AECC Non-Road Mobile Machinery (NRMM) Test Programme: Particle Measurement and Characterisation

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Association for Emissions Control by Catalyst AISBL

Association for Emissions Control by Catalyst (AECC) AISBL

AECC members: European Emissions Control companies

Technology for exhaust emissions control on all new cars (OEM and Aftermarket) and an increasing number of commercial vehicles, non-road applications and motorcycles.

Content

- Engine and emissions control system
- Test equipment and procedures
- Particulate Mass measurement
- Particle Number measurements
- Particle size distributions
- Chemical analysis of particulate matter
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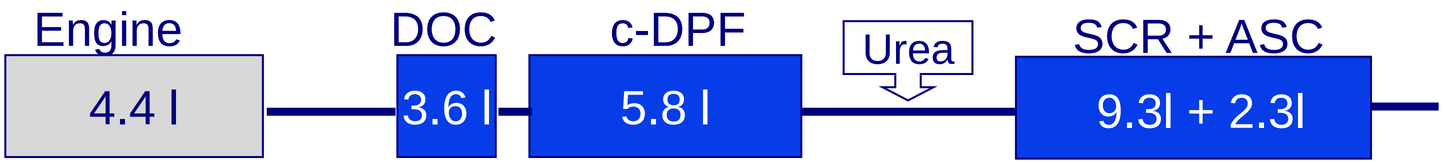
Test Engine & Emissions Control System

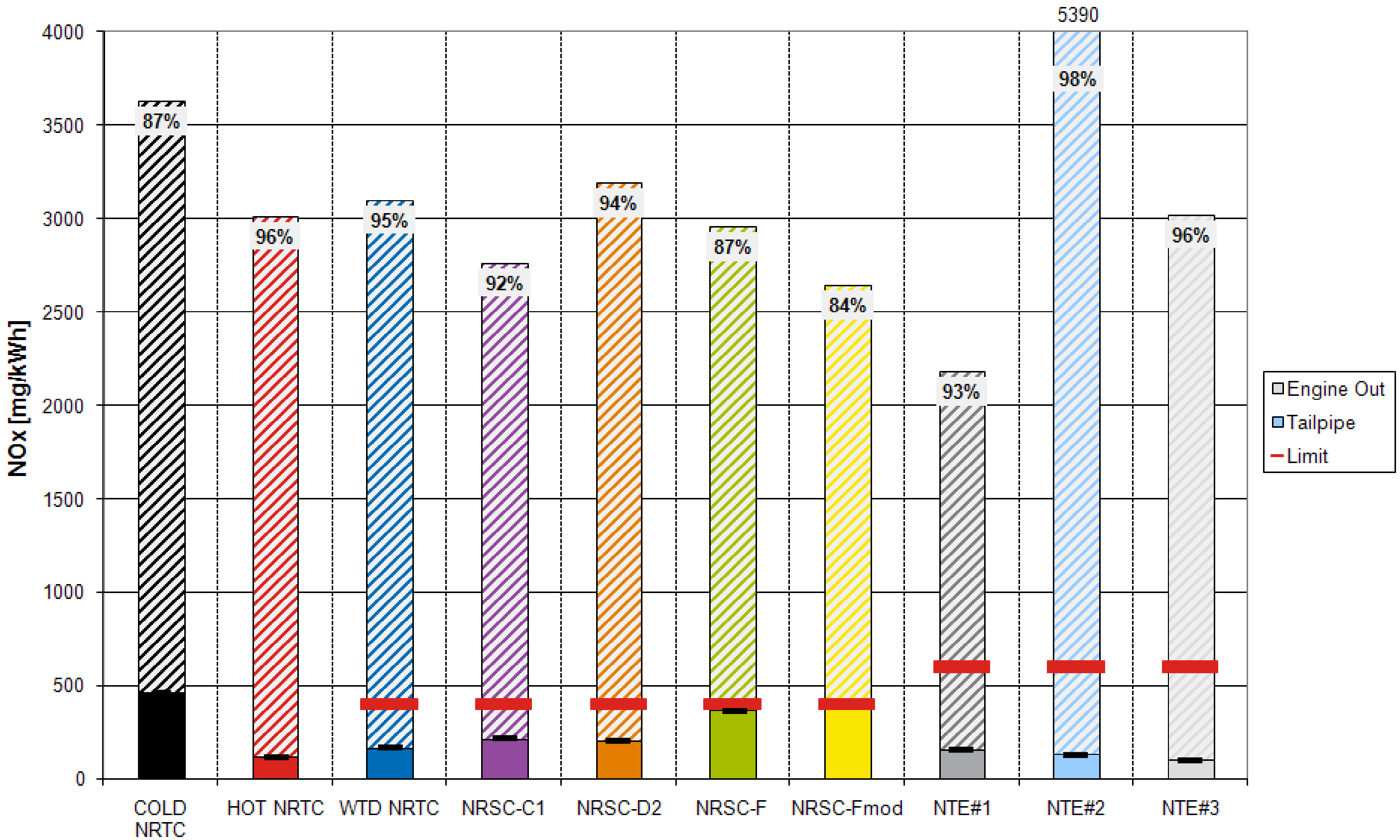
- 4 cylinder, 4.4 litre industrial prototype engine developed for NRMM Stage IIIB, provided by OE manufacturer.
  - High Pressure Common Rail (set at 160 MPa), Variable Geometry Turbocharger and cooled, electronically controlled EGR.
  - Modified Stage IIIB engine calibration to be compatible with AECC-supplied Emissions Control System on the NRTC.
  - PM ~ 35 mg/kWh, NOx ~ 3.0 g/kWh
- Emissions Control System (ECS) provided by AECC
  - System hydrothermally aged for 200hours at 600°C.



- Non-Road Transient Cycle (NRTC) and range of steady-state (NRSC) cycles plus 3 Not-to-Exceed (NTE) test points.
- Preconditioning regime to provide day-to-day repeatability for both NOx and PM without excessive loading.

