AECC Clean Diesel Euro 6
Real Driving Emissions Project

AECC Technical Seminar
on Real-Driving Emissions

Brussels, 29 April 2015

Association for Emissions Control by Catalyst AISBL

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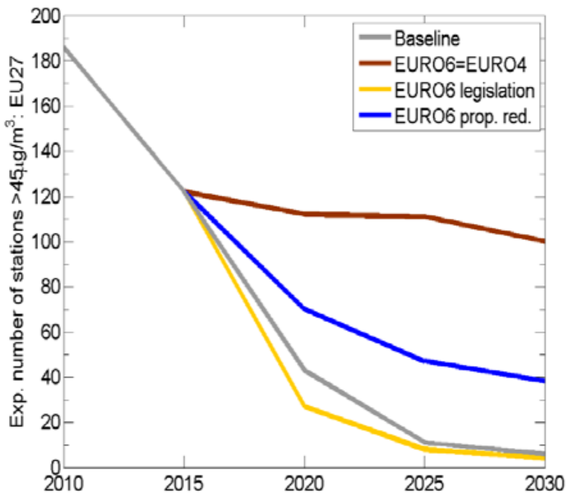
The role of AECC

- The purpose of AECC is to demonstrate the potential of emissions control technologies, upon the request of the regulators.

Diesel NOx and air quality

- The 2007 emissions Regulation (EC 715/2007) requires emissions to be effectively limited throughout the normal life of the vehicles under normal conditions of use.
  - Control of Diesel NOx in real-world driving conditions is an essential step towards EU Member States meeting air quality targets.
- Emissions inventory and projections by DG Environment for different NOx Conformity Factors:
  - Baseline CF=1.5
  - Euro 6 does not reduce real-world NO_2 further compared with Euro 4 (CF~10)
  - Euro 6 NOx RDE reduce proportionally (CF=4)
  - CF=1, Euro 6 limits met in real-world
  - With a CF~4, NO_2 non-compliance in 2020 is 3 times higher than in the baseline (CF=1.5) scenario ("stations substantially above the NO_2 limit would increase from 3 to 10%").

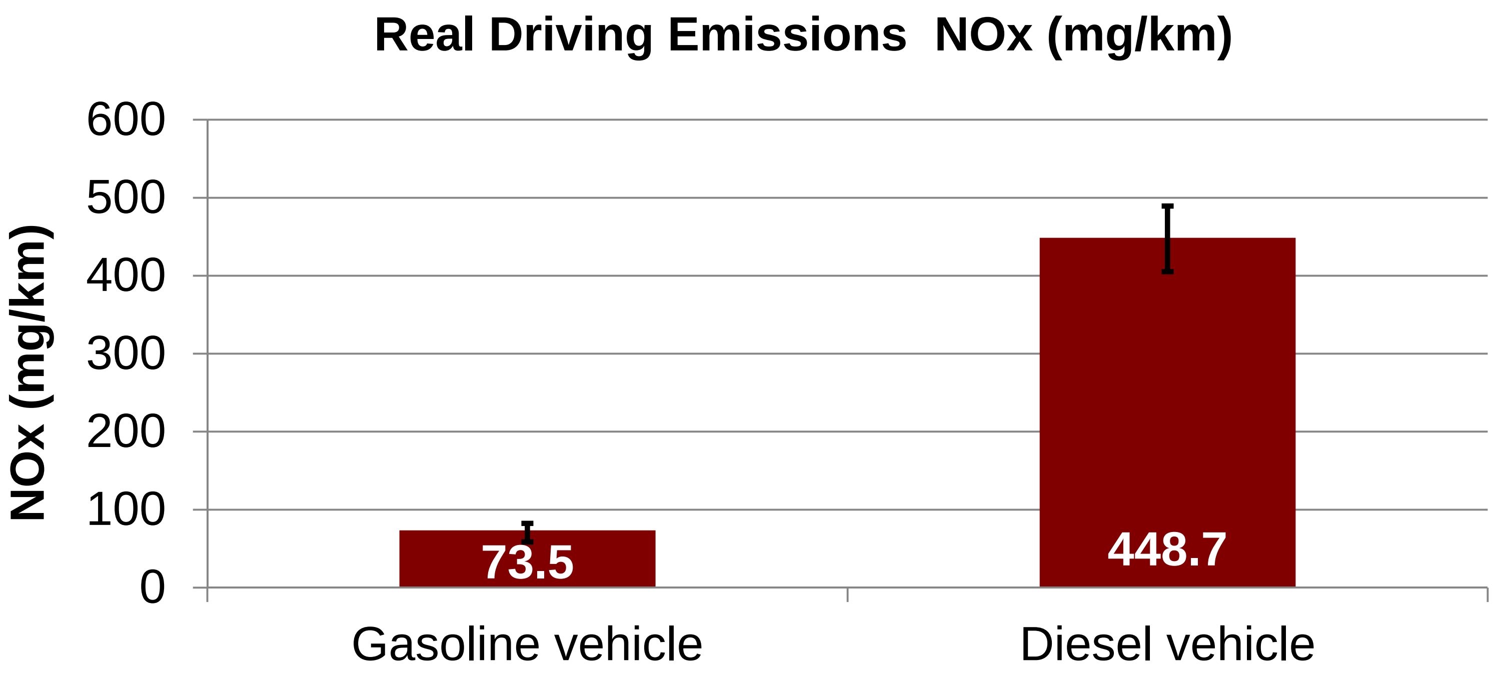
Figure 8: Baseline projected compliance with NO2 standards in case Euro 6 would not correct the real world emission problems



Source: European Commission Staff Working Document – Impact Assessment accompanying the Clean Air Package, SWD(2013)531, 18 December 2013.

Urban air quality

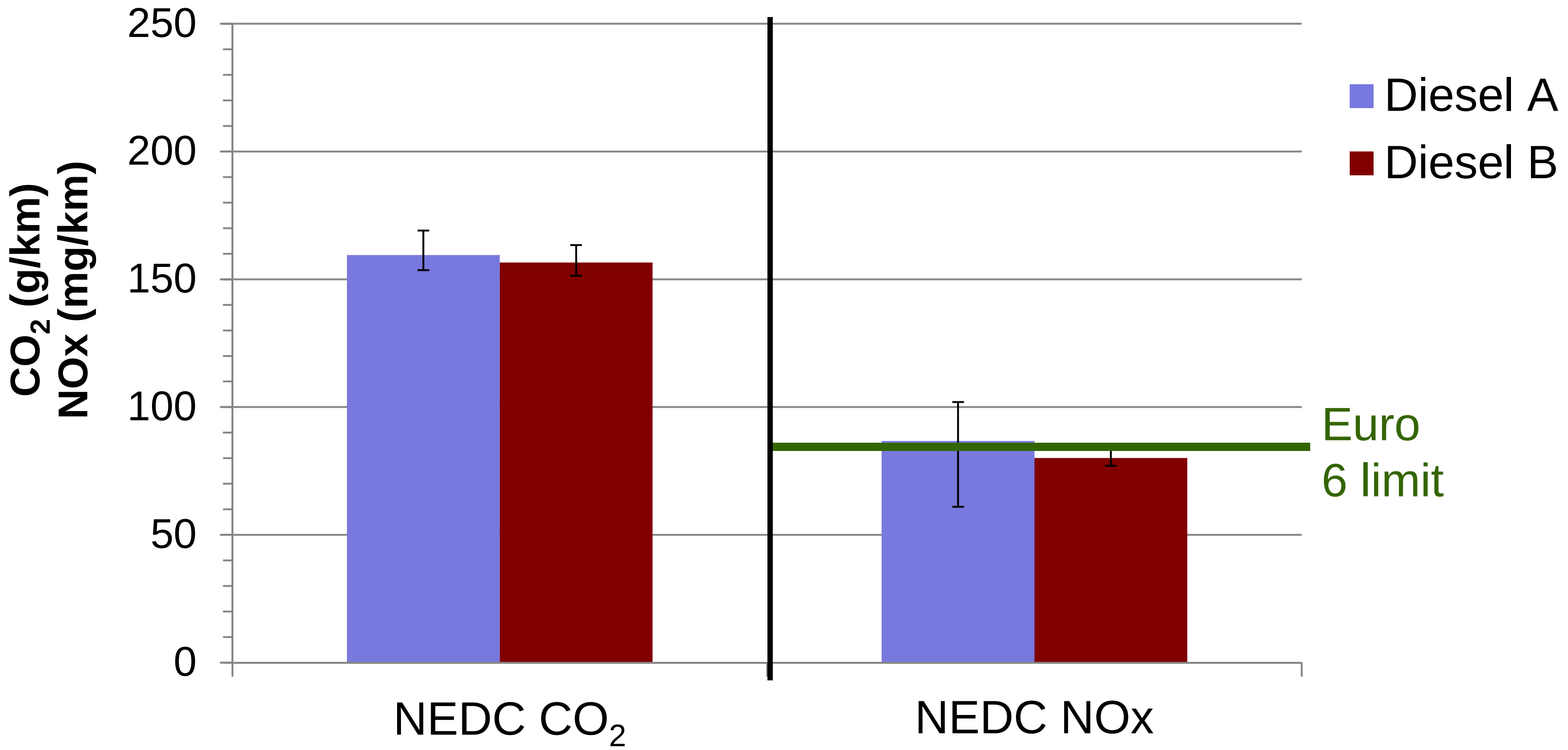
- Diesel is widely seen as a cause of urban air quality problems despite significant improvements in particulate emissions due to fitment of DPFs.
- Gasoline vehicles with Three Way Catalysts produce very little tailpipe NOx in real driving.



Source: AECC test programmes 2011-2013

The CO_2- driveability-emissions balance

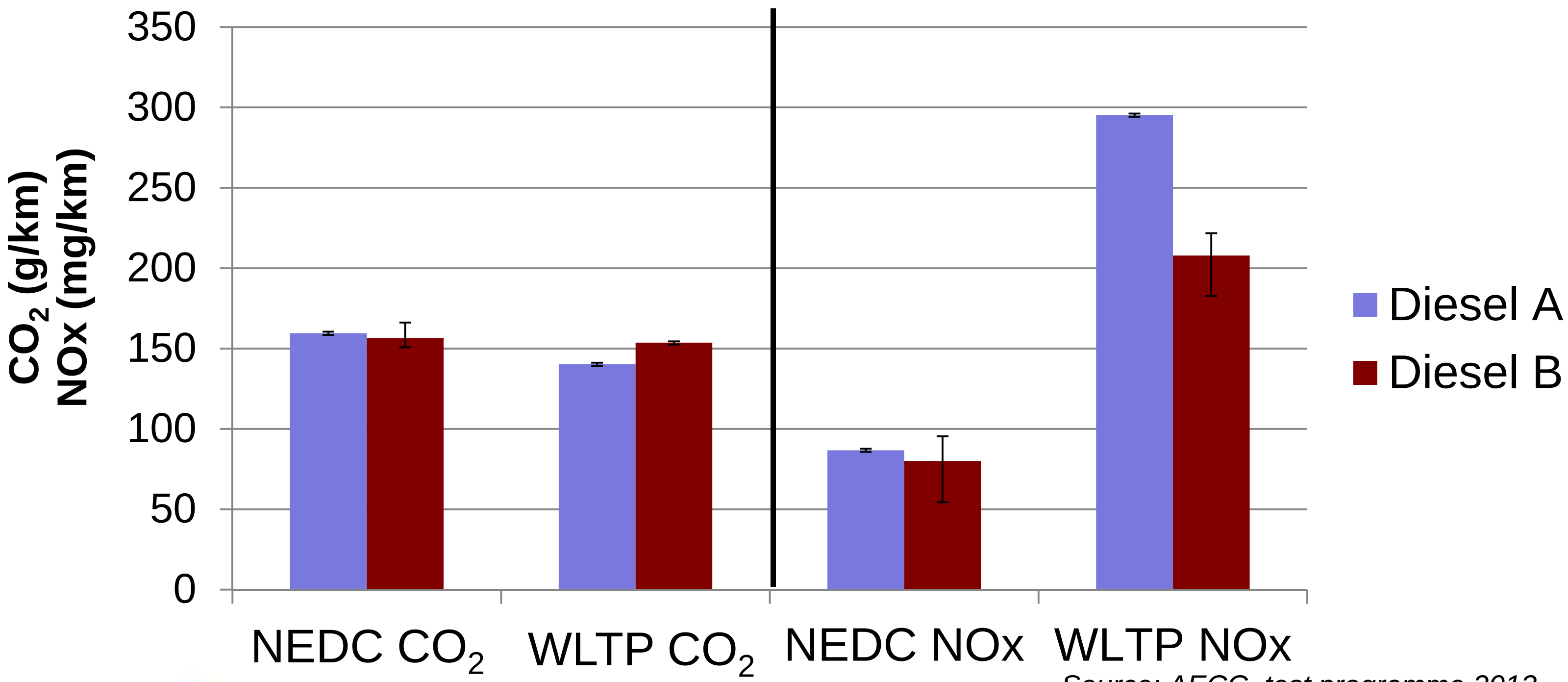
- Manufacturers have to provide vehicles that meet CO_2 requirements and provide a good driving experience – NOx emission control is currently focussed on NEDC requirements.



