Real Driving Emissions and Test Cycle Data from 4 Modern European Vehicles

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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 cars, buses and commercial vehicles and an increasing number of non-road applications and motorcycles.

Background

- The 2007 emissions Regulation (EC 715/2007) requires emissions to be effectively limited throughout the normal life of the vehicle under normal conditions of use.
- Concerns over real-world emissions compared to test cycle Type Approval data have resulted in European Commission proposals for additional ‘Real Driving Emissions’ (RDE) test using Portable Emissions Measurement Systems (PEMS).
- Anticipated EU implementation of Worldwide harmonised Light vehicles Test Procedure (WLTP) and cycle (WLTC).
- The effects of these developments on measured emissions and their control technologies needs to be understood.
- Key area of interest is Diesel NOx, but Particle Numbers, especially for DI Gasoline vehicles, are also a concern.

Test Regimes

- Tests conducted at two independent laboratories
  - Lab 1: a gasoline vehicle and an early Euro 6 diesel
  - Lab 2: two further Euro 6 diesel vehicles using different NOx emission control technologies.
- All vehicles were tested using
  - PEMS in real driving,
  - NEDC (current Type Approval test),
  - CADC (Artemis; used in modelling),
  - WLTC (proposed new Type Approval test) and
  - 3 different Random Cycles.
- PEMS data was evaluated by 2 methods being considered by the European Commission.

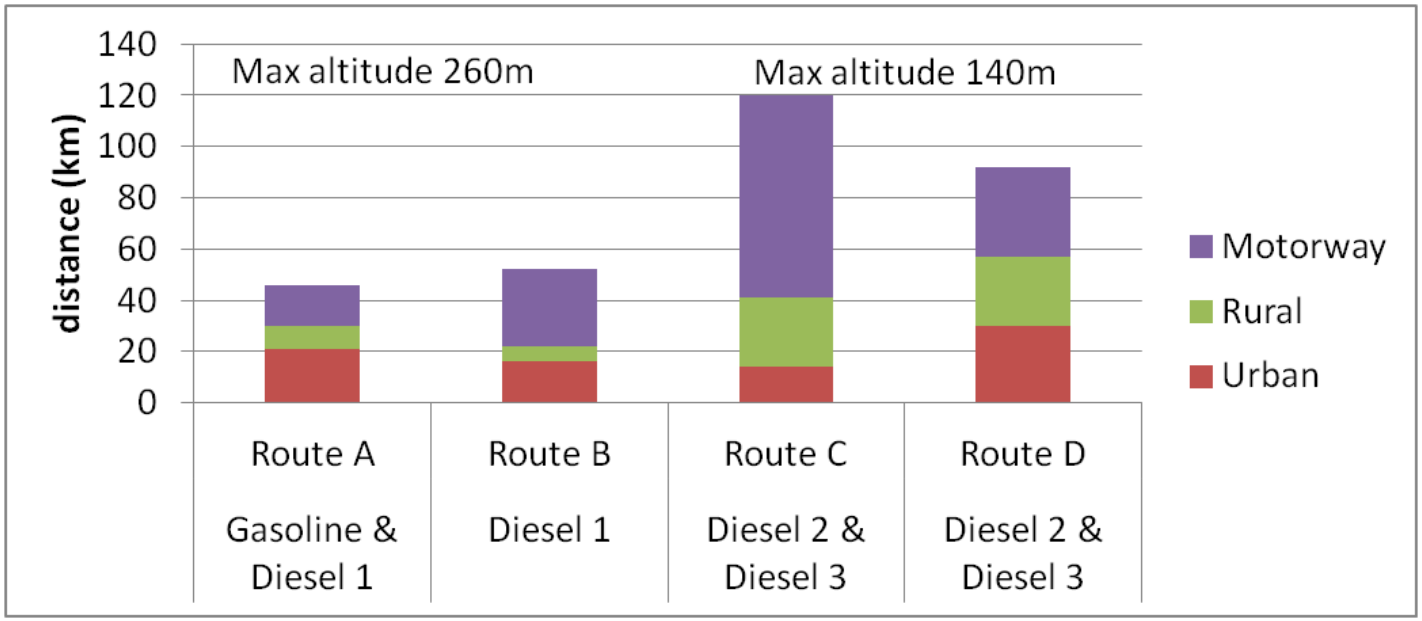
Test Vehicles

- Normal production vehicles taken from the EU market.
- Tested ‘as received’ after checks for no faults / OBD flags.

Vehicle	Engine size (litres)	Power (kw)	Euro standard	Engine technology	Emissions control technology	Transmission	Mileage at start of testing (km)
Gasoline	1.8	125	Euro 5b	PFI + DI	TWC	6-speed manual	4 000
Diesel 1	3.0	180	Euro 6b	Turbocharged DI Diesel	DOC + DPF + LNT + urea-SCR	8-speed automatic	22 900
Diesel 2	2.0	103	Euro 6b	Turbocharged DI Diesel	DOC + DPF + urea-SCR	6-speed manual	13 500
Diesel 3	2.1	125	Euro 6b	Turbocharged DI Diesel	High pressure EGR + DOC + DPF + Low pressure EGR	7-speed semi-auto	11 000

Test Cycles/ Routes

- Chassis dyno cycles
  - All tests were run in triplicate.
  - WLTC tests used the 4-phase test for Class 3b vehicles (power to mass ratio >34 W/kg and v_{max} >120km/h).
  - CADC test were sampled and measured over the full cycle.
- RDE – PEMS Routes



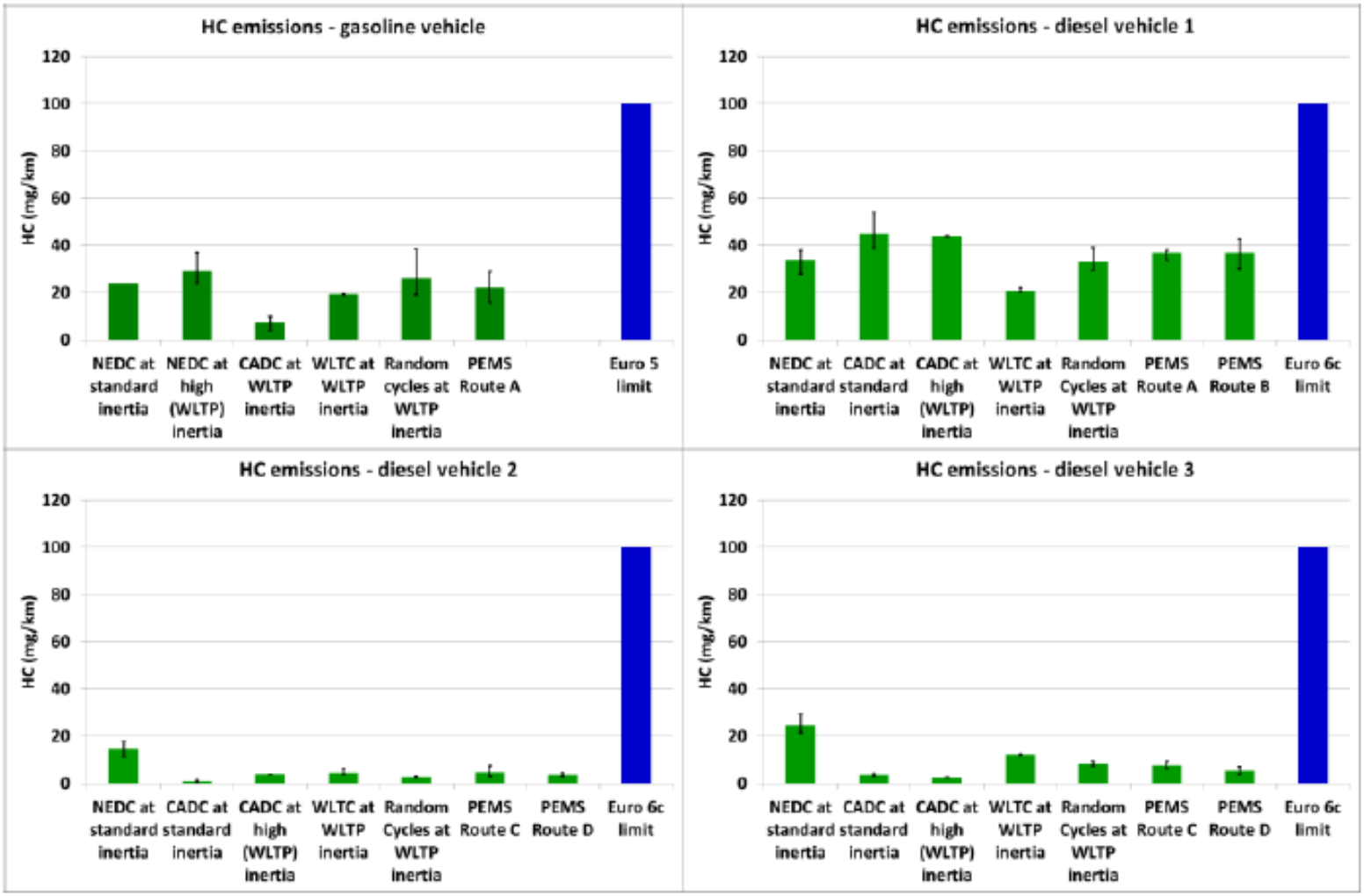
Inertia Masses

- WLTP introduces new requirements for road load determination and inertia setting, resulting in settings that differ from those for NEDC.
- For the first vehicle, all tests were run at the new (WLTP) inertia. In the light of experience this was modified for subsequent tests, as shown below.

	NEDC inertia (kg)	WLTP inertia (kg)	Inertia used for tests				
			NEDC tests	CADC tests	WLTC tests	Random Cycles	Other
Gasoline vehicle	1590	1930	WLTP	WLTP	WLTP	WLTP	Extra NEDC at NEDC inertia
Diesel vehicle 1	2150	2460	NEDC	NEDC	WLTP	WLTP	Extra CADC at WLTP inertia
Diesel vehicle 2	1700	1810					
Diesel vehicle 3	1470	1590					

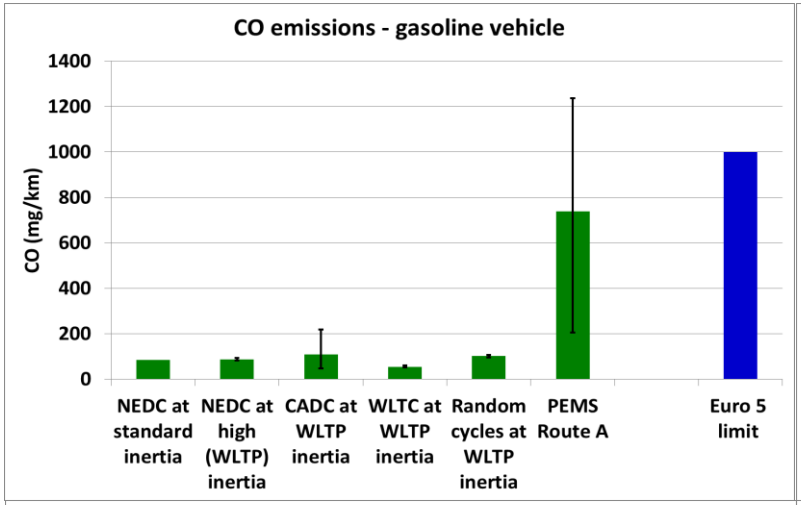
HC Emissions

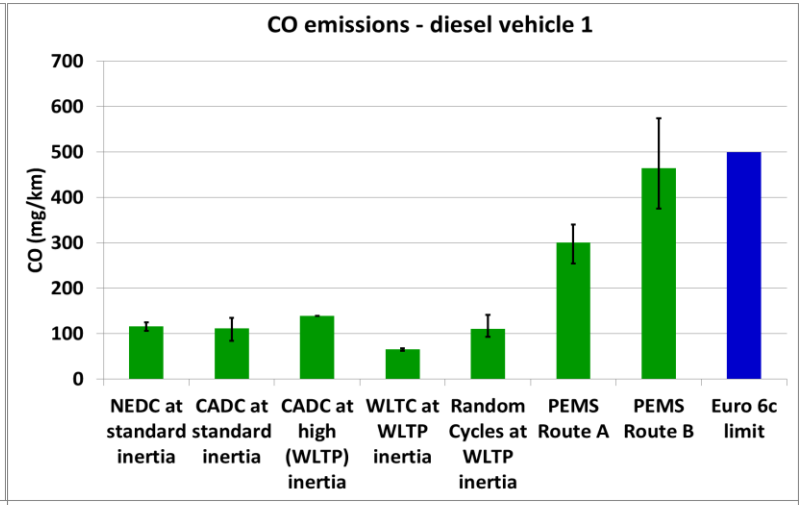
- HC emissions all well within the legislative limits.