Regulated Emissions

- Engine-out CO and HC Emissions below Stage IV limits.
- NOx conversion is high (85-95%) over most test cycles, limits are readily met with the exception of NRSC F & Fmod cycles which are close to the limits.



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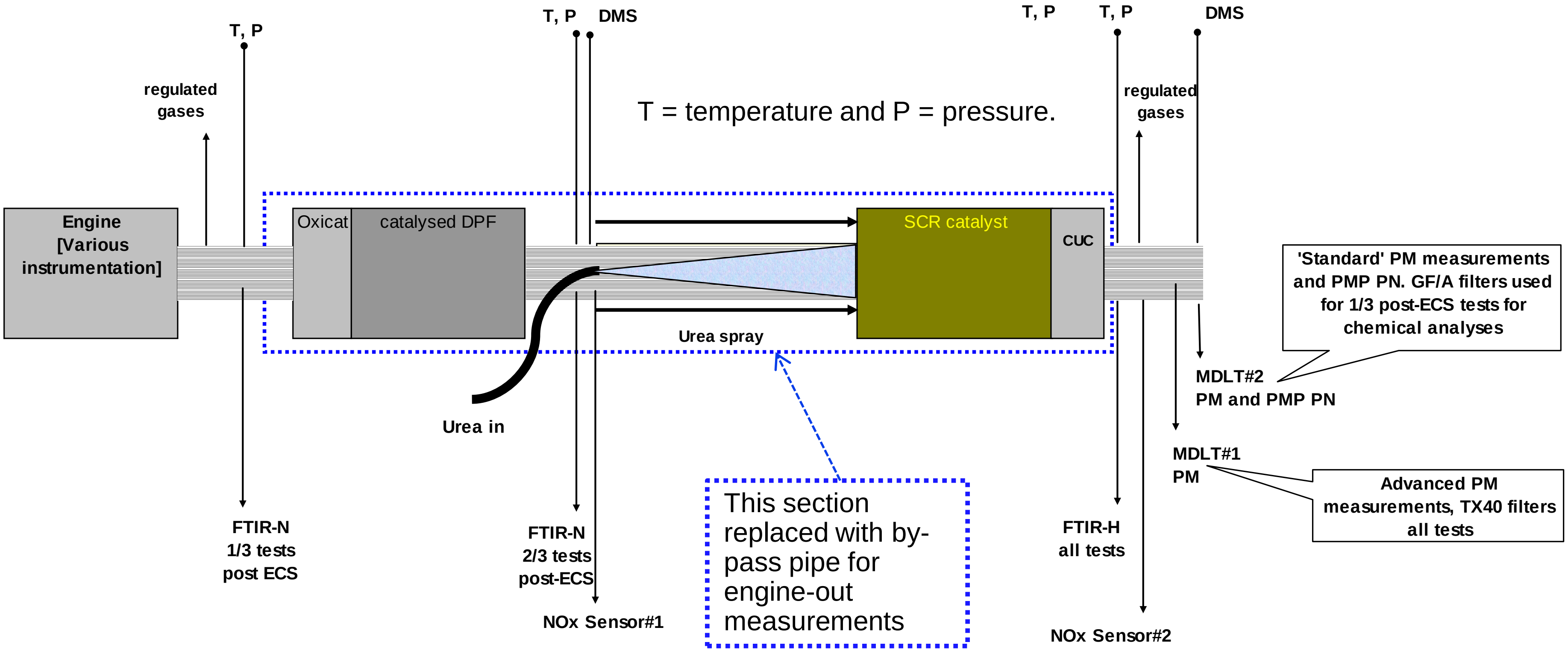
Particulate Analyses

- Twin Horiba MDLT partial flow systems at tailpipe position. Emissions system bypass used for engine-out data.
  - One MDLT for standard PM and PMP PN measurements.
    - 47mm filters; TX40 for most tests, GF/A for chemical analysis.
    - 120cm/s filter face velocity and 1/400th exhaust split.
    - Software correction to compensate for additional flow drawn by SPCS.
  - One MDLT for advanced PM measurements (to Euro VI).
    - 47mm TX40 filters.
    - 80cm/s filter face velocity and 1/600th exhaust split.
- Particle Number (PN) measurements were taken from the partial flow system according to the latest Heavy-duty PMP inter-laboratory correlation exercise guide and ECE R49.
    - Horiba MEXA2000-SPCS system used.
    - PN data have not been corrected for background.
- Differential Mobility Spectrometer (Cambustion DMS500)
    - size distribution and number concentration from 5 nm to 1µm.

Exhaust System Layout - Sampling Points



	Standard Particulate Mass (PM)	Particulate for chemical analysis	'Advanced' Particulate Mass (PM)	Particle Numbers to PMP (PN)	Differential Mobility Spectrometer
Direct engine-out	0	0	0	0	0
Engine-out via by-pass	1	1	1	1	1
Post-DPF/pre-SCR	0	0	0	0	1
Tailpipe after ECS	2	1	3	3	2