Source: AECC test programmes 2011-2013

Effect of WLTP introduction

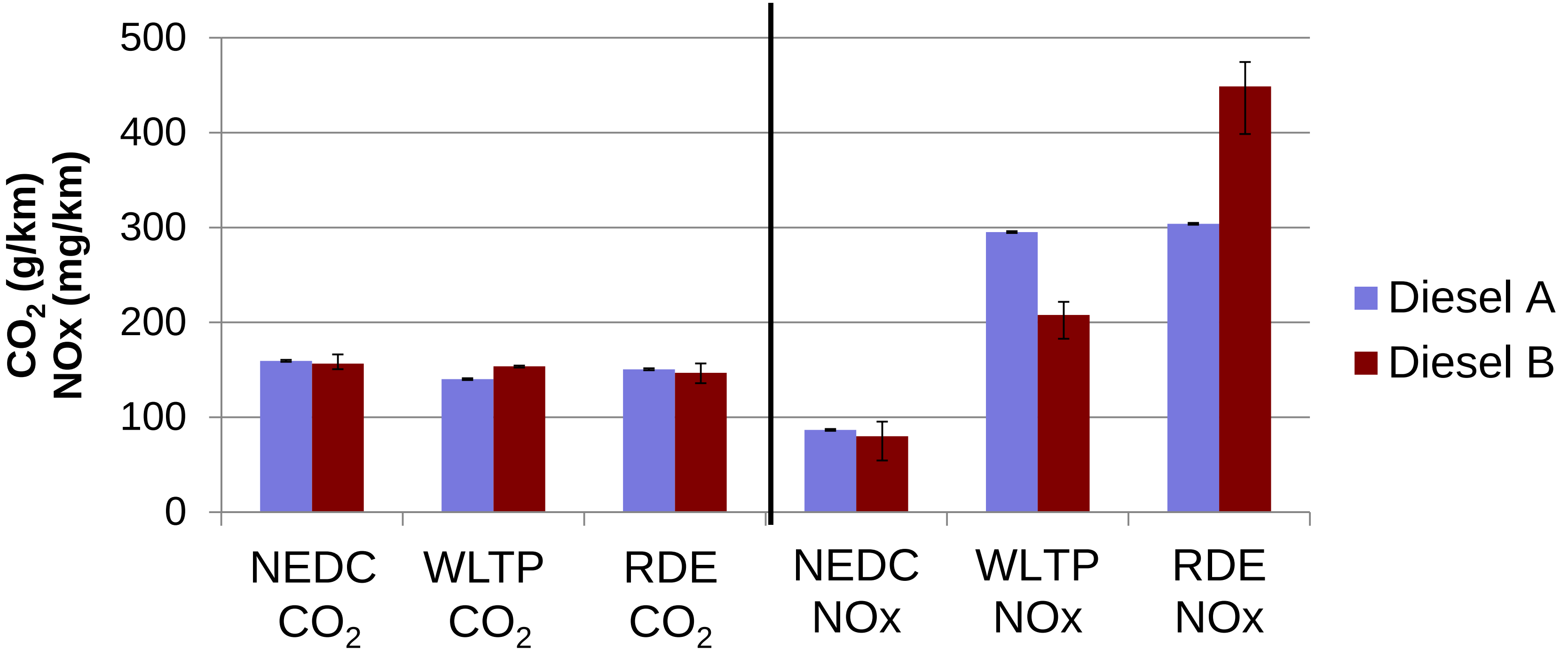
- The planned introduction of WLTC for fuel economy reporting means that many OEMs are now using this cycle to achieve the fuel economy/driveability balance.
- When WLTP is formally introduced NOx emissions will need to be met under the wider set of more transient conditions.



Source: AECC test programme 2013

Emissions in real driving

- NOx emissions from diesels without catalytic aftertreatment are very sensitive to power delivery.
- Diesels have been calibrated to meet NEDC NOx limits until recently, so are not optimised for the moderate and high load points found in normal driving.



Source: AECC test programme 2013

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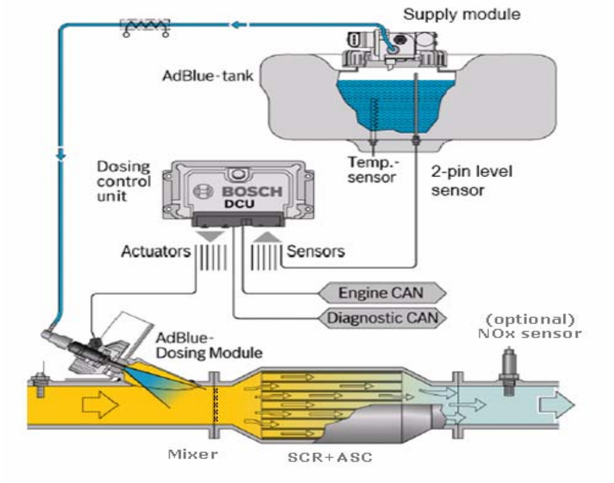
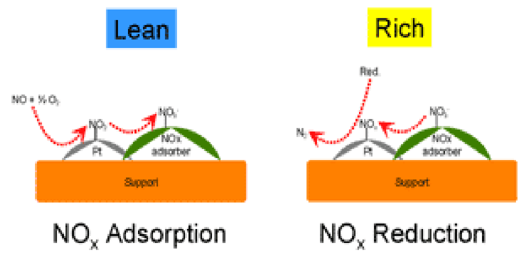
Commercialised Diesel DeNOx Technologies

Urea SCR

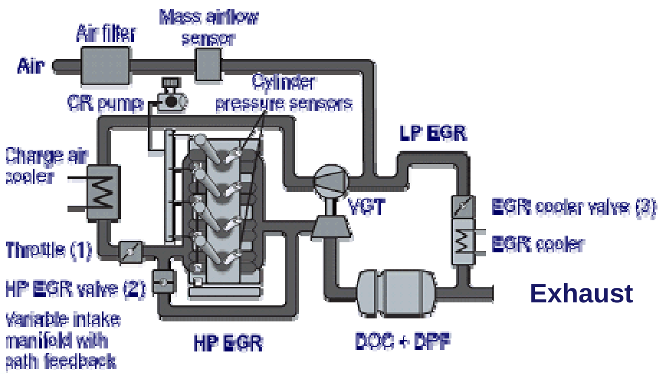


Source: Bosch, drawing adapted

Lean NOx Trap (LNT)

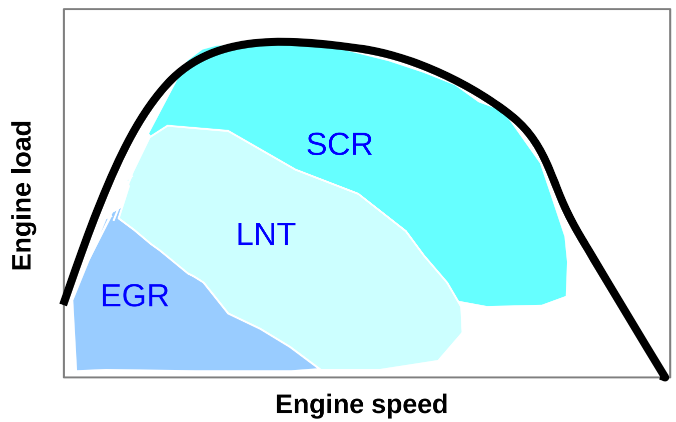


High- & Low-Pressure EGR



Source: Dieselnet

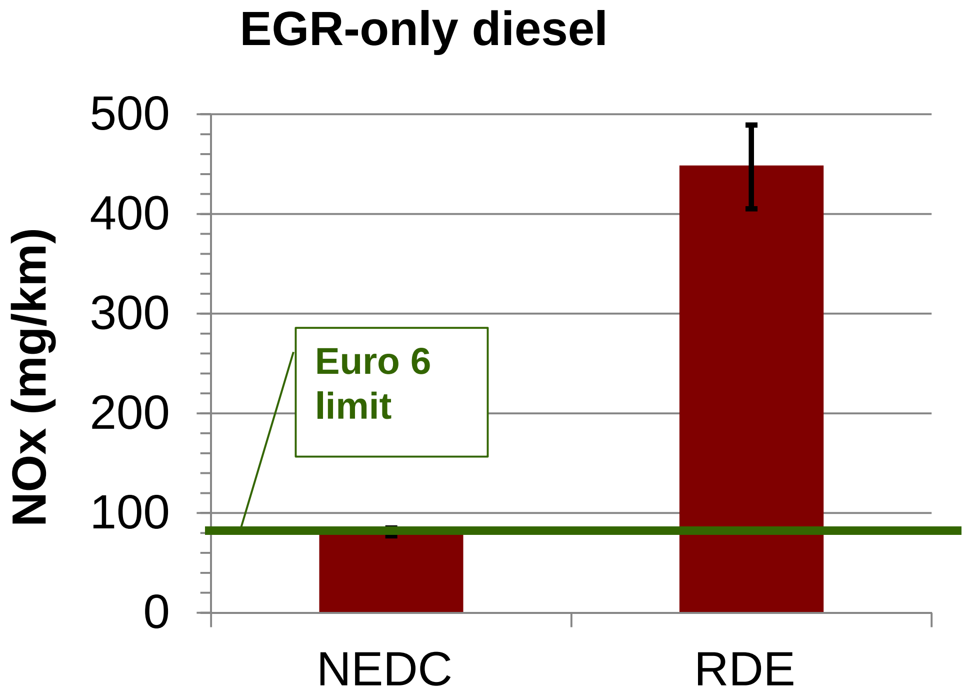
DeNOx optimization



Optimisation based on test procedures

- Current EU test procedures provide averaging over high and low NOx areas of engine operation, allowing some leeway on NOx treatment under the high load points of the cycle.
- Careful optimisation allows some manufacturers to achieve Euro 6b NOx emissions without catalytic aftertreatment.

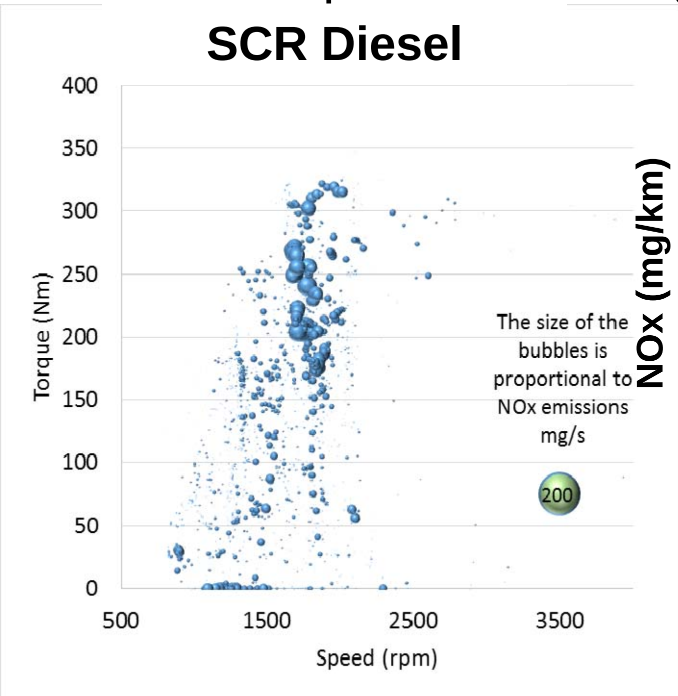
But these measures are inadequate under real world driving conditions

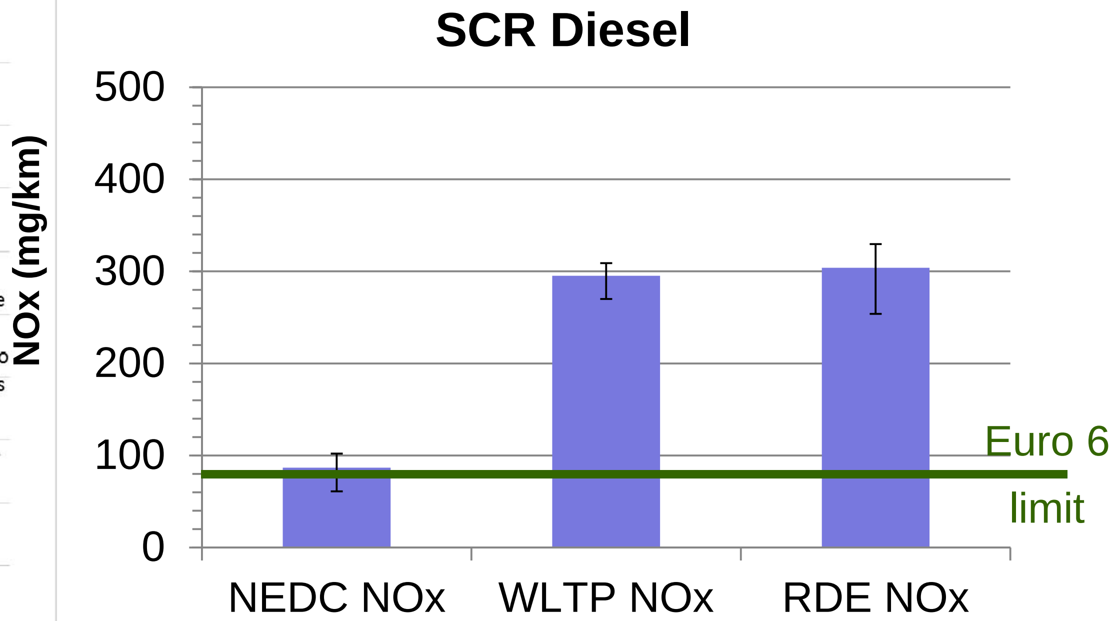


Source: AECC test programme 2013

SCR

- Some manufacturers have adopted urea SCR for larger cars.
- But there is reduced urea usage outside the test cycle to ensure the urea tank does not have to be filled between service intervals.
- Most NOx is produced under higher load transient driving conditions not present in the NEDC, so Euro 6b cars with this urea strategy meet NEDC requirements but give unacceptable NOx in real driving.

