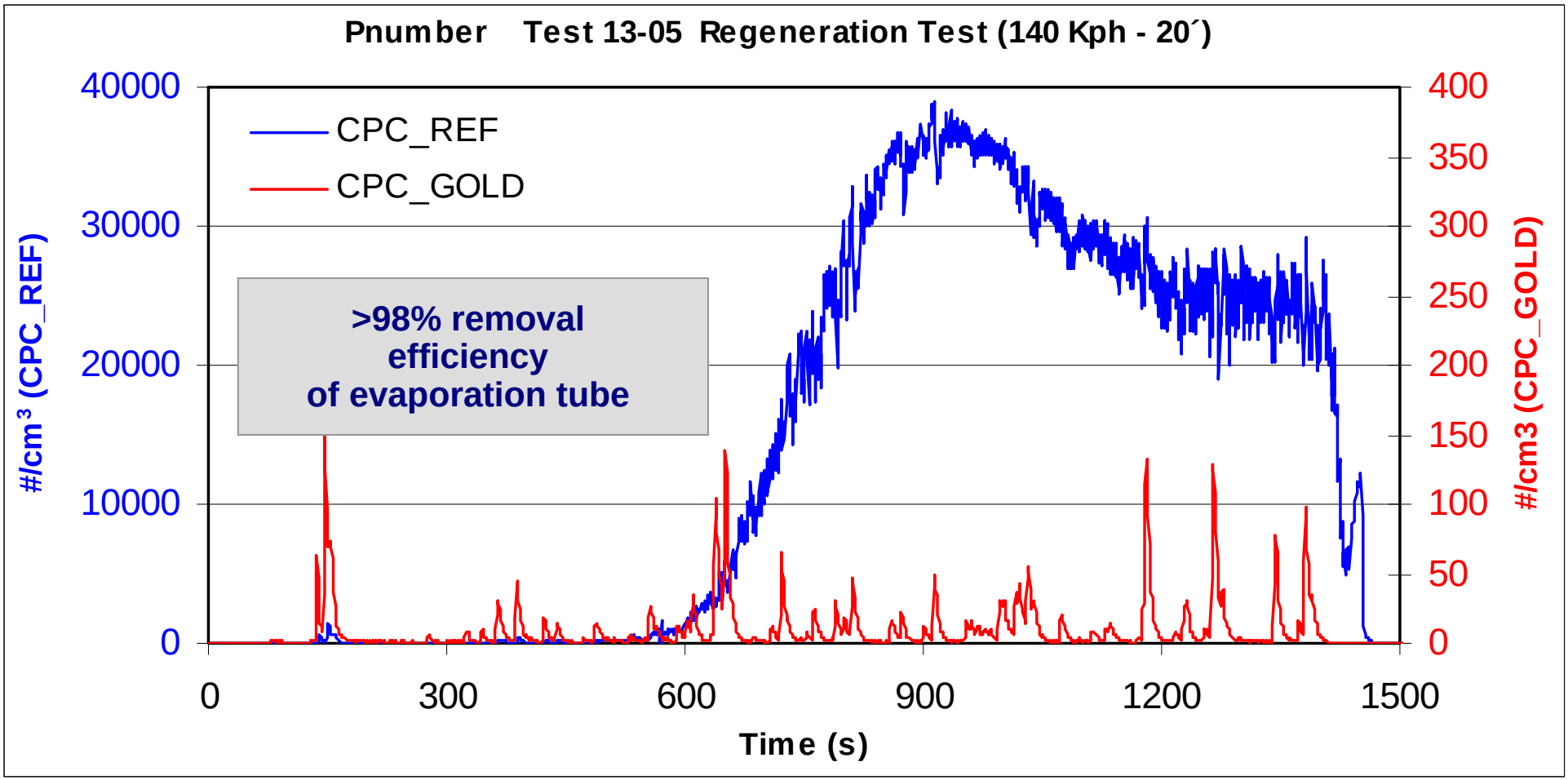
$T_{exhaust}$ = ~100°C higher than non-regenerating 120kph