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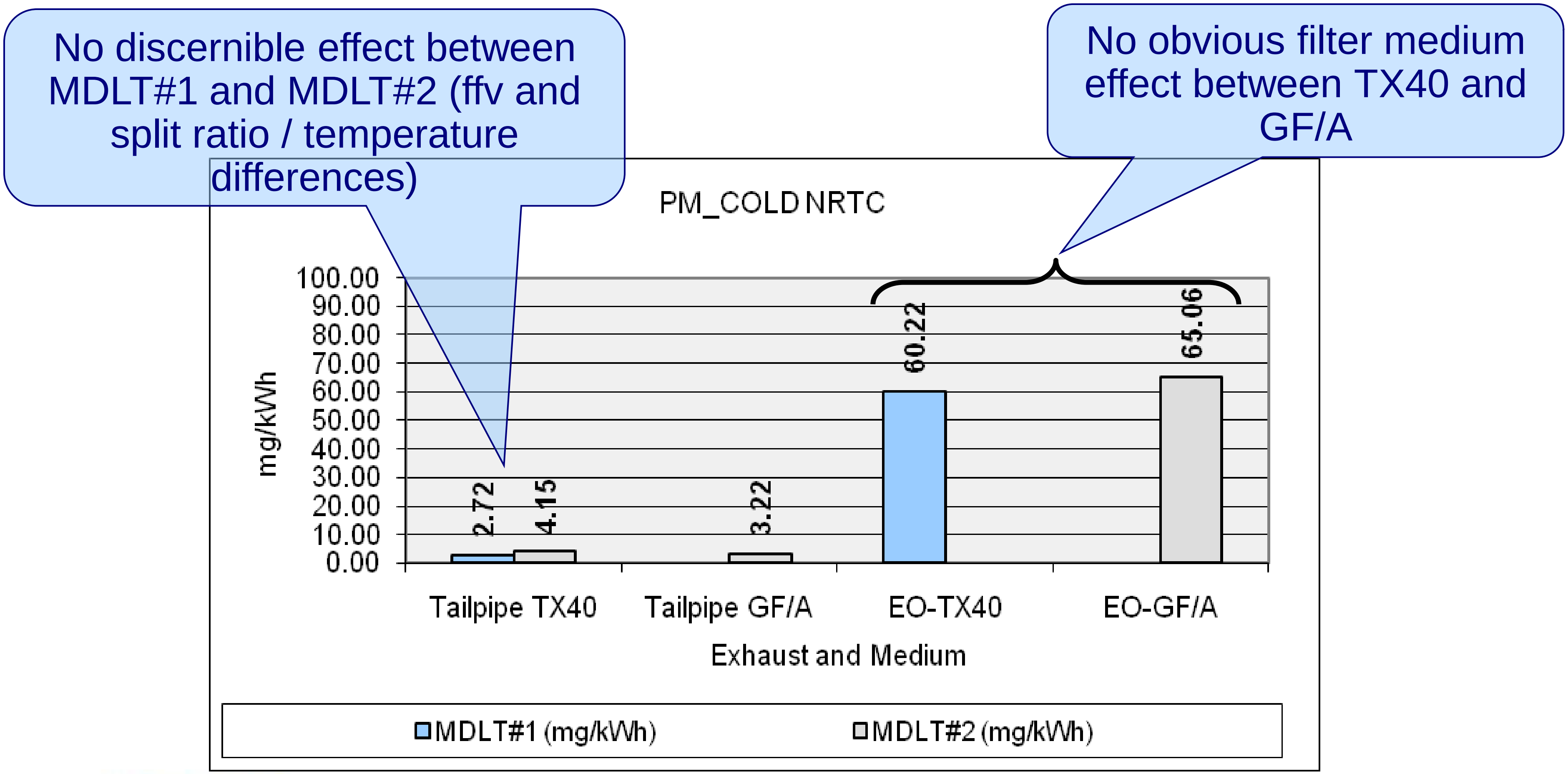
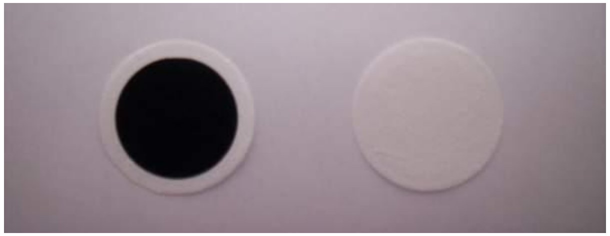
Partial-Flow Particulate Measurements

- No obvious effects of PM sampling or media on measured PM Tailpipe emissions levels.
  - 3-4 mg/kWh on Cold NRTC and 1.5 to 2.5 mg/kWh on hot NRTC.



