Investigation of the Feasibility of Achieving Euro VI Heavy-Duty Diesel Emissions Limits by Advanced Emissions Controls

D Bosteels, J May
AECC – Association for Emissions Control by Catalyst, Belgium

A J Nicol, C H Such, J D Andersson, R D Sellers
Ricardo UK Ltd

Association for Emissions Control by Catalyst AISBL

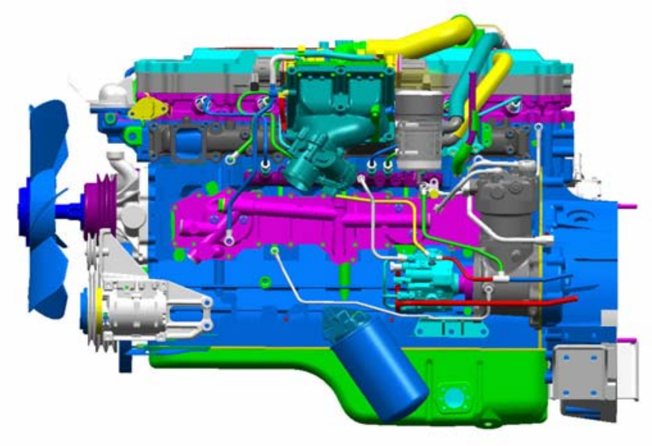
Contents

Objectives of AECC heavy-duty Euro VI test programme

- Demonstrate the performance of an integrated emissions control system on a modern, low NOx engine.
- Provide data on regulated and non-regulated emissions.
- Compare current gravimetric and heavy-duty PMP method for particulate mass (PM).
- Assess heavy-duty PMP particle number methodology.
- Provide data on European and World-harmonised transient and steady-state test procedures.

AECC heavy-duty Euro VI test engine

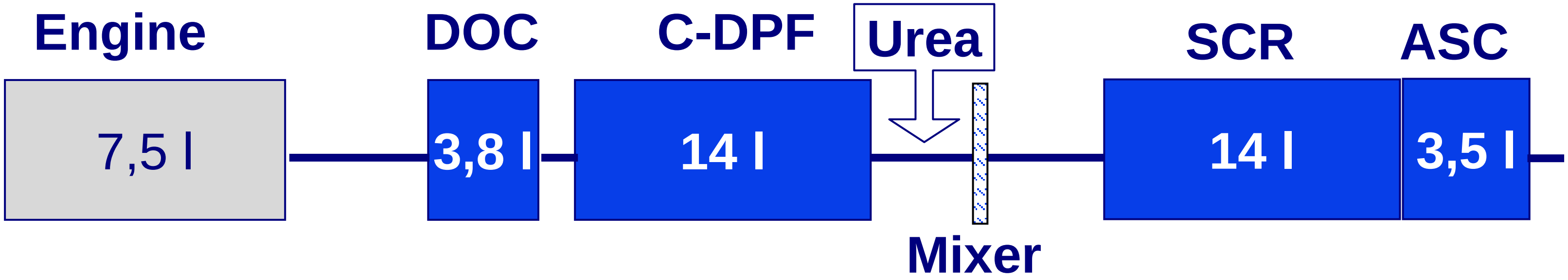
- Engine designed for US2007, provided by an engine manufacturer
  - 6 cylinder 7.5 litre engine
  - Common rail
  - Turbocharged (fixed vane)
  - Max. injection pressure 180Mpa
  - Cooled lambda-feedback EGR
  - Original particulate filter replaced by AECC system.



- No modification to base engine calibration
  - no changes made to optimise engine-out emissions on the European cycles
  - engine-out emissions are ‘as received’.

Emissions control system for AECC heavy-duty Euro VI test programme

- Oxidation catalyst (DOC), catalyst-based wall-flow particulate filter and urea-SCR with ammonia slip catalyst (ASC).



1m mixing length between injector and SCR face.

- System oven aged for 200hours at 600ºC.
- Bosch advanced airless urea dosing system.
- NOx sensors at engine-out and downstream of the SCR system (upstream as input for dosing control, second as monitor; not for closed loop control).
- No optimisation was undertaken.

Testing and Preconditioning procedures

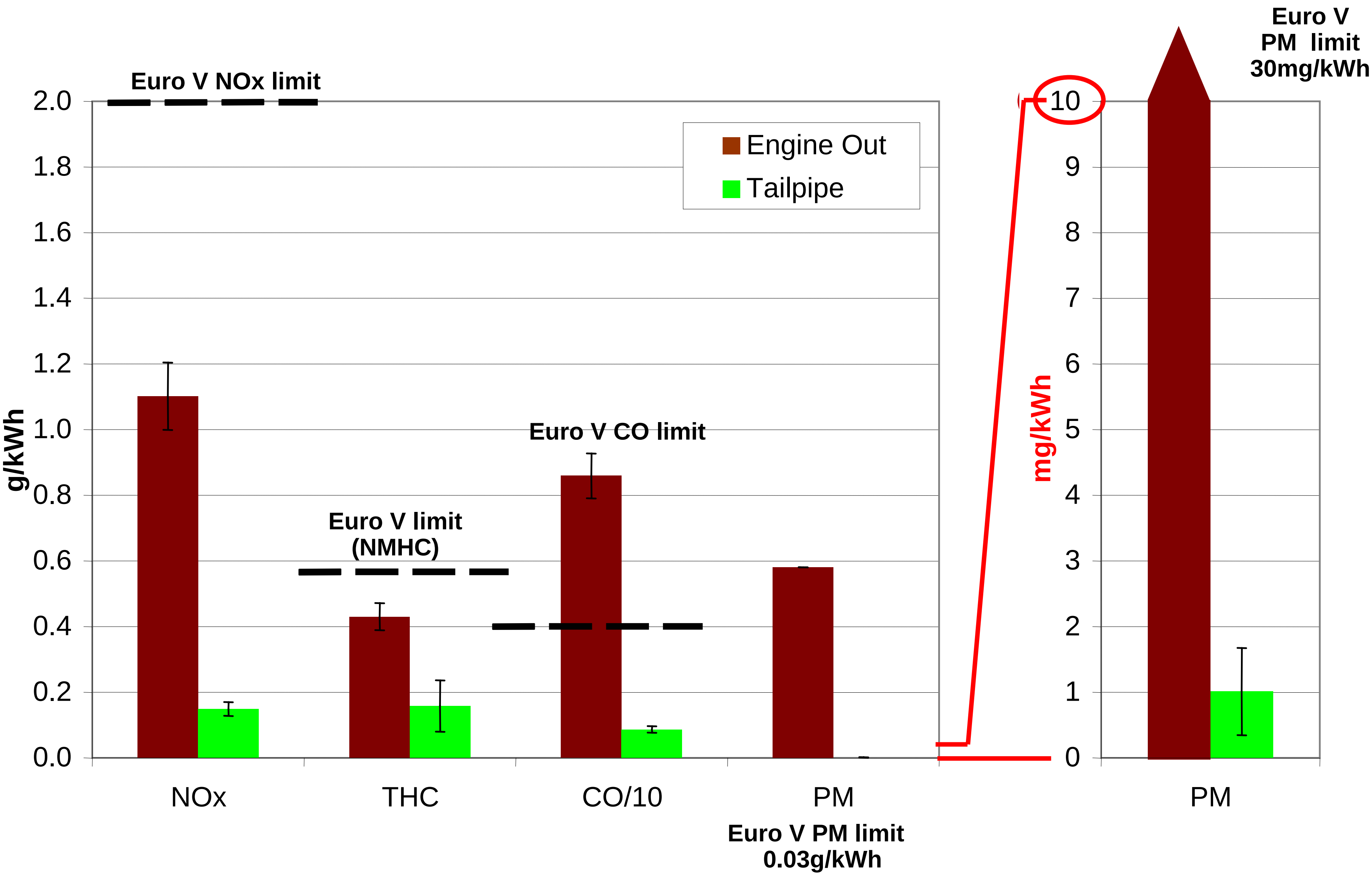
- Triplicate tests were carried out for tailpipe emissions on each of the test cycles. Average results are presented.
- Single additional tests were used to measure engine-out PM, particle number and some speciation analyses.
- For repeatability, each day started with a cold start test.
- Standard end-of day preconditioning was:

- mode 4 warm-up:	15 min.	2130 rev/min.	560 Nm
- followed by:	60 min.	2575 rev/min.	700 Nm
- then:	60 min.	1300 rev/min.	150 Nm

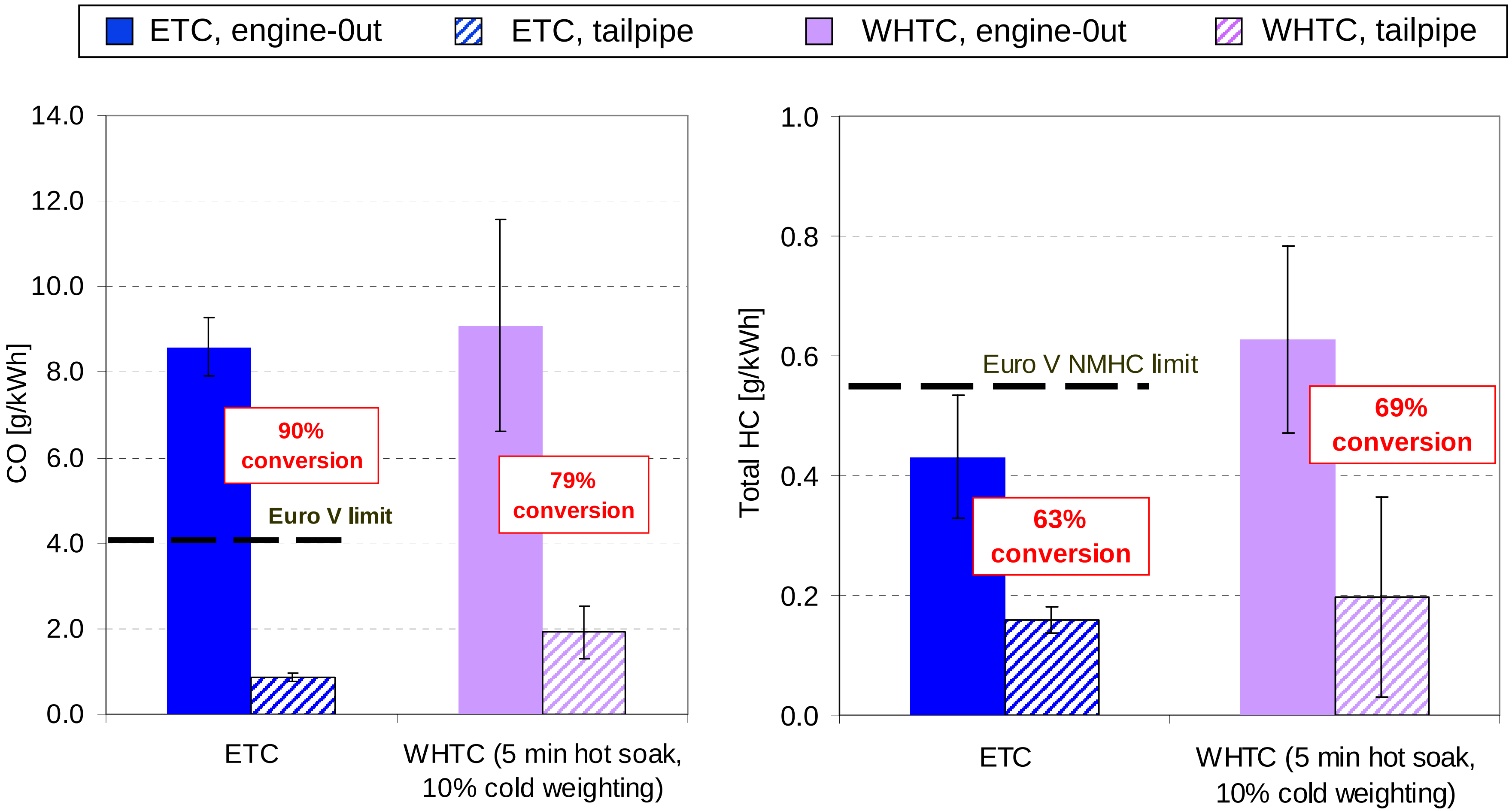
- Following each test cycle the engine was run at a Mode 4 standardisation condition for 15 minutes.
- Pre-test conditioning for hot cycles was:

- ETC, ESC:	7.5 min. mode 4 (2130 rev/min, 560 Nm)
- WHSC:	10 min. mode 9 (1816 rev/min, 373 Nm) followed by 5 min. soak.