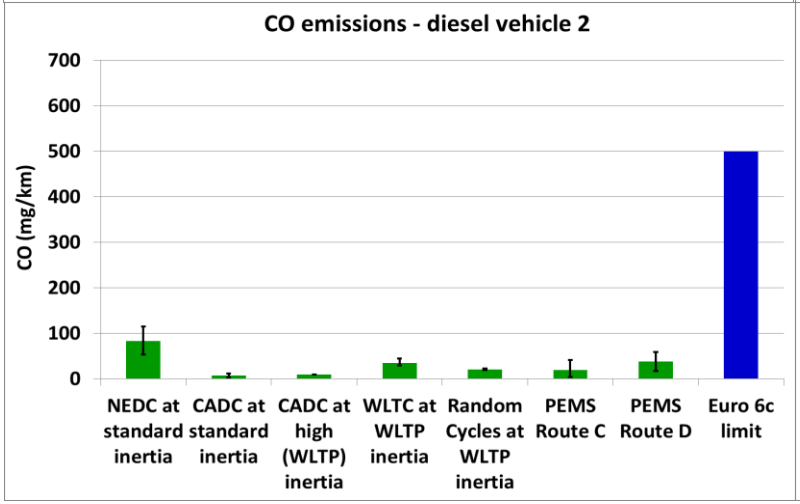


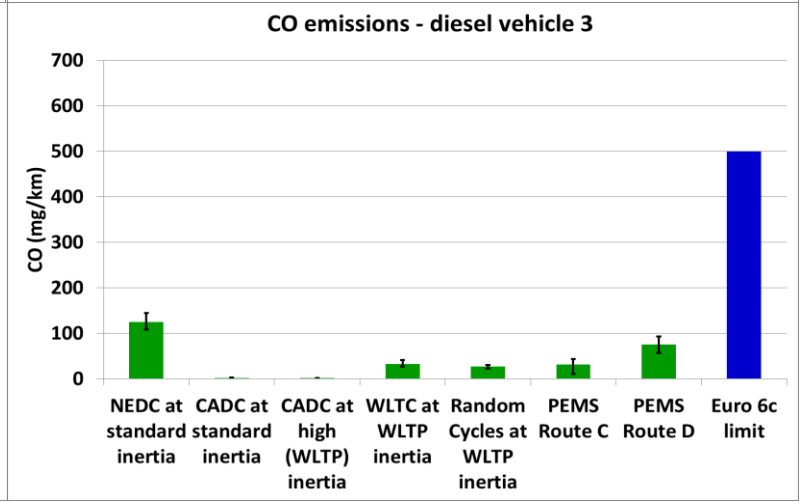
CO Emissions

- Average CO emissions all within legislative limits.
- PEMS CO emissions varied considerably for the gasoline car.









Particulate Mass (PM) Emissions

- PEMS-PM tests:

  Gasoline vehicle and Diesel 1:

  – Photoacoustic sensor measures the soot content of PM.

  – It therefore registers lower mass than filter measurement.

  Diesels 2 & 3:

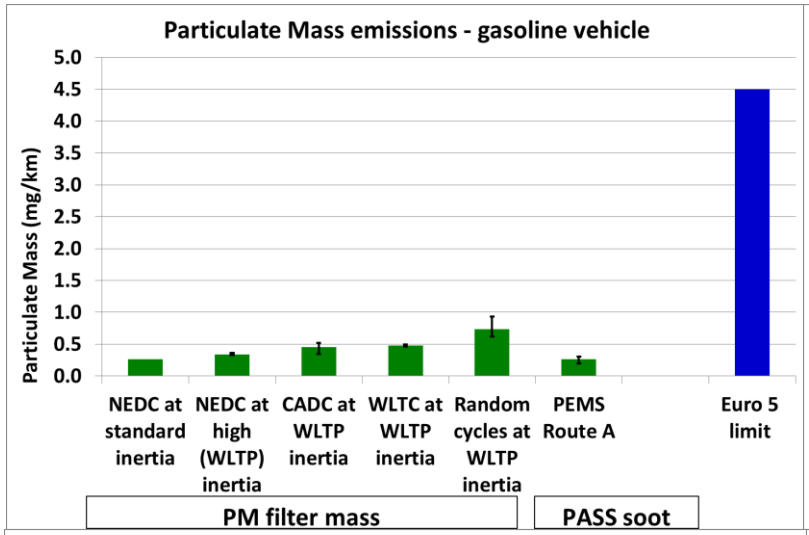
  – Filter-based system.

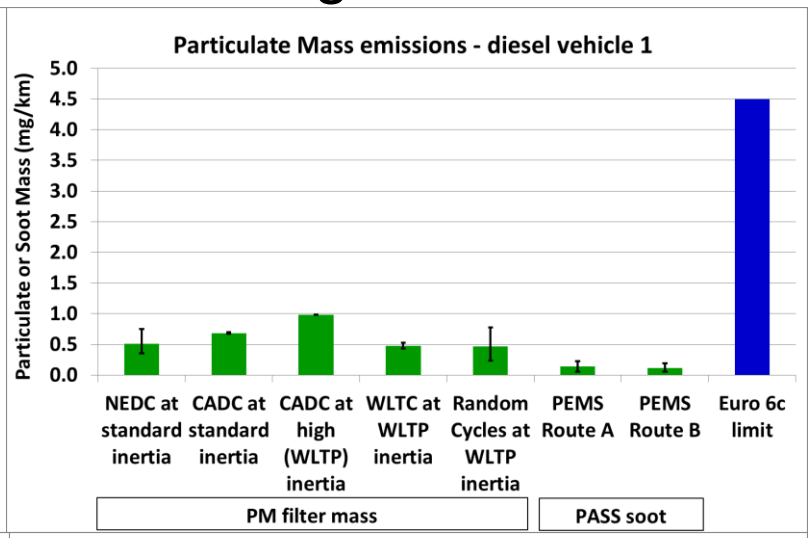
  – Collected mass was similar to that for chassis dyno tests.

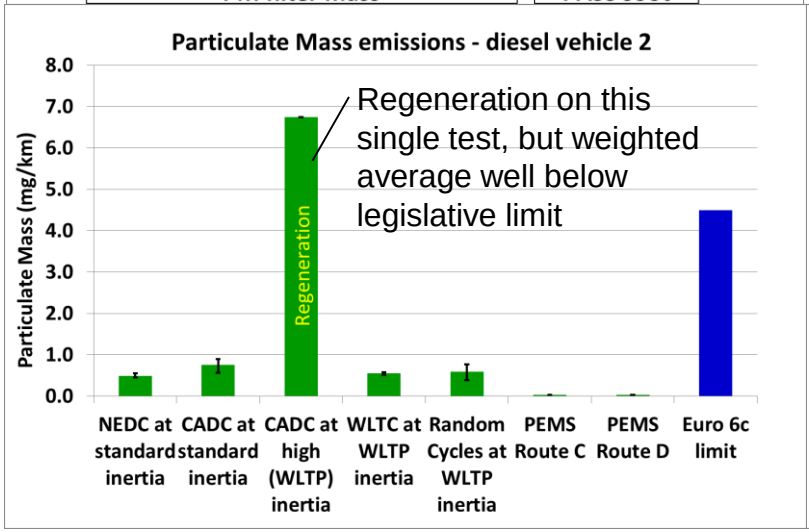
  – The low g/km PM for these tests compared to chassis dyno may be due to collection and removal of volatiles over this much longer test.

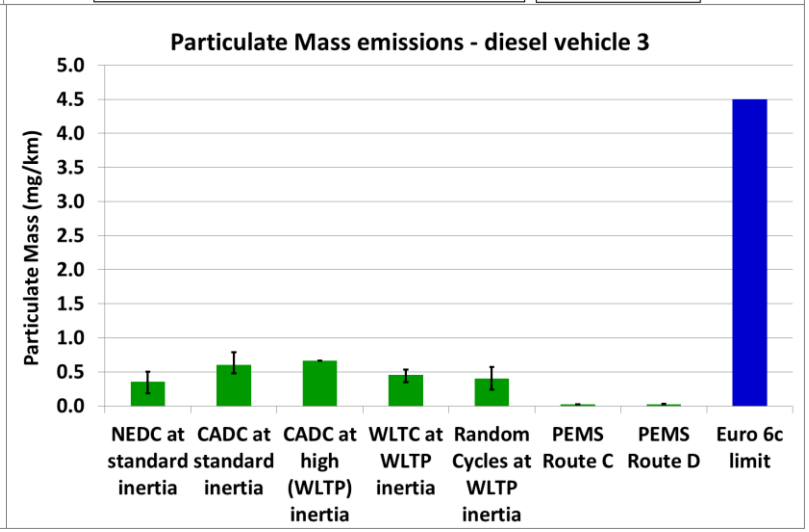
Particulate Mass (PM) Emissions

- PM emissions all well within the legislative limits.