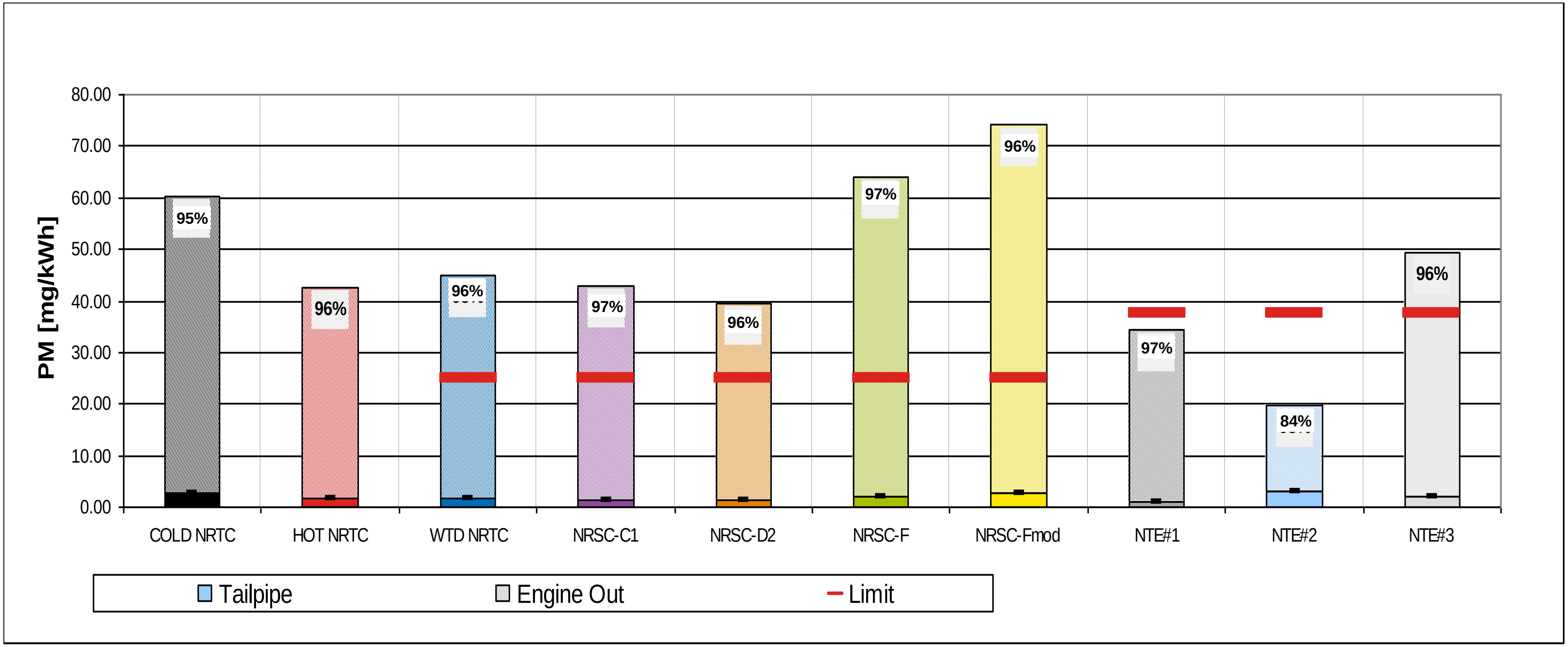
PM Regulated Emissions

- PM reduction across DPF meets limits with considerable margin over all cycles.



Hot NRTC Engine-out

Hot NRTC post-ECS



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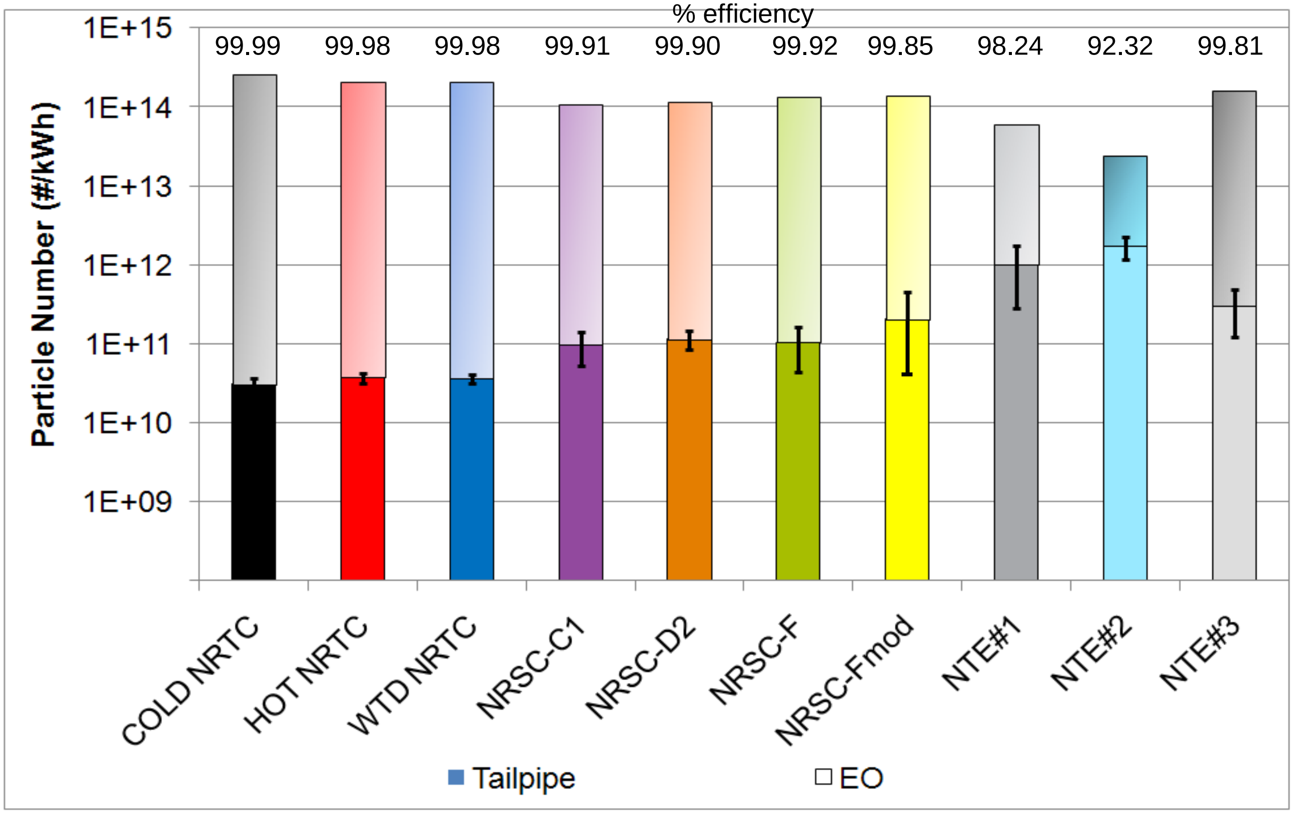
PMP Particle Number Results

