Particulate emissions from a 'Euro VI' heavy-duty engine

Cambridge Particles meeting

16 May 2008

Association for Emissions Control by Catalyst AISBL

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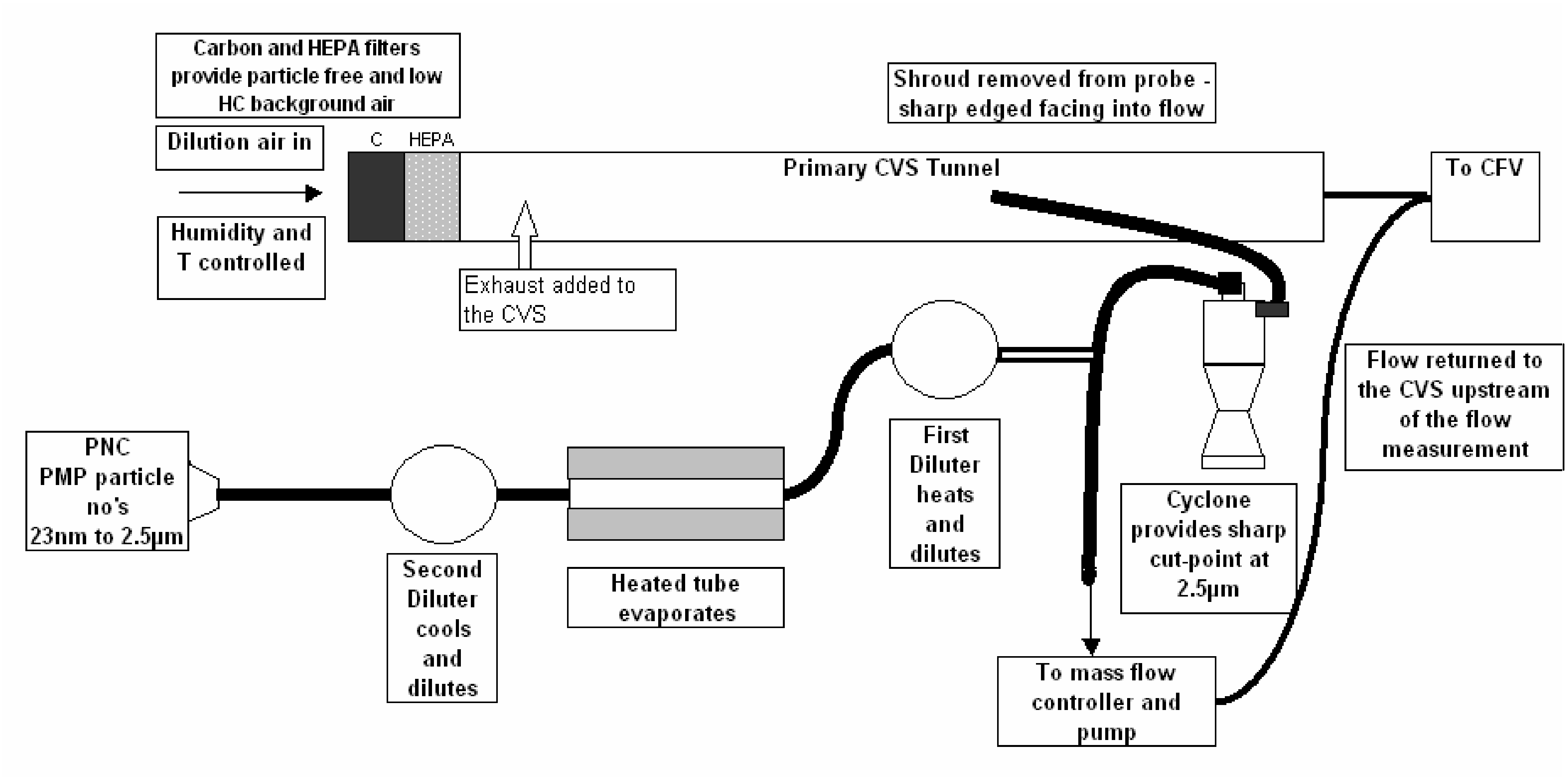
Objectives & Test System

- Objective: Assess the UN-ECE heavy-duty PMP particle number methodology and compare the PMP method for particulate mass (PM) with current gravimetric methods.
- Engine: designed for US2007, provided by manufacturer
  - 6 cylinder turbocharged (fixed vane) common rail 7.5 litre engine,
  - Cooled lambda-feedback EGR,
  - Max. injection pressure 180Mpa.
- Emissions Control System: Original DPF replaced by AECC:
  - oxidation catalyst, catalysed wall-flow particulate filter, urea-SCR system.
- Calibration: No modification to base engine calibration
  - no optimisation of engine-out emissions on the European cycles,
  - no change to calibration or regeneration strategy,
  - engine-out emissions are ‘as received’.

Emissions Measurement

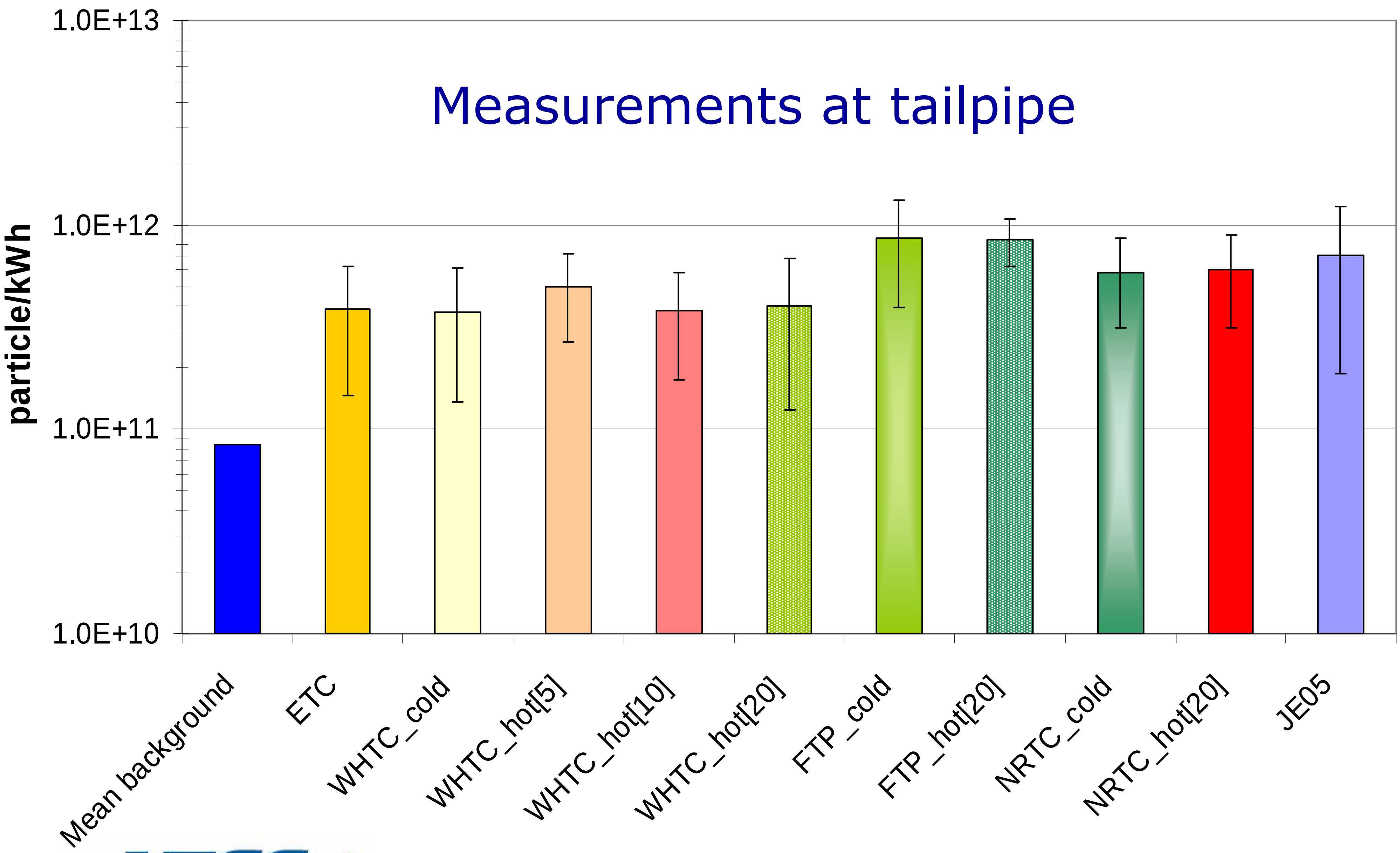
- Triplicate tests for tailpipe emissions.
- Additional tests to measure engine-out emissions.
- Standard EU Diesel reference fuel (max. 10ppm sulfur).
- Low ash 10w-40 engine lubricant.
- Experience with light-duty PMP showed that the particle number method is sufficiently sensitive for DPF fill state to affect particle number emissions. So for repeatability, each day began with a cold start test and finished with a standard preconditioning regime.
- ESC Mode 4 standardisation was run after each test cycle.