Particle Number (PN) Emissions

- All chassis dyno tests used regulatory (PMP) procedure.
- PEMS-PN tests:

  Gasoline vehicle and Diesel 1:

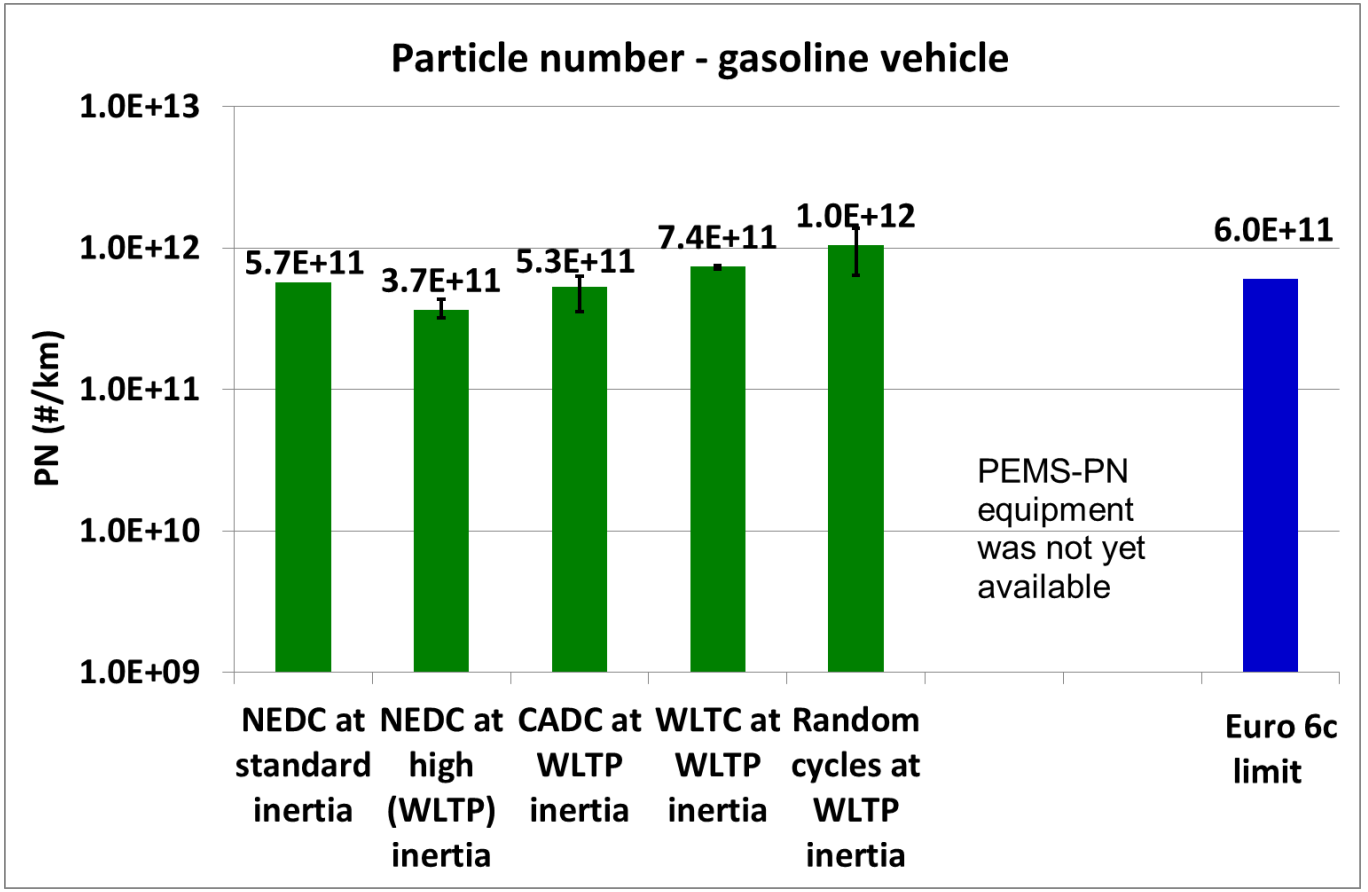
  – No PEMS PN equipment was available at this time.

  Diesels 2 & 3:

  – New particle mobility-based candidate system.
  – Set to have a 23 nm particle size cut-off so as to be comparable to the PMP system.
  – No Volatile Particle Remover (VPR) - this may result in slightly higher results, especially during regenerations.

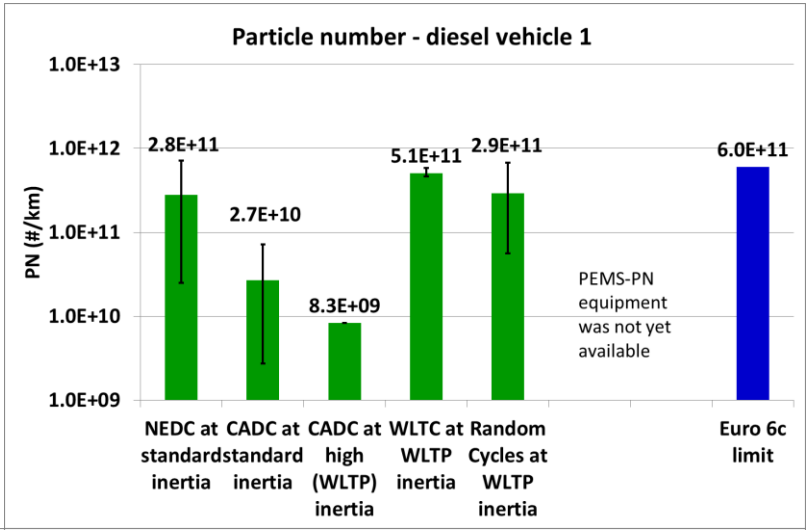
Particle Number (PN) Emissions – Gasoline Vehicle

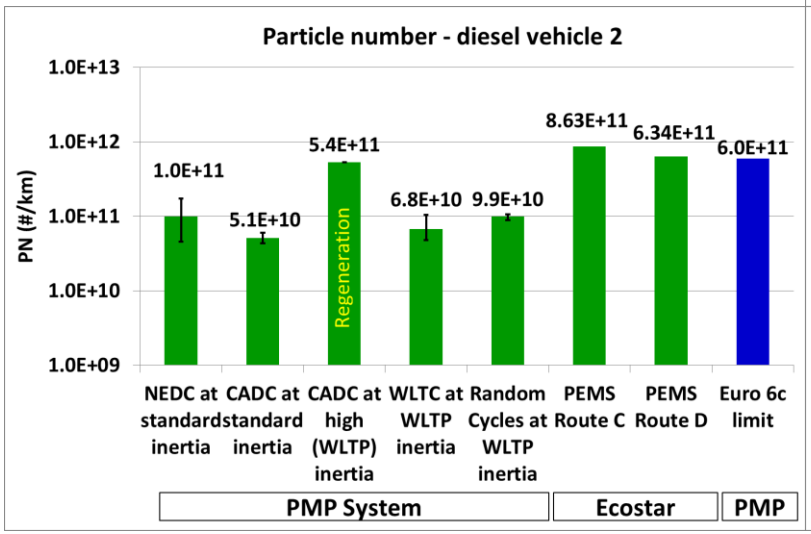
- The Euro 6b PN limit was met on all tests, but the Euro 6c limit was exceeded on the WLTC and Random Cycle tests.

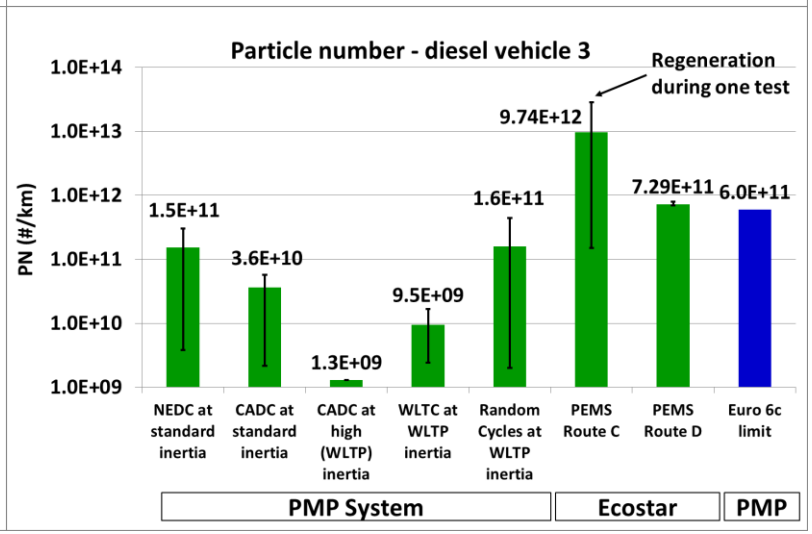


Particle Number (PN) Emissions – Diesel Vehicles

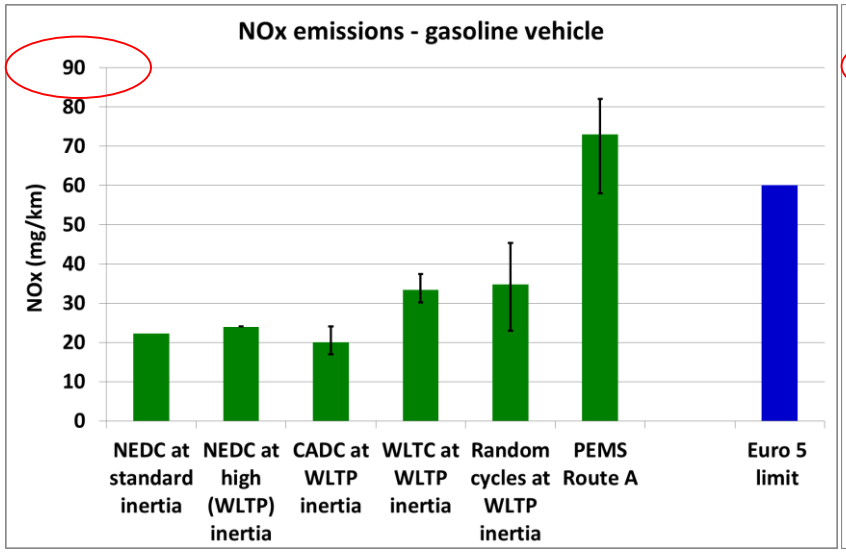
- The results show the effectiveness of diesel particulate filters over a range of different conditions.