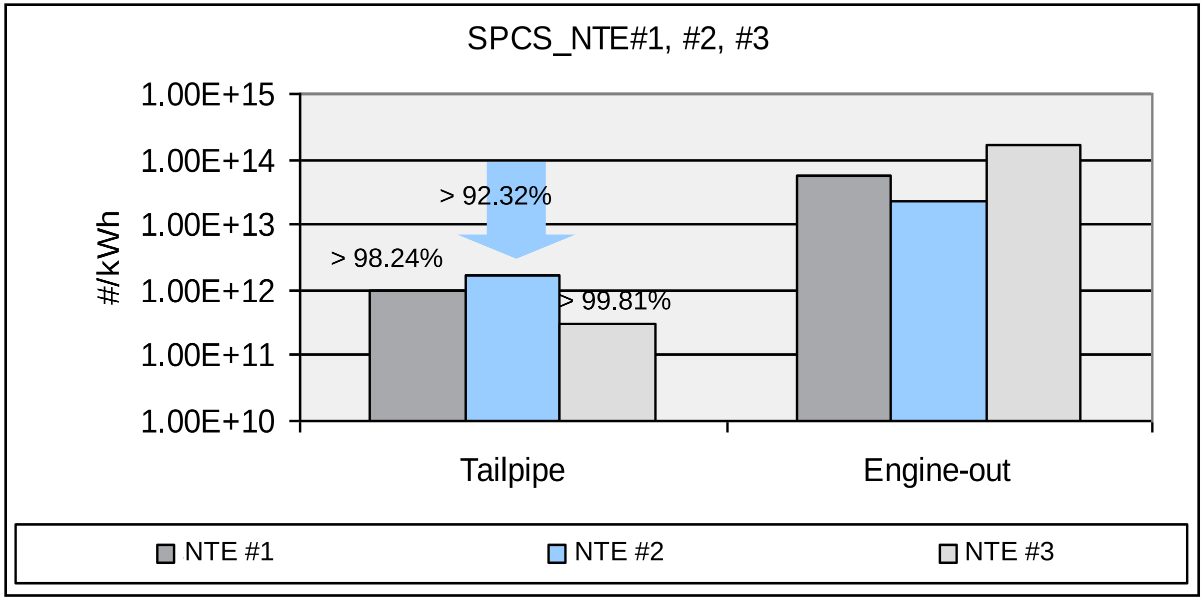
- Cold and hot transient cycle tailpipe PN results well below 10^{11}/kWh.
- Steady state cycles (NRSC variants) all at PN levels ~10^{11}/kWh or below.
- NTE points PN emissions all >10^{11}/kWh and NTE #2 >10^{12}/kWh.
- Engine-out PN from all cycles ranged from ~$6x10^{13}$ to ~$3x10^{14}$/kWh.

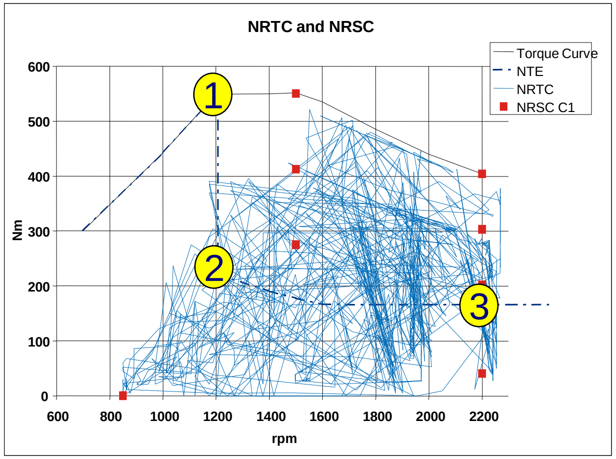
- Tailpipe PN range ~10^{10} to <$1.8x10^{12}$
- Engine-out PN range ~10^{13} to >10^{14}
- ECS efficiency always >92%.



PMP Particle Number for NTE #1, 2, 3

NTE#1	NTE#2	NTE#3
1200 rpm, 550 Nm	1200 rpm, 220 Nm	2200 rpm, 165 Nm





- Some passive regeneration during F and F-mod cycles preceding NTE #1.
- NTE#1: substantial passive regeneration.
- NTE #2: filtration efficiency lowest.
- NTE #3: no passive regeneration.

Mean Exhaust temp [°C]	DPF	SCR
COLD NRTC	283	234
HOT NRTC	285	261
NRSC-C1	335	333
NRSC-D2	346	338
NRSC-F	323	342
NRSC-Fmod	326	342
NTE#1	411	378
NTE#2	388	343
NTE#3	319	300