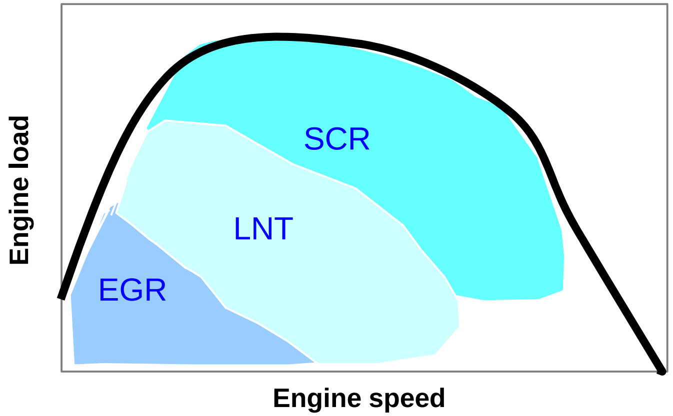


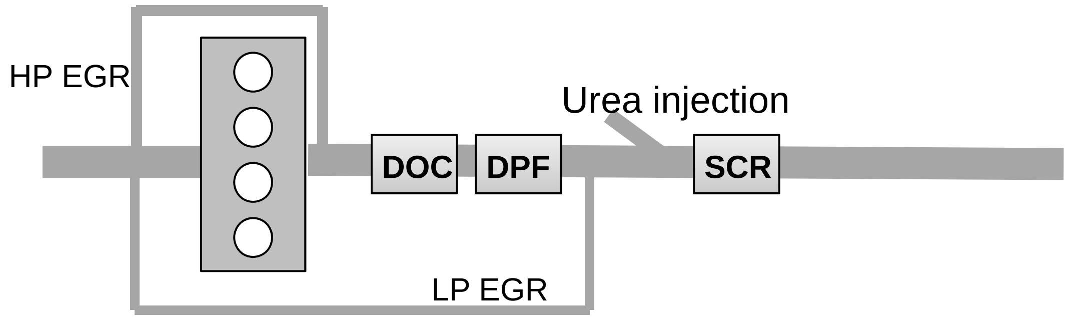


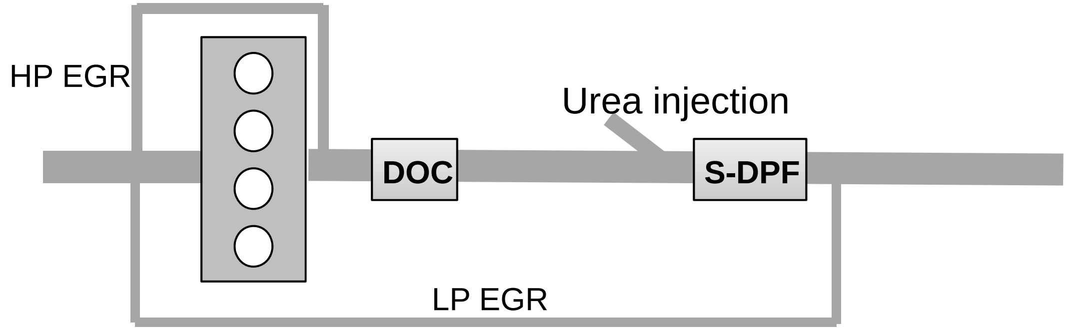
Source: AECC test programme 2013

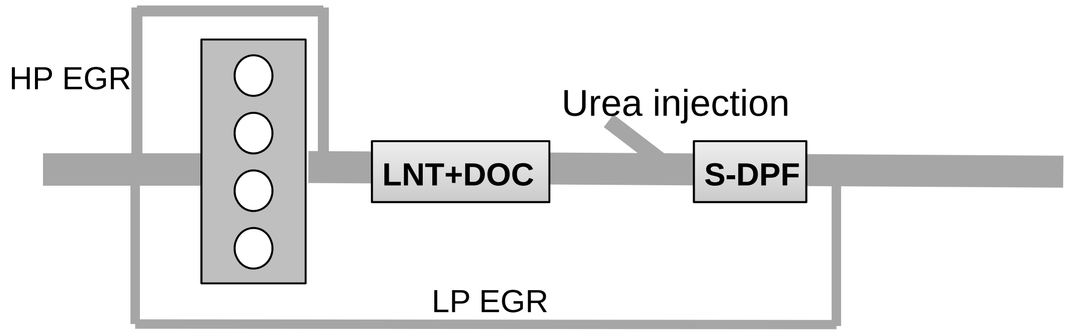
Combining technologies for lower RDE NOx

DeNOx optimization









Purpose of the AECC test programme

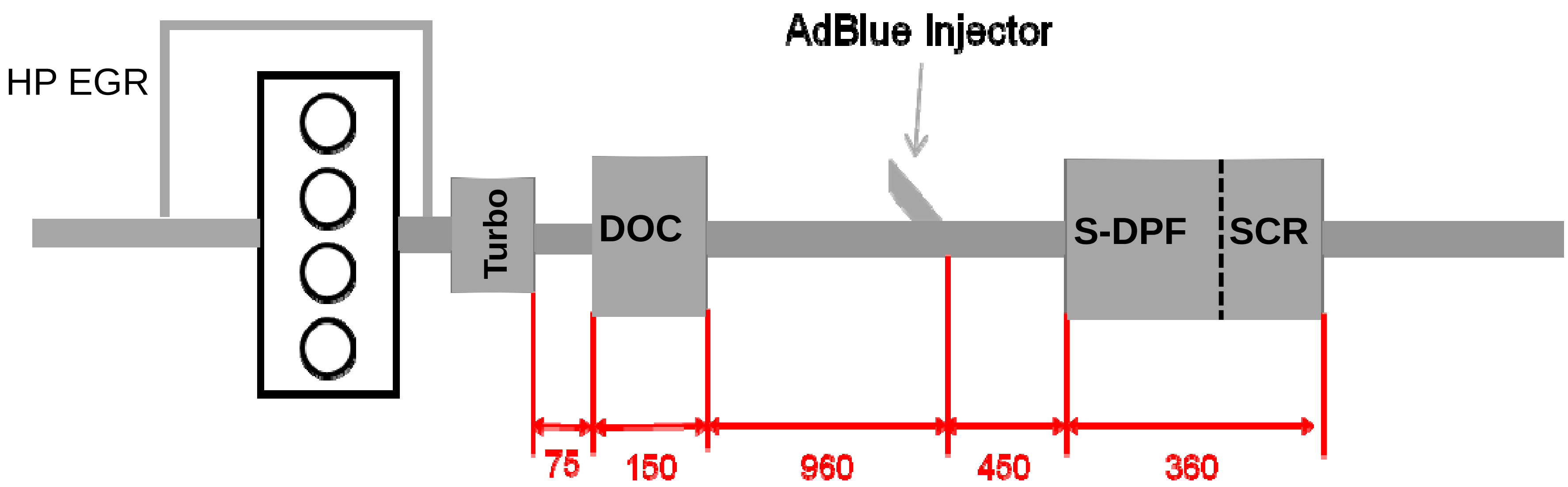
- AECC investigated the feasibility of minimising the deviation from current Euro 6 emissions limits using existing emission control approaches.

Objectives of the programme

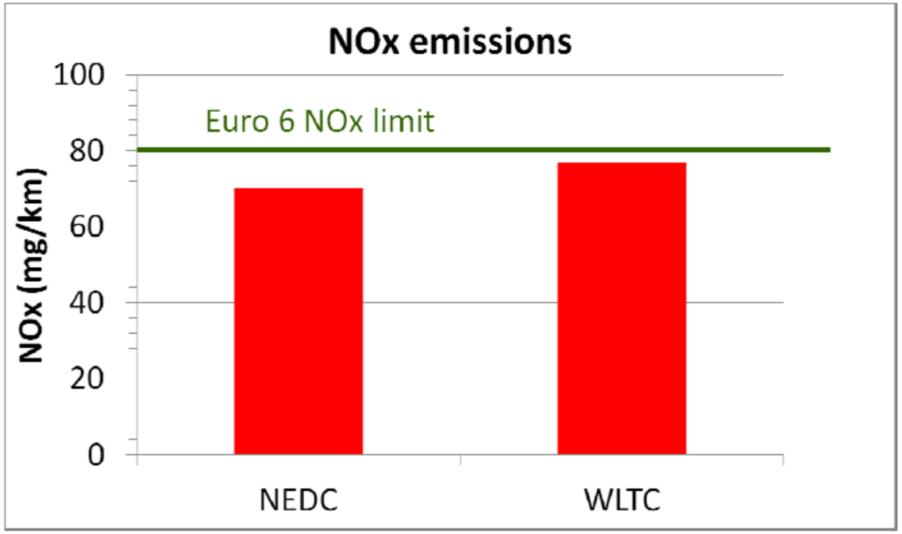
- Basis: take an existing diesel test vehicle meeting Euro 6b and move to Euro 6c (including RDE).
- Modify urea injection & EGR calibration to substantially reduce RDE NOx emissions.
- No hardware changes.
- Maintain driveability.
- Minimise any impact on CO_2 and fuel consumption.

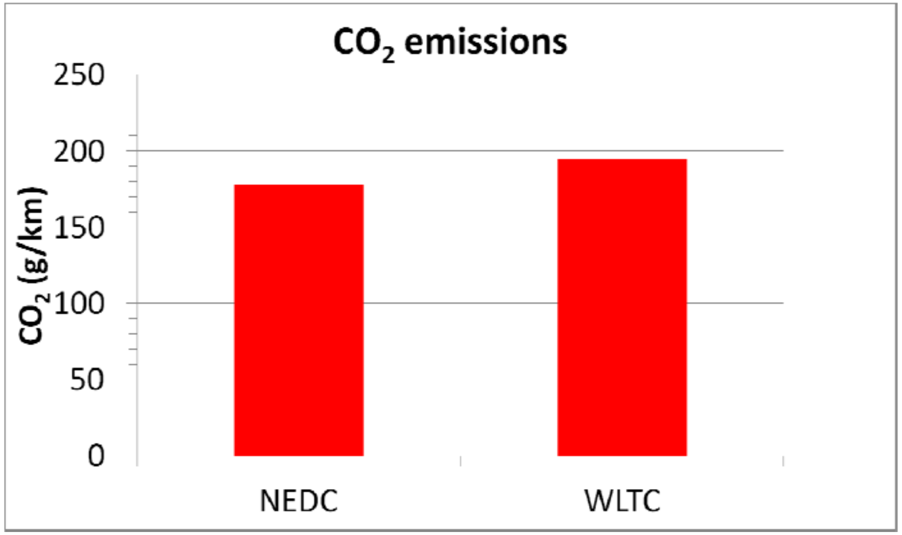
Test vehicle

- 2 litre class E segment car, 67 kW/litre 4-cylinder diesel.
- Single stage boosting, cooled high-pressure EGR.



Test results with baseline calibration





	NEDC	WLTC	Euro 6 limit
Test mass / inertia class	1810kg (T/A figure)	2091 kg (TM_H)	(NEDC)
NOx (mg/km)	70	77	80
CO (mg/km)	148	27	500
CO_2 (g/km)	178	195	-

Recalibration measures

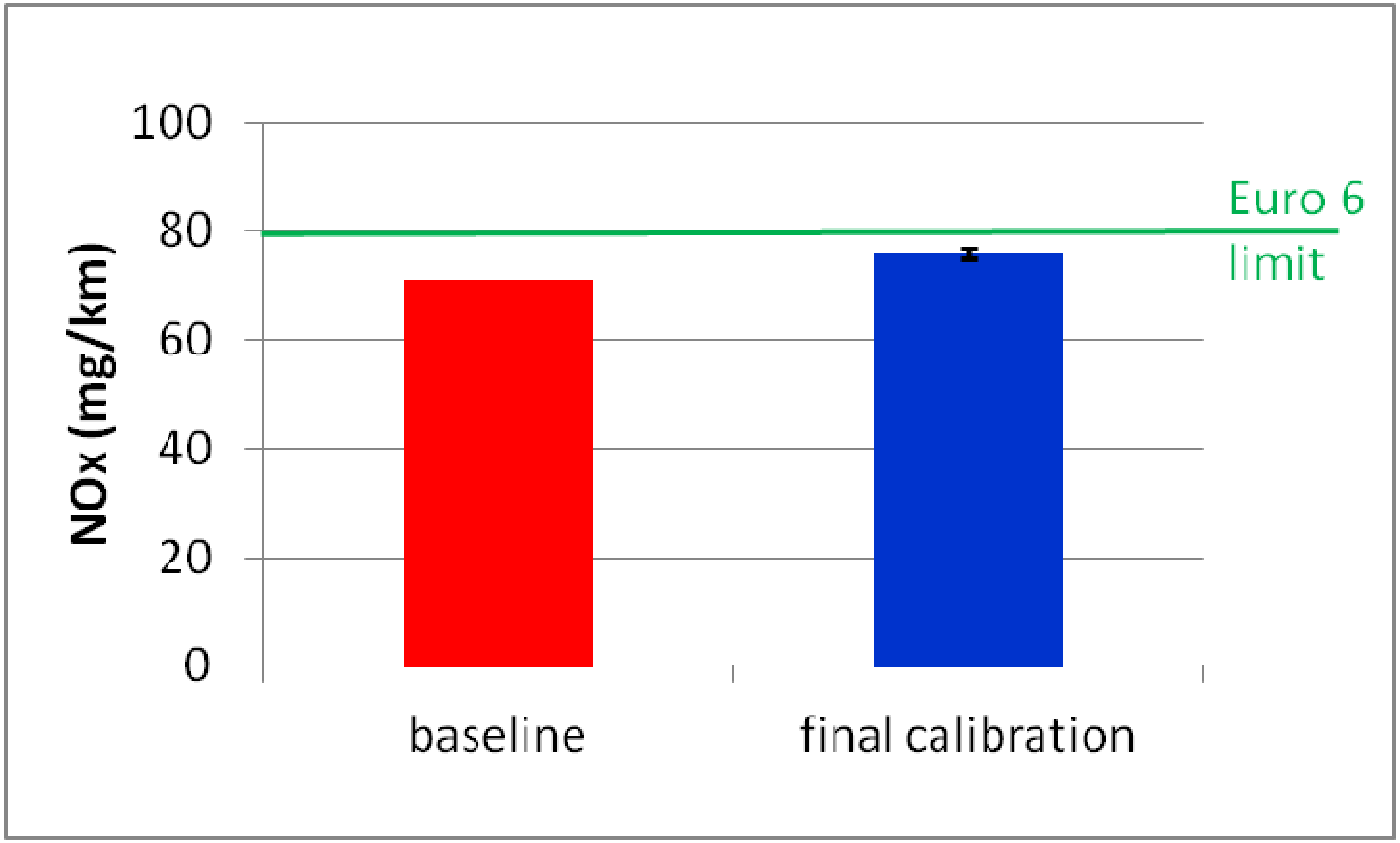
- Urea injection calibration modified
  - increased NH_3 storage parameter,
  - extension of storage controlled map area,
  - extension of ambient temperature boundary conditions.
- Reduction of fuel post injection quantities.
- Recalibration of gear dependency of EGR calibration.
- Recalibration of EGR at high loads.
- An iterative process was used to achieve optimum balance of key parameters.