Particle Number Measurement



Source: UN-ECE PMP programmes

Particle Numbers: Transient Cycles



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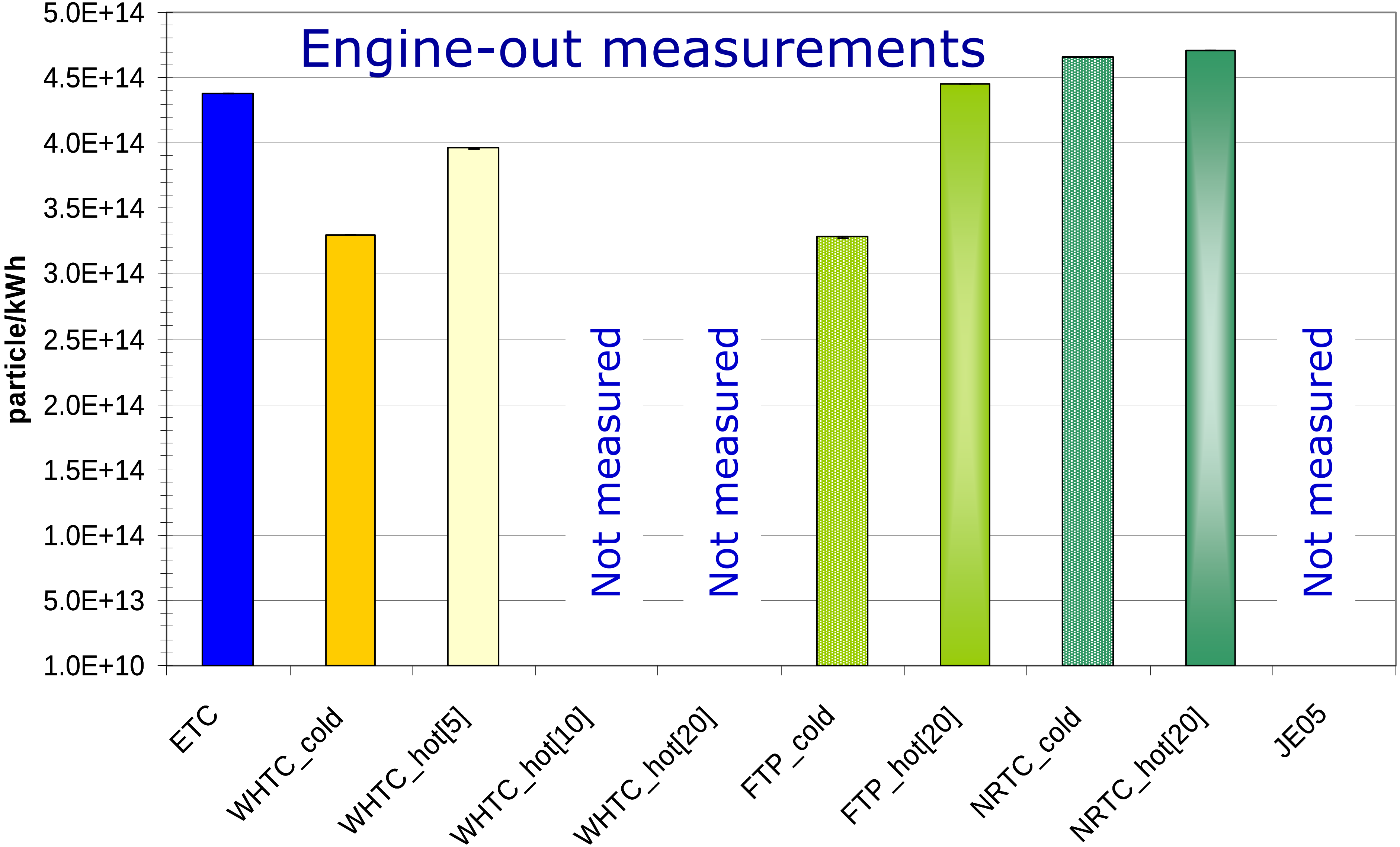
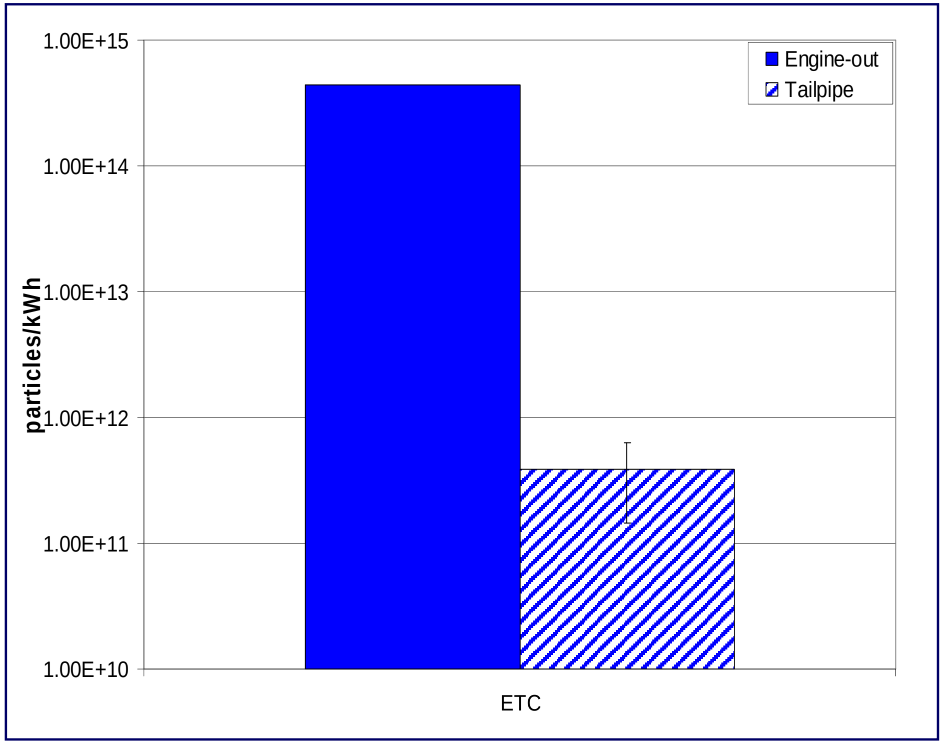
Particle Numbers: Transient Cycles