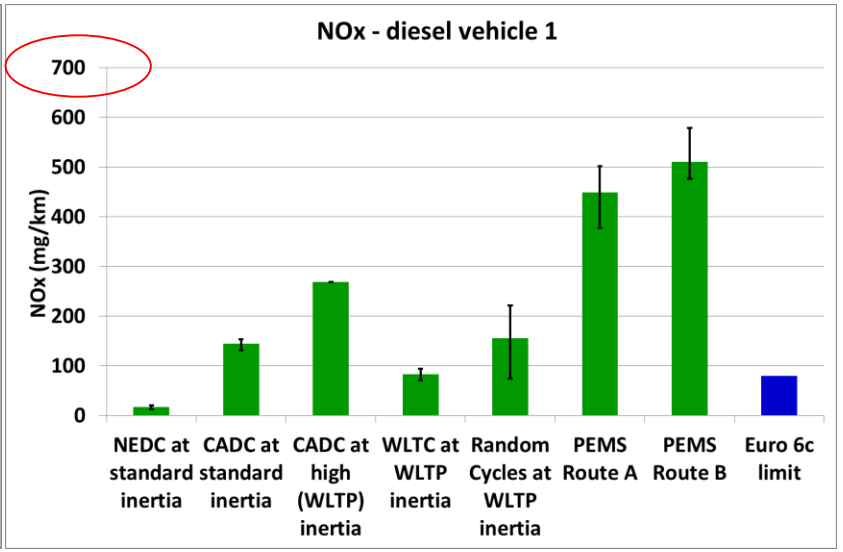


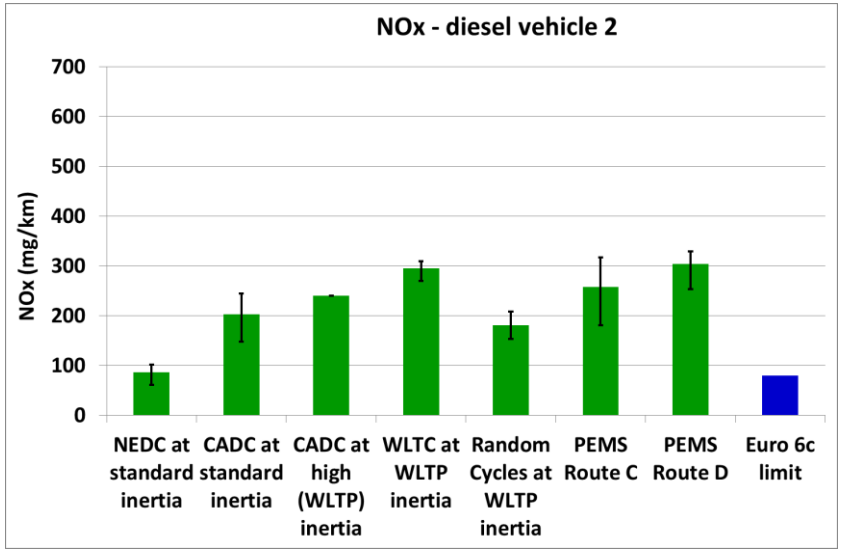


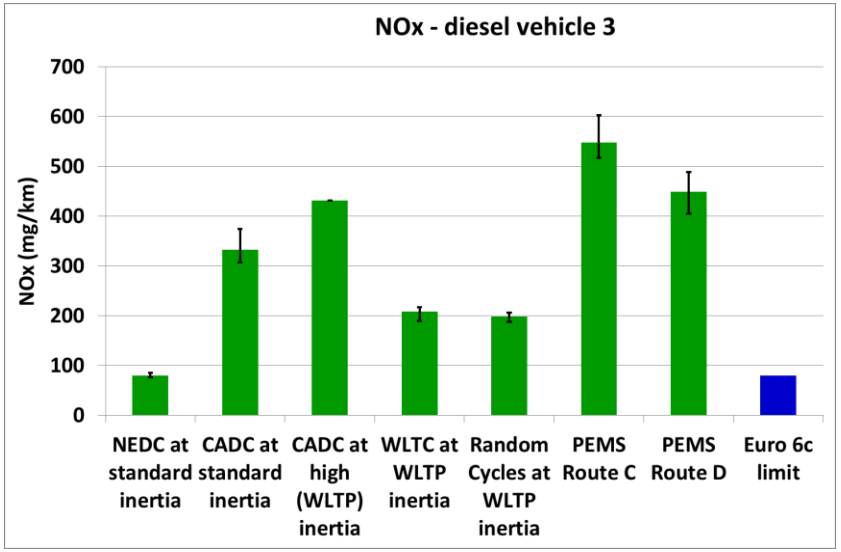


NOx Emissions – All Vehicles



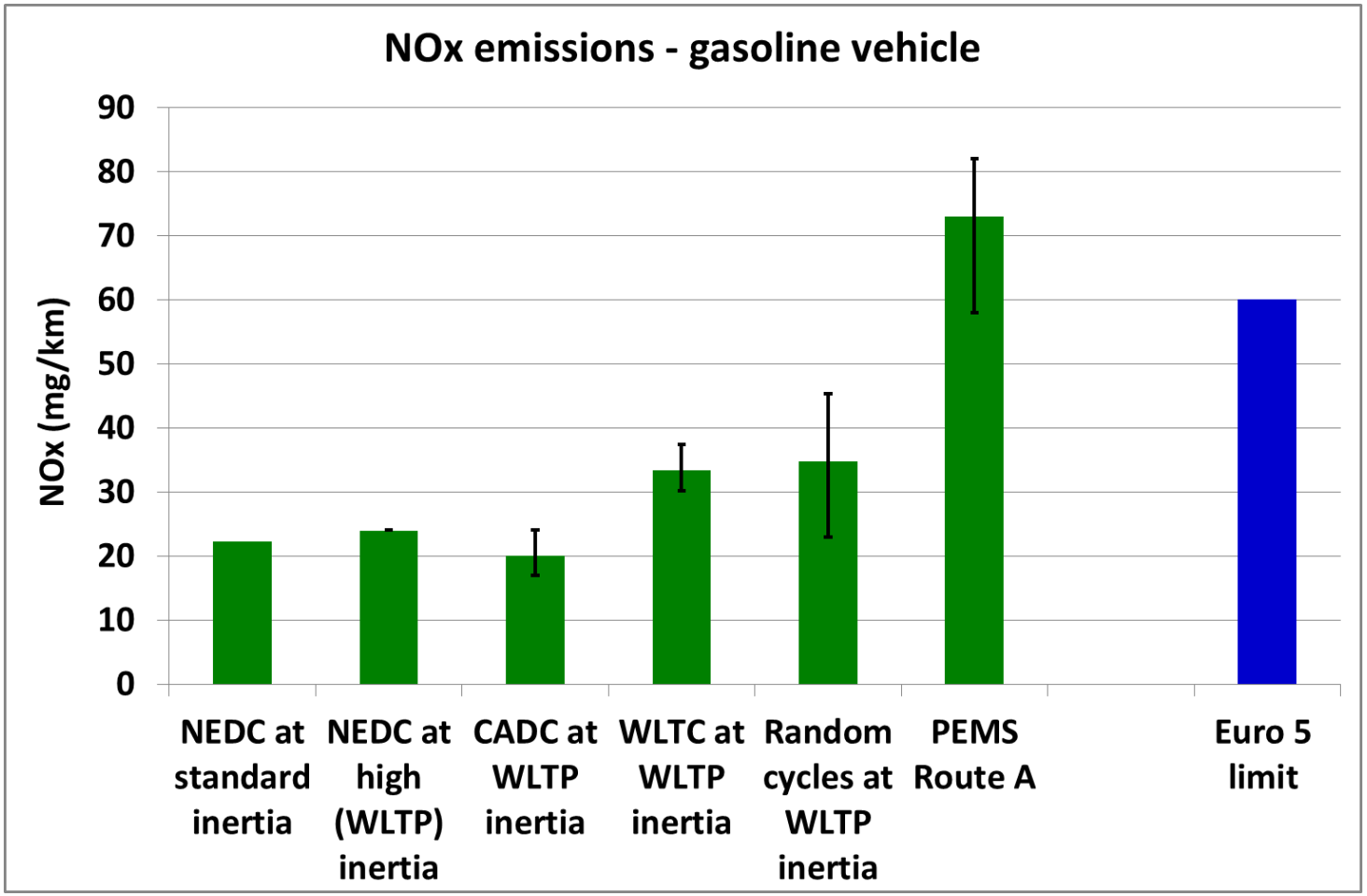






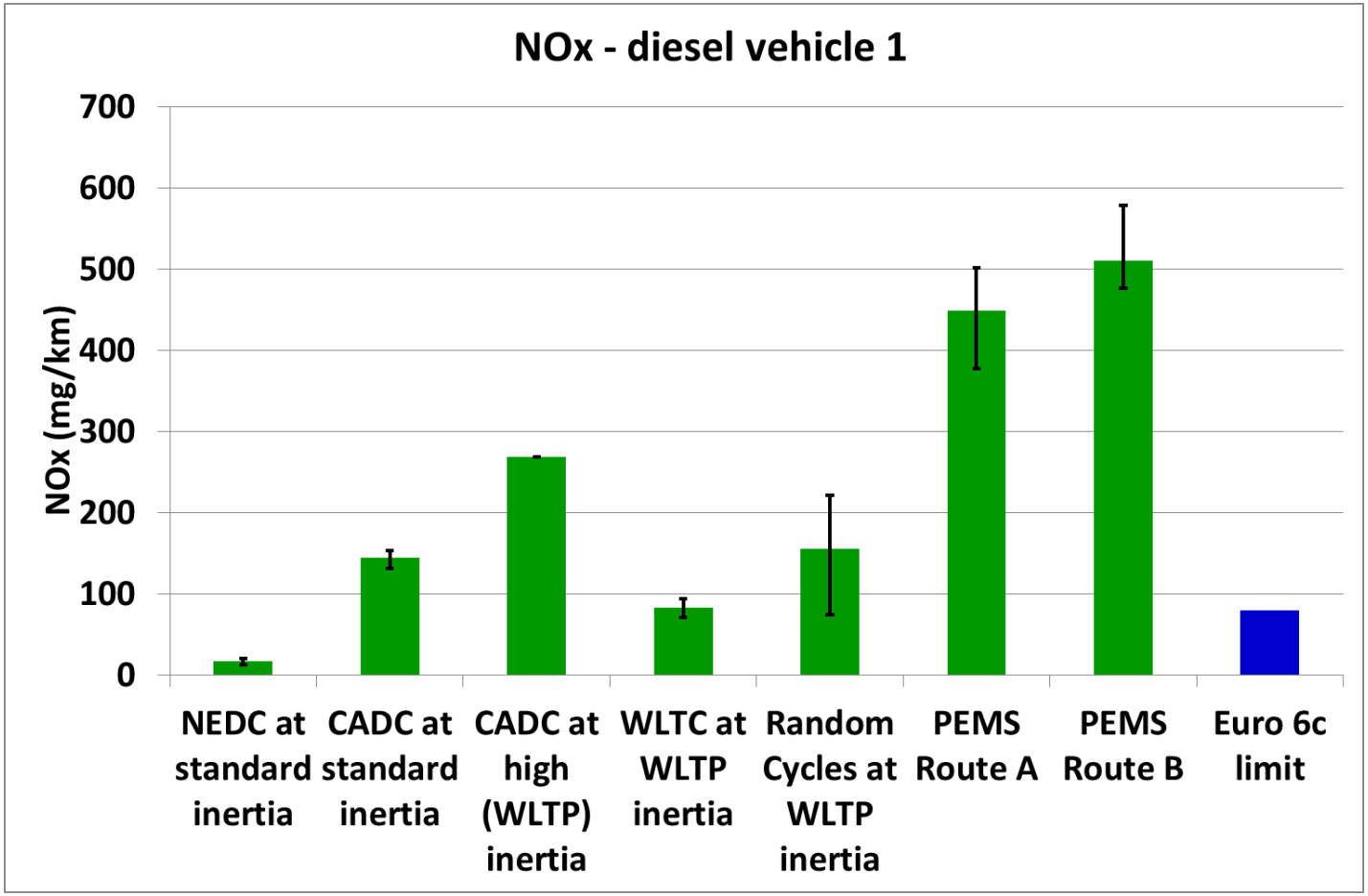
NOx Emissions – Gasoline Vehicle

- Legislative NOx limits were met on all chassis dyno cycles.
- Slightly higher RDE result perhaps due to PEMS mass.



