Emissions from Euro 3 to Euro 6 light-duty vehicles equipped with a range of emissions control technologies

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Association for Emissions Control by Catalyst (AECC) AISBL

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Technology for exhaust emissions control for cars, buses and commercial vehicles, and an increasing number of non-road mobile machinery applications and motorcycles.

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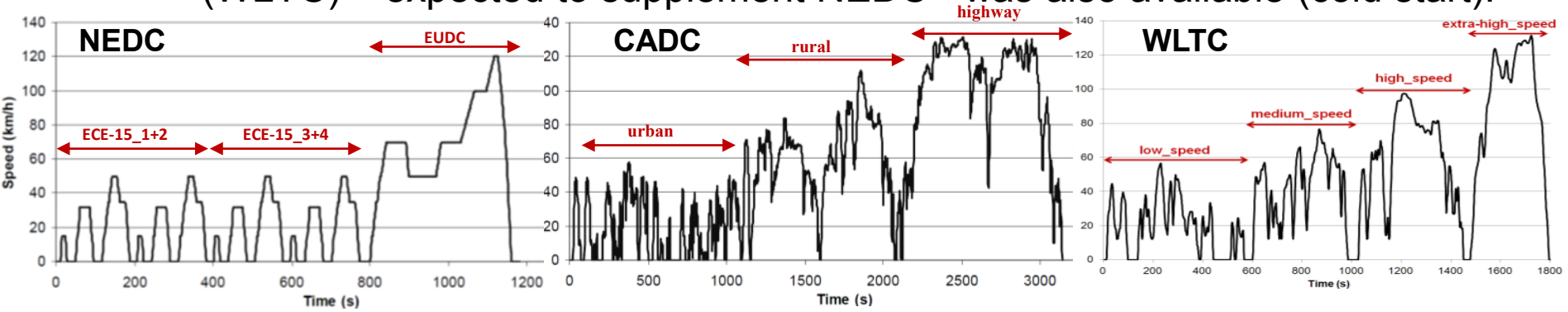
Background

- EU emissions limits have been reduced in regular steps since the introduction of ‘Euro1’ in 1992.
- AECC conducted a series of tests at an independent laboratory to assess the emissions of a range of light-duty vehicles built from 1999 onwards, meeting the Euro 3 to Euro 6 emissions standards.
- Vehicles were tested over:
  - the current cold-start Type Approval cycle (NEDC), which is now considered to be insufficiently representative of real driving conditions;
  - the hot-start Artemis cycle (CADC) that is used for development of emissions factors for modelling by the EU and Member States;
  - for the final 2 vehicles, the new UN Worldwide Light-duty Test Cycle (WLTC) – expected to supplement NEDC - was also available (cold start).



Test vehicles

The test vehicles covered a broad range of technologies:

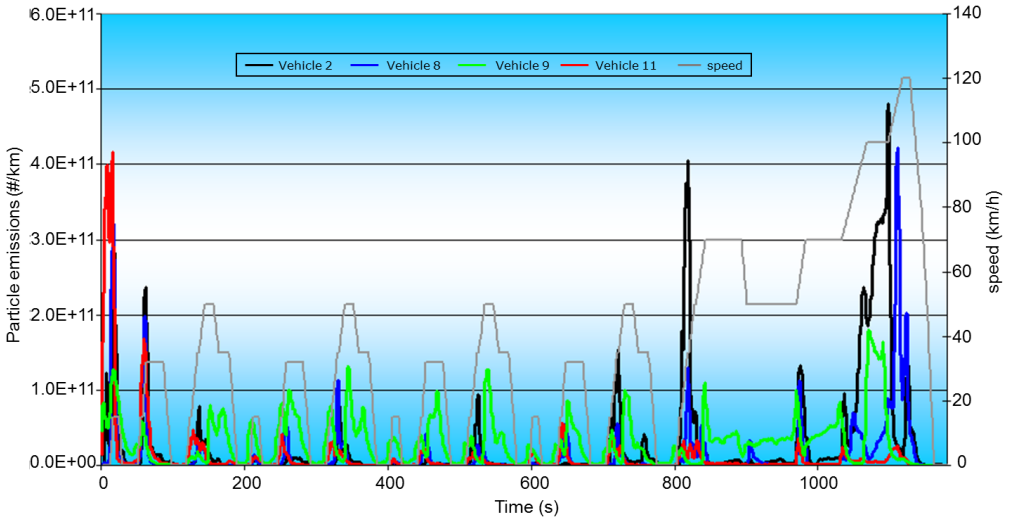
	Euro 3	Euro 4	Euro 5	Euro 6
Petrol - port fuel Injection	1	1		At the time of testing petrol vehicles could not be approved to Euro 6
Petrol – lean direct injection		1	1	
Petrol – stoichiometric direct injection		1 (Euro 4/5)	2	
Petrol – stoichiometric combining direct injection & port fuel injection			1 (Euro 5b)	
Diesel without particulate filter	1	1		
Diesel with particulate filter		4		
Diesel with particulate filter & de-NOx system		1		3 candidate Euro 6a systems 1 Euro 6b