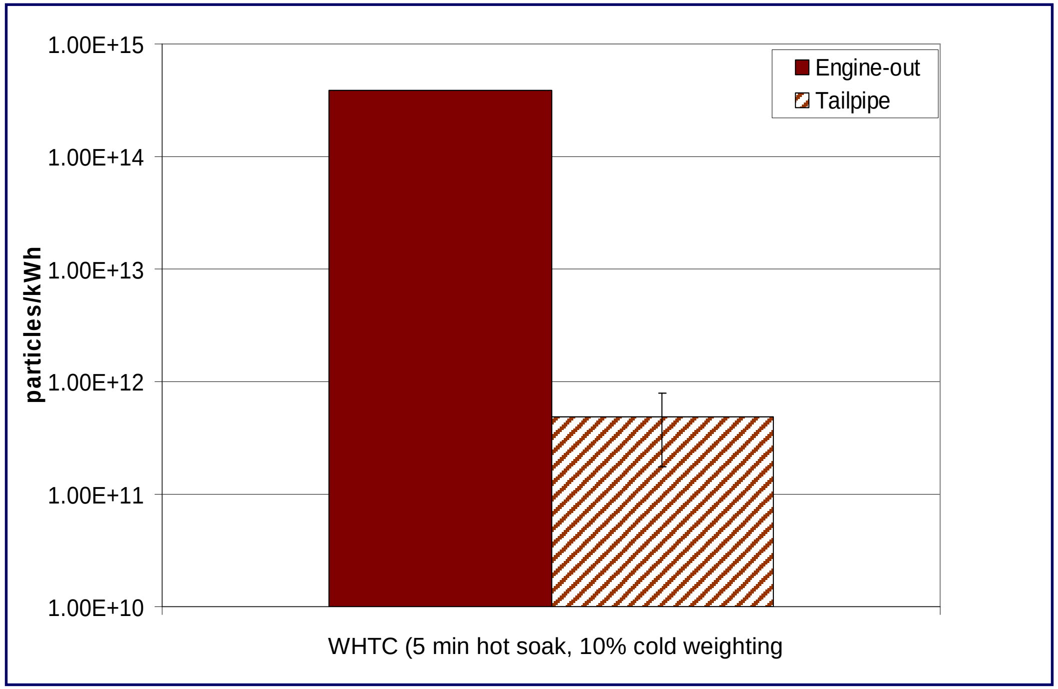


Engine-out vs. Tailpipe Particle Numbers



WHTC

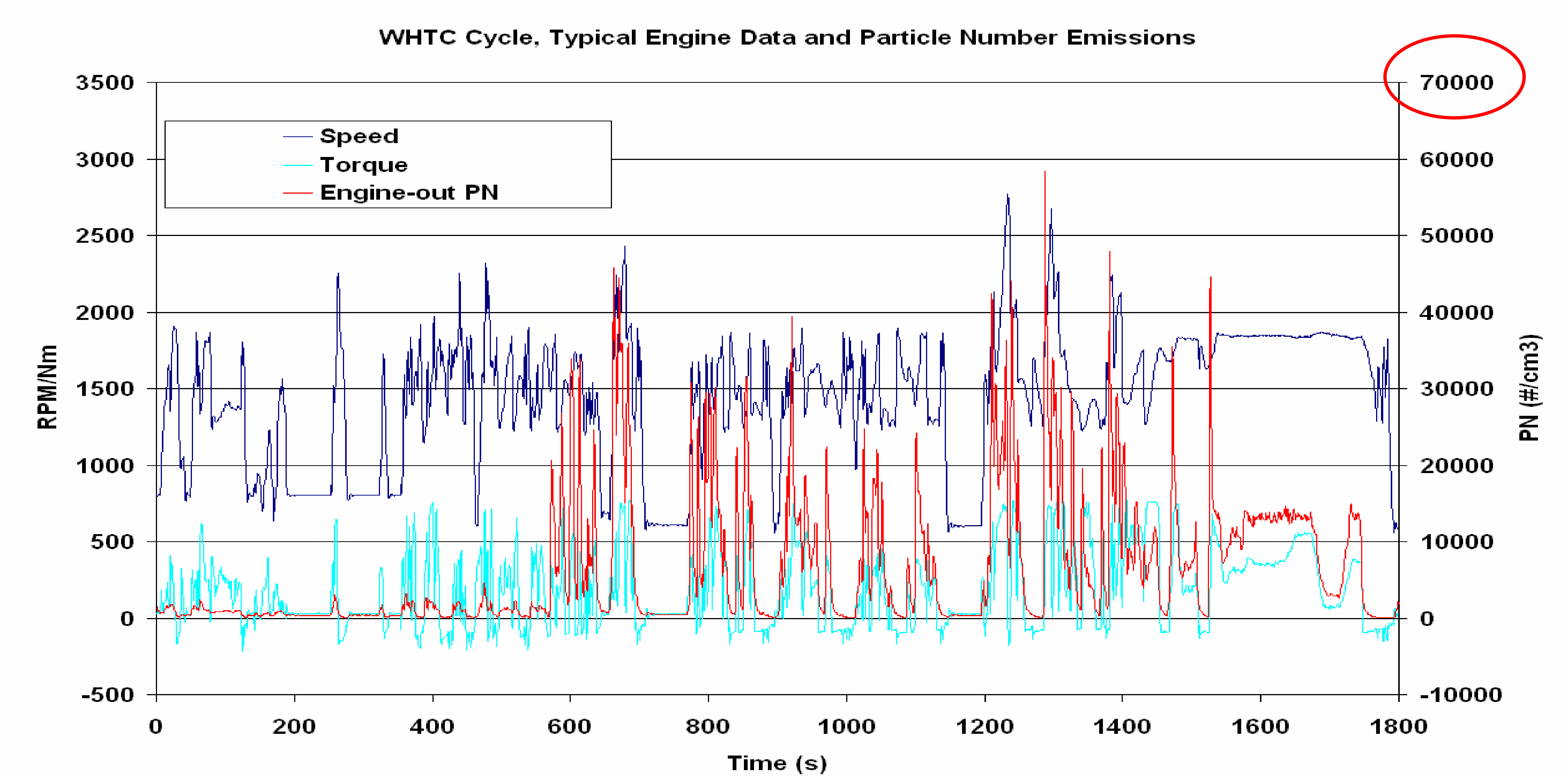
- Tailpipe particle number emissions < 5 x 10^{11}/kWh.
- DPF Efficiency > 99.8%.