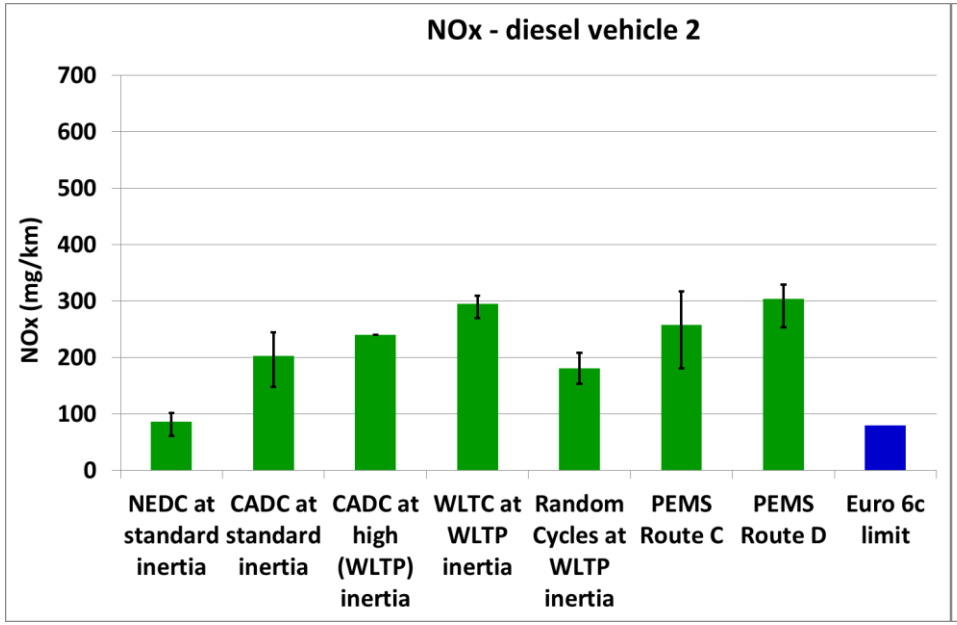
NOx Emissions – Diesel 1

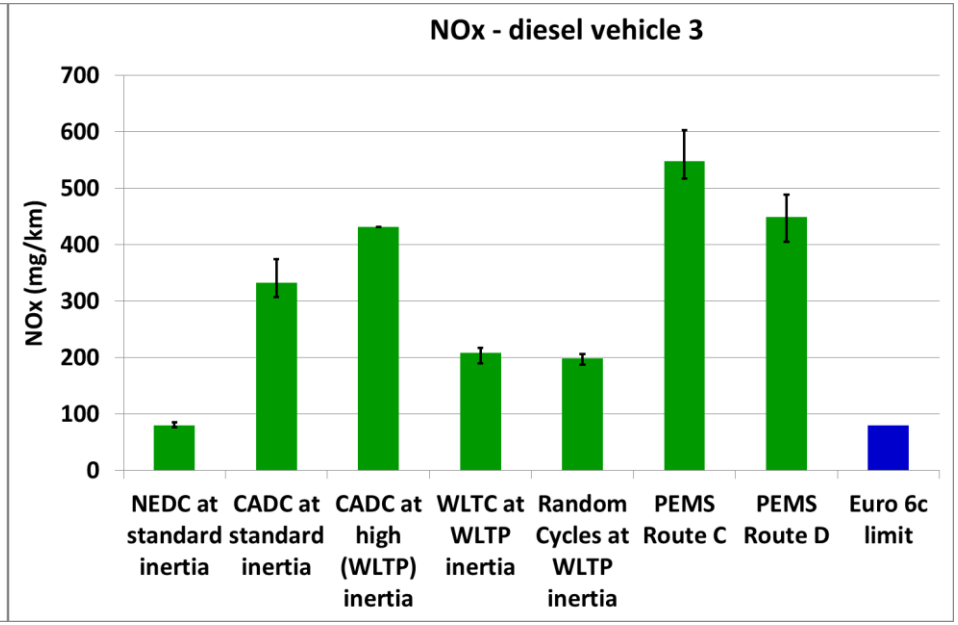
- Diesel 1 gave good NOx emissions on the NEDC and WLTC.
- However, NOx on the PEMS routes was ~ 400 - 600mg/km.



NOx Emissions – Diesels 2 & 3

- Diesel vehicles 2 & 3 met legislative limits only on the NEDC.
- On RDE tests, the EGR-only vehicle emitted up to 600mg/km.
- The SCR vehicle showed better overall control, but clearly work is still needed to bring NOx emissions to NEDC levels.



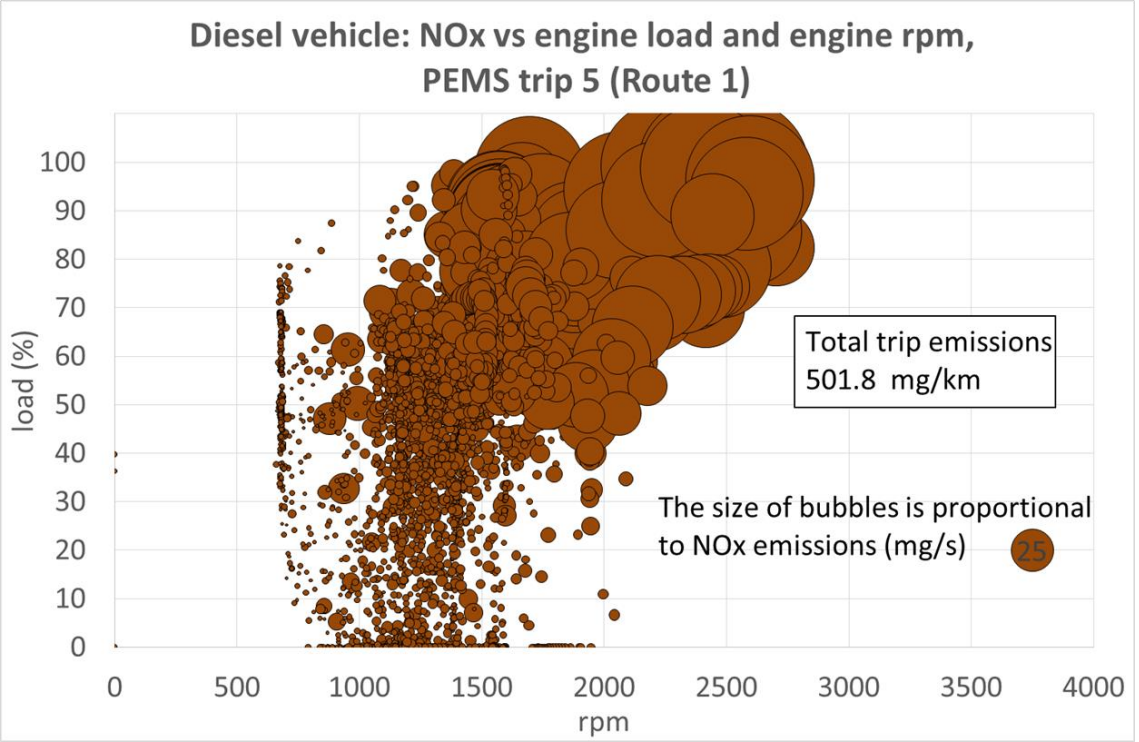


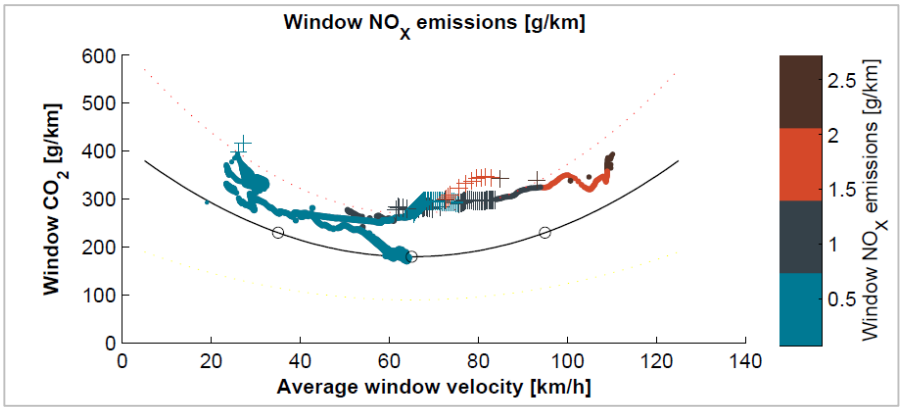
PEMS Data Analysis Methods

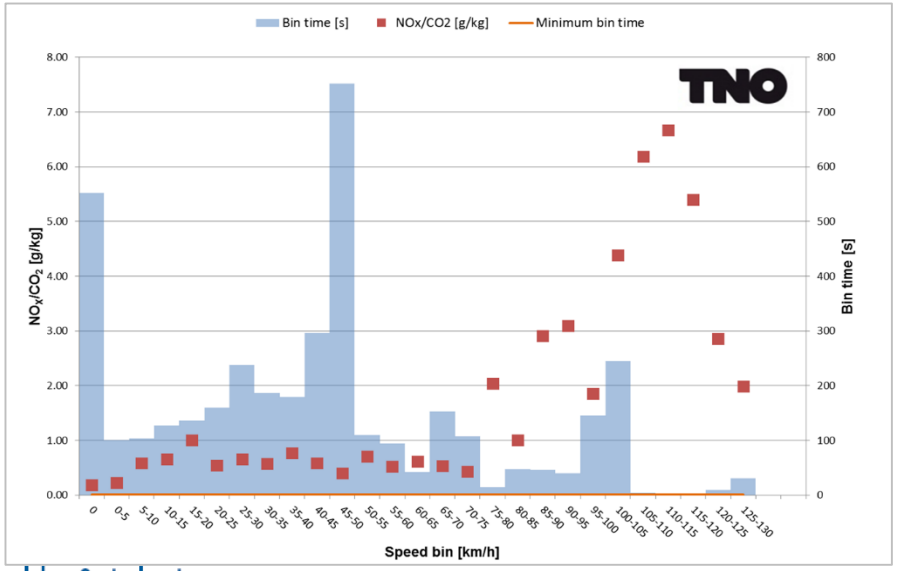
- Two alternative methods are currently considered for PEMS data analysis:
  - EMROAD developed by DG-JRC; already used for Heavy-duty PEMS testing.
  - CLEAR developed by TU Graz.
- Both have been run for Diesels 2 & 3.
- The ICCT provided an EMROAD-based analysis for Diesel 1.
- TNO originally proposed a binning method and this was evaluated for Diesel 1.
- In addition NOx emissions were plotted on bubble charts of speed vs. load or torque.

Diesel 1 PEMS NOx Evaluation

- Analyses all show high NOx emissions at high engine loads.
- This is observed for NOx emissions expressed in mg/s, in g/kg CO_2, or in g/km.