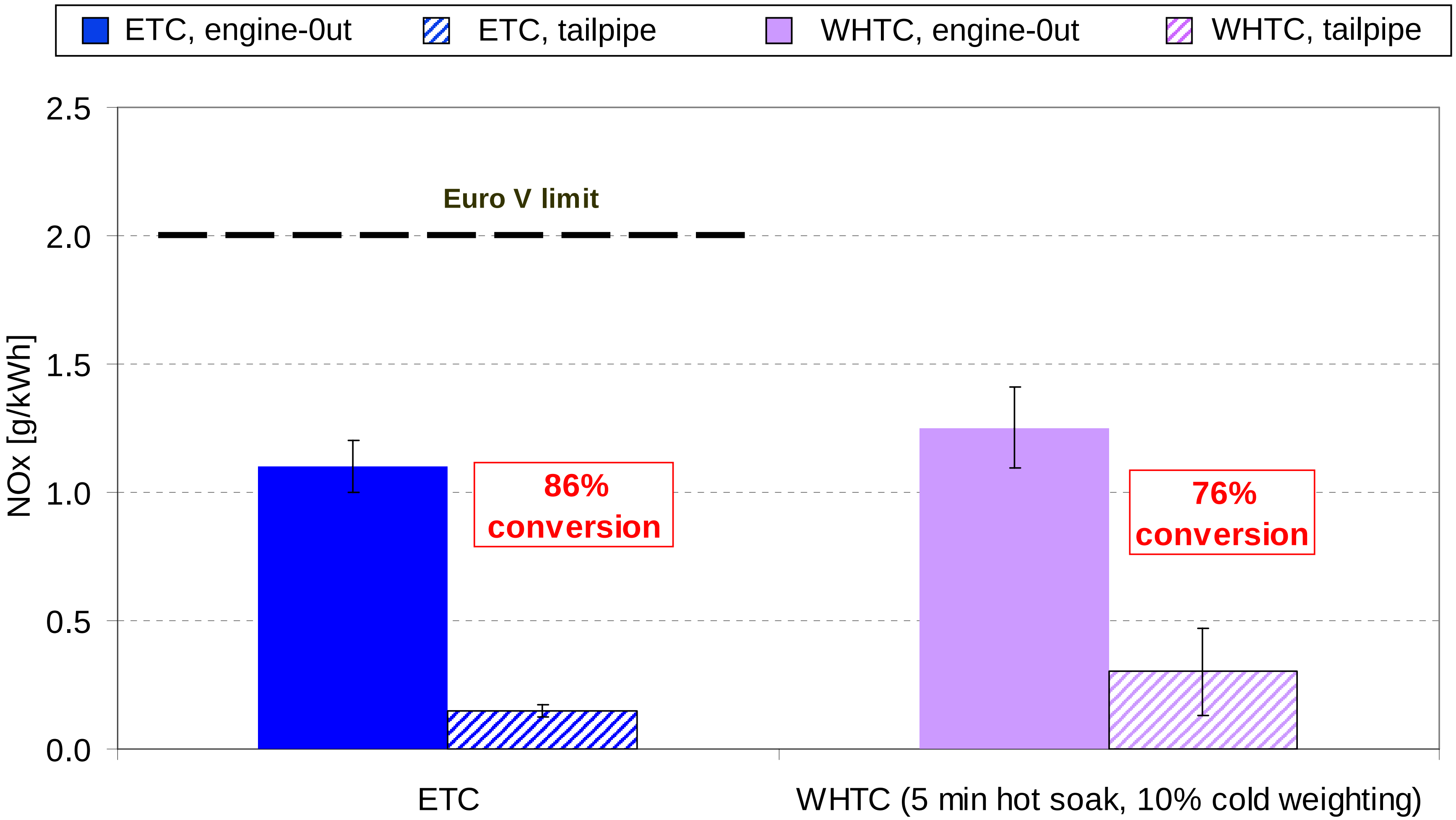
ETC results for engine-out and tailpipe



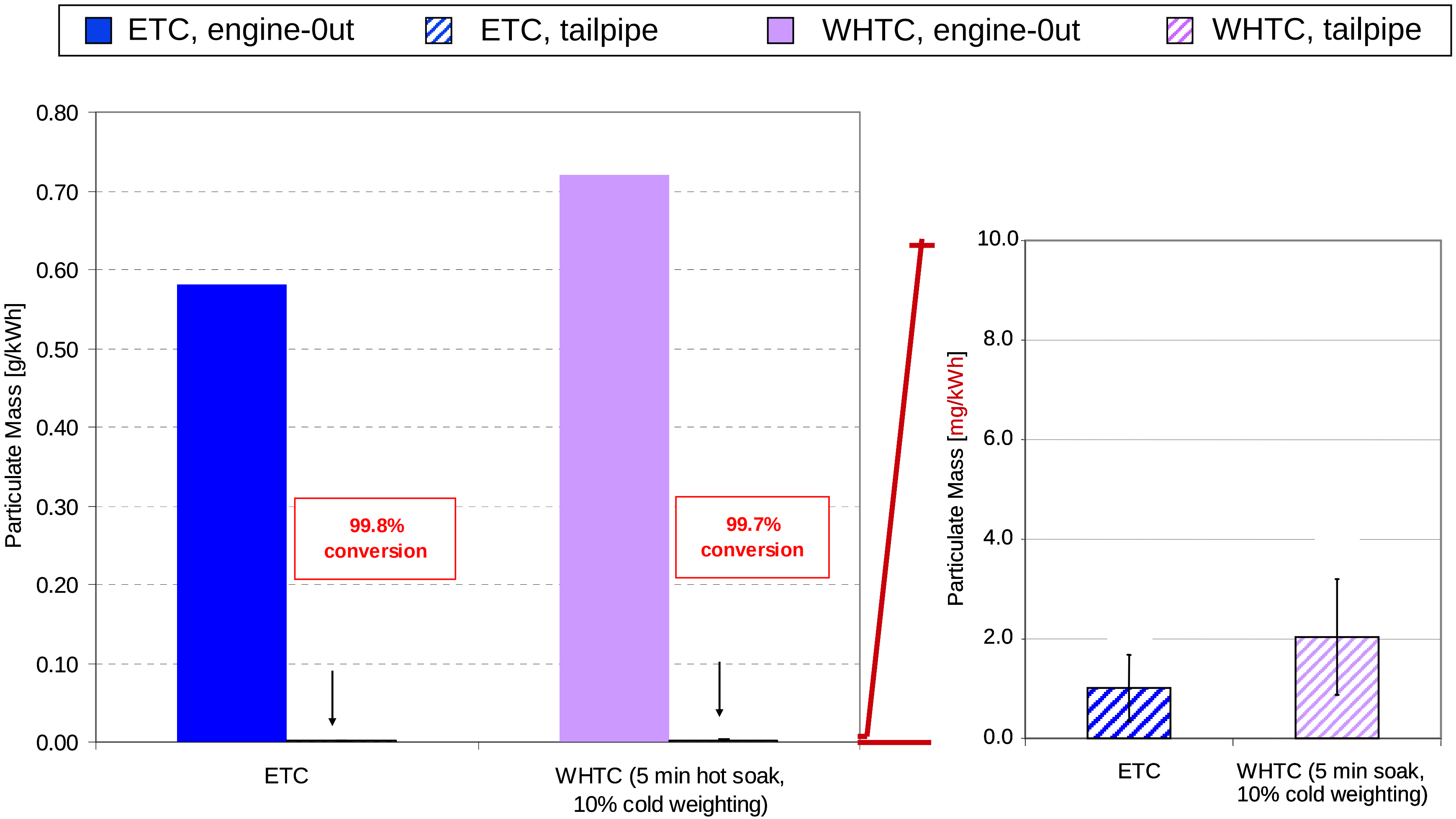
ETC and WHTC tests
CO & HC emissions, engine-out and tailpipe