Engine sizes ranged from 1.2 to 3.5 litres; power from 63 to 180 kW

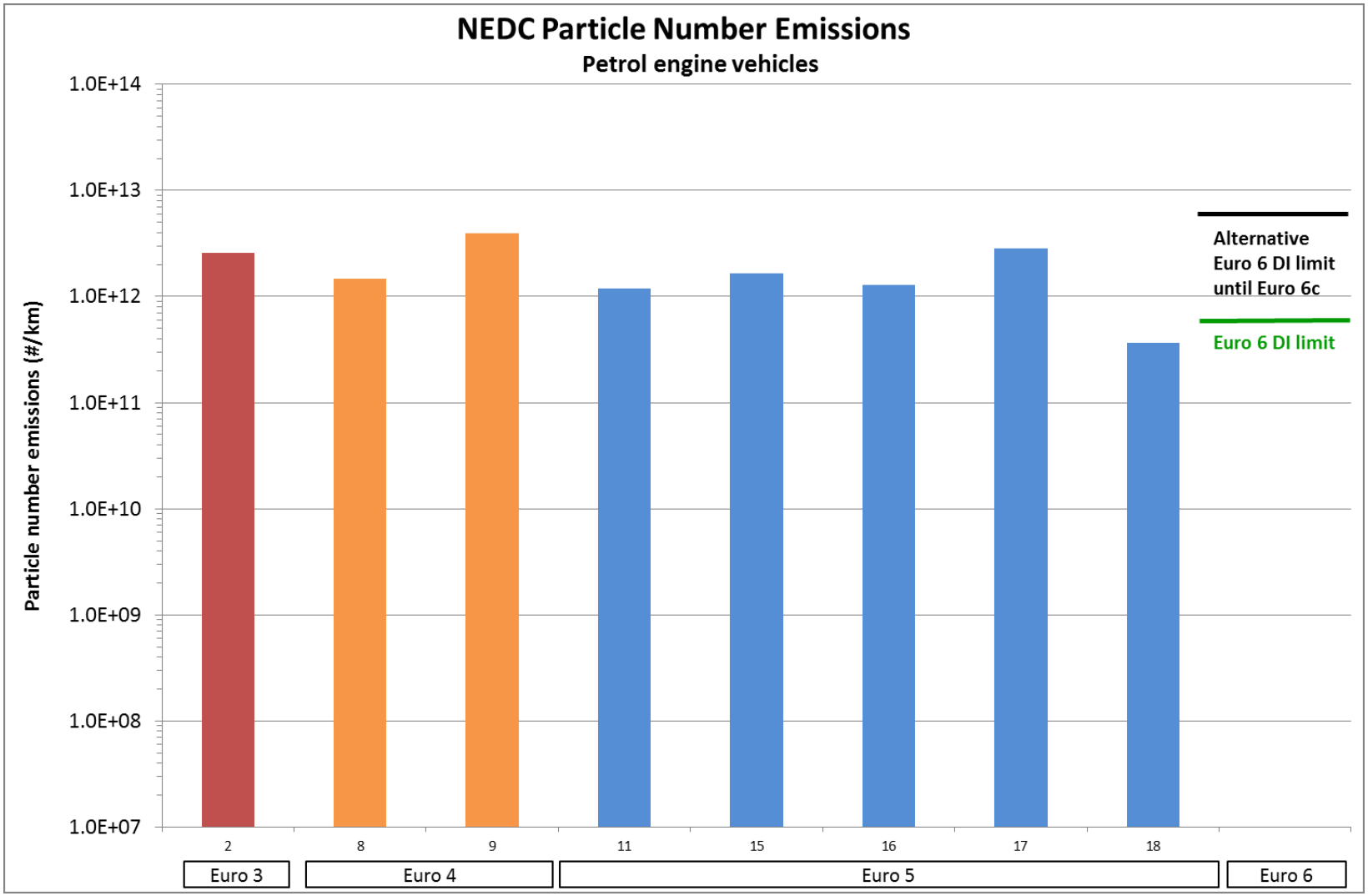
Petrol vehicles

NEDC emissions

- All petrol engined vehicles readily met even the current (Euro 5/6) limits of 1000 mg/km CO, 100 mg/km HC and 60 mg/km NOx.
- For NOx, all results were between 15 and 40 mg/km, with no definitive trend from Euro 3 to Euro 5 (Euro 5/6 limit is 60mg/km).
- Particulate mass was not limited for petrol vehicles until Euro 5. Nevertheless, all vehicles met the Euro 5 limit.
- Particle numbers are limited from the Euro 6 stage, only for GDIs. All vehicles would meet the 'Euro 6b' limit (6×10^{12} particles/km) The most recent vehicle (PFI/GDI) met the Euro 6c limit (6×10^{11}/km).
- Both PFI cars (No.2 & No.8) gave higher than expected PN results, largely from particles emitted during the extra-urban part of the test cycle.