Source: EMROAD analysis of AECC data conducted by ICCT

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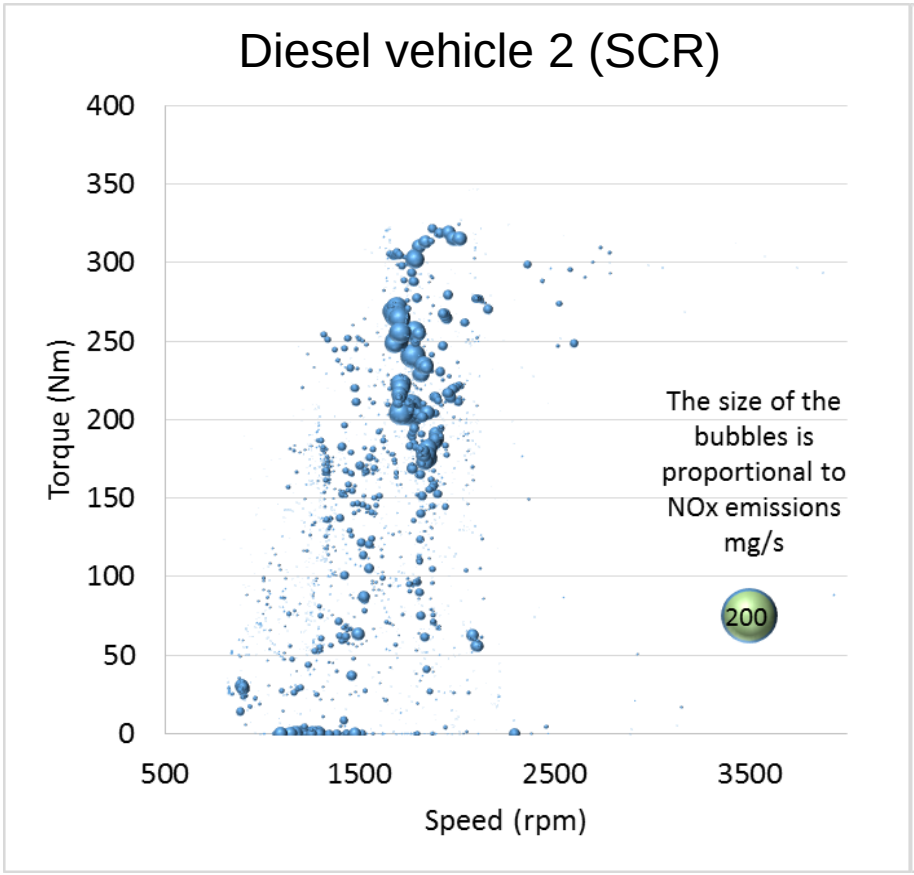
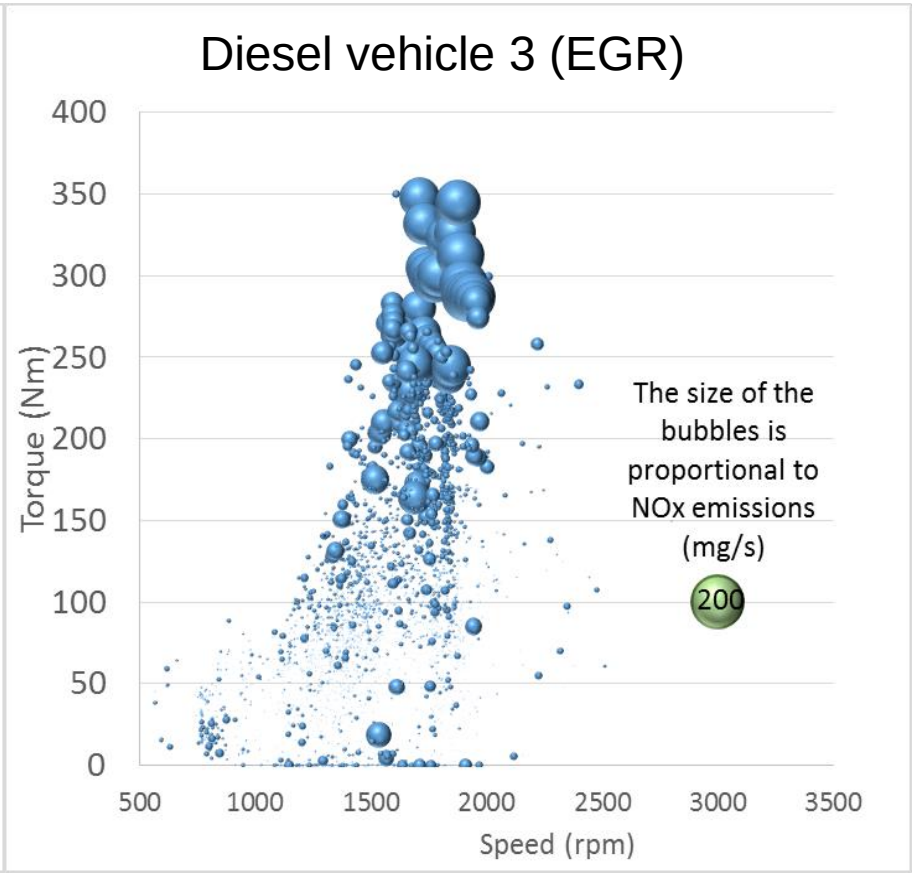
Diesels 2 & 3 PEMS NOx Evaluation

- As for Diesel 1, analysis of PEMS NOx results shows highest instantaneous NOx is seen at high engine loads.



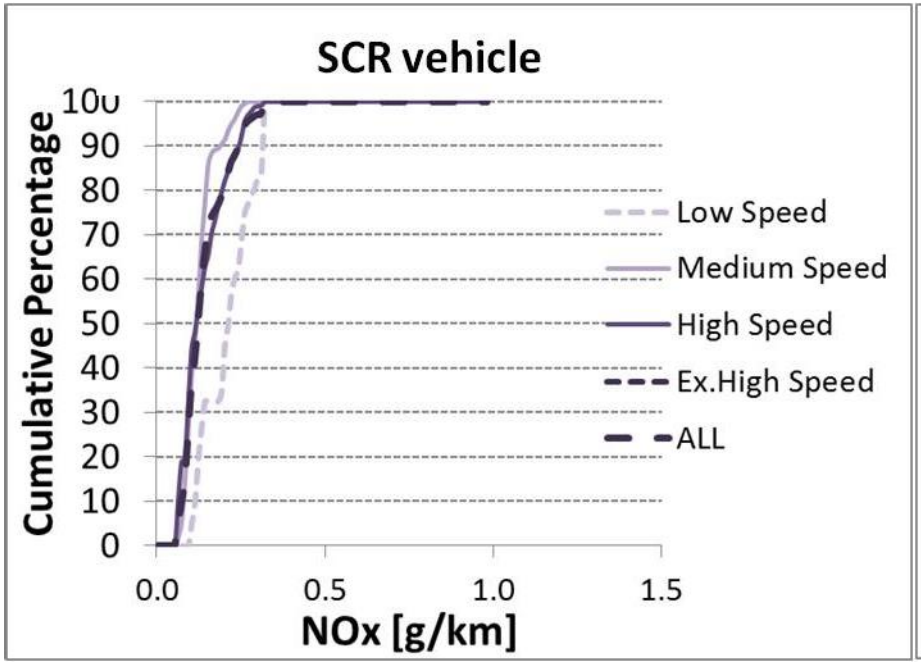


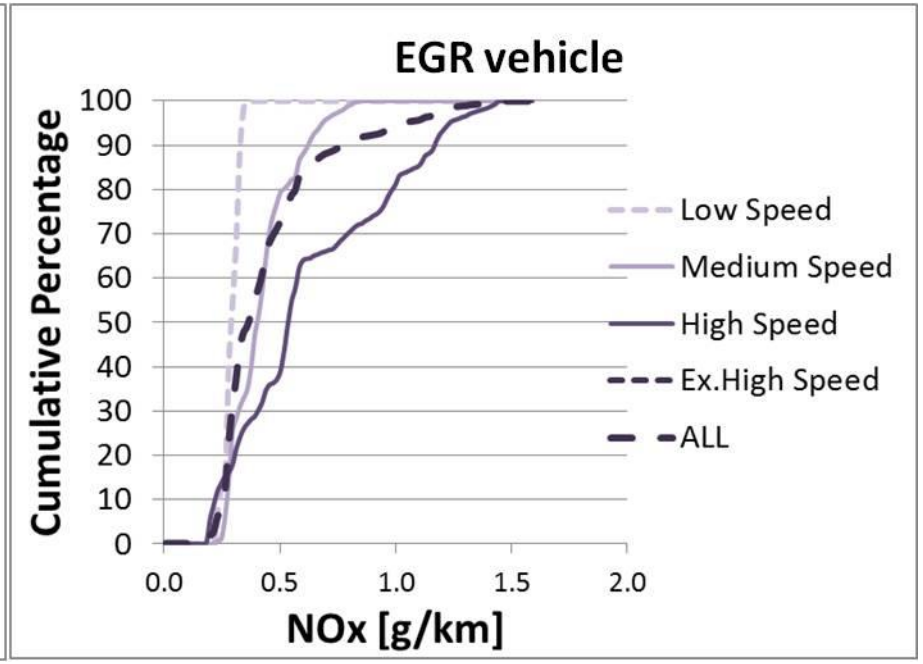
PEMS Data Analysis

- At the time of this work available tools were:
  - EMROAD version 5.6 Build 2 (from DG-JRC) and
  - CLEAR version 1.1 (from TU Graz)
- Both have since been updated.
  - EMROAD v.5.8 now adjusts for the additional PEMS mass and includes weighted windows within the ‘soft’ and ‘severe’ bands.
  - CLEAR has also been updated but not yet released at the time of writing.

EMROAD

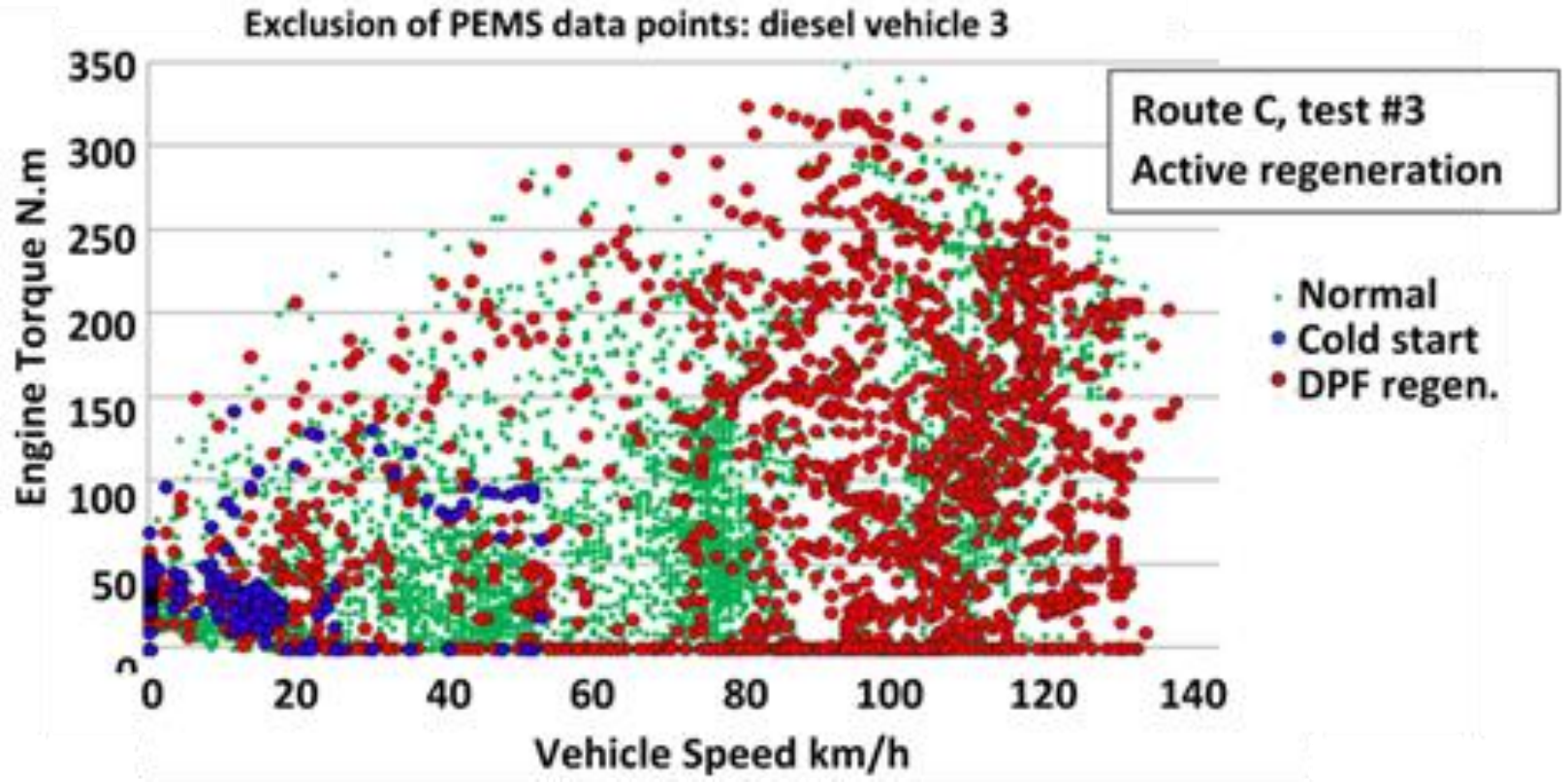
- EMROAD output includes cumulative percentage of ‘normal’ band windows.
- The NOx windows highlight the importance of higher speeds for assessing real-life NOx.