ETC

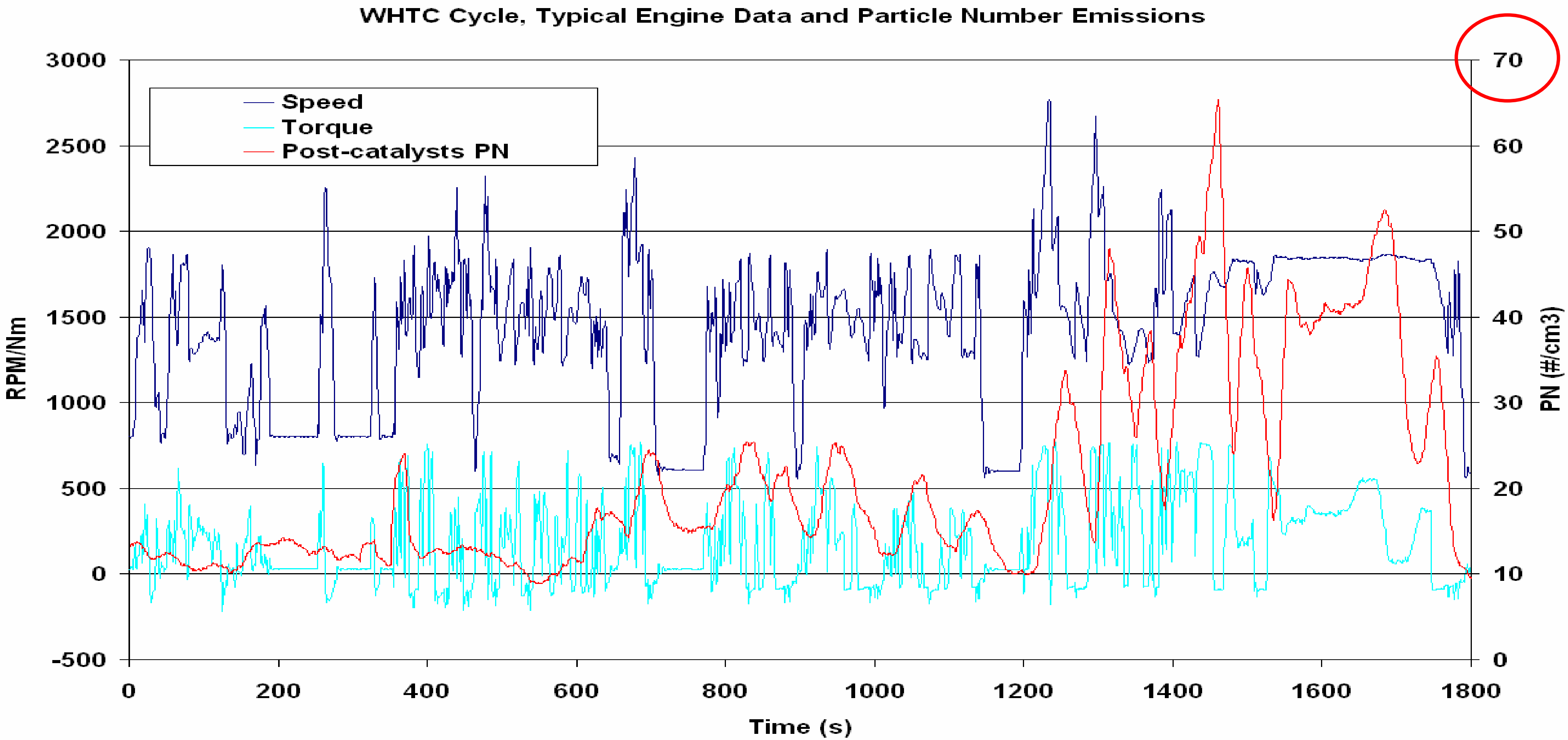
- Tailpipe particle number emissions ~ 4 x 10^{11}/kWh.
- DPF Efficiency > 99.9%.

Engine-out Particle Numbers



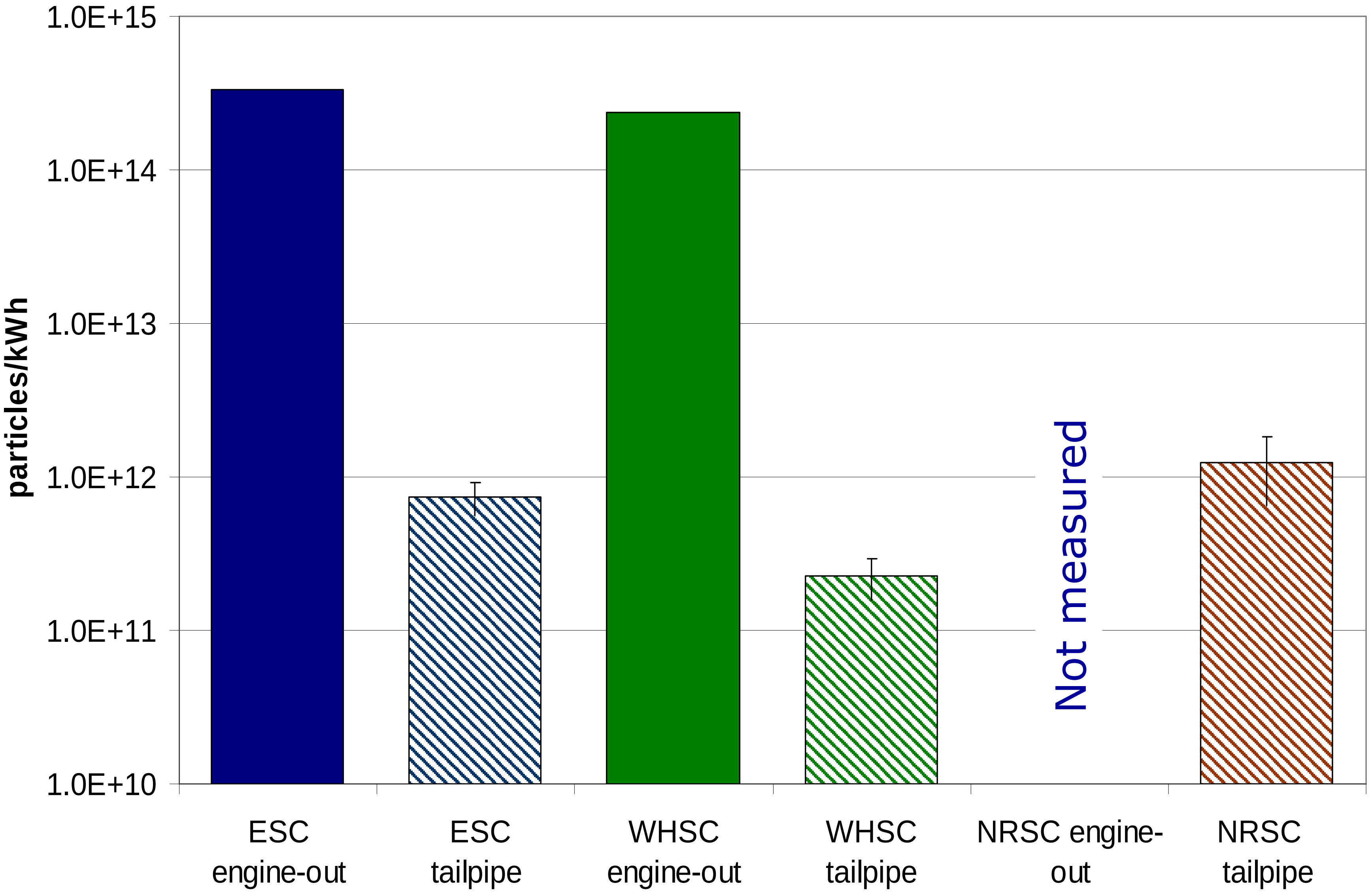
Engine-out particle emissions generally track the torque profile.