Forced (Passive) Regeneration at 140km/h
High oxygen levels lead to more efficient oxidation – few solid particles post ET



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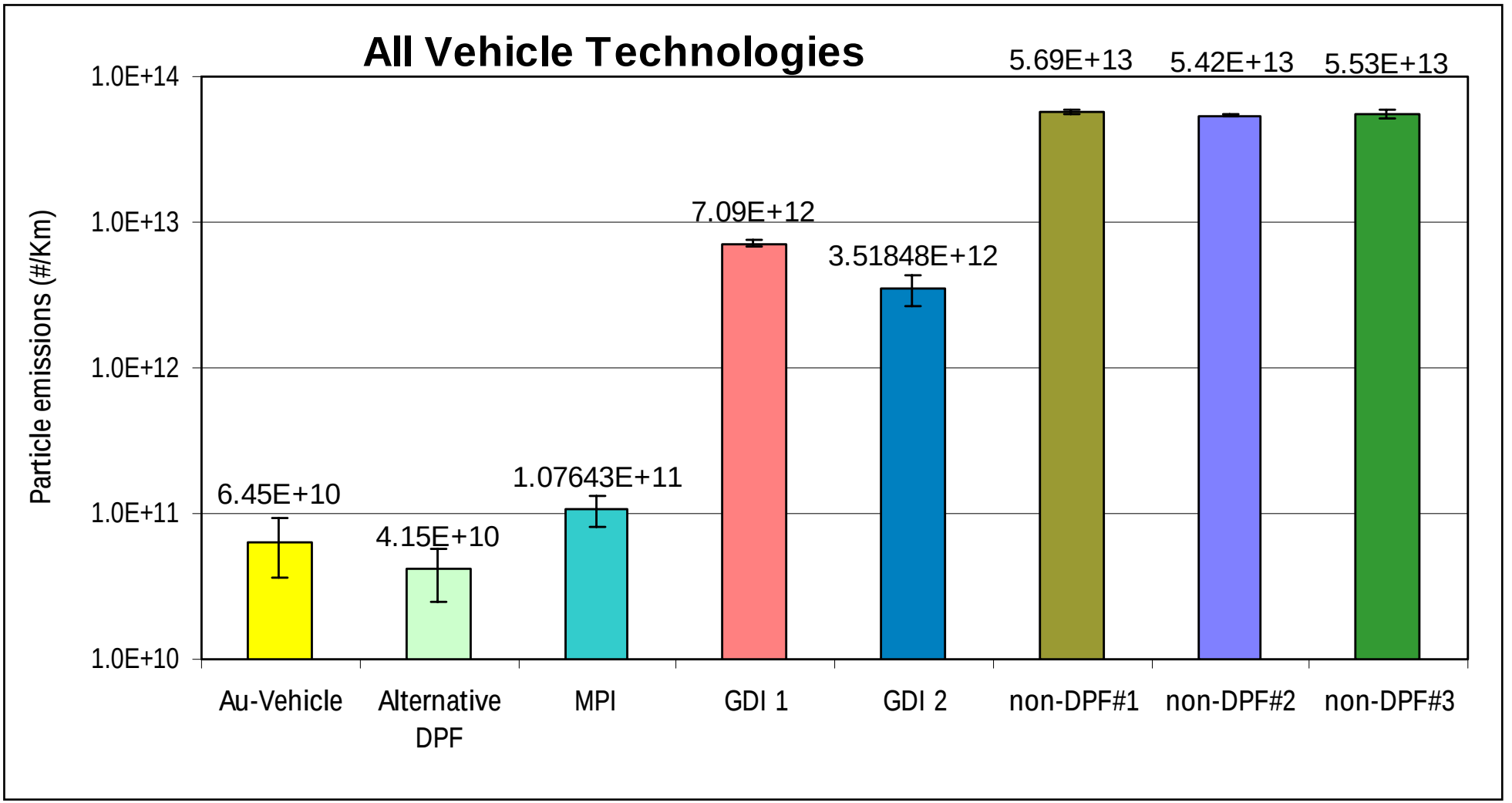
NEDC Particle Numbers (#/km)
Factor of 500 –1000 between DPF & Non-DPF Diesels