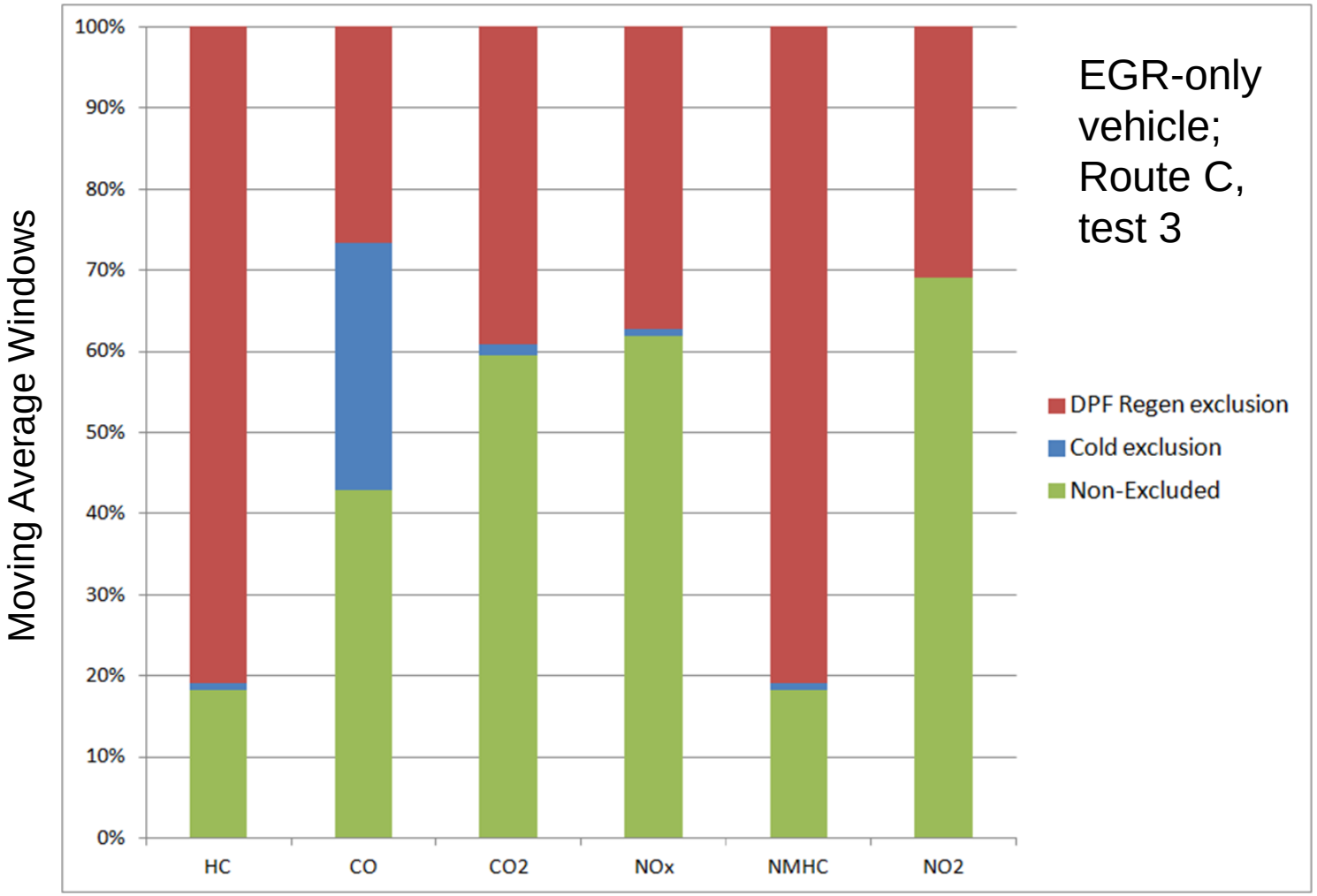
EMROAD

- Exclusion of cold-start and DPF-regenerations data is under discussion but can cover a significant number of data points.



Cold-start exclusion criterion: Coolant temperature < 70°C. DPF regen exclusion criterion: temperature rise with post-injection and subsequent return to 'normal' temperature (identified from INCA logs).

Effect of Exclusions



Percentage of Moving Average Windows excluded by cold-start and DPF regen exclusions.

EMROAD Analysis Output

SCR vehicle (Diesel 2)

DISTANCE SPECIFIC MASS EMISSIONS:		COMPLETE TRIP	COLD EXCLUDED	COLD + DPF EXCLUDED
HC	g/km	0.00	0.00	0.00
CO	g/km	0.04	0.03	0.02
CO2	g/km	160.37	159.13	159.54
NOx	g/km	0.35	0.34	0.32

- NOx emissions some 4.4 times higher than the TA limit.

EGR vehicle (Diesel 3)

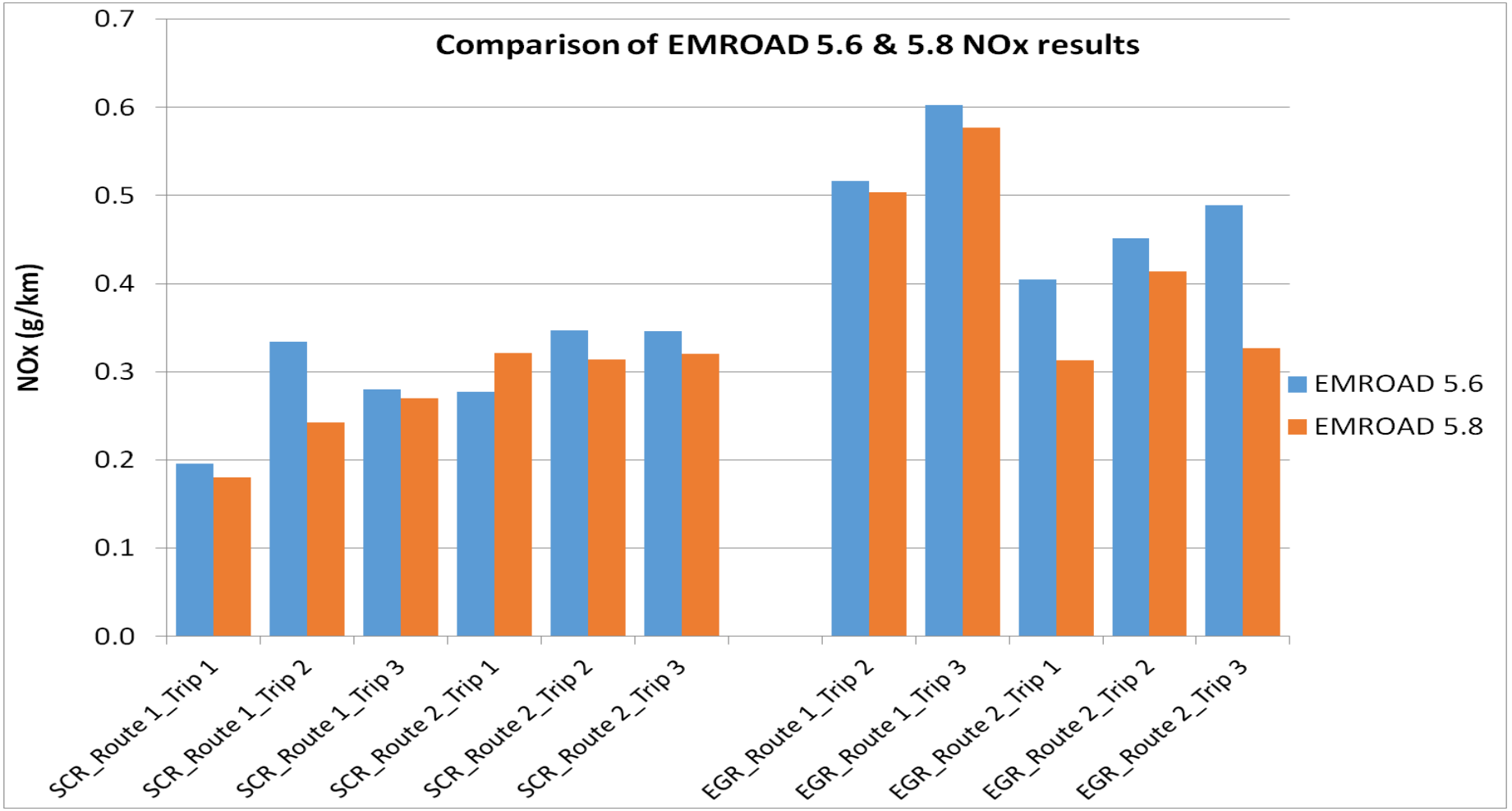
DISTANCE SPECIFIC MASS EMISSIONS:		COMPLETE TRIP	COLD EXCLUDED	COLD + DPF EXCLUDED
HC	g/km	0.007	0.007	0.002
CO	g/km	0.044	0.031	0.028
CO2	g/km	161.53	160.09	146.13
NOx	g/km	0.603	0.600	0.567

- NOx emissions some 7.5 times higher than the TA limit.

Analysis Updates

- The following slides show a comparison of results from the original and latest versions of the EMROAD and CLEAR evaluations.