NEDC

NEDC NOx emissions

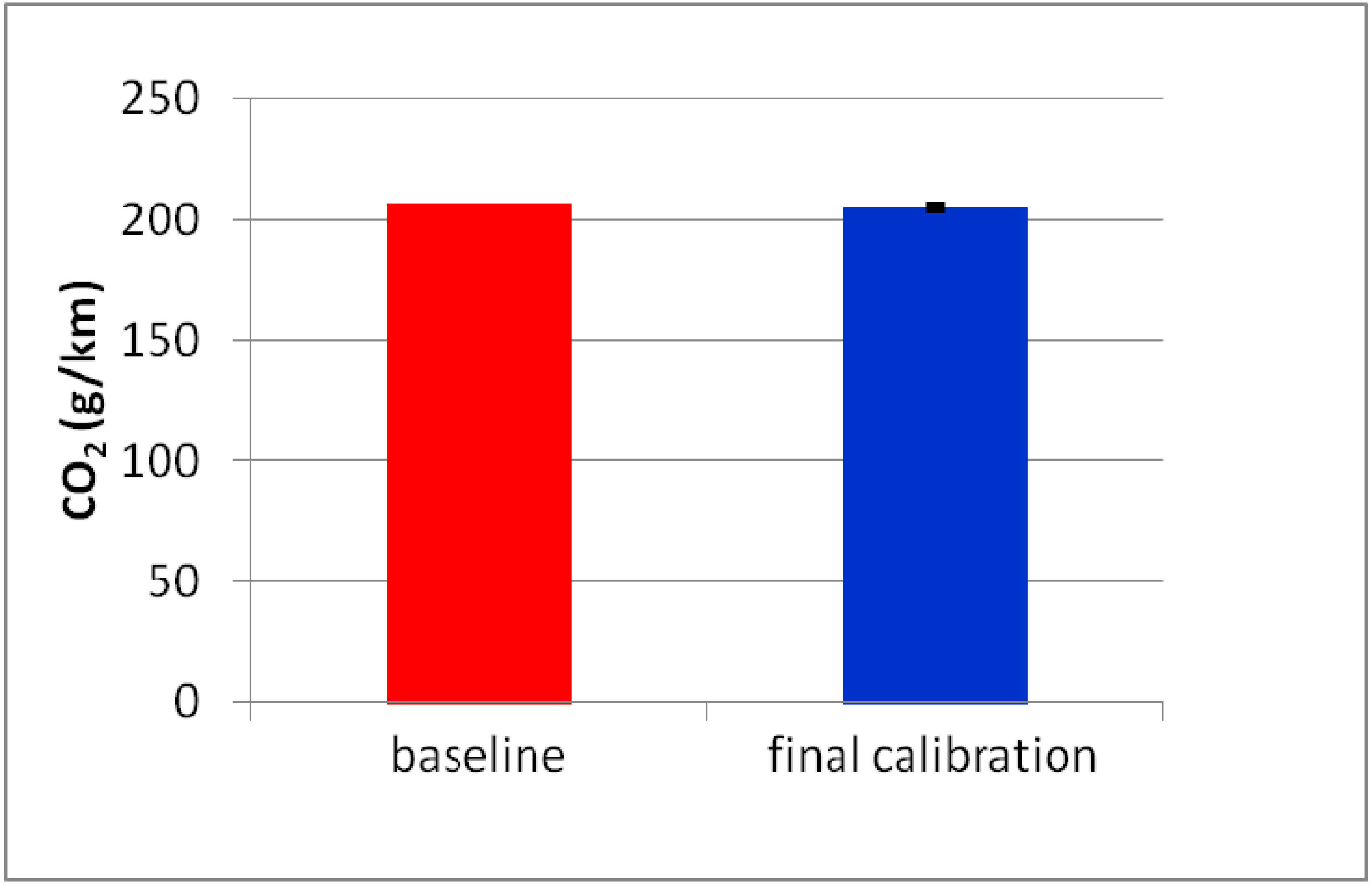
- NOx emissions with the final calibration remain below Euro 6 limit.
- NOx increased slightly due to lower exhaust temperature caused by reduced post injection quantity.

Ammonia slip <2ppm



Baseline test with 2040 kg inertia from actual vehicle weight and test vehicle coast-down

NEDC CO_2 emissions are comparable

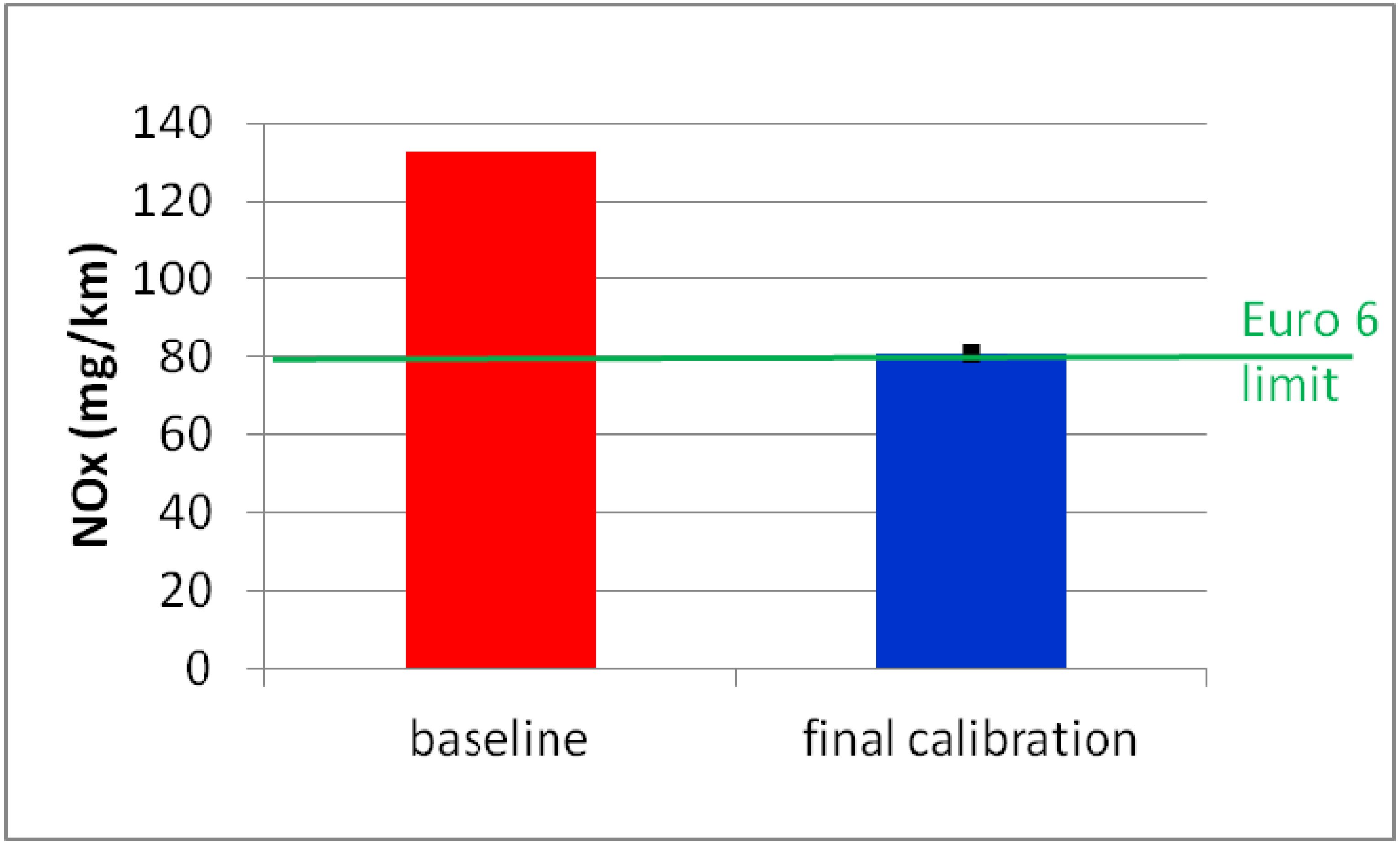


Baseline test with 2040 kg inertia from actual vehicle weight and test vehicle coast-down

WLTP

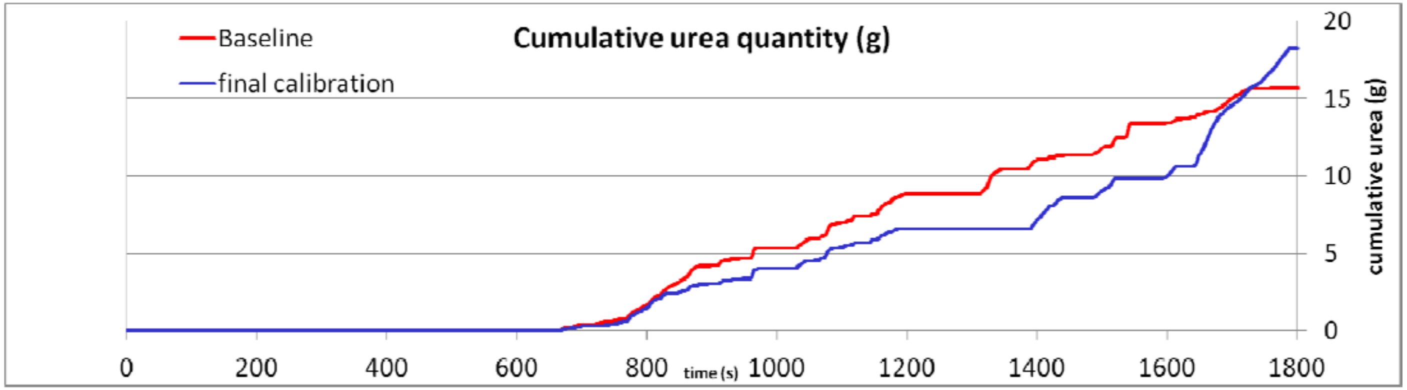
WLTP NOx emissions

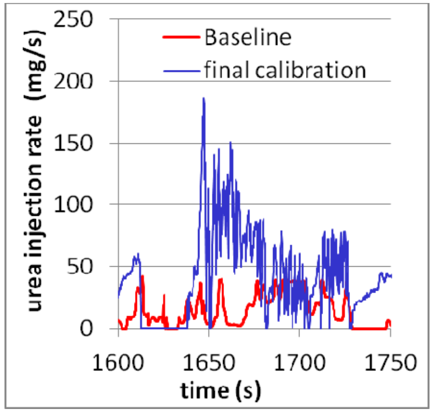
- NOx emissions with final calibration were reduced by 40%.