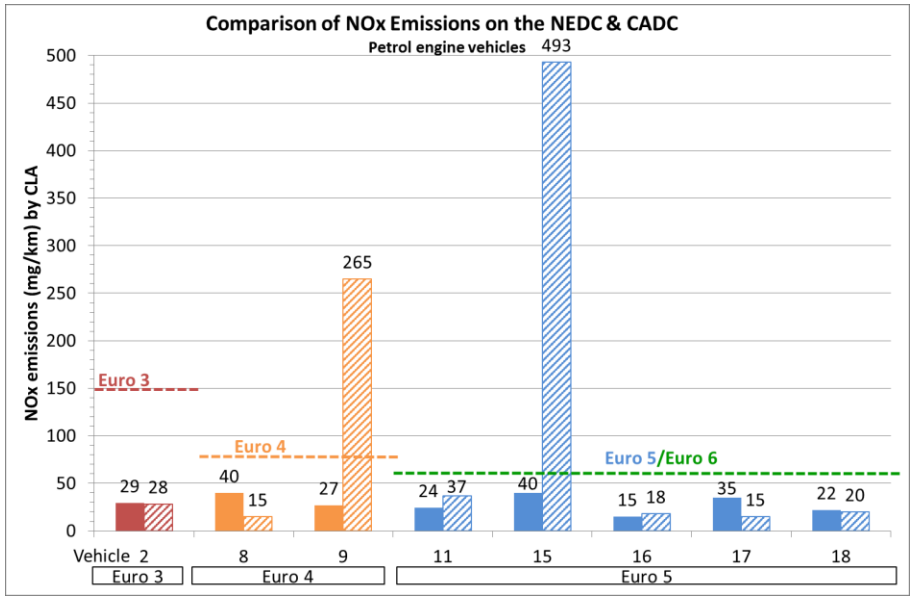
NEDC particle number emissions



CADC emissions

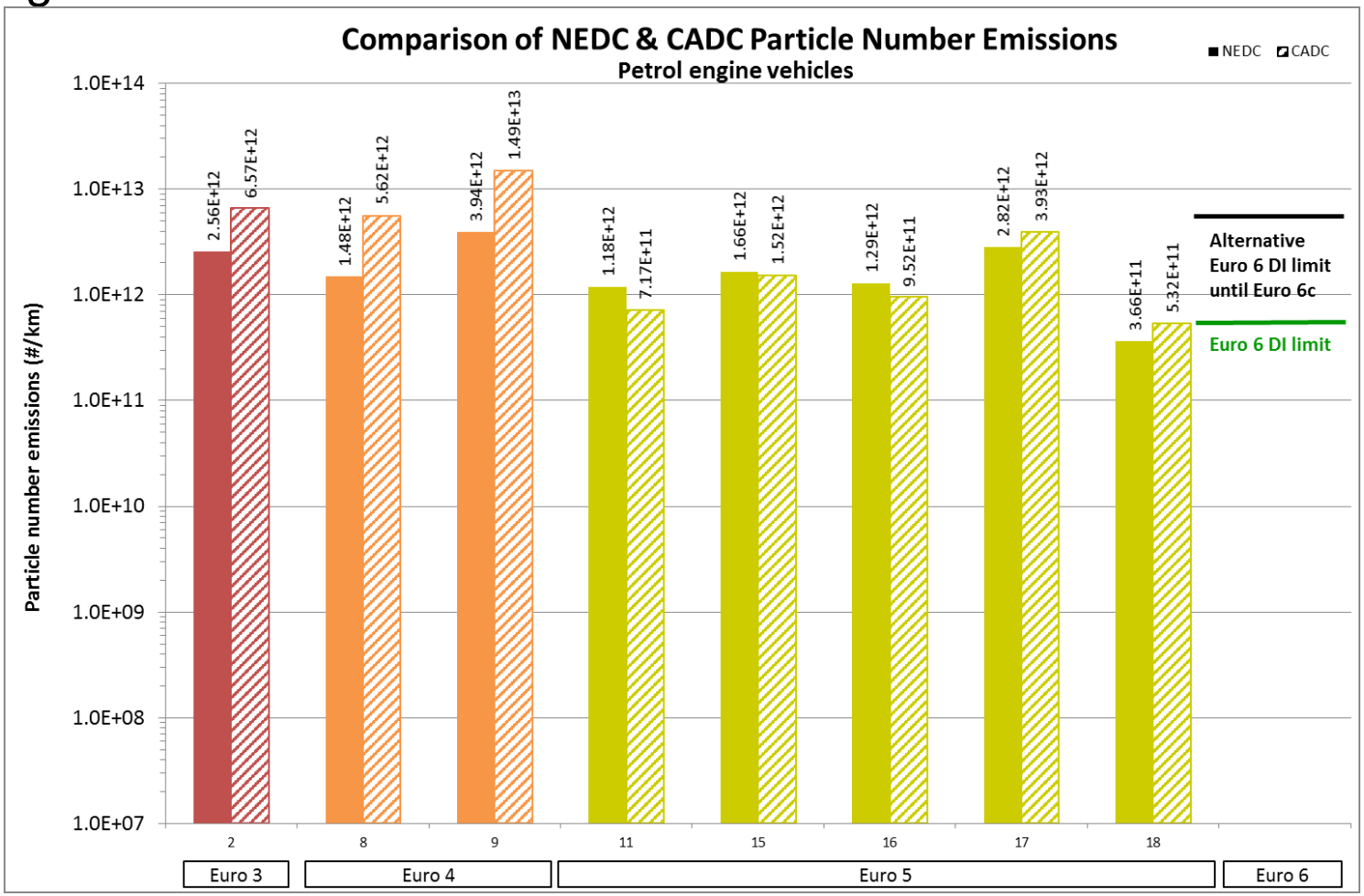
- CO and HC emissions for most petrol vehicles were lower than on the NEDC and well within the Type Approval (NEDC-based) limits.
- A low-powered stoichiometric DI petrol vehicle (No.17) gave a significantly higher CO result on the Artemis tests than on the NEDC (2613 mg/km over the full Artemis cycle, 81 mg/km on NEDC).