EMROAD Revision



Diesel vehicle 2 **Diesel vehicle 3**

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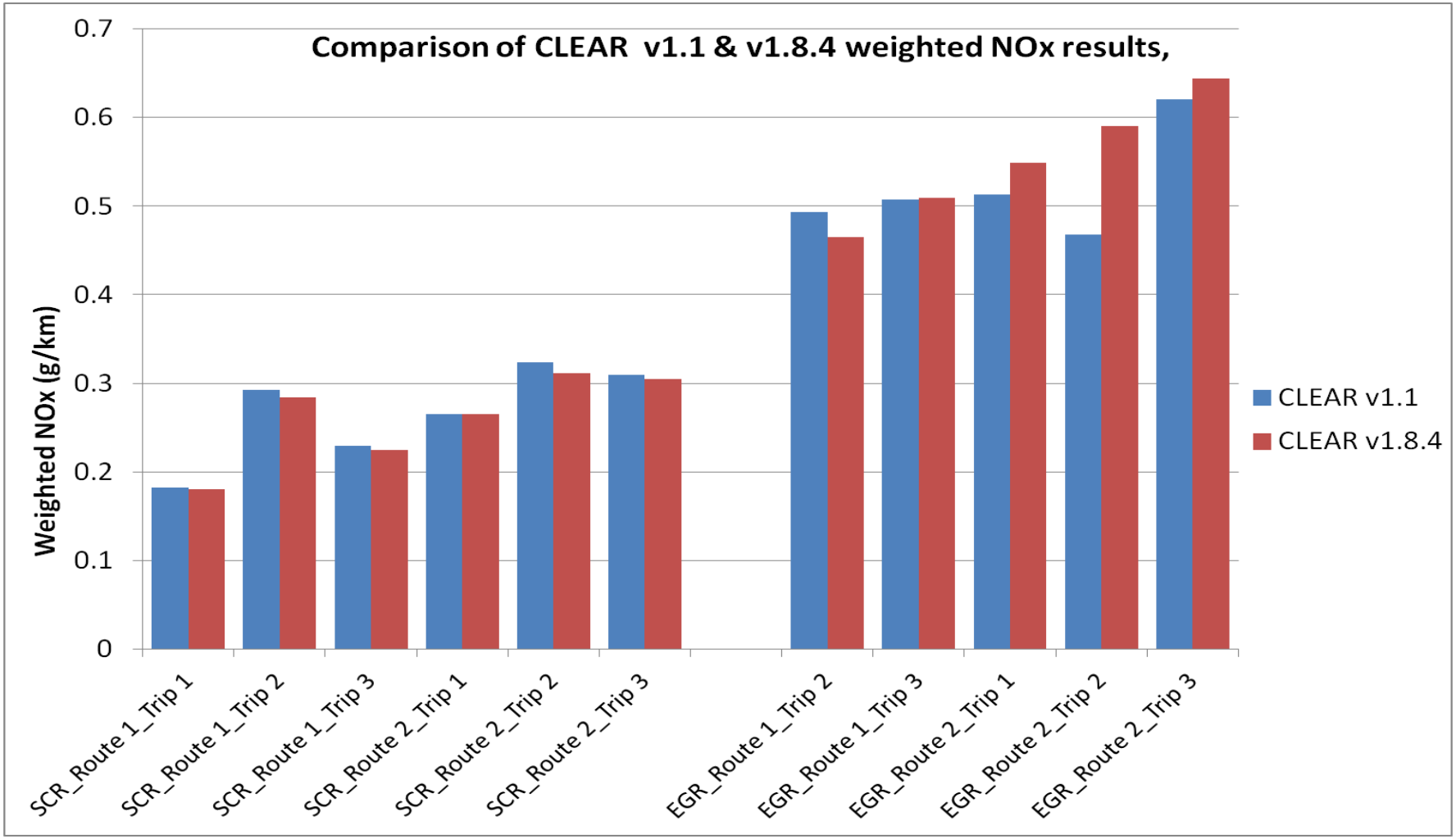
CLEAR Revision



Diesel vehicle 2 **Diesel vehicle 3**

CLEAR analyses kindly provided by TU Graz.

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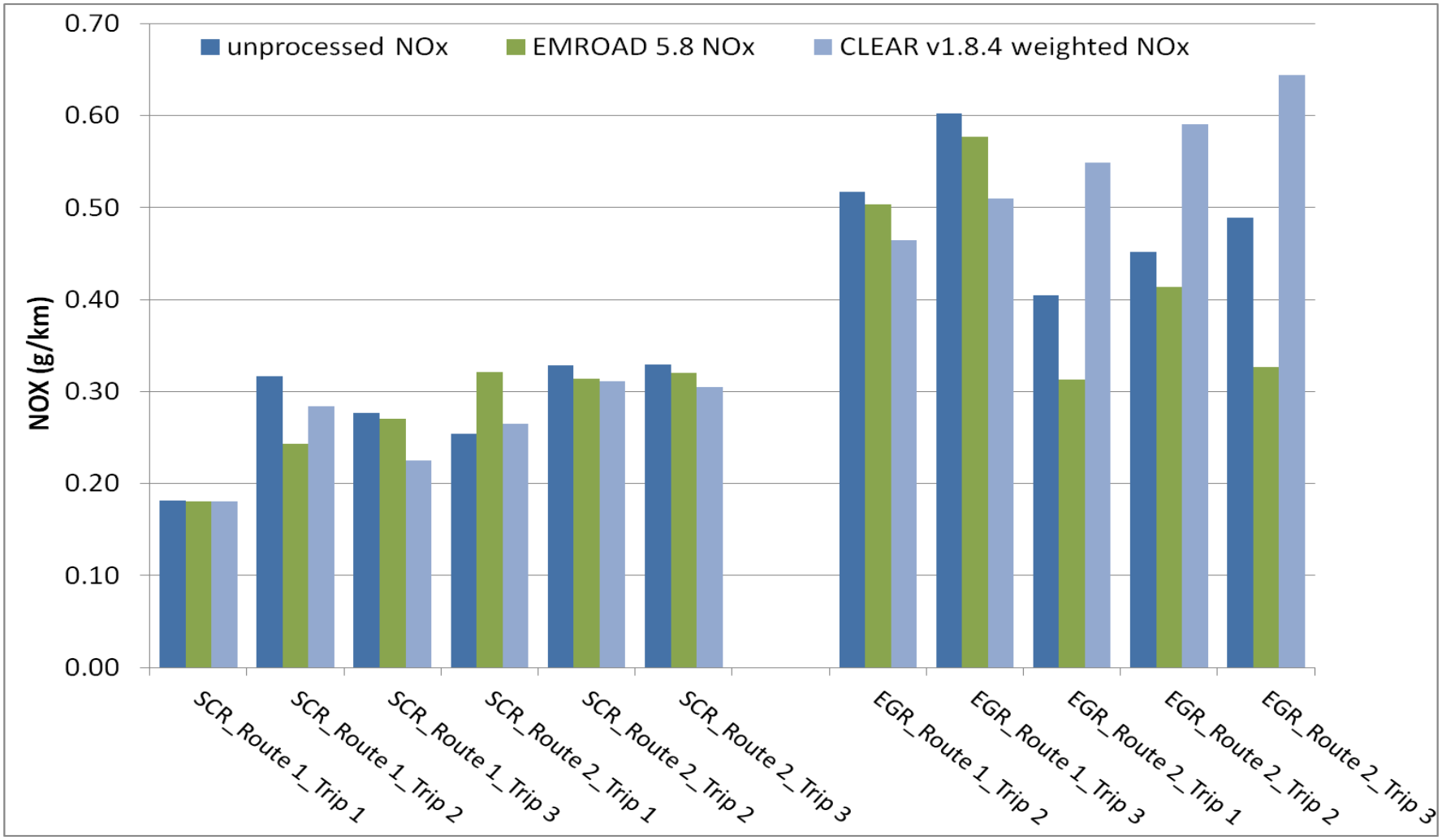
Comparison of Evaluations



Diesel vehicle 2 **Diesel vehicle 3**

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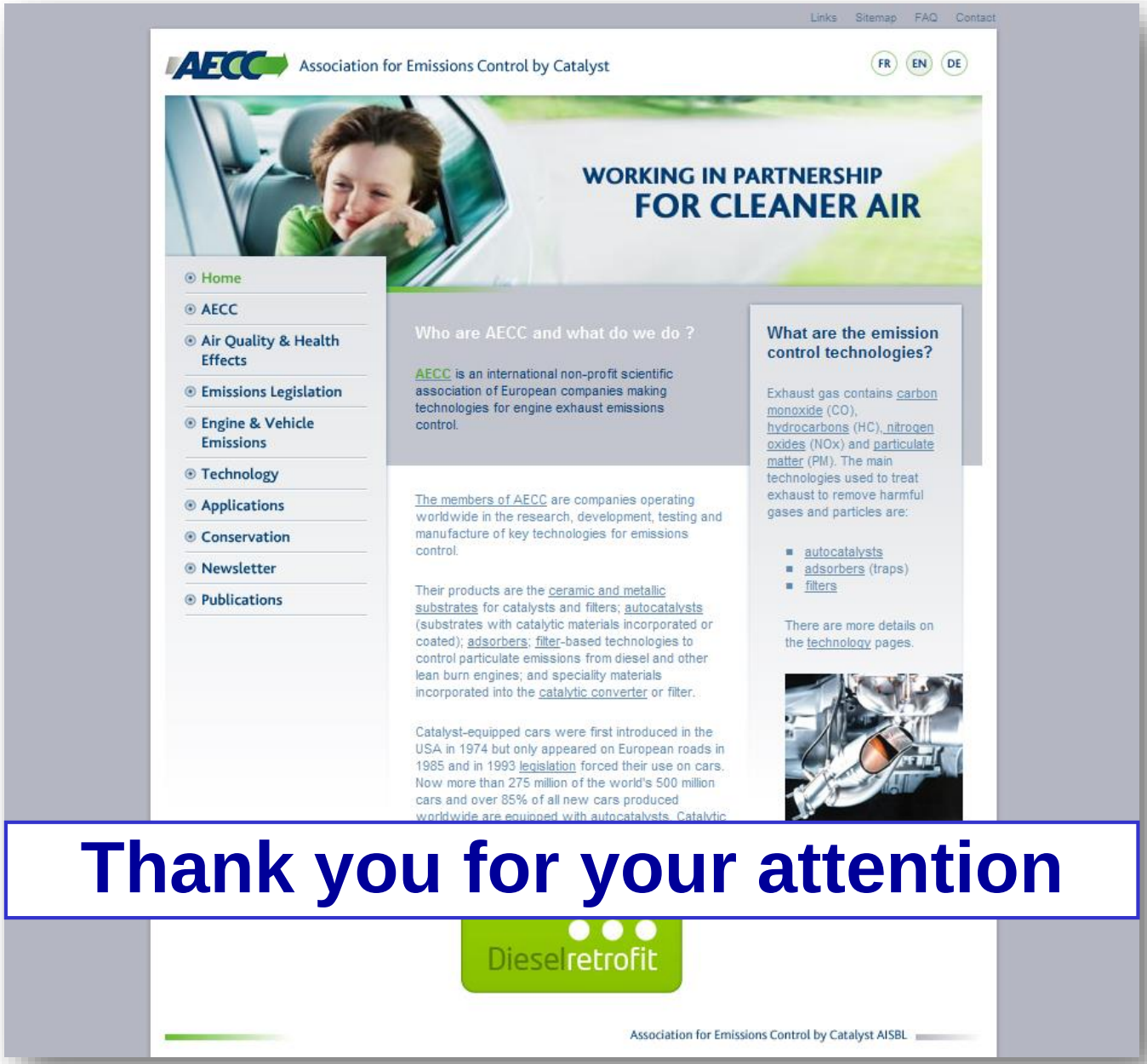
Conclusions

- Tests of four modern vehicles (1 gasoline, 3 diesels) showed that in real driving some emissions can be significantly different from Type Approval limits and values.
- For Gasoline Direct Injection vehicles, the tests suggested that engine measures may offer the potential to meet future the particle number limit on Type Approval cycles, but may not offer the same control under all driving conditions.
- The diesel vehicles tested exceeded the Euro 6 NOx limits in real-world driving by factors of 2.3 to 7.5 times.
- Meeting the expected RDE requirements will need more comprehensive calibration and system strategies, rather than new technologies.
- The two proposed data evaluation methods can give significantly different results. A single method is preferred.



Thank you for your attention