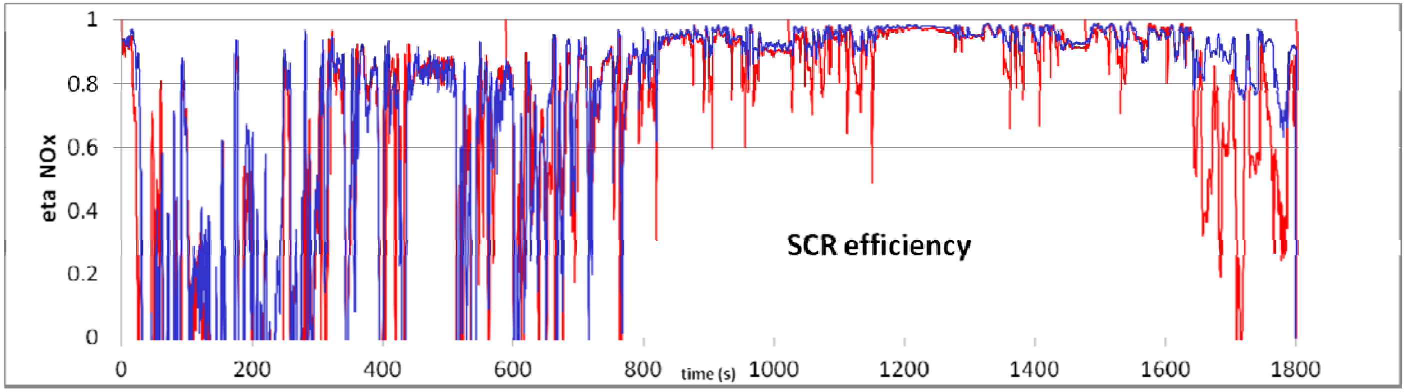


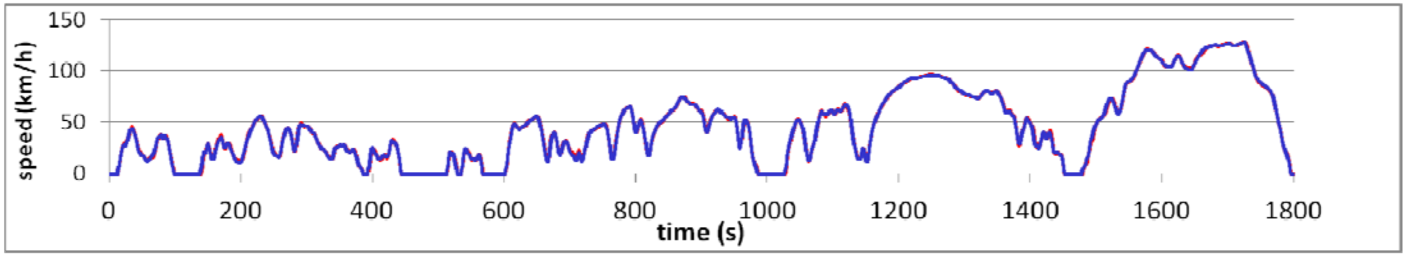
Note: All tests run with PEMS fitted. The additional 232kg of the PEMS increased NOx emissions.

The revised urea dosing strategy increased urea consumption on WLTC by ~25%



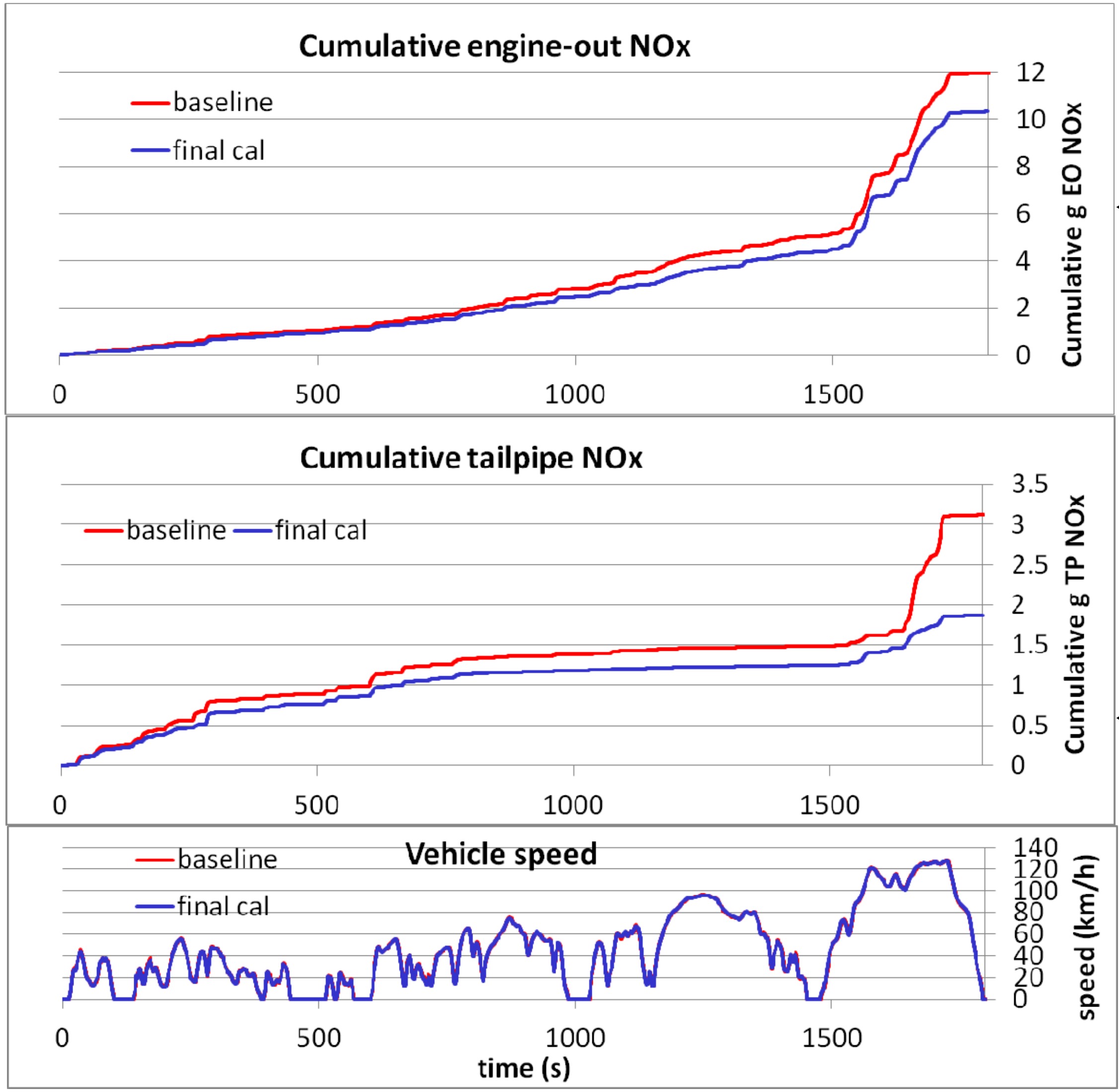






- SCR efficiency improved from 74 to 83%.
- Improved SCR efficiency was mainly in the highway phase.

WLTP NOx emissions

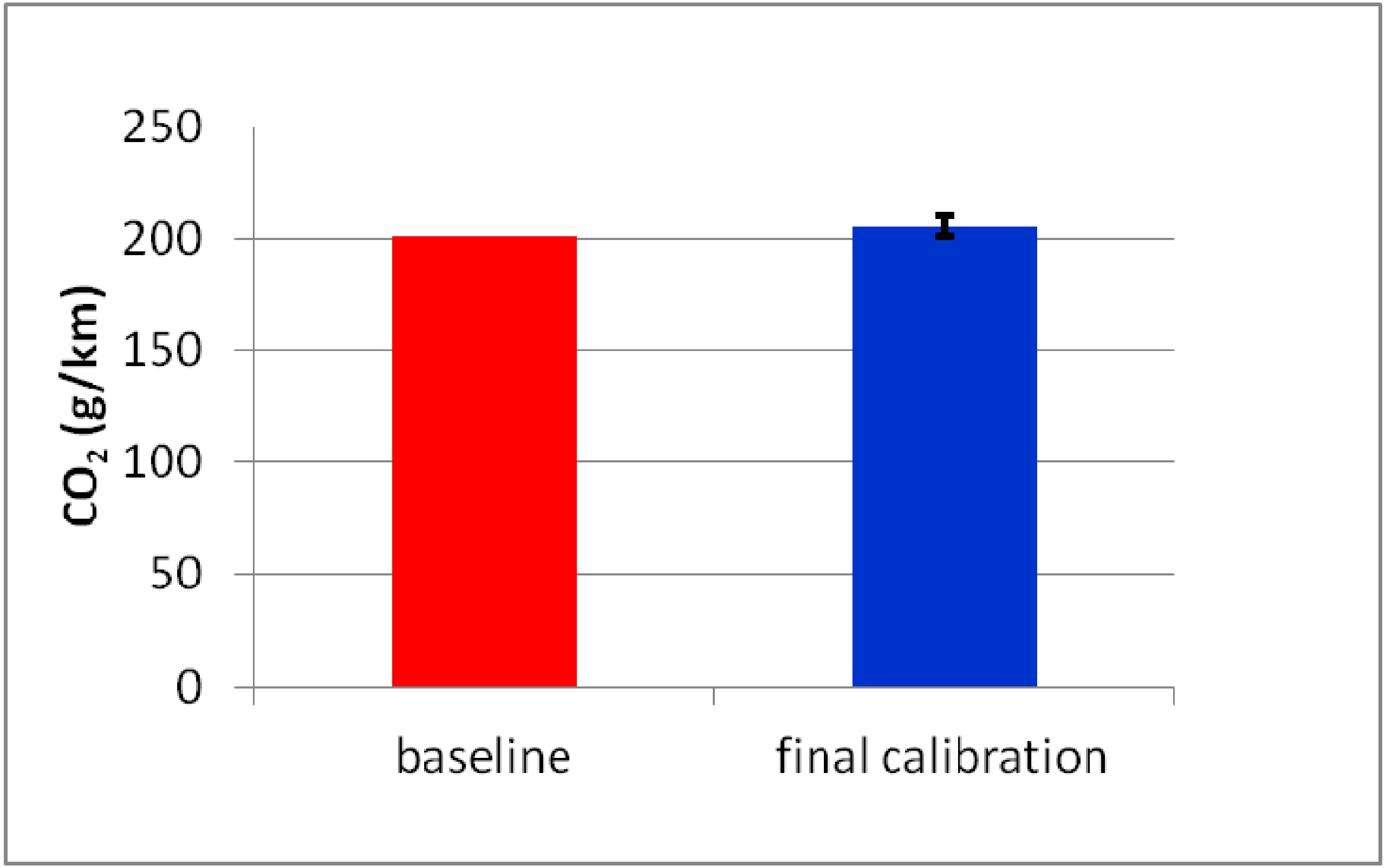


- 10% reduction of NOx raw emissions was achieved by recalibration

- lower raw emissions and greater SCR efficiency led to a reduction of tailpipe NOx emissions of ~40%

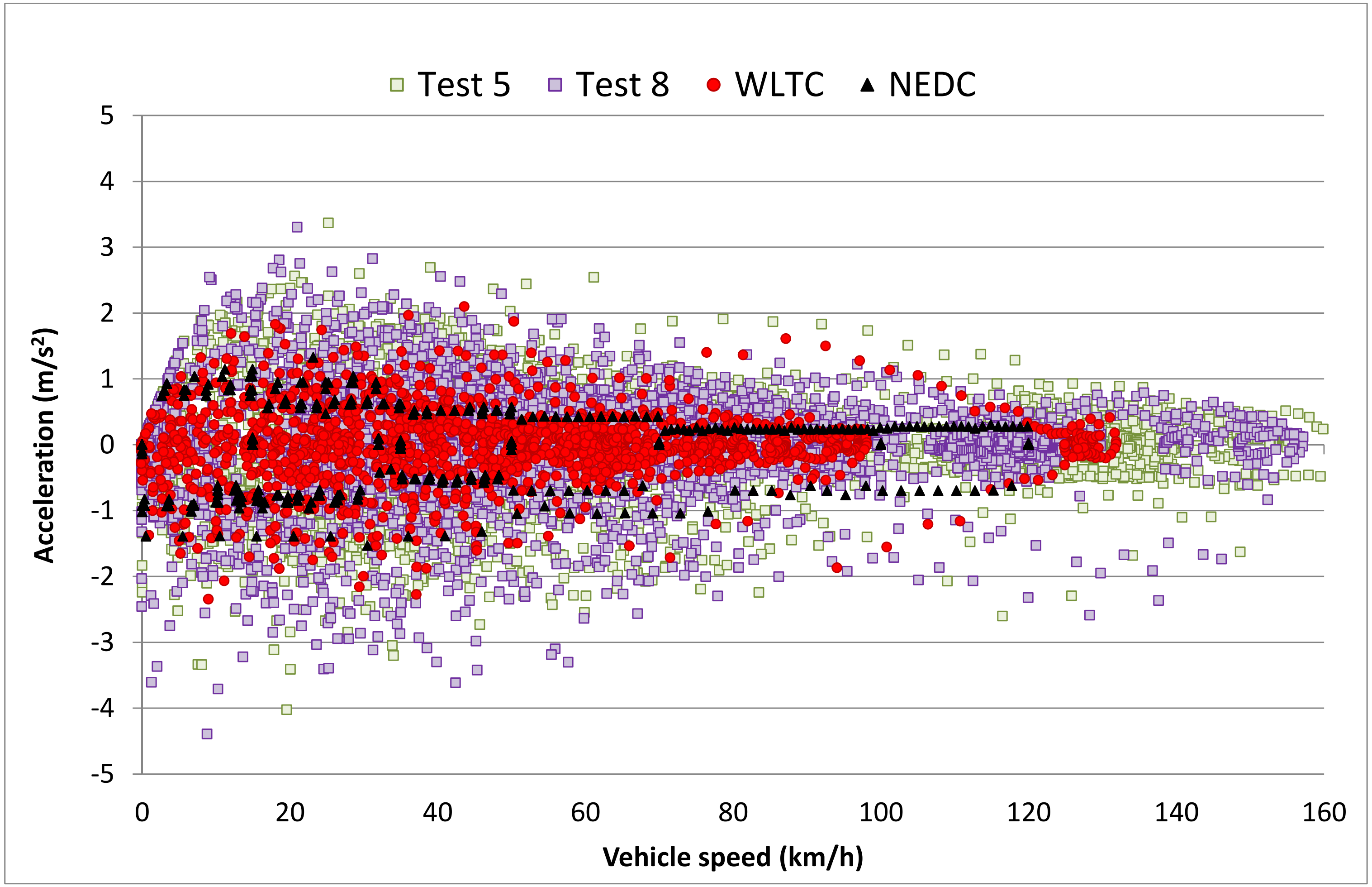
- Ammonia slip <4ppm.