  This was due to very high, repeatable, emissions over the highway part of that cycle (4294 to 4854 mg/km), where comparatively high speeds are maintained for much of the test phase, which must have required higher engine torque.
- The two lean DI vehicles (No. 9 & No. 15) gave significantly higher NOx over the Artemis tests. These results also related to high emissions over the Highway portion of the test.



CADC & NEDC particle number emissions

- Particle number emissions were, in general, of the same order of magnitude over the CADC tests as over the NEDC.



WLTC test

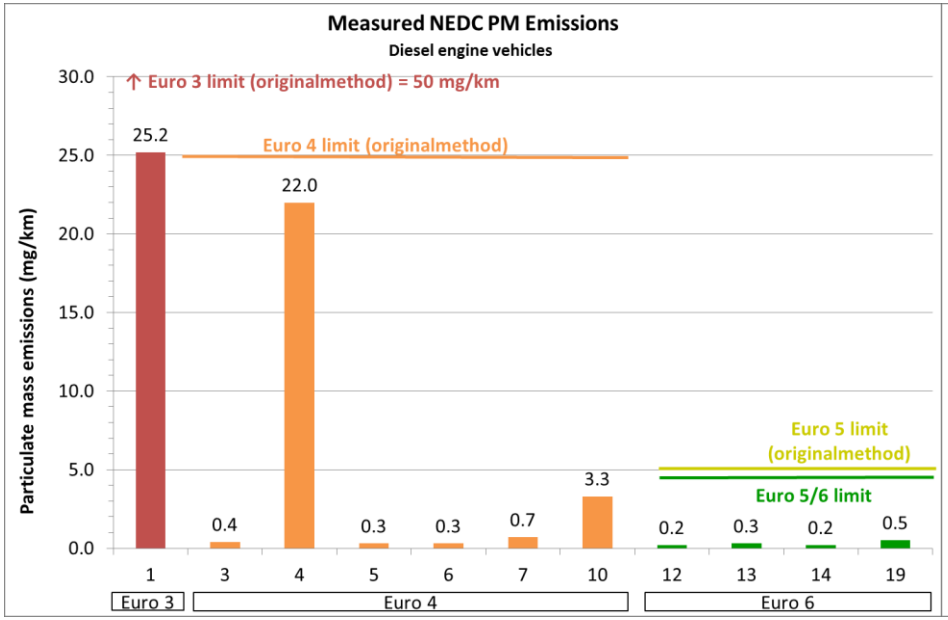
- The World-harmonised Light vehicle Test Procedure introduces both the new cycle (WLTC) and revised procedures. These include higher inertia weights for testing.
- Vehicle 18 was tested using the higher inertia weight for all tests, but with a single NEDC test at the 'normal' (NEDC) inertia weight to provide a comparison.
- The higher inertia resulted in slightly higher pollutant emissions (except PN) and significantly higher CO_2.
- The new WLTC test gave lower CO and HC emissions than the current NEDC test, somewhat higher NOx and PM (but still within current limits) and higher PN (within Euro 6b but not 6c).

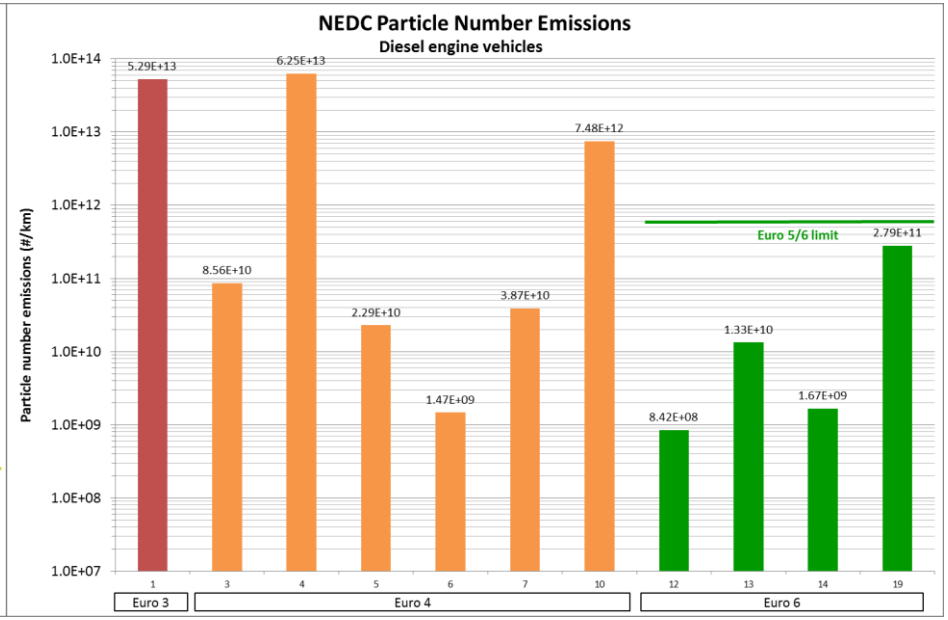
Cycle	Inertia	Number of tests	CO	HC	NOx	PM	PN	CO_2
	kg		mg/km				#/km	g/km
NEDC	1590	1	84	24	22	0.27	5.7×10^{11}	131.3
NEDC	1930	3	86	29	24	0.34	3.7×10^{11}	146.8
CADC	1930	3	108	7	20	0.45	5.3×10^{11}	156.8
WLTC	1930	3	55	19	33	0.48	7.4×10^{11}	145.2