Tailpipe Particle Numbers



Post-DPF particle emissions are some 3 orders of magnitude lower than engine-out. They are somewhat smoothed and slightly time-offset from engine-out emissions.

Particle Numbers: Steady-State Cycles

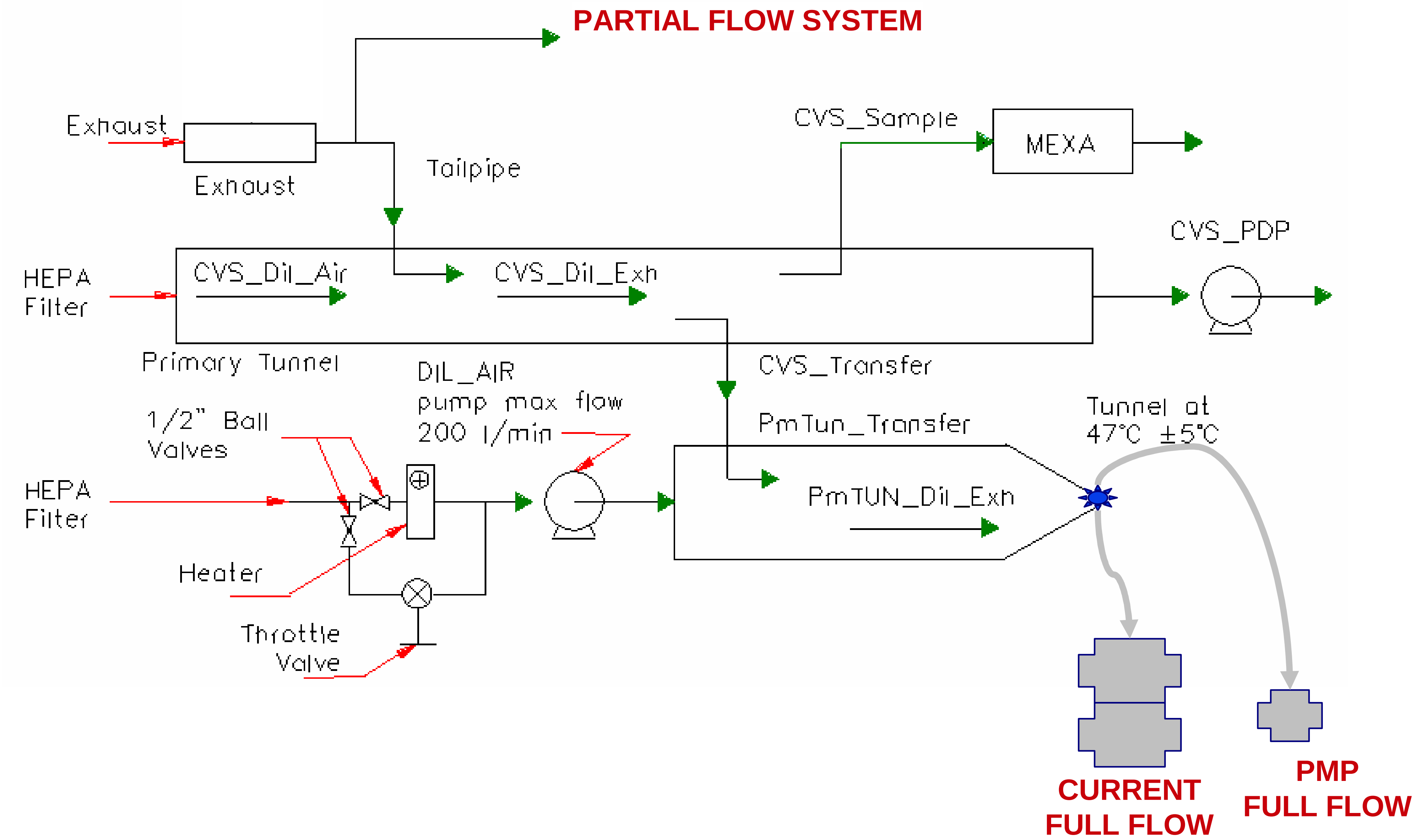


Particulate Mass Measurement

- Partial flow system using mini dilution tunnel (MDLT)
  - Sample taken directly from exhaust, before CVS system and diluted (variable rate) in the MDLT before collection.
  - Current EU legislation allows this as alternative to full flow.
- Current full flow legislative method
  - Diluted sample from CVS system, further diluted in 2nd tunnel.
- PMP method
  - Sample taken from secondary tunnel, as for current method.
  - Tighter control on sampling parameters; single smaller filter.

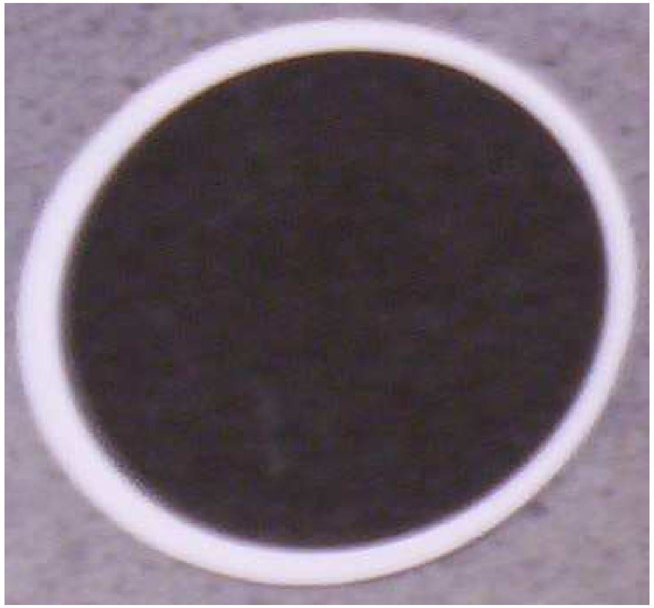
Method	Dilution System	Aerosol sampled	Additional Comments
Partial Flow PM	MDLT	Tailpipe	All tests
Partial Flow PM	MDLT	Engine-out	≥1 test, all cycles measurements in parallel with PM
PMP Mass Method	CVS and secondary dilution system	Tailpipe	Heated dilution air, 47mm TX40 filters, face velocity constrained
Current Mass Method	CVS and secondary dilution system	Tailpipe	Heated dilution air, 70mm TX40 filters, 120l/min