WLTC CO_2



RDE

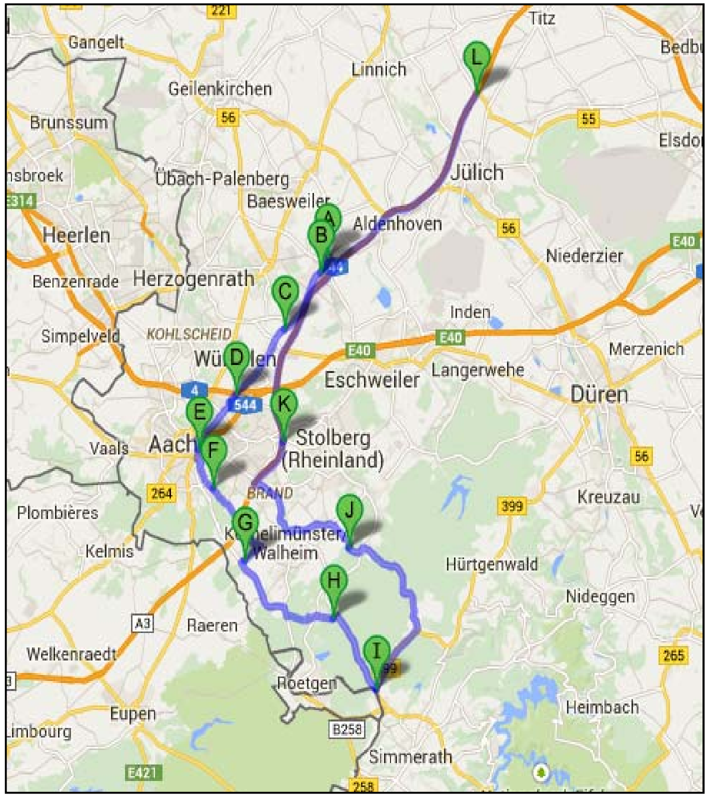
RDE/PEMS tests; speed vs. acceleration



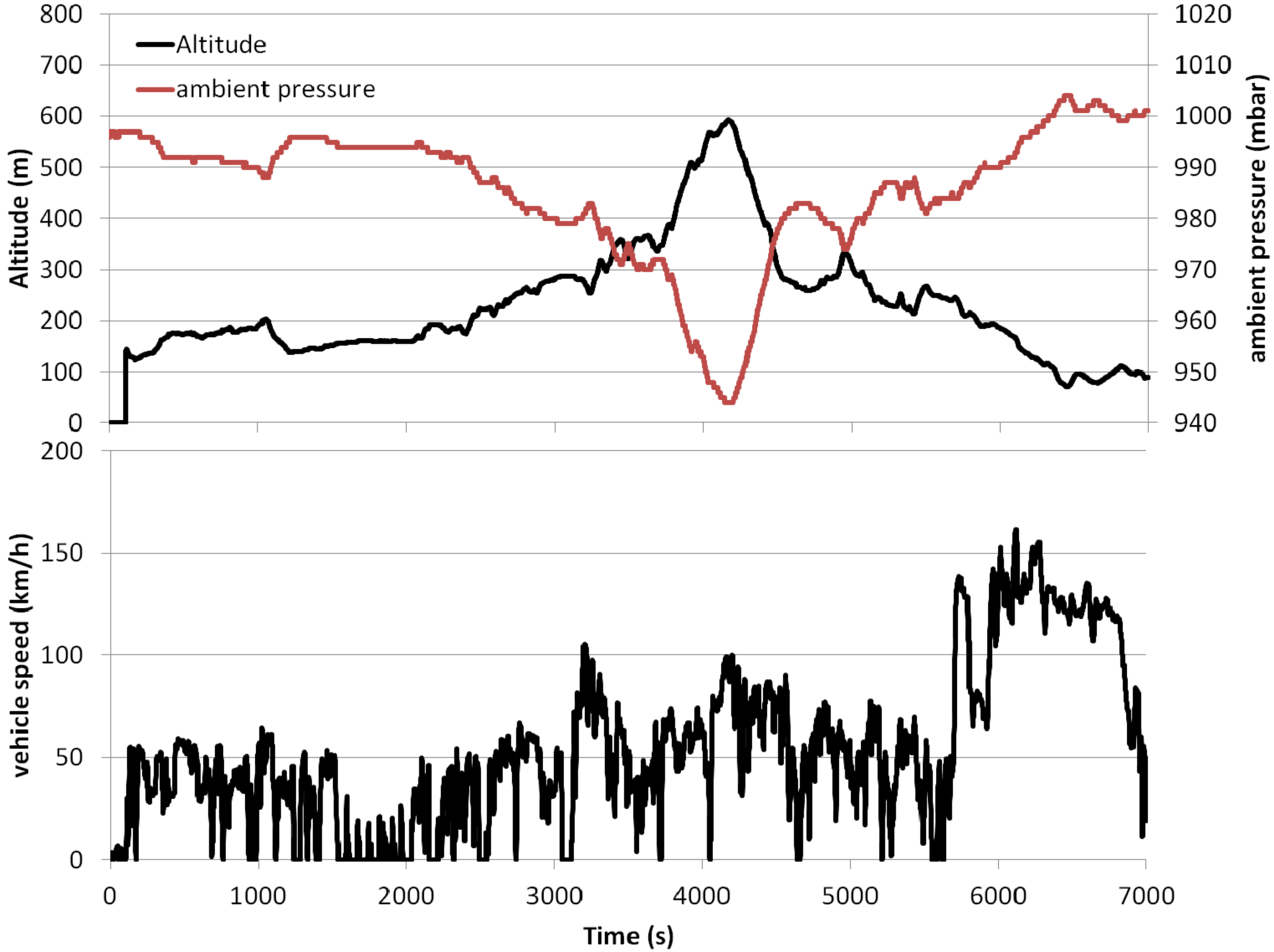
RDE route

- The test route was intended to give valid conditions when analysed by EMROAD, and to give the correct balance of urban, rural, motorway driving.

Distance	107 km
Typical duration	119 min
Average speed	~57 km/h
Maximum speed	160 km/h
Altitude	101 to 594 m
Ambient temp.	2 to 8°C

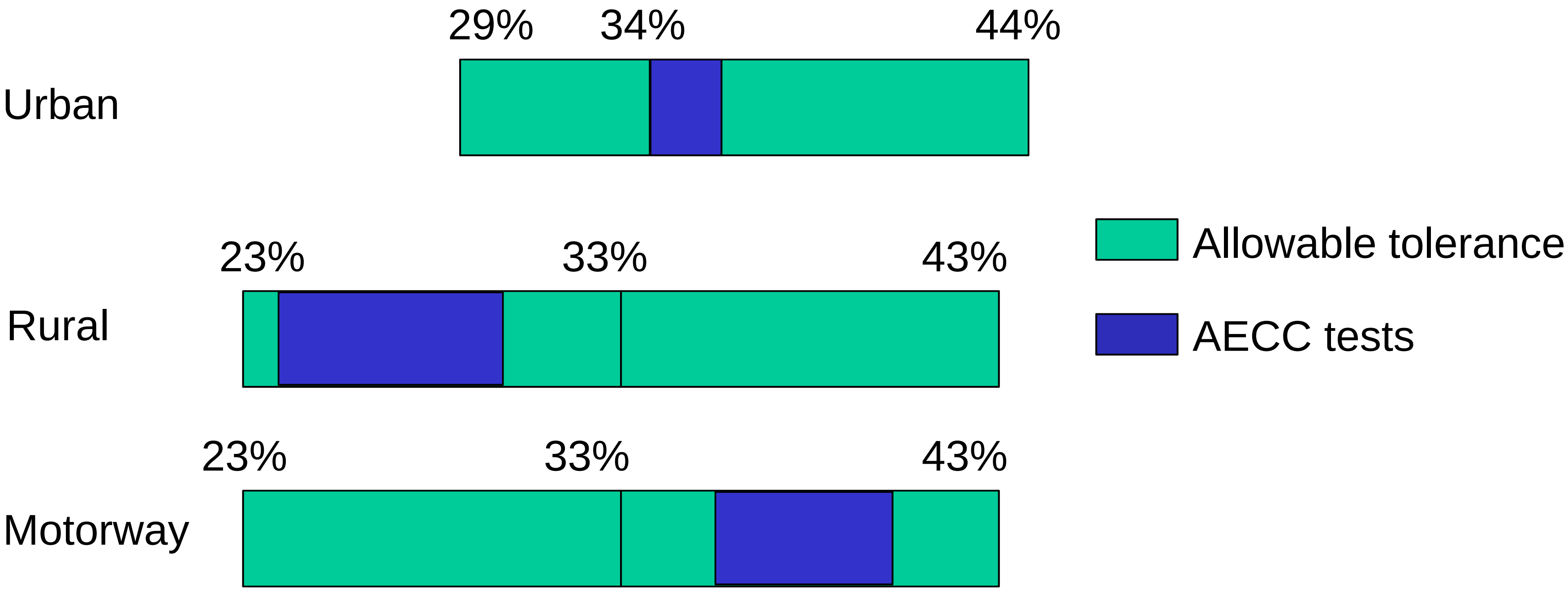


RDE route


Altitude
ambient pressure
Altitude (m)
ambient pressure (mbar)
vehicle speed (km/h)
Time (s)
800
700
600
500
400
300
200
100
0
1020
1010
1000
990
980
970
960
950
940
200
150
100
50
0
0
1000
2000
3000
4000
5000
6000
7000

RDE route characteristics

The chart below shows the percentages of urban, rural and motorway driving, compared to the current proposal for the RDE Regulation.



We recognise the challenge of realising valid routes for RDE trips

Urban driving

Rural driving

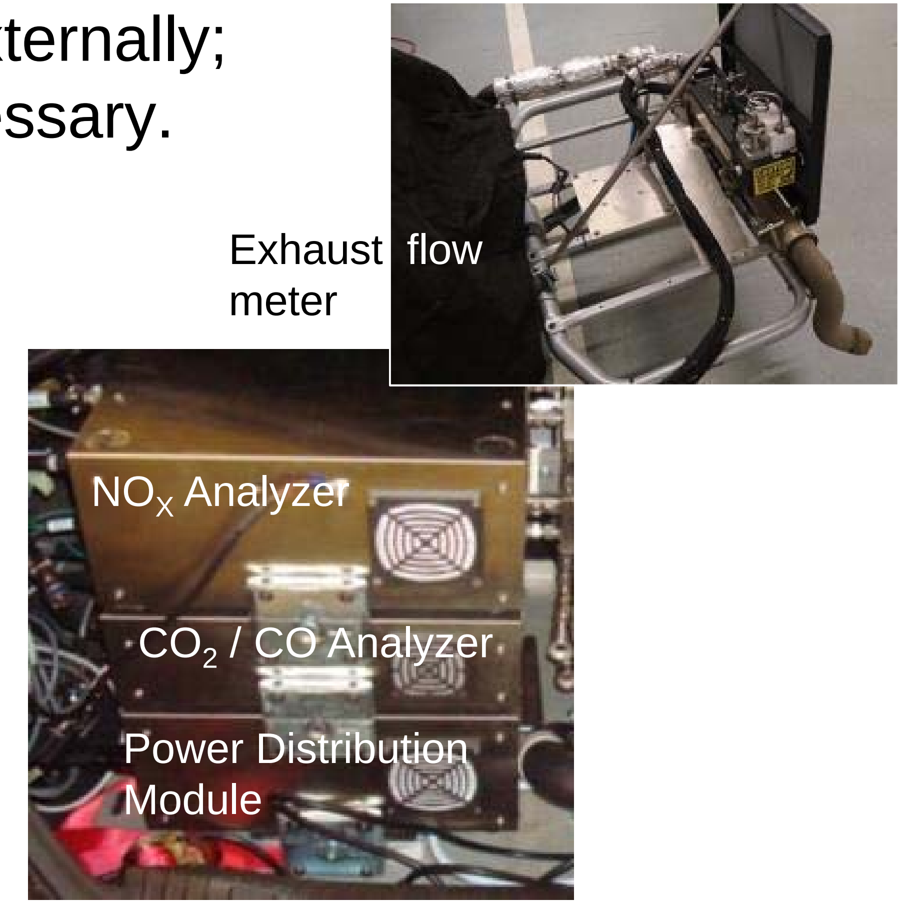
Motorway driving

PEMS test equipment

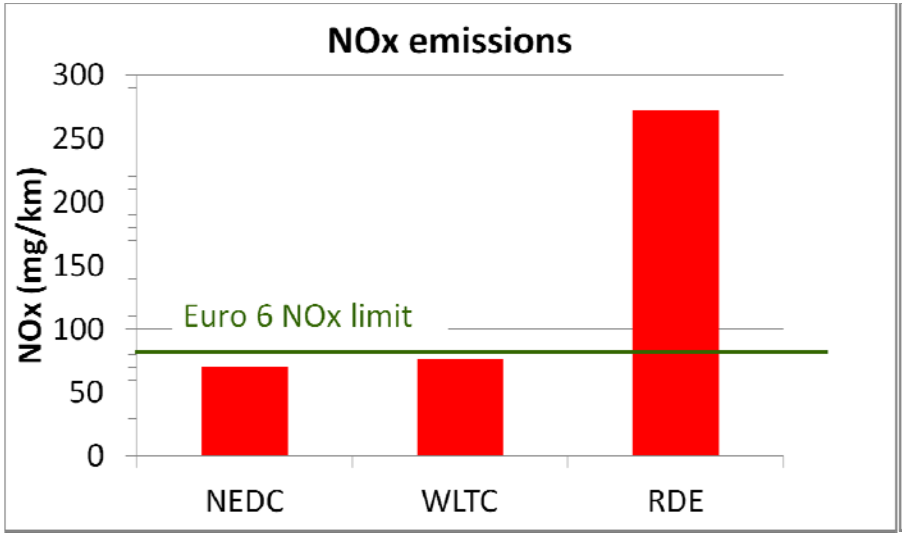
- Sensors Europe GmbH Semtech Ecostar for CO & NOx installed in vehicle trunk.
- Exhaust flow meter installed externally; extension of exhaust pipe necessary.
- Additional mass of PEMS equipment: 232 kg.