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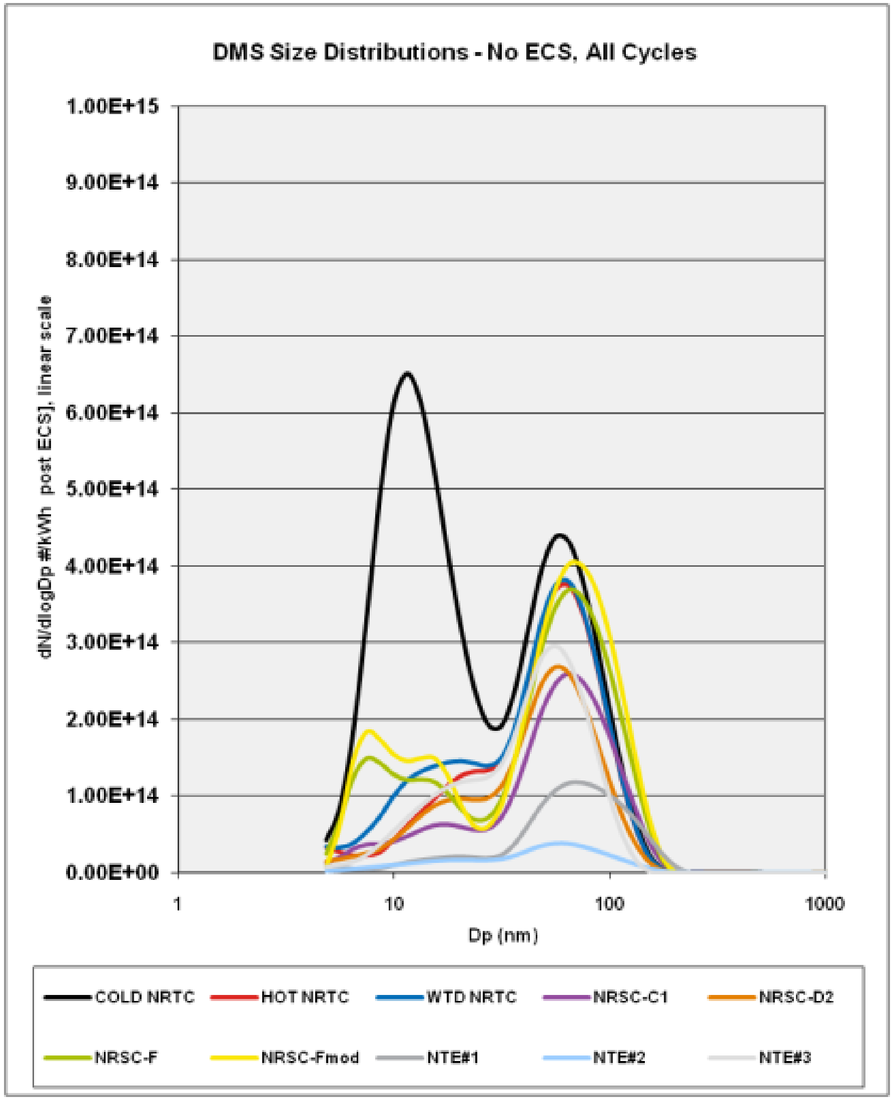
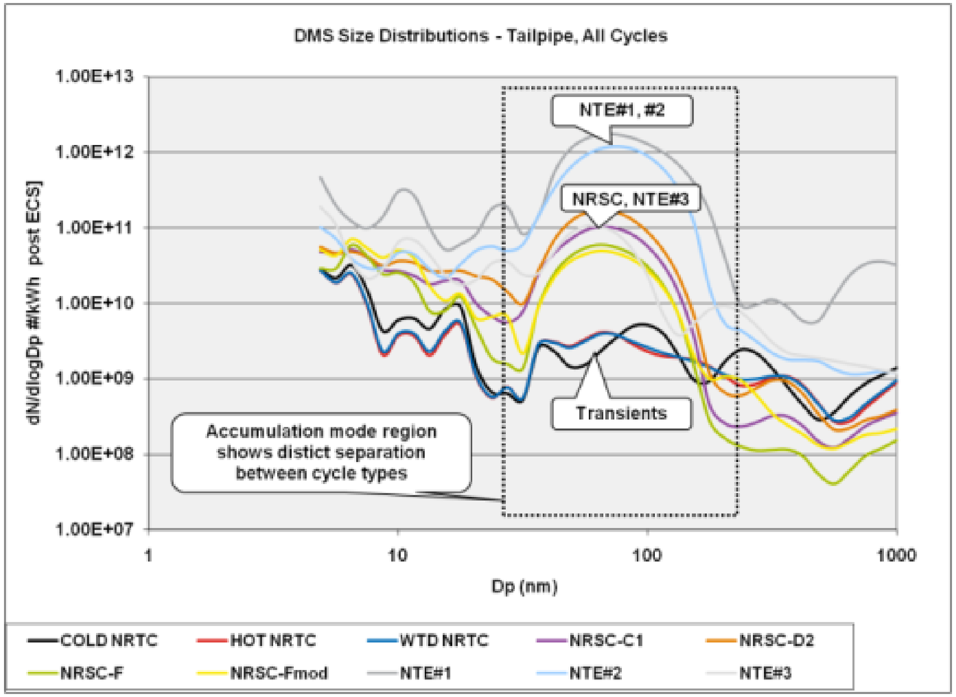
DMS Size Distribution Results – Engine-out



- Transient cycle engine-out PN were high and substantial dilution ratios were required (c.1000).
- Almost all operating conditions showed bimodal character.
  - Consistent with low PM (low EC) calibration for this engine.
- Highest nucleation mode with cold start NRTC.
- Highest accumulation modes with cold NRTC, NRSC F and NRSC F-mod.
- Lowest specific PN emissions from NTE #1 and #2.

DMS Size Distribution Results - Tailpipe

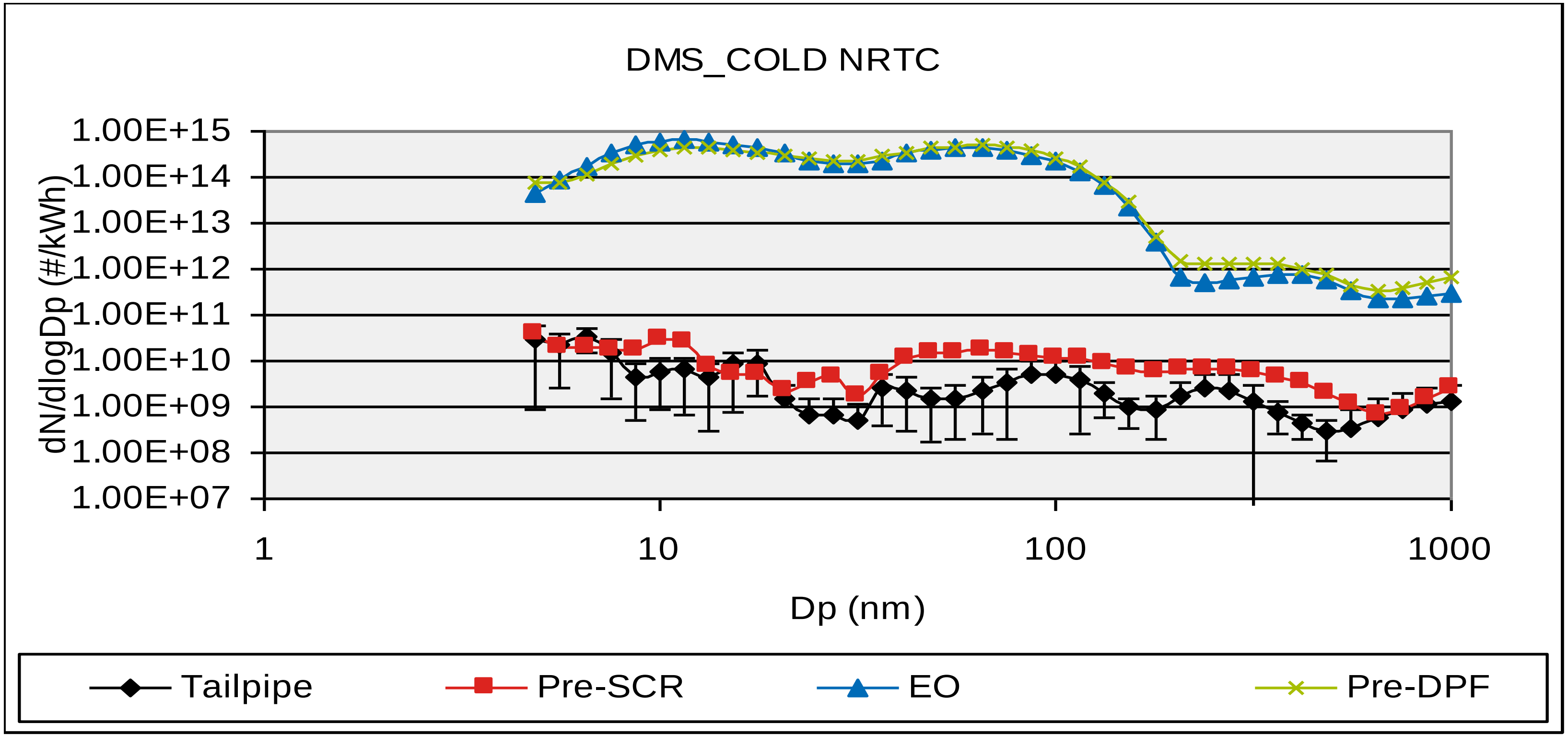
- Transient cycle tailpipe PN were very low and at the limit of DMS detection (at DF=4).
- Particle size distributions still reasonable in the accumulation mode region.