ETC and WHTC tests
NOx emissions for engine-out and tailpipe



ETC and WHTC tests
PM emissions for engine-out and tailpipe



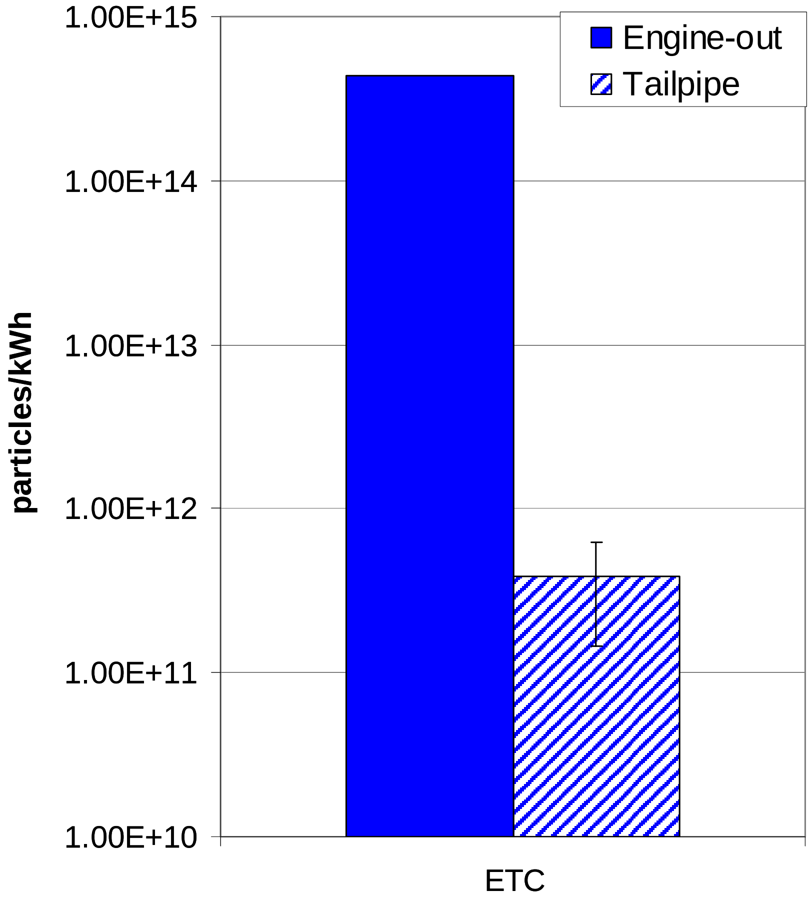
Measurements using partial flow (mini-dilution tunnel) system

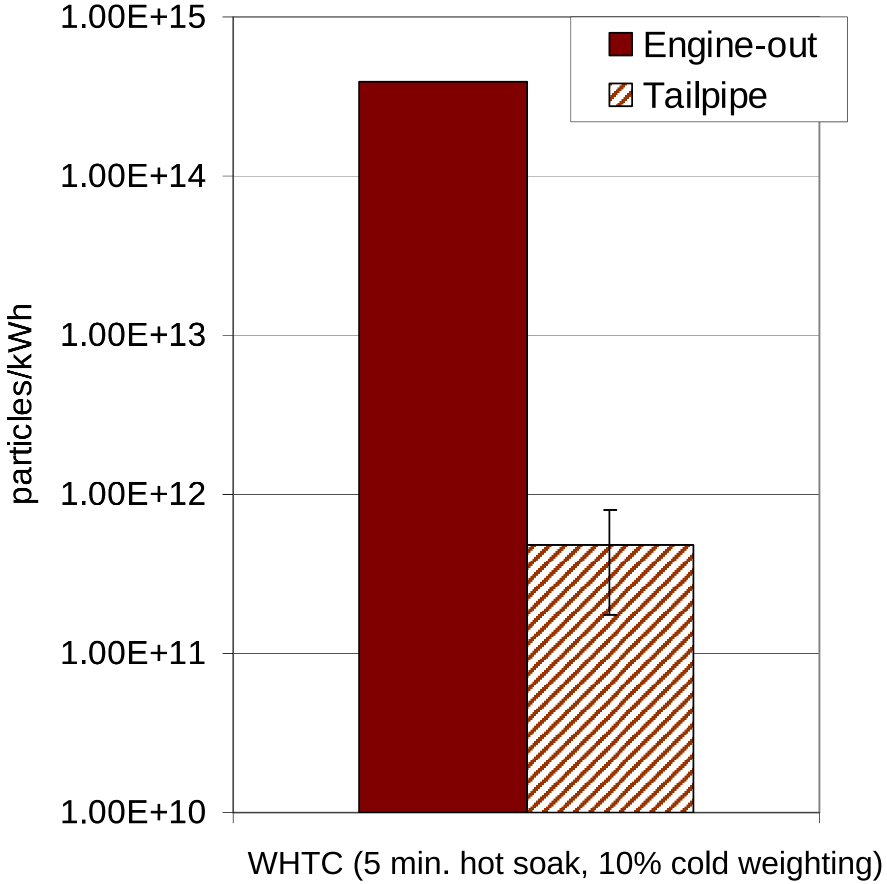
PMP particle number results for ETC & WHTC

- Particle measurements WERE MADE according to the latest draft of the heavy-duty PMP inter-laboratory correlation exercise guide