Diesel vehicles

NEDC emissions

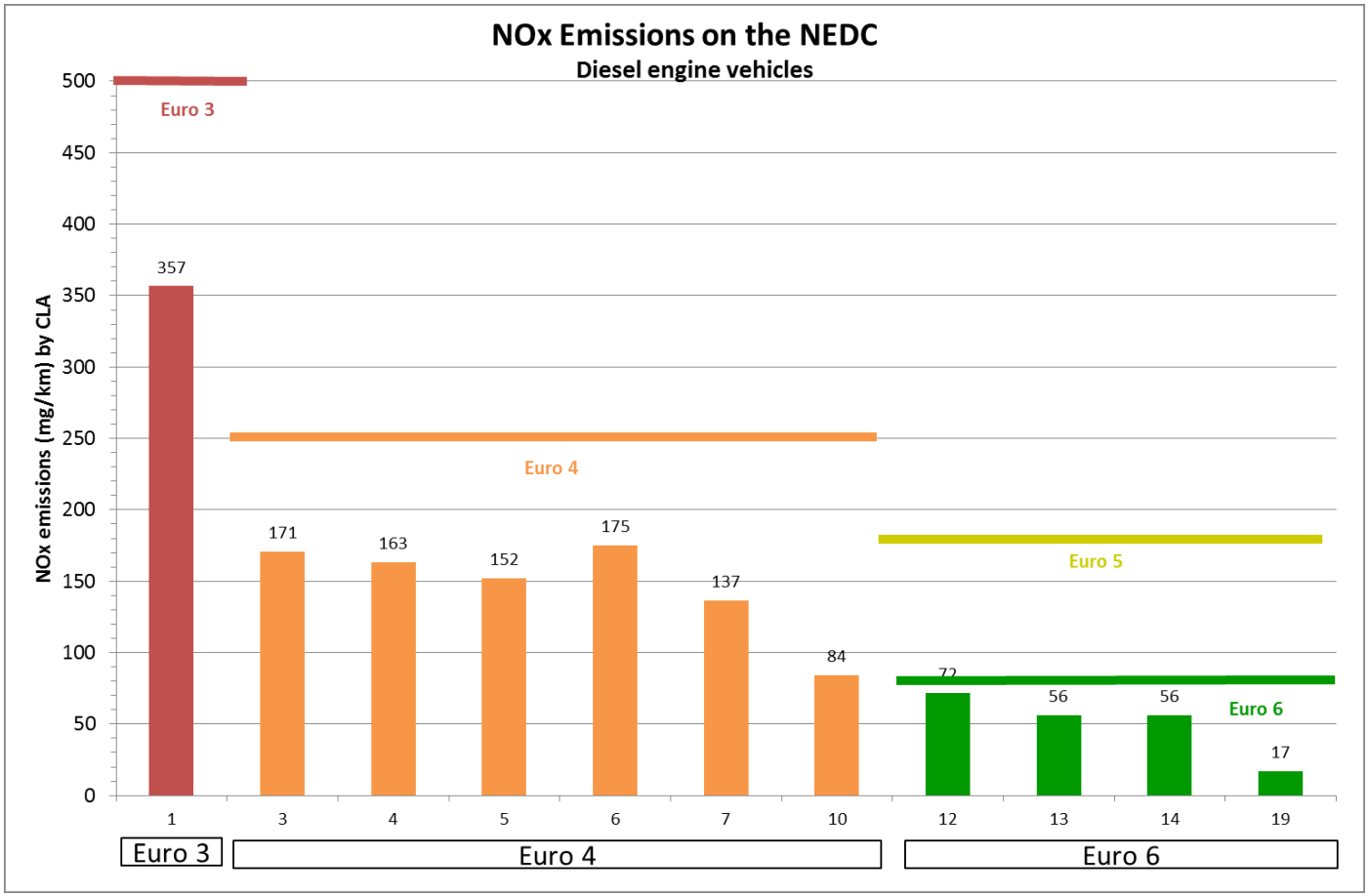
- All vehicles met even the Euro 5/6 limit for CO.
- All gave low HC emissions, with 68 mg/km being the highest result.
- For PM & PN, there was clear differentiation between vehicles that had DPFs (mostly <1mg/km) and those that did not (22 & 25 mg/km).
- One vehicle (No. 10) with DPF had higher PM and PN emissions. This was an early example of a system with both a DPF and de-NOx system and was approved only to Euro 4, when there was no PN limit.