- Transient cycle PN (always initial cycles in the daily protocol) show lowest accumulation mode levels.
  - DPF fill during preconditioning has limited PN emissions.
- NRSC cycles' accumulation mode results higher, as some passive regeneration reduces soot cake.
- NTE points always highest
  - Tested at the end of the day, following NRSC and transients.
  - Important passive regeneration during NTE #1.
  - NTE #3 levels at the high end of NRSC results.

DMS Size Distribution through the ECS

- The cold-start NRTC shows the high nucleation mode and accumulation mode levels at Engine-out.
- Pre-SCR and tailpipe levels are similar, although there is possibly some acc. mode reduction across the SCR.



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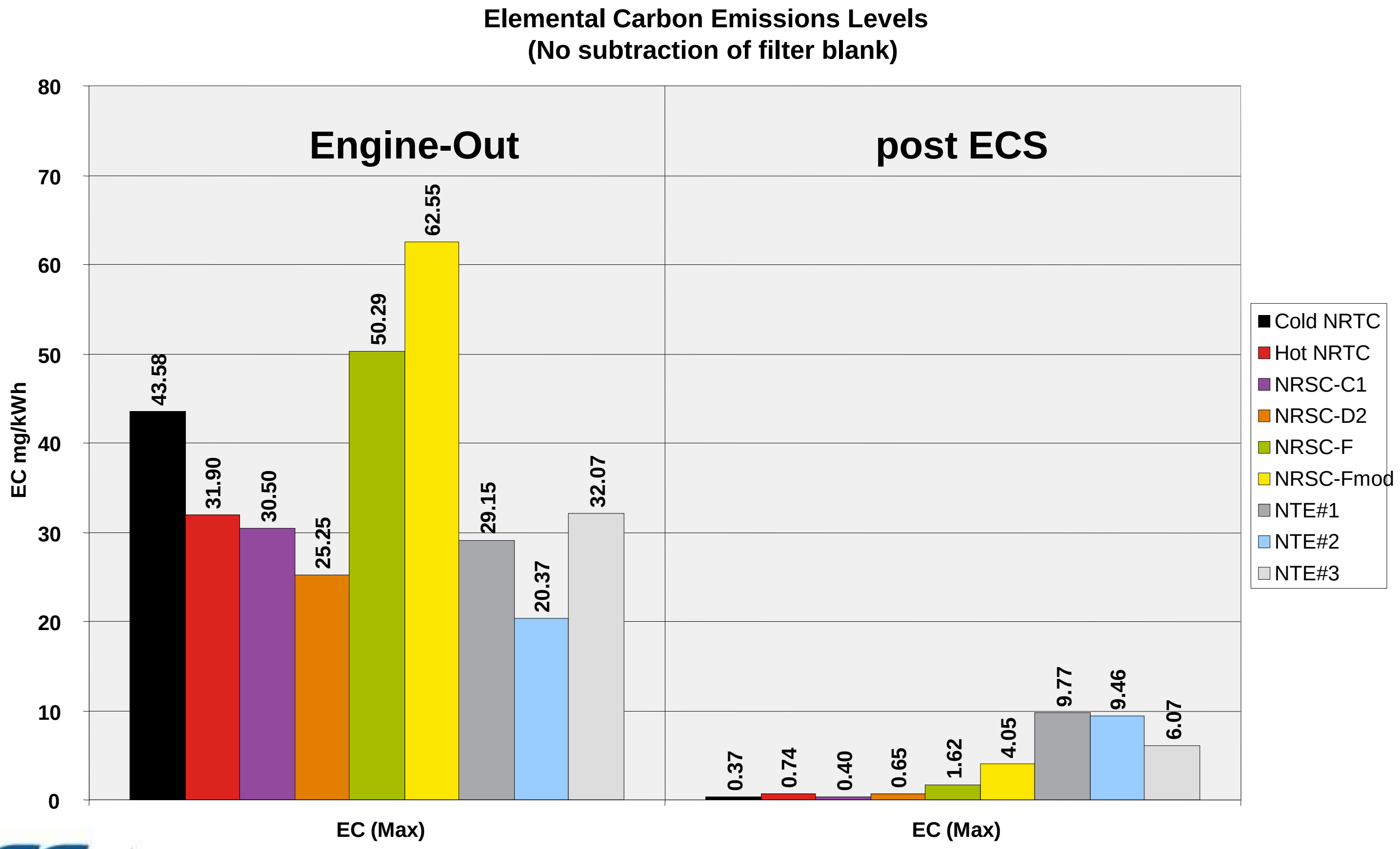
Emissions Levels of Elemental Carbon (EC)

- Substantial reduction in EC from engine-out to tailpipe.
- Filtration efficiencies similar to PN
  - Elemental carbon comprised ~45% to ~70% of engine-out PM.
  - Volatiles dominated post-DPF filters, carbon fraction negligible.