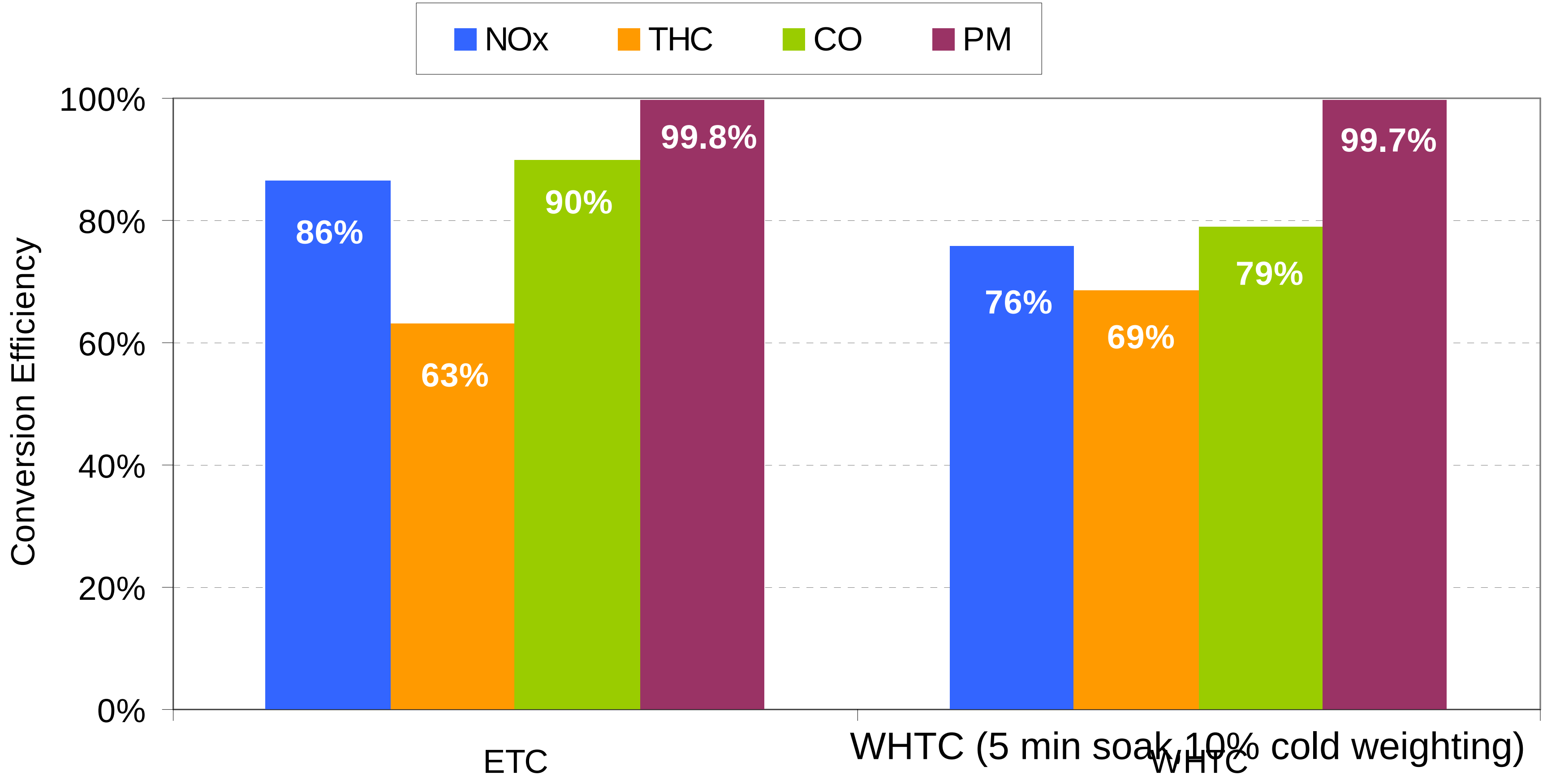
- ETC tailpipe emissions ~ 4 x 10^{11}/kWh
- DPF Efficiency > 99.9%

- WHTC tailpipe emissions < 5 x 10^{11}/kWh
- DPF Efficiency > 99.8%





Conversion efficiencies for ETC and WHTC



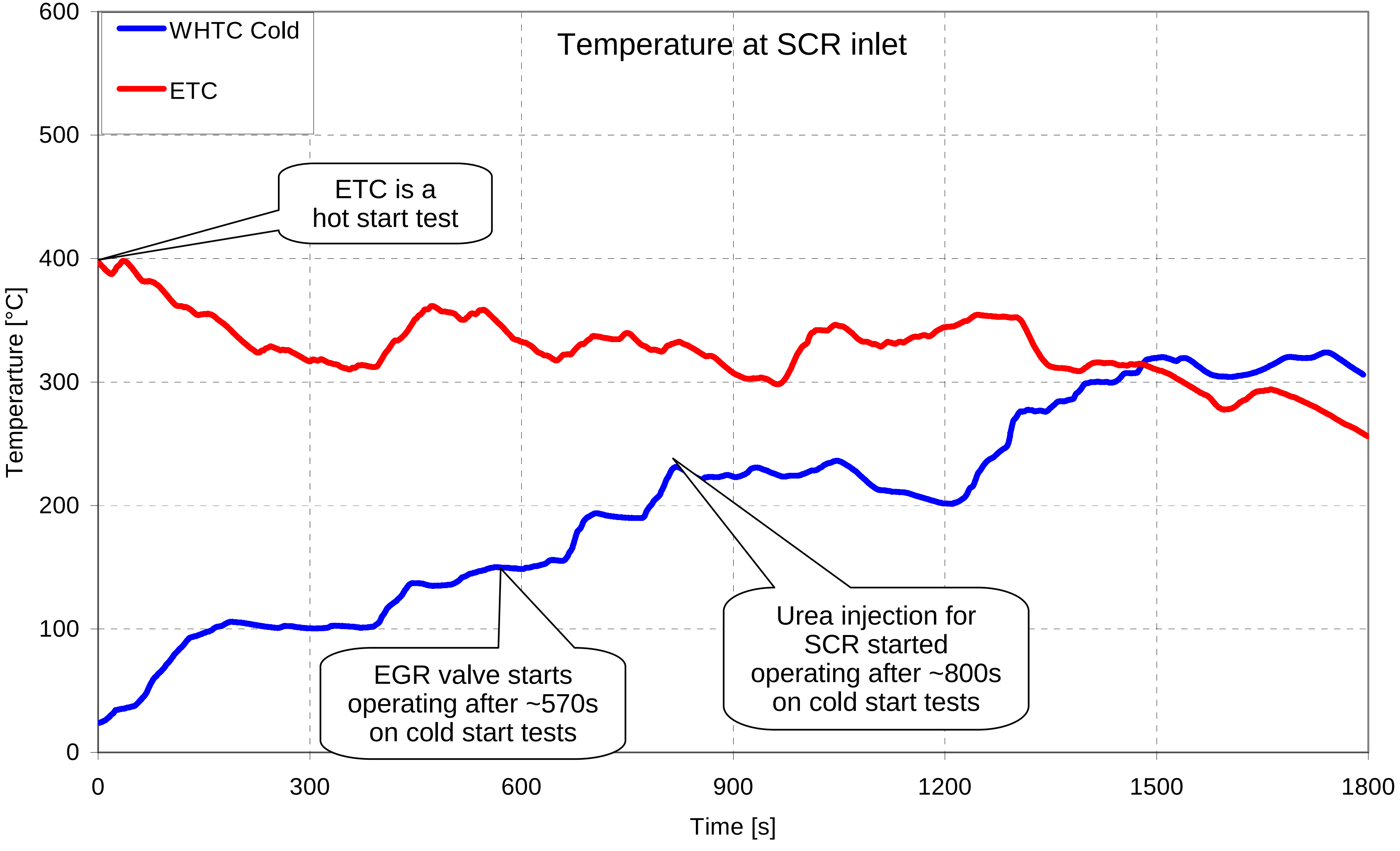
WHTC (5 min soak,10% cold weighting)