Particulate Mass Measurement

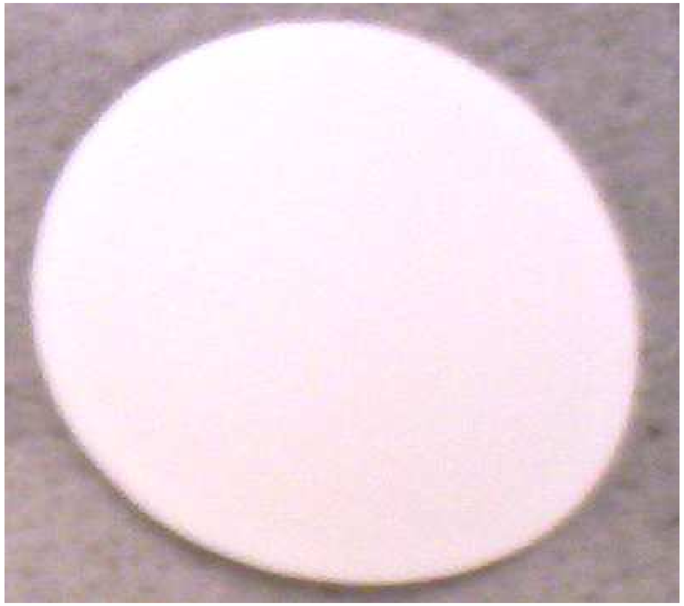


Visual Comparison

Engine-out PM

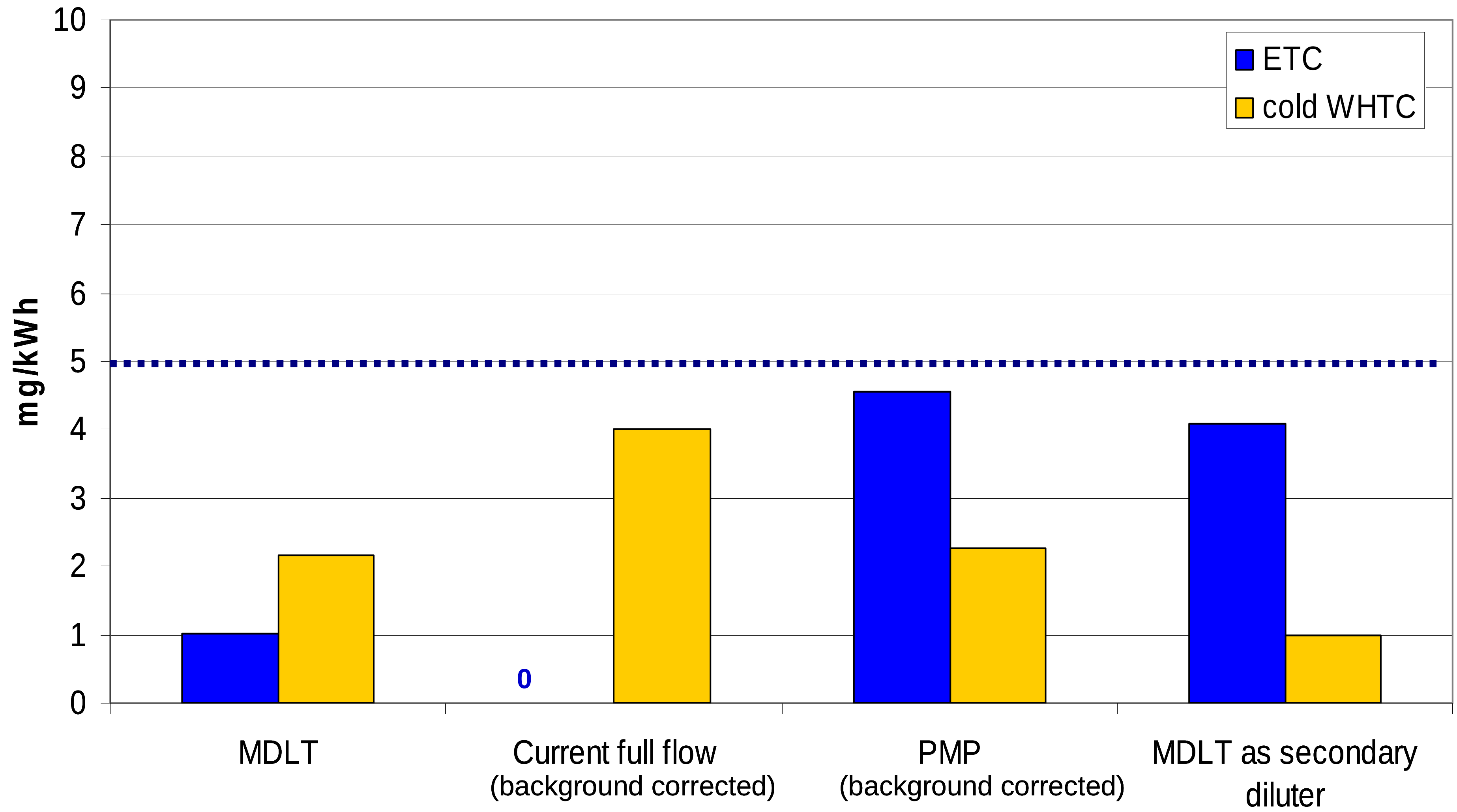


Tailpipe PM



- Engine-out PM showed dense black PM material.
- Post-DPF measurements with PMP, Standard and MDLT methods all showed filters indistinguishable from unused ones.

Differences between PM Methods



Mean Tailpipe PM results using different approaches all show emissions <5mg/kWh for ETC and WHTC.