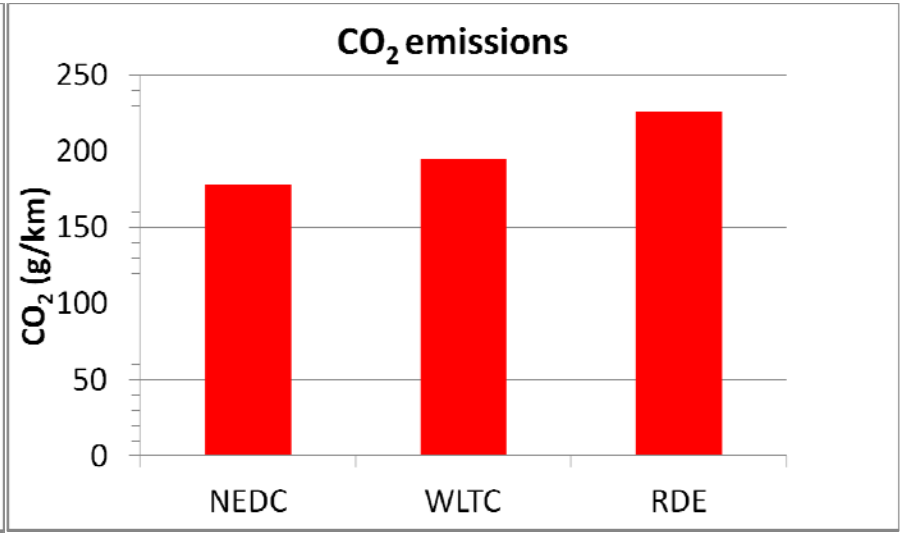
Note:

- PEMS equipment was fitted for some WLTC tests (identified in results).



Test results with baseline calibration

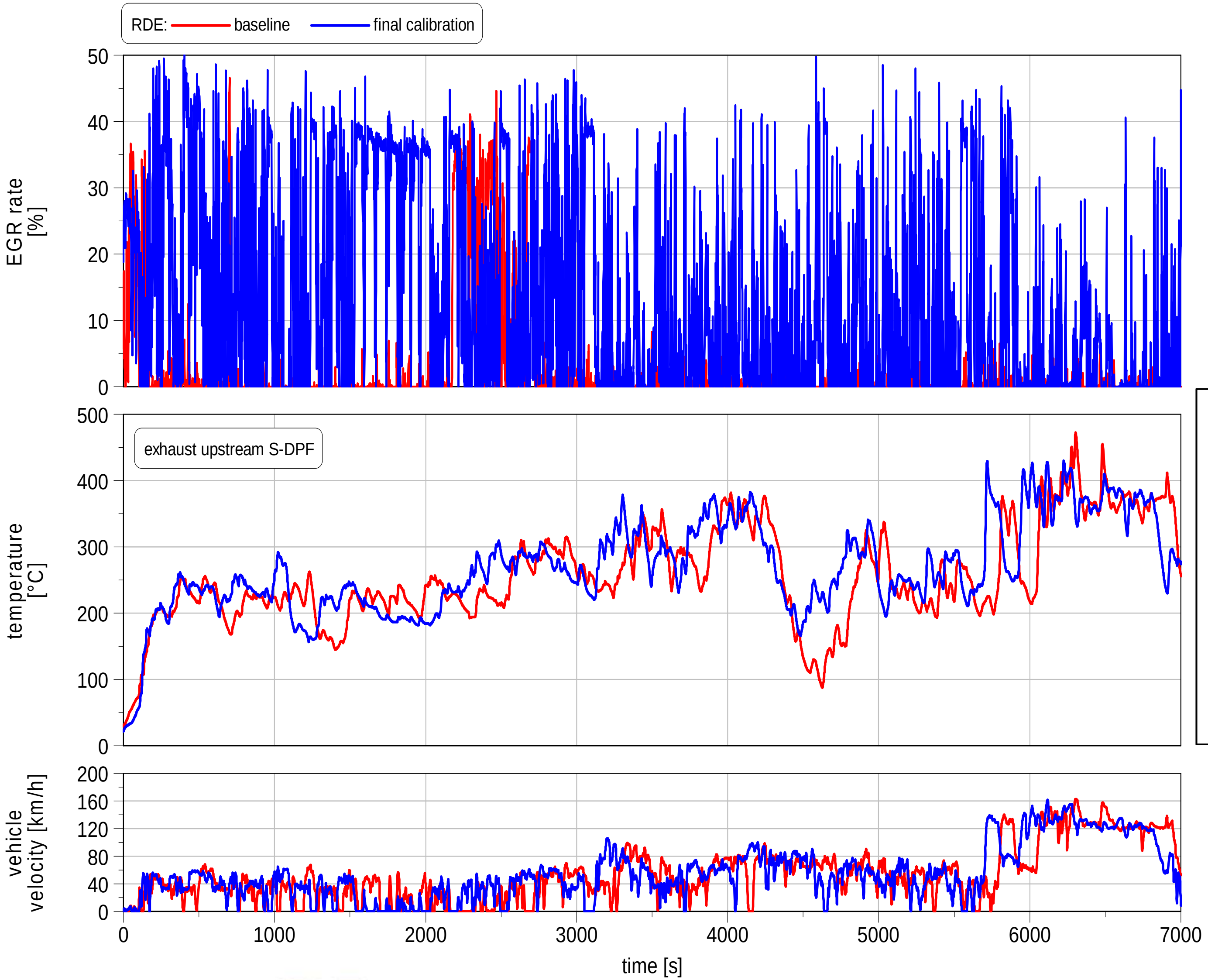




	NEDC	WLTC	RDE	Euro 6 limit
Test mass / inertia class	1810kg (T/A figure)	2091 kg (TM_H)	2237 kg incl. PEMS	(NEDC)
NOx (mg/km)	70	77	272	80
CO (mg/km)	148	27	154	500
CO_2 (g/km)	178	195	226	-

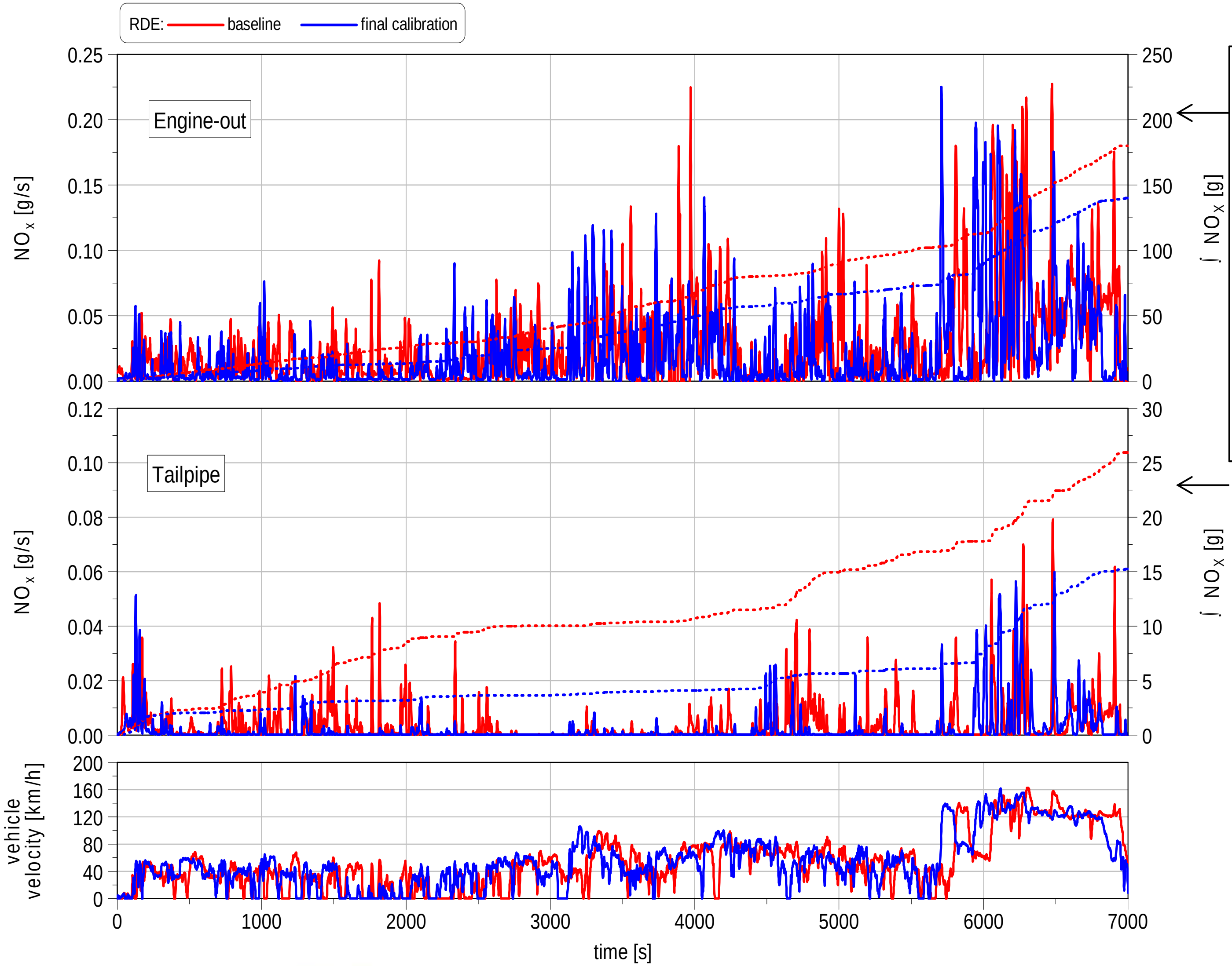
RDE NOx emissions were 3.4 times the Euro 6 limit

EGR strategies in real driving



- The final calibration used an ambient temperature independent EGR strategy.

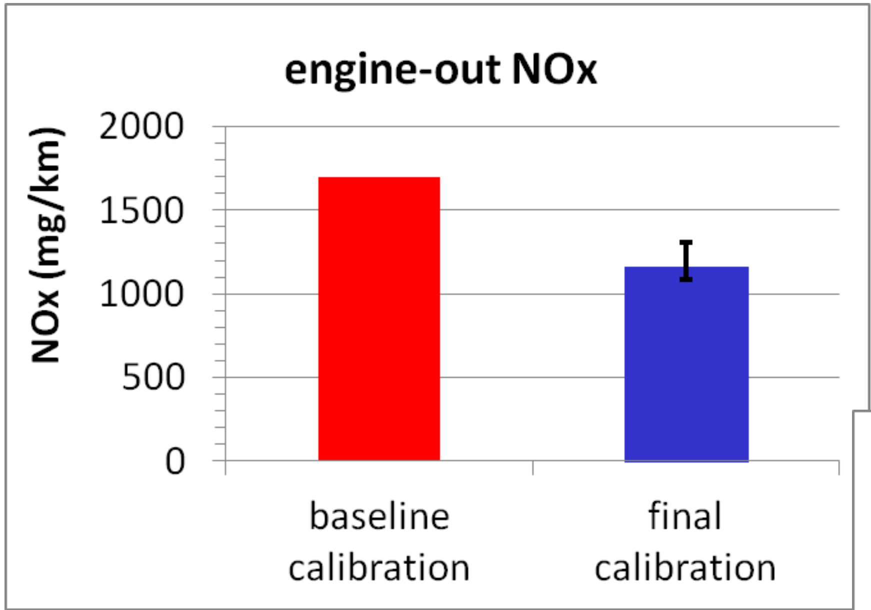
NOx emissions during real driving



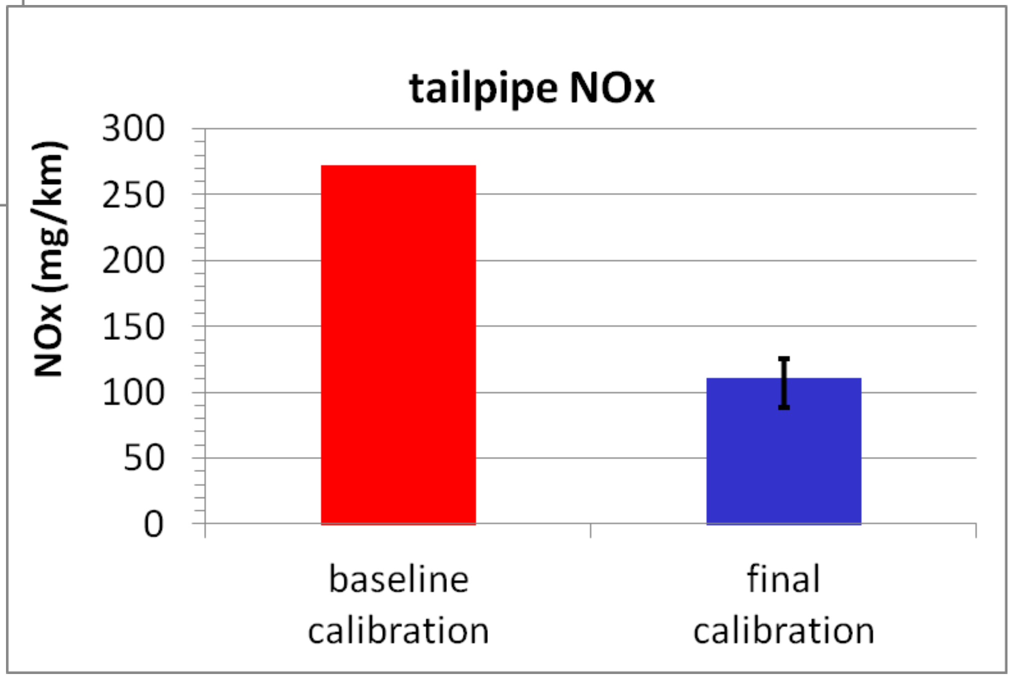
- With the final calibration there is a significant reduction of raw NOx emissions (~25%) by the increased EGR.