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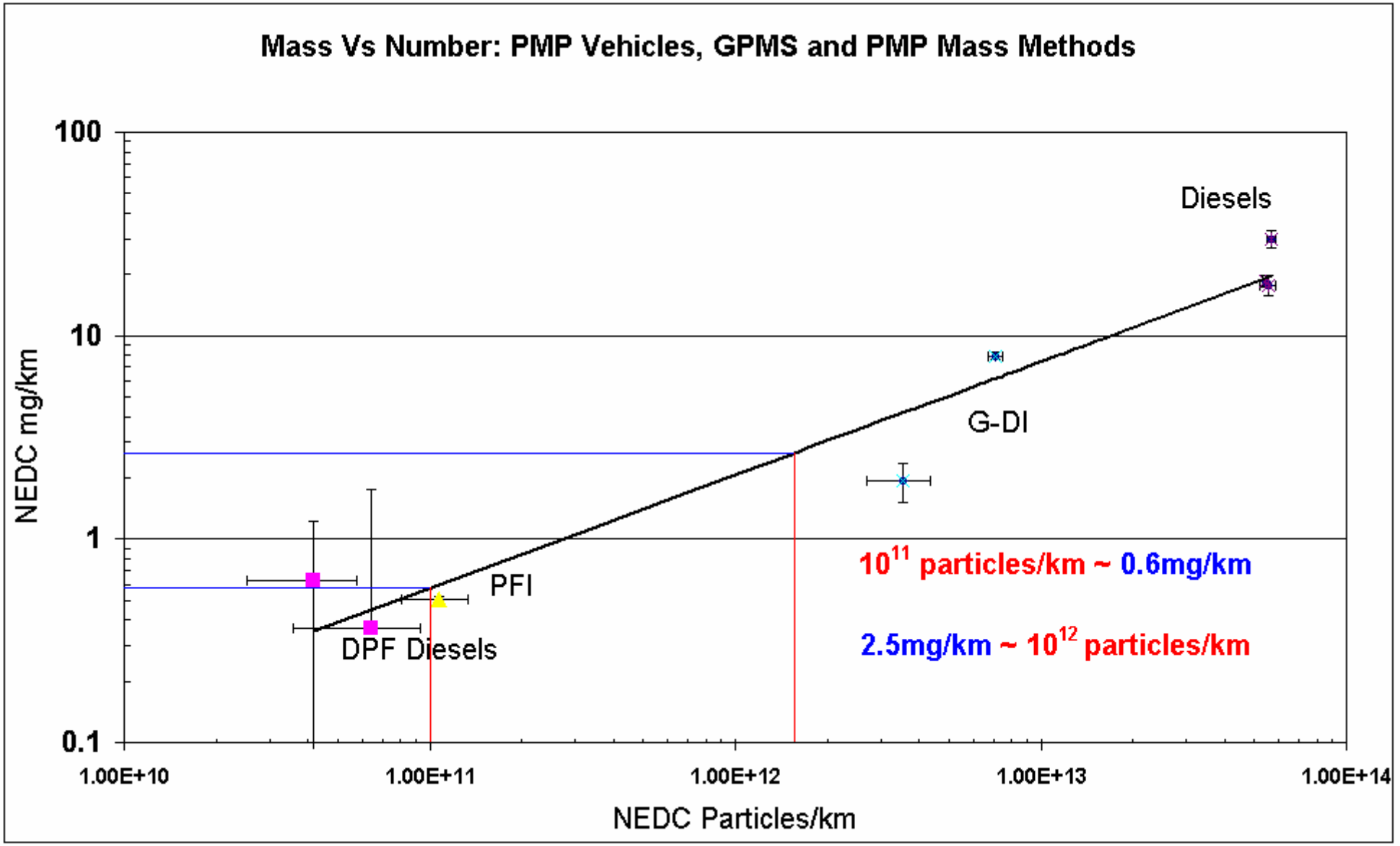
PMP Mass and PMP Number shows Directional Relationship