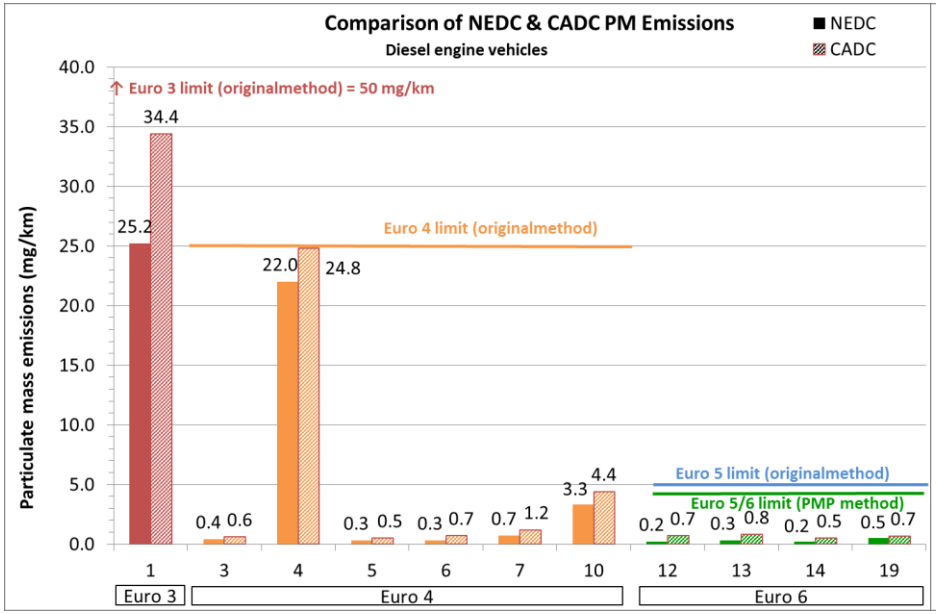
NEDC NOx emissions

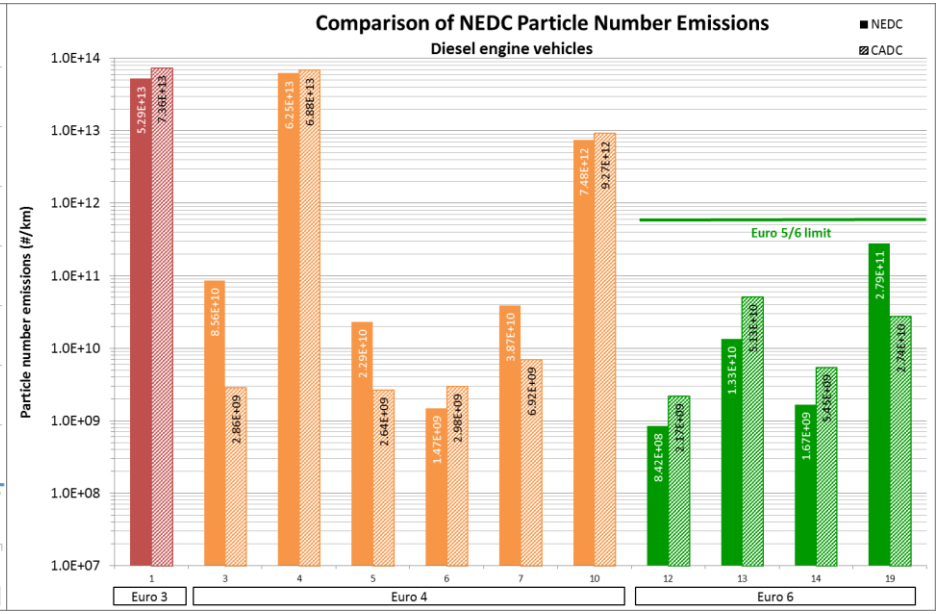
- All vehicles met their respective NOx limits, with a clear downward trend from Euro 3 to Euro 6.



CADC emissions

- As with the petrol vehicles CO and HC emissions were generally lower over the CADC tests than on the NEDC, most likely due to the hot-start nature of the test.
- PM and PN results primarily differentiated between vehicles with and without DPFs, with Euro 4 vehicle 10 remaining an outlier.
- All Euro 6 vehicles met the Euro 5/6 PM & PN limits on both cycles.