Non-optimised system – no thermal management

Further optimisation potential

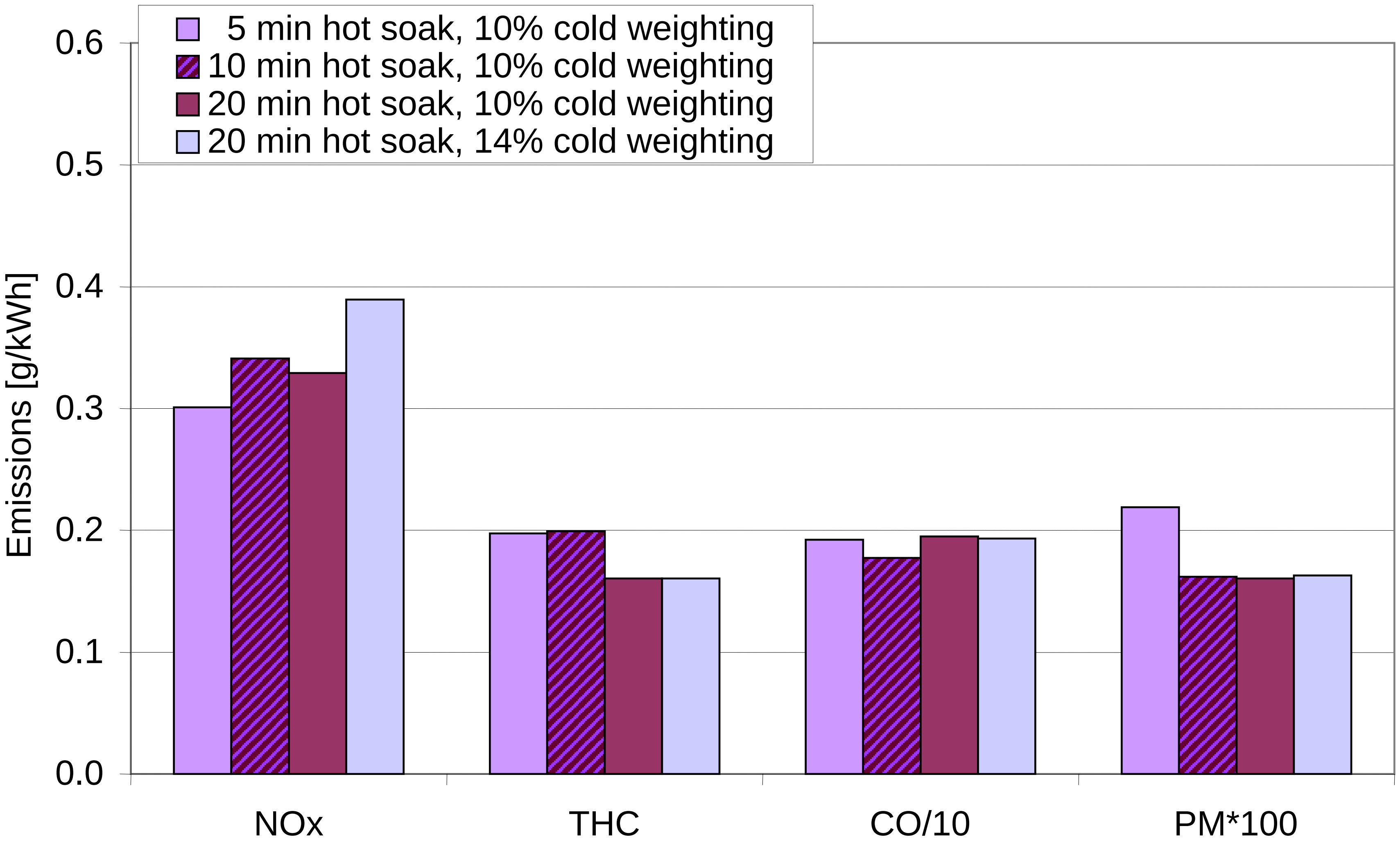
- Thermal Management
  - a heating strategy is expected to be used in future to further improve cold NOx emissions and particulate filter regeneration.
- System design
  - Component volumes and integration would be optimised for a production application.
- System optimisation
  - including urea dosing and distribution.
- Engine calibration.

SCR temperatures for ETC and cold WHTC



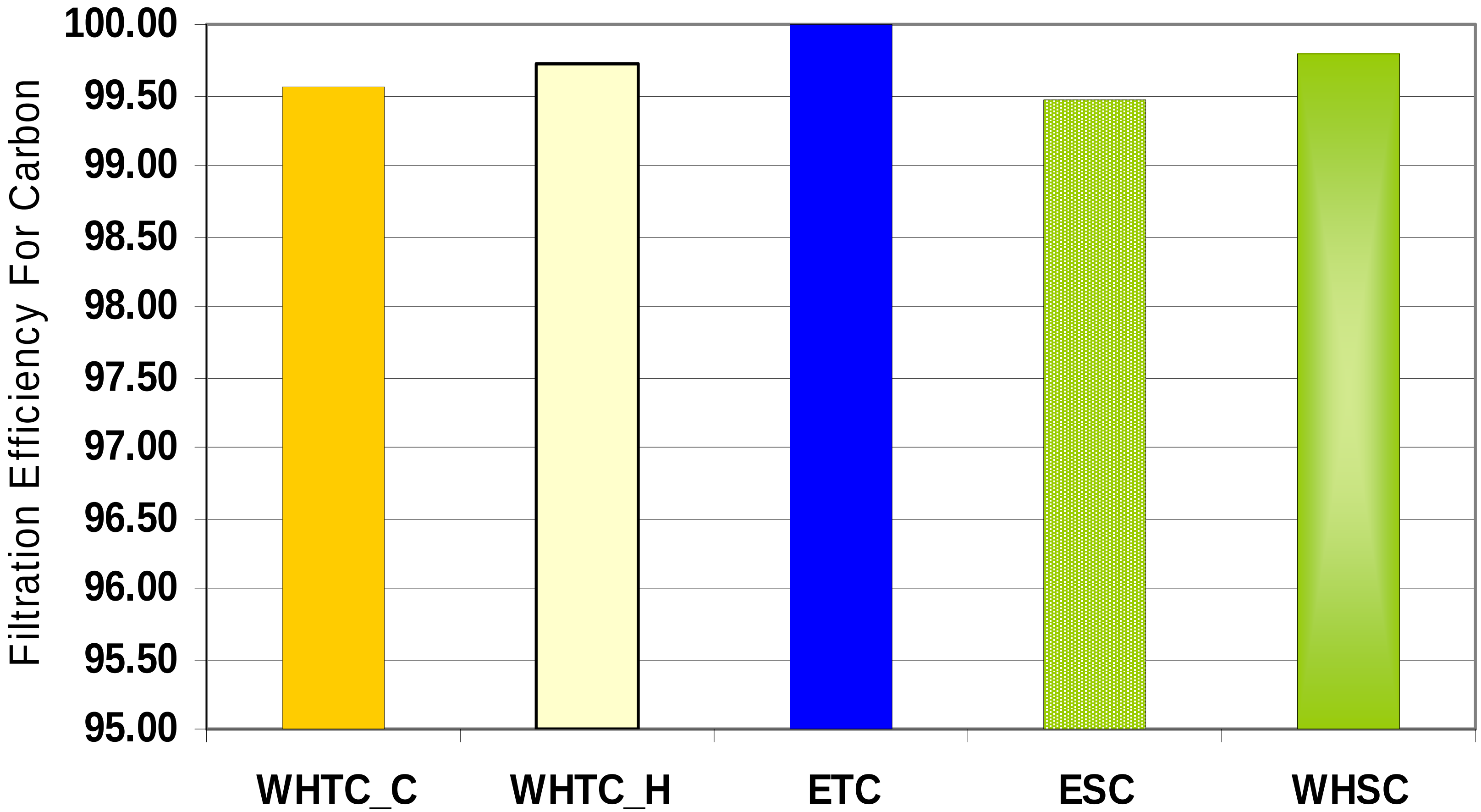
The results indicate that there is potential for further improvement of emissions on cold-start cycles through thermal management