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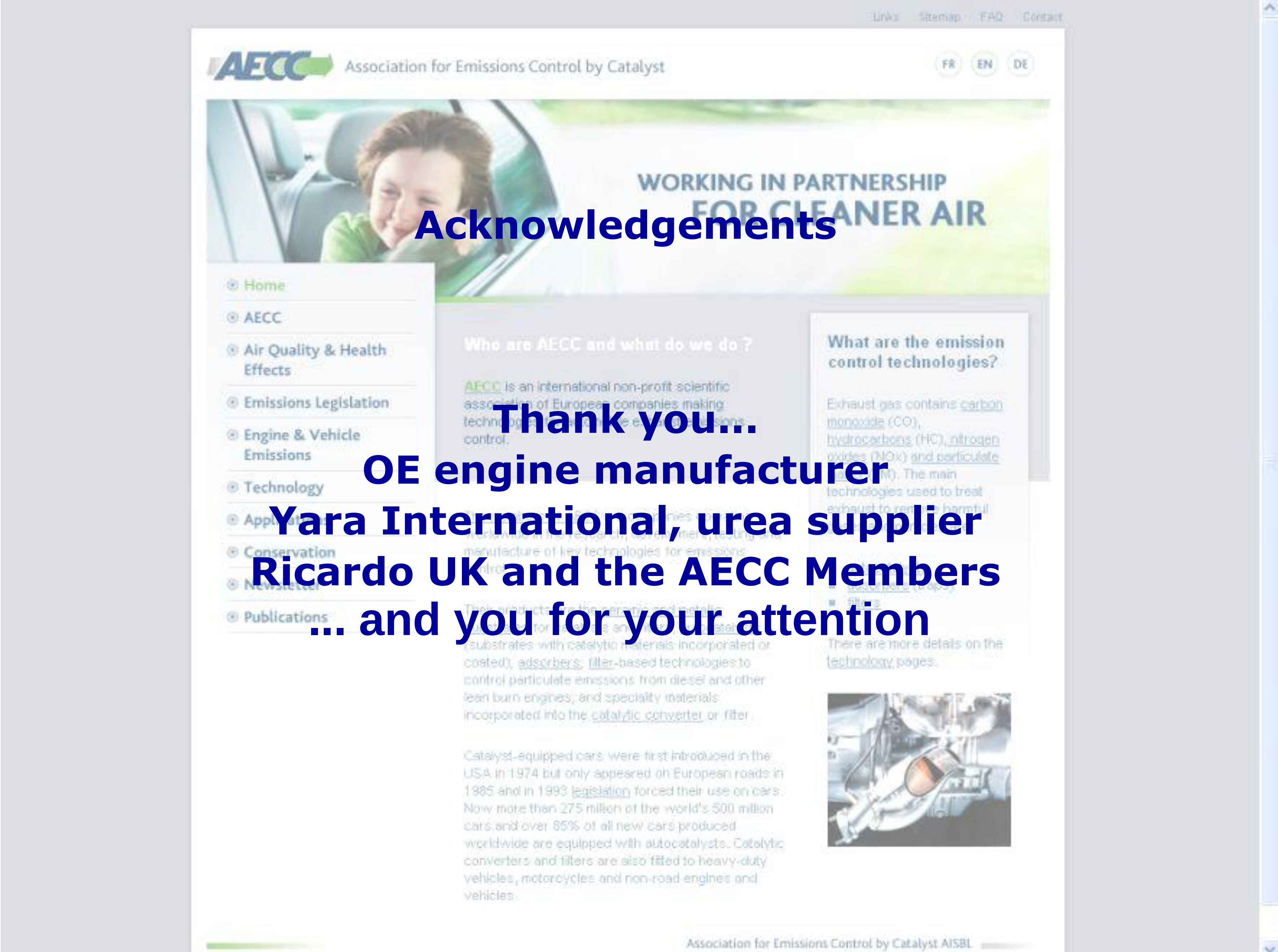
Summary (1)

- PM conversion efficiencies were 96% and 97% over the NRTC and NRSC C1 cycles respectively, resulting in tailpipe PM levels of 1 to 2 mg/kWh when measured with the partial flow method.
- Tailpipe Particulate Mass emissions from two different sampling media appeared broadly similar.
- Withdrawing a sample from a partial flow dilution system for PN measurements can result in a substantial reduction in measured Particulate Mass , if a correction is not made.
  - In this program, 13% of mass was removed.
- Elemental carbon emissions were reduced by the ECS.
  - >99% for all transient and steady state cycles once the filter background for EC was taken into account.
  - With subtraction of EC blank, tailpipe EC levels were negligible.

Summary (2)

- The HD-PMP method as developed by UN-ECE GRPE for on-road HD engines could readily be used to measure particle emissions (PM and PN) of NRMM engines.
- All transient cycles' data showed tailpipe Particle Number emissions well below 10^{11}/kWh.
- Steady state cycles' data showed emissions below 10^{12}/kWh.
- Passive regeneration occurring during one NTE point influenced PN emissions for the following NTE point. Tailpipe particle numbers were still more than an order of magnitude below engine-out levels.
- ECS efficiency for PMP Particle Numbers was >99.8% for all transient and steady state cycles.
- The production-intent Stage IIIB prototype engine fitted with the AECC Emissions Control System readily met Stage IV emissions limits over a range of test cycles.



Acknowledgements

Thank you…

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… and you for your attention