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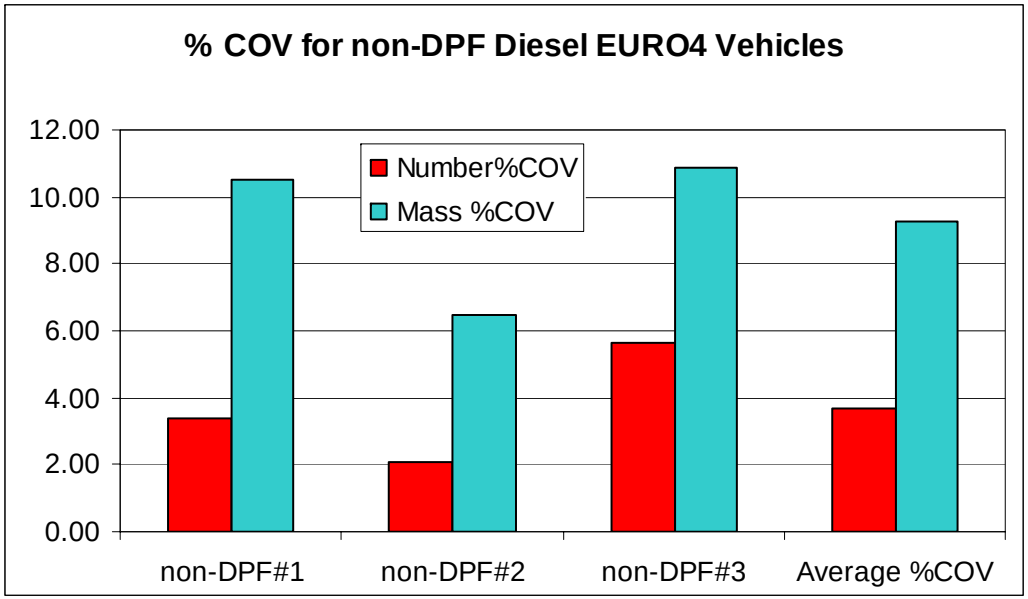
Comparison between mass and number
EURO 4 Conventional Diesel Vehicles

	non-DPF#1	non-DPF#2	non-DPF#3	Average %COV
Number	5.69E+13	5.42E+13	5.53E+13	
STD	1.91E+12	1.13E+12	3.10E+12	
%COV	3.36	2.08	5.62	3.69
Mass	29.943	18.666	17.695	
STD	3.143	1.21	1.93	
%COV	10.50	6.49	10.88	9.29



- With PMP solid particles, number measurements are less variable than mass for EURO-4 non-DPF Diesel cars

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Preliminary Conclusions

- Mass method sufficiently sensitive to permit repeatable measurements at well below 2.5 mg/km level
  - Significant questions remain regarding sampling and retention of volatiles by filter media in absence of carbon
- Number method ~20 times more sensitive than mass
  - Emissions of ~10^{11}/km achievable with DPF Diesels, similar to modern MPI
  - GDIs between 10^{12} /km and 10^{13}/km
  - Conventional Diesels' emissions ~ 500 times higher (at ~5 x 10^{13}/km) than DPF equipped ones
- PMP number method less variable than PMP (or current)mass method for EURO-4 non-DPF diesel cars

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Preliminary Conclusions-2

- Mass and number measurement equipment presented no significant functional or maintenance challenges during the programme
- PMP mass and number methods sufficiently sensitive to discriminate between current non-DPF and DPF equipped Diesels
- PMP number metric provides best sensitivity and avoids uncertainties with volatile components for DPF equipped Diesels
- Current technology GDI falls between DPF Diesel and non-DPF Diesel both in mass and number
- Solid particle numbers from DPF regenerations depend on the vehicle driving prehistory and type of regeneration

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Next Steps

- 2nd Phase of testing
  - Asia (NTSEL, NMVERL)
  - Europe (UTAC, SHELL, JRC)
- Analyse all data and prepare final reports for PMP WG
- Further revision of draft regulatory documents
  - Fine tuning
  - Integration of necessary validation and calibration procedures for number measurement equipment
- Submission of drafts to EC in Brussels as protocols in regulation format for consideration as part of Euro V
- Heavy Duty Inter-lab exercise – Currently under development