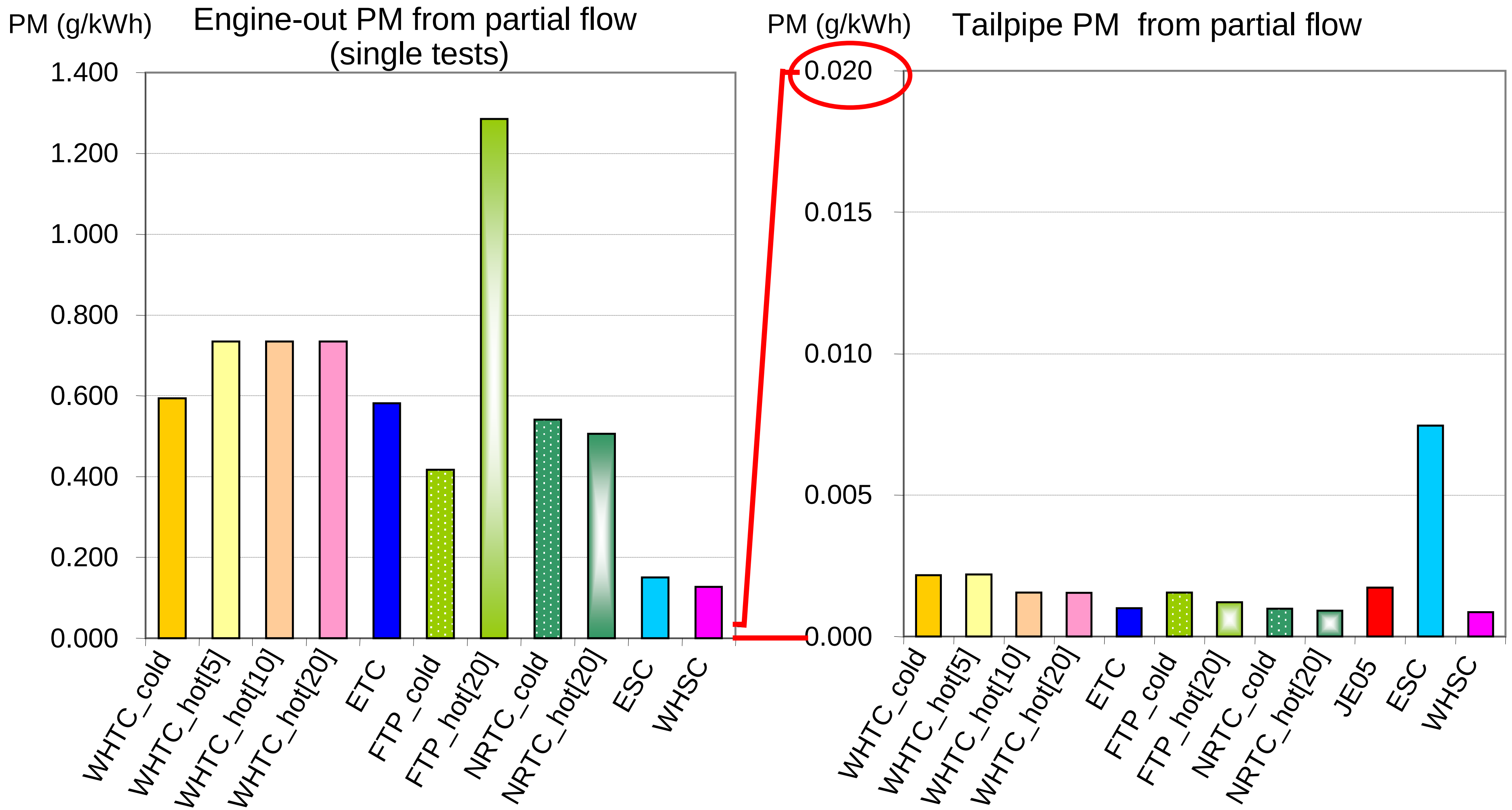
PM Investigation

- Both sample and background (before and after test) filter papers showed similar masses for the two full flow methods.
- Particulate analysis showed tailpipe elemental carbon levels close to detection limit and close to blank, for all PM methods.
- Chromatographic analysis of full flow filter papers showed identical profiles at levels well above unused papers.
- Chromatographic profile of blank papers drawn from partial flow were indistinguishable from a unused blank papers.
- Chromatographic profile did not match either fuel or engine lubricant.
- Background from primary tunnel did not show same problem.

PM Measurements

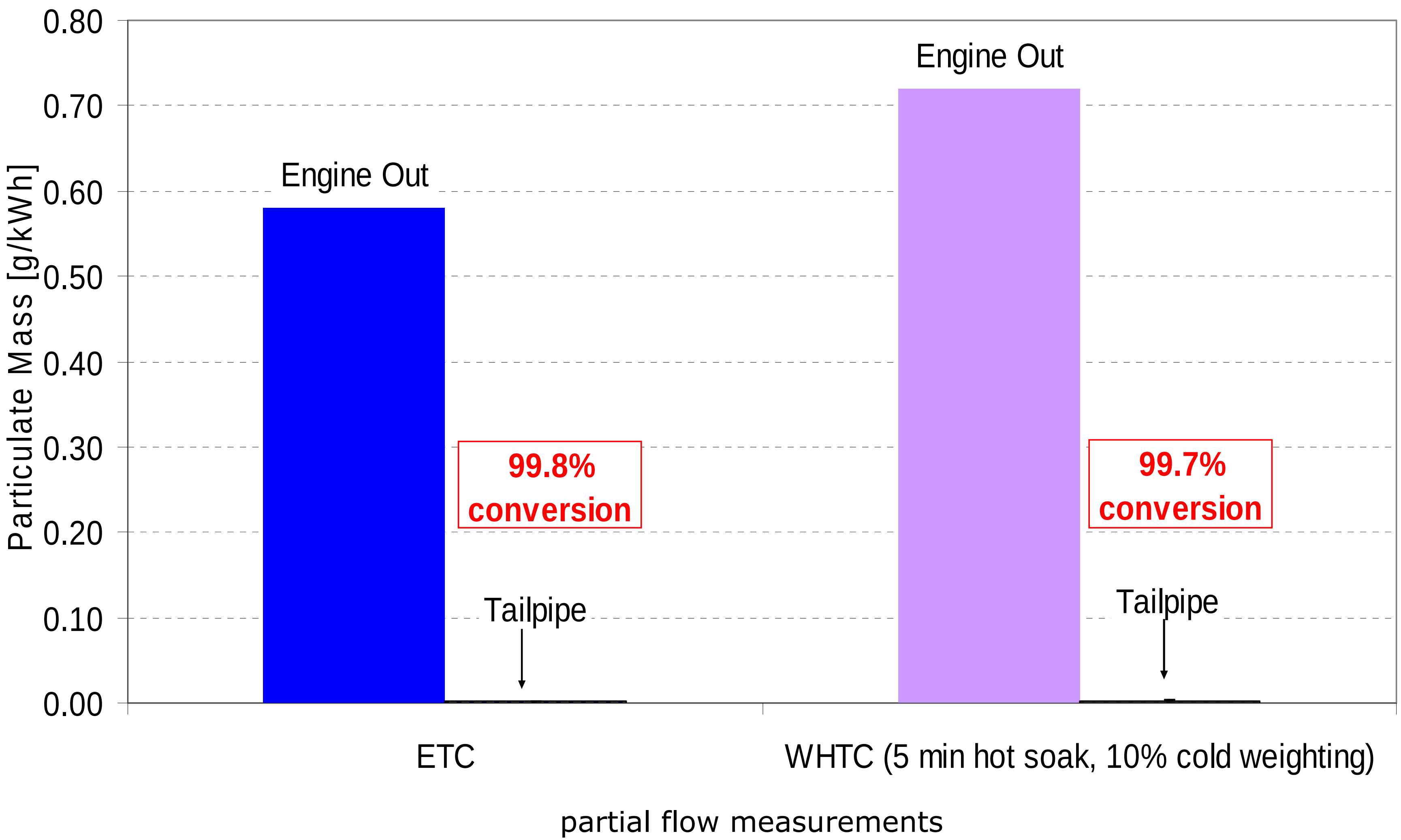
- Problem identified as contamination from make-up air pump used to supply additional air from HEPA filter to secondary tunnel to allow simultaneous sampling by two methods.
- Pump is downstream of the HEPA filter.
- Seal found to have perished, allowing pump lubricating oil to volatilise and be carried into secondary dilution system.
- MDLT was used as secondary dilution tunnel to validate the problem identification – background contamination was removed.