Effect of cold weighting and soak period on composite WHTC results



Filtration efficiency for elemental carbon

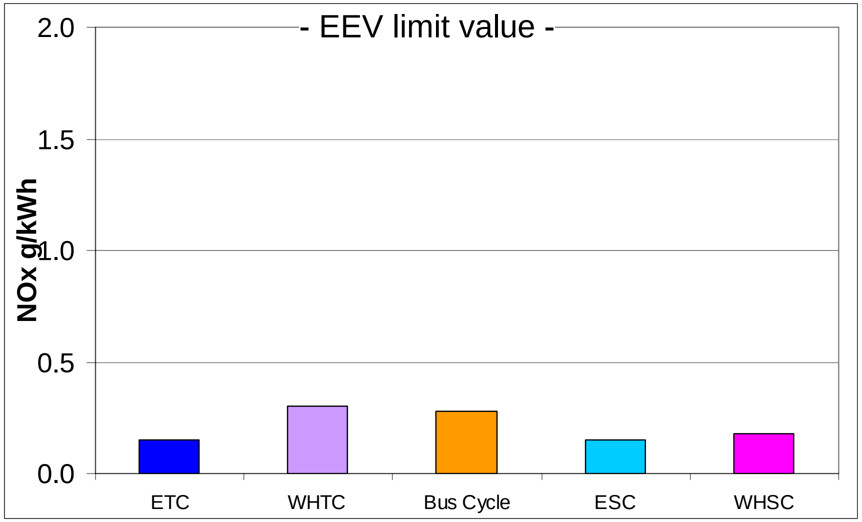
- Particulate filter efficiency for removal of elemental carbon is > 99%.
- Efficiencies for particles and elemental carbon are very similar.