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Thank you for your attention

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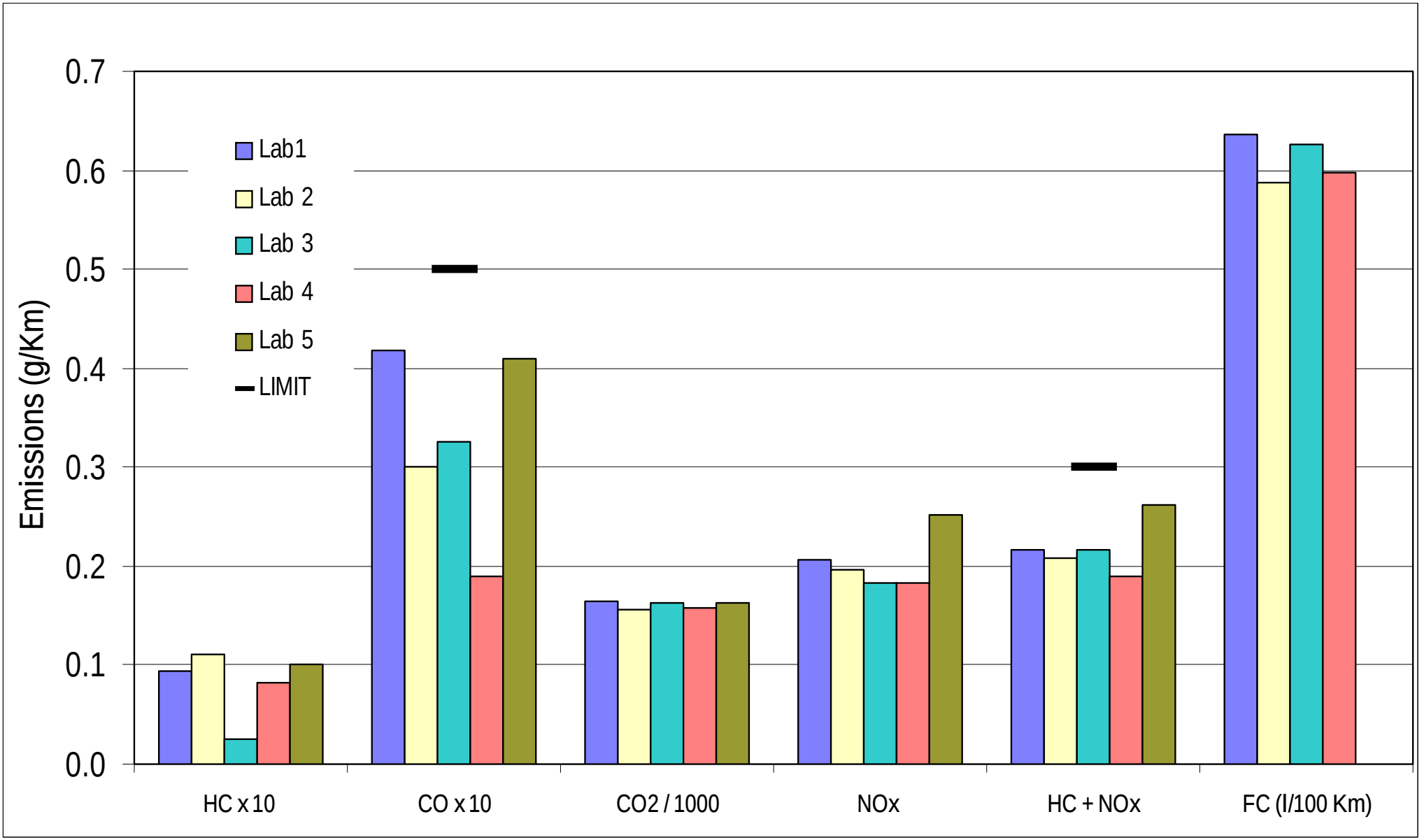
Regulated emissions Reproducibility



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