Average PM: Engine-out and Tailpipe



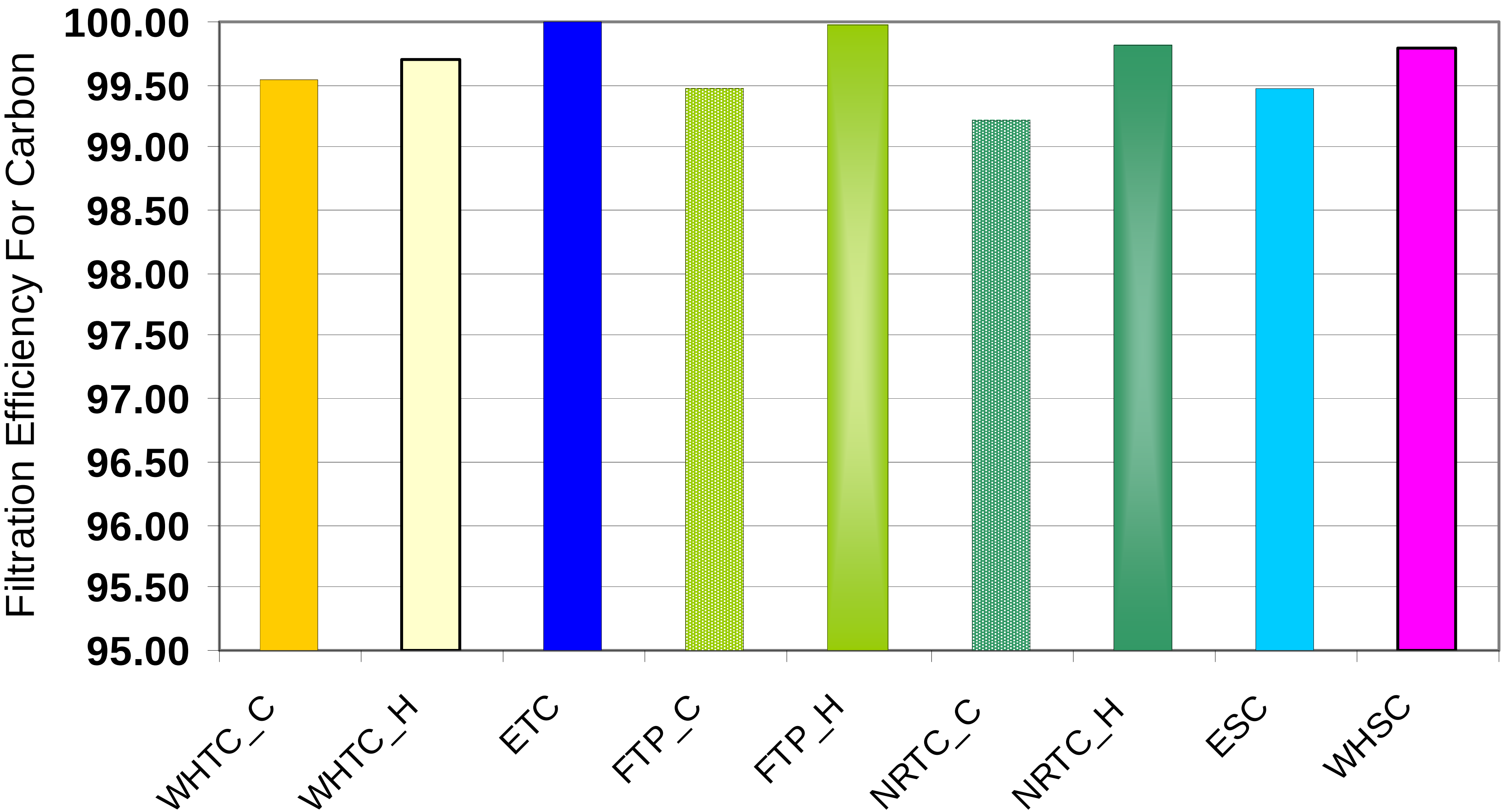
- Tailpipe ESC results believed to be due to mode 10 desorbing low volatility materials
- Filtration efficiencies for PM typically 94 to 99%.

Typical PM Conversion



Elemental Carbon Filtration Efficiency

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

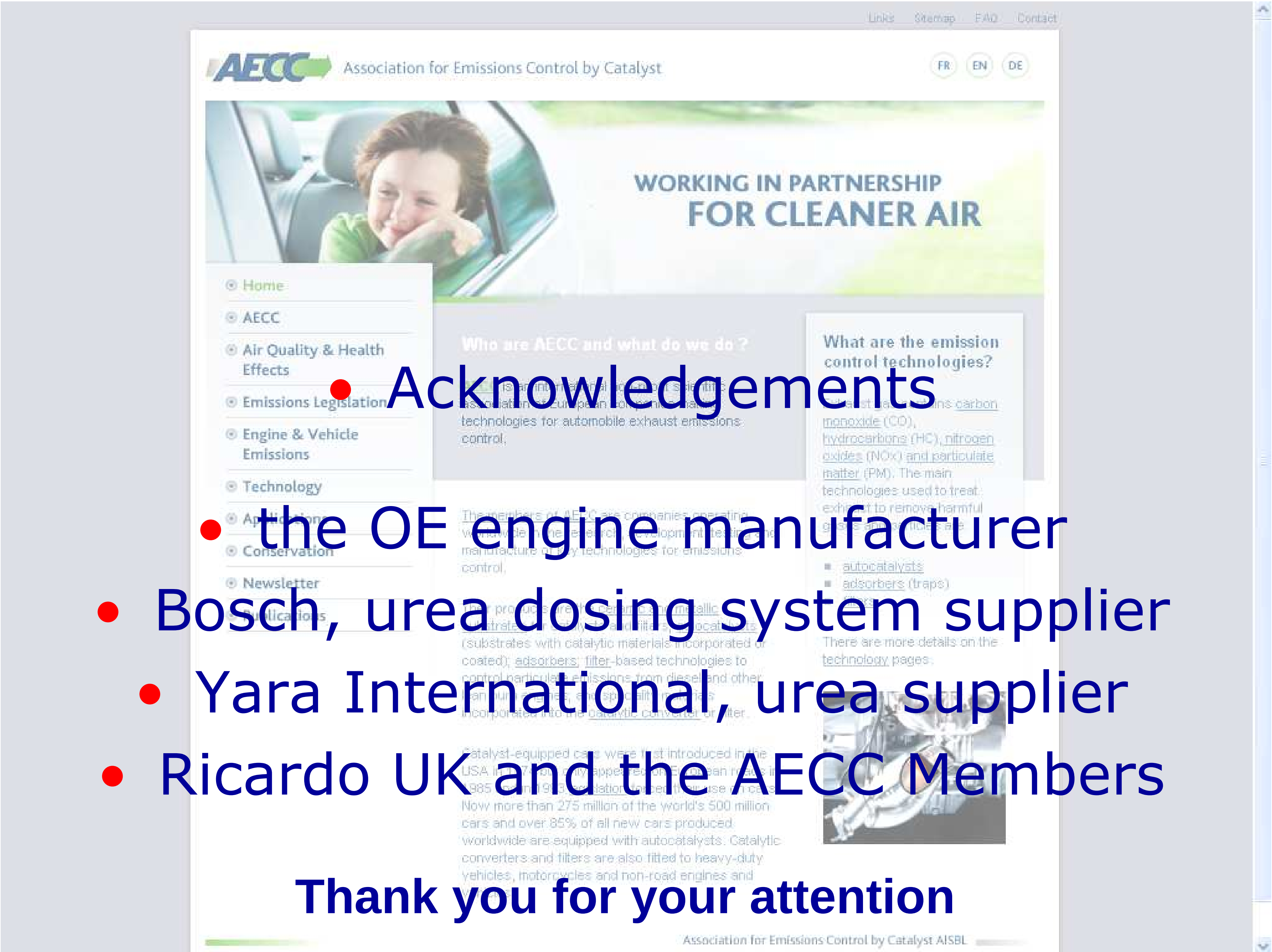


Summary – Particle Mass

- Particulate mass emissions from a variety of regulatory transient cycles were <5mg/kWh.
- Collection of parallel full flow samples resulted in contamination problems, but background-corrected results from all methods were <5mg/kWh.
- Partial flow results proved the more reliable method because of this contamination problem.
- Conversion efficiencies over the European and World Harmonised Transient Cycles were >99.5%.

Summary – Particle Number

- The PMP particle number method proved very reliable even at near-ambient particle emissions levels.
- Particle numbers were essentially cycle-independent. Engine-out particle number emissions were in the range of 2.5×10^{14} to 5×10^{14}/kWh.
- All transient cycles showed tailpipe particle number emissions below 10^{12}/kWh, and the range was well within an order of magnitude.
- Filtration efficiencies for particle number were ~99.9%.



- 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