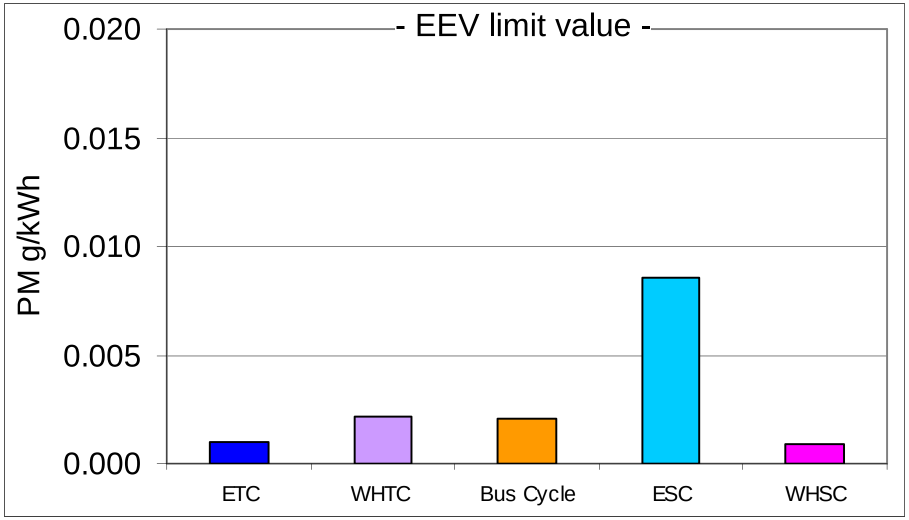


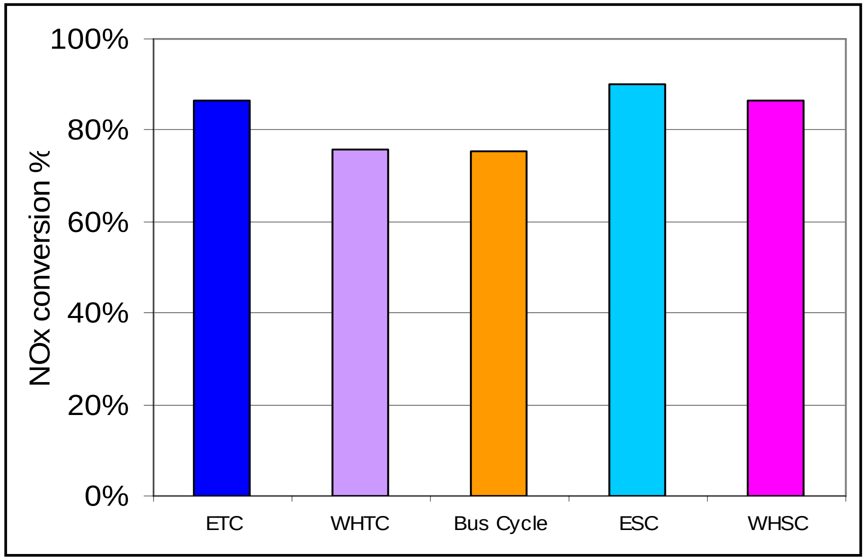
PAH emissions essentially eliminated

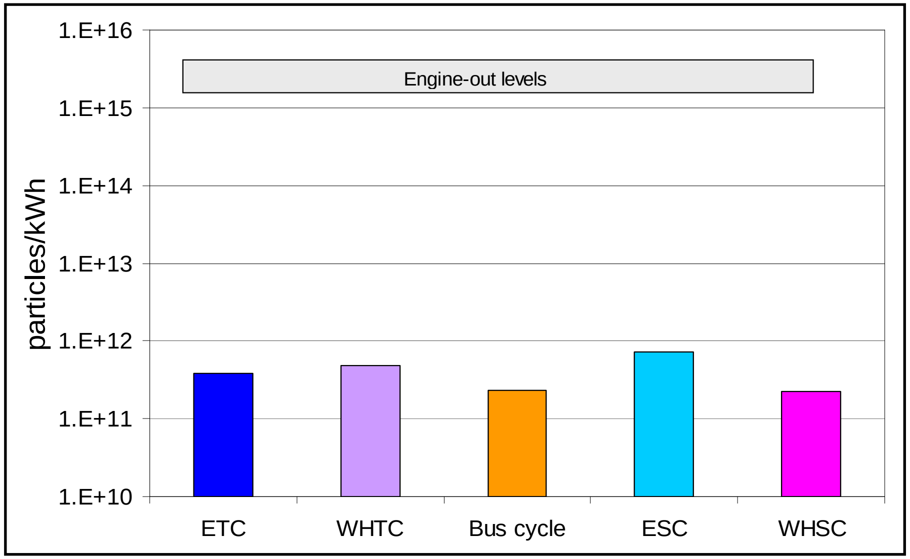
ETC results	MDLT Split Ratio 1910	MDLT Split Ratio 1003	
	Engine-out	**Post-cats**	**System**
	ng/µl	**ng/µl**	**Efficiency**
FLUORENE	0.01880	0.00000	**100.00**
PHENANTHRENE	0.28530	0.00170	**99.69**
ANTHRACENE	0.00320	0.00009	**98.61**
FLUORANTHENE	0.19390	0.00040	**99.89**
PYRENE	>0.53	0.00050	**>99.95**
BENZ(A)ANTHRACENE	0.00450	0.00030	**96.50**
CHRYSENE	0.01130	0.00020	**99.07**
BENZO(B)FLUORANTHENE	0.01130	0.00010	**99.54**
BENZO(K)FLUORANTHENE	0.00310	0.00006	**98.98**
BENZO(A)PYRENE	0.00300	0.00000	**100.00**
BENZO(GHI)PERYLENE	0.04450	0.00000	**100.00**
INDENO(1,2,3CD)PYRENE	0.01330	0.00010	**99.61**

NOx, PM and particle number comparisons









PM result on ESC appears due to desorption of low volatility materials in Mode 10.

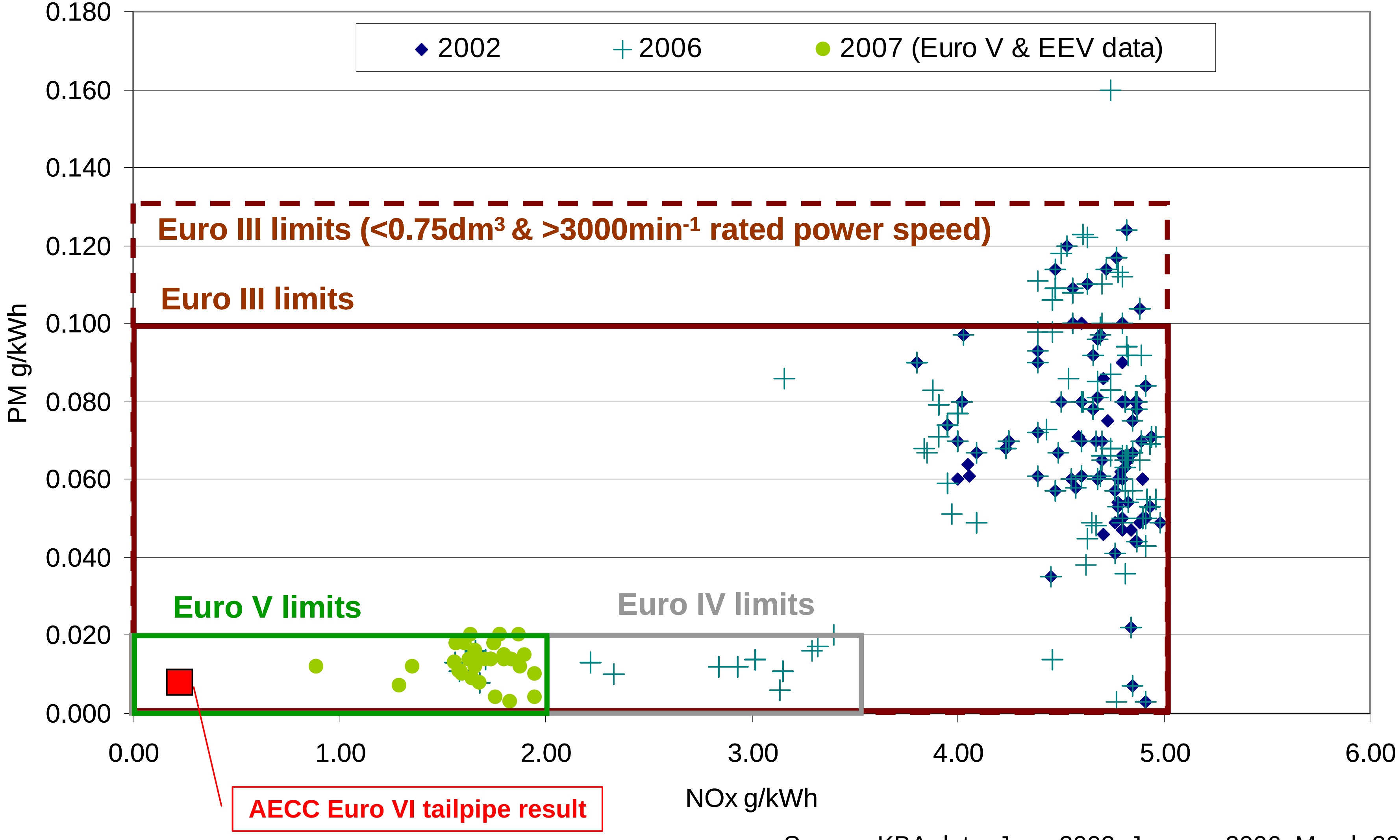
Summary of findings of the AECC heavy-duty Euro VI test programme

- A state-of-the-art engine system comprising a low emissions “world engine” and an emissions control system produced substantial reductions in all regulated pollutants.
- NOx conversion efficiencies were 86% and 76% over the ETC and EU-composite WHTC respectively, resulting in tailpipe levels of 150 and 300mg/kWh.
- PM conversion efficiencies were >99.5% over the ETC and EU-composite WHTC, resulting in PM tailpipe levels of 1 to 2mg/kWh when measured with the partial flow method.
- There is potential for further improvement of emissions through thermal management and optimised system design and engine and urea dosing calibration.

Summary of findings of the AECC heavy-duty Euro VI test programme

- The PMP particle number method proved very reliable even at near-ambient particle emissions levels.
- Engine-out particle emissions of 2.5 to 5 x 10^{14}/kWh were reduced to levels below 10^{12}/kWh at tailpipe and were essentially cycle-independent.
- The emissions control system reduced elemental carbon emissions by more than 99% and virtually eliminated PAH emissions.
- The combined engine and emissions control system met the most stringent scenarios from the Commission's Euro VI validation exercise.

PM vs NOx (ESC test)



Source: KBA data, June 2002, January 2006, March 2007

Acknowledgements

the OE engine manufacturer

Bosch, urea dosing system supplier

Yara International, urea supplier

Ricardo UK and the AECC Members

Thank you for your attention