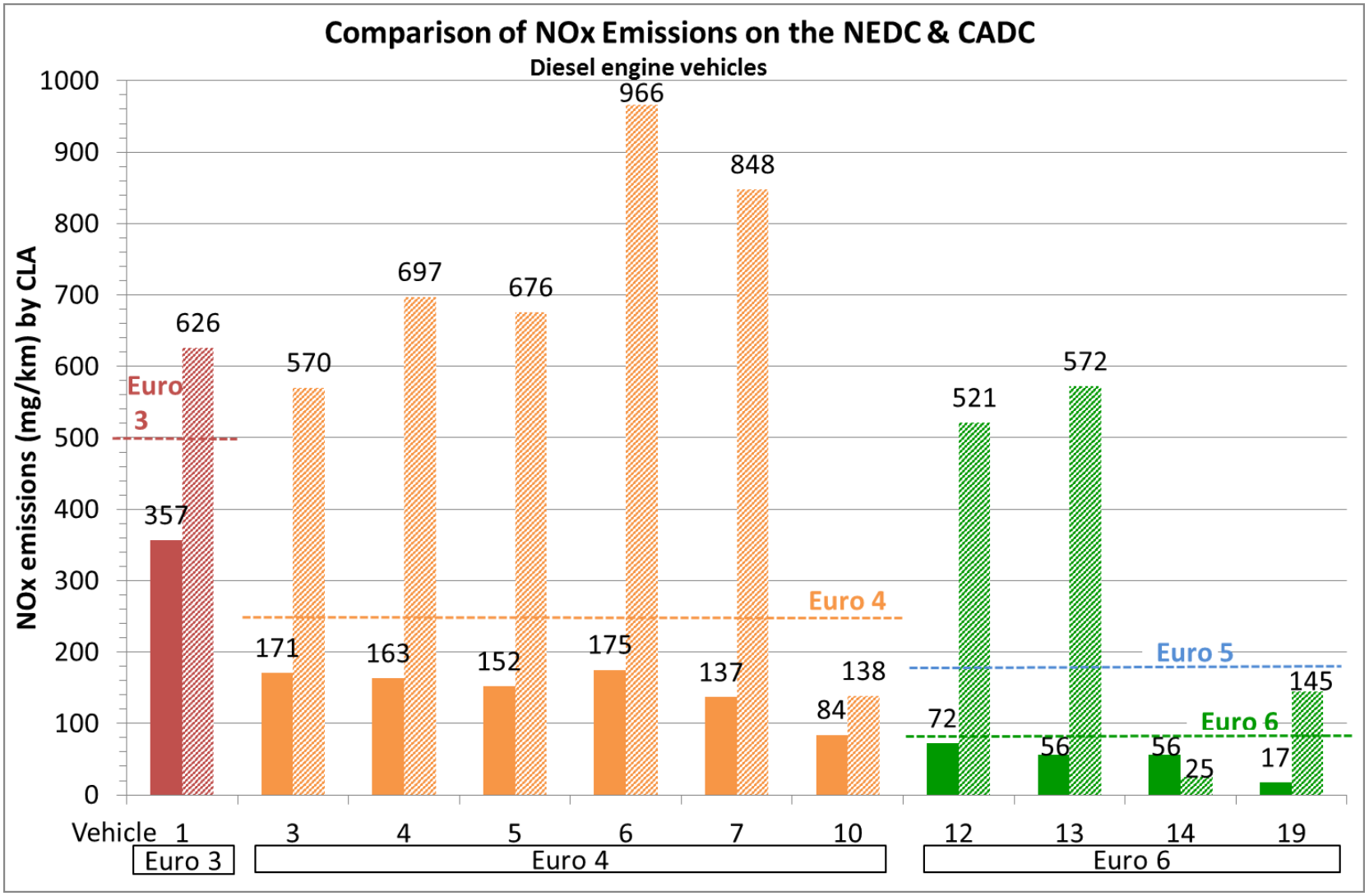




CADC & NEDC NOx emissions

- For almost all vehicles, the CADC NOx results were substantially higher than those on the NEDC.
- Only 1 vehicle showed lower NOx emissions on the CADC than the NEDC. This candidate Euro 6a system (vehicle No. 14) met the Euro 6 limit over both cycles, demonstrating the feasibility of a calibration that produces low NOx over a wider range of conditions.
- The Euro 4 vehicle with an early DPF+deNOx system met the Euro 5 NOx limit of 180 mg/km NOx over both test cycles, but not the Euro 6 limit of 80 mg/km NOx.
- All other vehicles produced NOx emissions over the CADC that were 1.7 to 10.2 times higher than the NEDC NOx emissions.
- It must be recognised that none of these vehicles would have been calibrated for the CADC.
- Nevertheless, the results highlight the importance of the European Commission's initiative for a 'Real Driving Emissions' (RDE) test.

CADC and NEDC NOx emissions



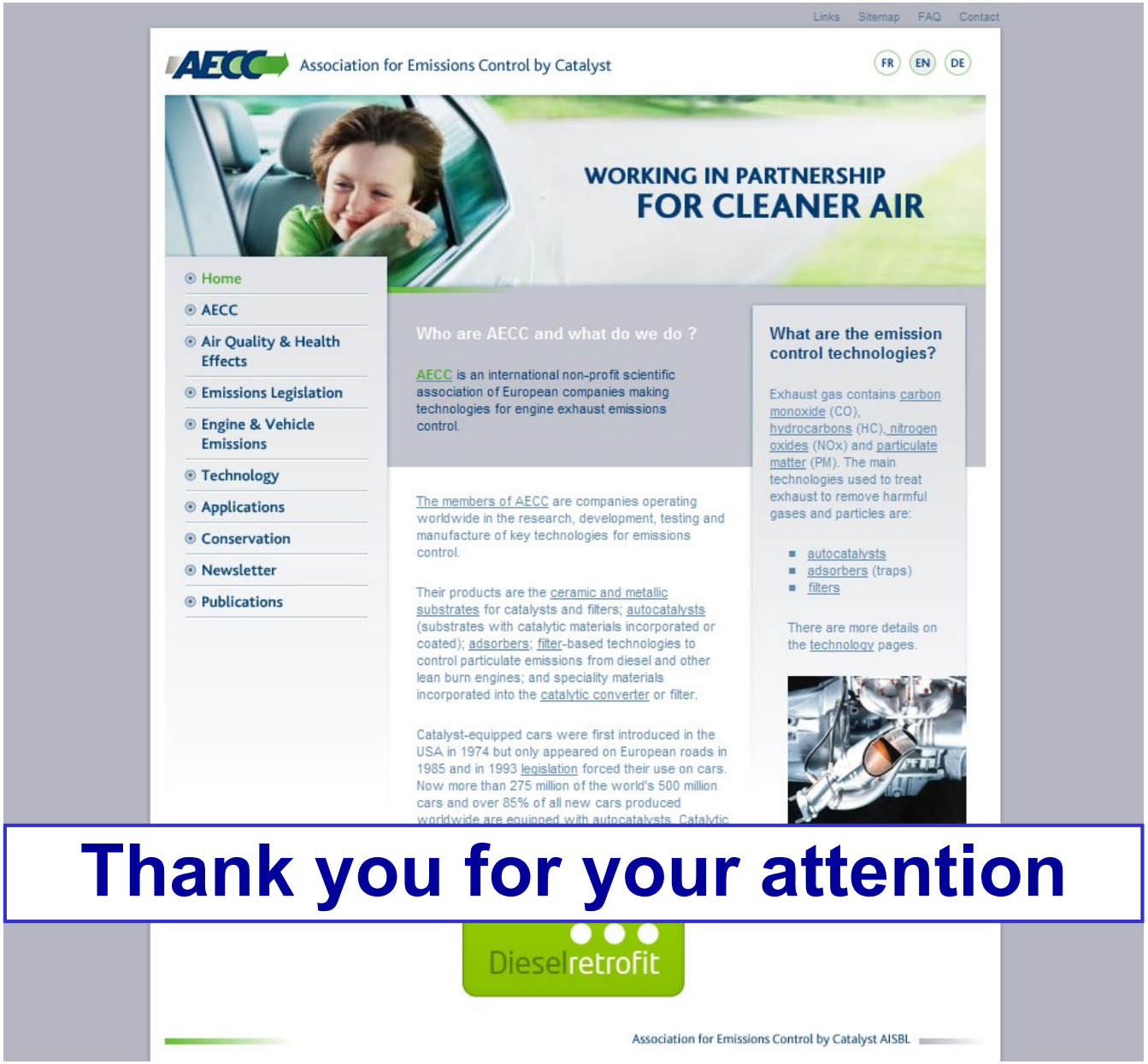
WLTC tests

- For vehicle 19, NEDC and CADC tests were run at the normal inertia weight, WLTC tests used the higher (WLTP) inertia. A single CADC was run at higher inertia to provide a comparison point.
- Gaseous and PM emissions (including CO_2) were generally higher at the higher inertia.
- PN at the higher inertia was lower than the average of 3 tests for the lower inertia, but within the range (2.7×10^{9} to 7.2×10^{10} particles/km).
- As for the petrol vehicle, the CO and HC results were lower on the new WLTC than on the current NEDC.
- NOx was higher on the WLTP – marginally above the current test limit.
- PM and PN emissions met the Euro 5/6 limits on all cycles.

Cycle	Inertia	Number of tests	CO	HC	NOx	PM	PN	CO_2
	kg		mg/km				#/km	g/km
NEDC	2150	3	116	34	17	0.51	2.8×10^{11}	222.5
CADC	2150	3	112	45	145	0.68	2.7×10^{10}	213.2
CADC	2460	1	139	44	269	0.98	8.3×10^{9}	232.4
WLTC	2460	3	65	21	83	0.47	5.1×10^{11}	227.1

Summary & Conclusions

- A range of Euro 3 to Euro 6 cars, including both petrol and diesel vehicles and using a variety of technologies were tested over the current Type Approval cycle and other more transient cycles.
- The WLTP tests suggest that the effect of higher (WLTP) inertia is significant, but also indicate that there may not be a major difference between most results on this cycle and those resulting from the current NEDC procedures.
- The CADC appears to provide a wider and more demanding set of conditions than the new WLTC.
- The results show the effectiveness of 3-way catalysts and modern air-fuel ratio control for petrol-engined vehicles over a wide range of driving conditions.
- The most recent petrol vehicle would meet the Euro 6c particle number limits on the NEDC and CADC but not the WLTC.
- For the diesel vehicles, particle filters continued to give good particulate control over the higher transients and speeds likely to be encountered in real driving.
- The results indicate that further work is likely to be needed, especially on diesel NOx, to ensure that vehicles can meet the forthcoming requirements on ‘Real Driving Emissions’ (RDE). Nevertheless, vehicles 14 & 19 indicate that good diesel NOx and particulate control is achievable over a range of test conditions.



Thank you for your attention

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