SCR efficiency	
baseline (red)	85.6 %
final calibration (blue)	89.1 %

Engine-out & Tailpipe RDE NOx emissions

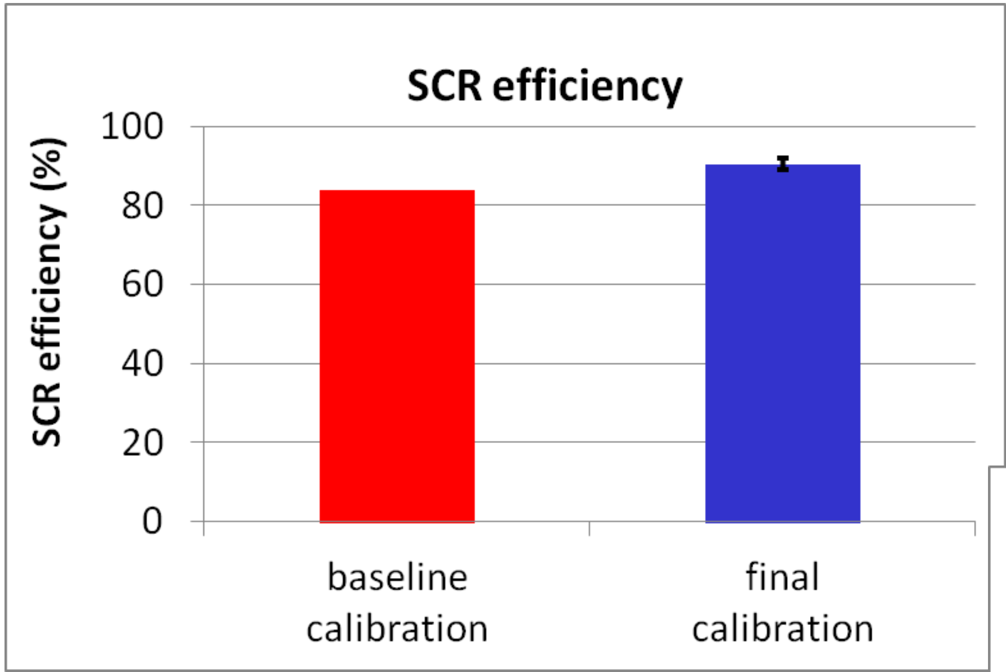


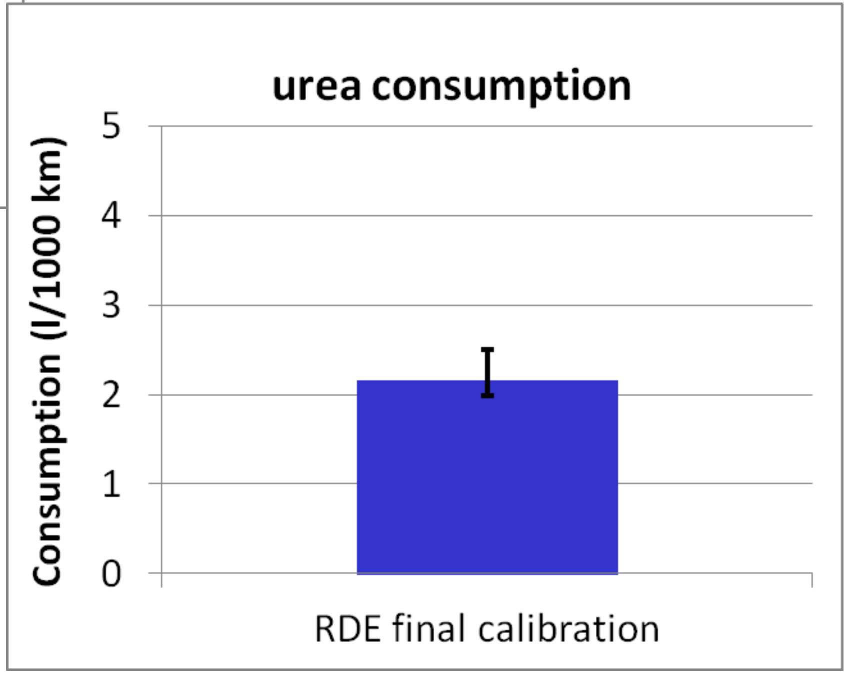
- Both engine-out and tailpipe NOx were reduced.
- The base calibration gave tailpipe NOx emissions of 272 mg/km; 3.4 times the Euro 6 limit.



- With the modified calibration, NOx averaged 111 mg/km on the RDE tests and the average was 1.4 times the Euro 6 limit.

RDE SCR efficiency and urea consumption



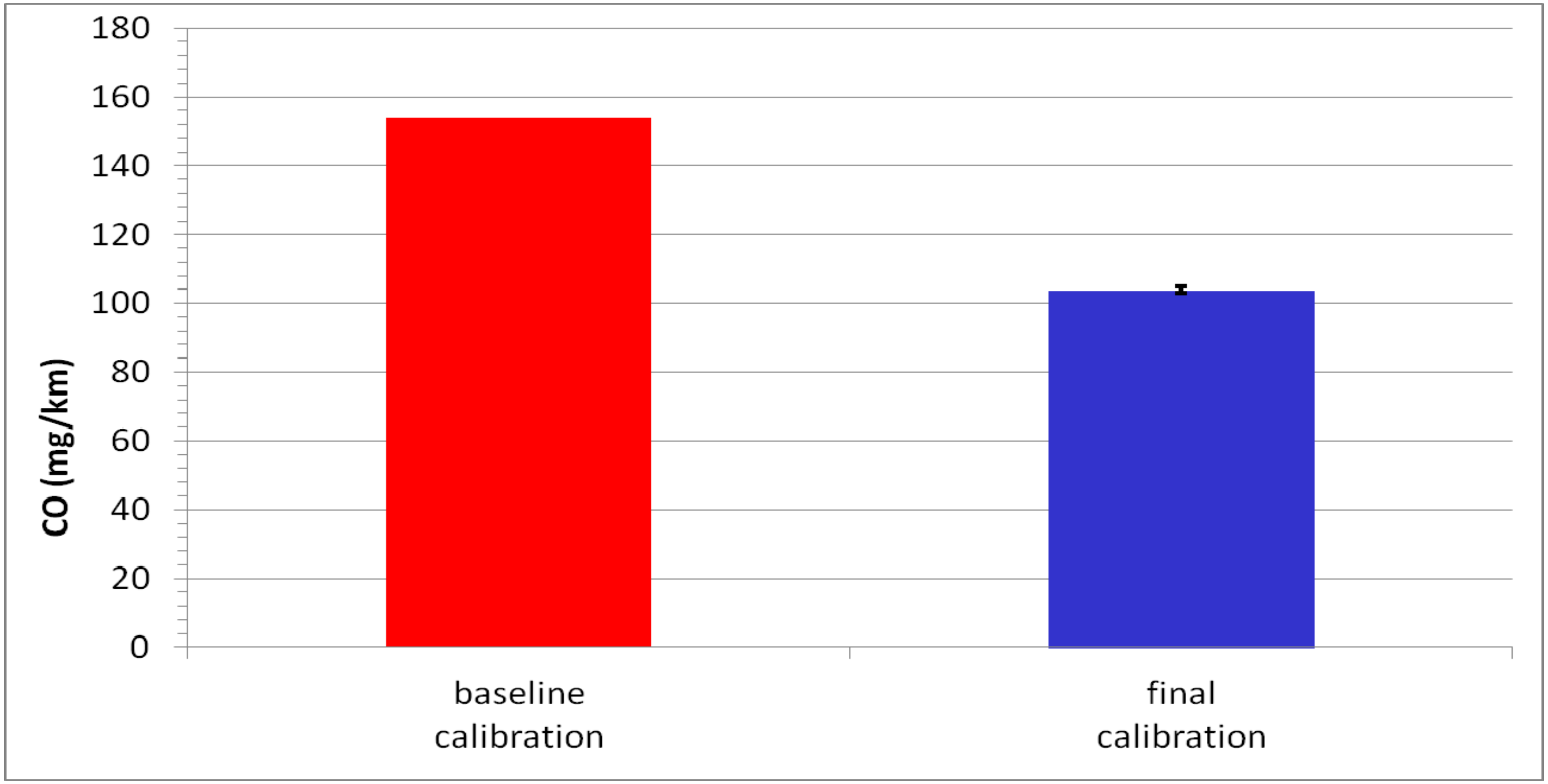


- The urea consumption to achieve this SCR efficiency would require refilling of a typical 16 litre tank at intervals of 6400 to 8000 km.

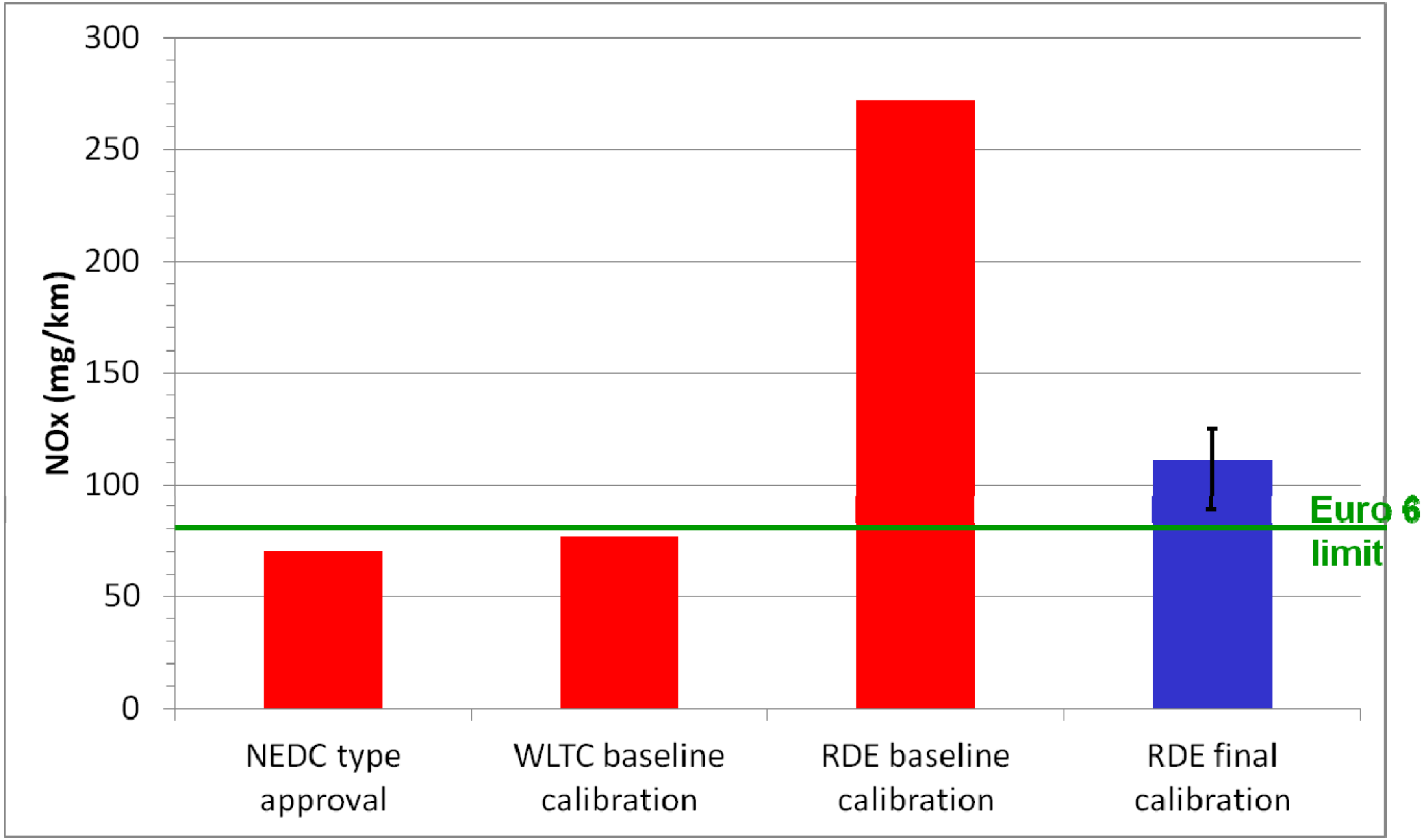
RDE CO emissions

baseline vs final calibration

- CO emissions were significantly below Euro 6 limits of 500 mg/km for all RDE tests.

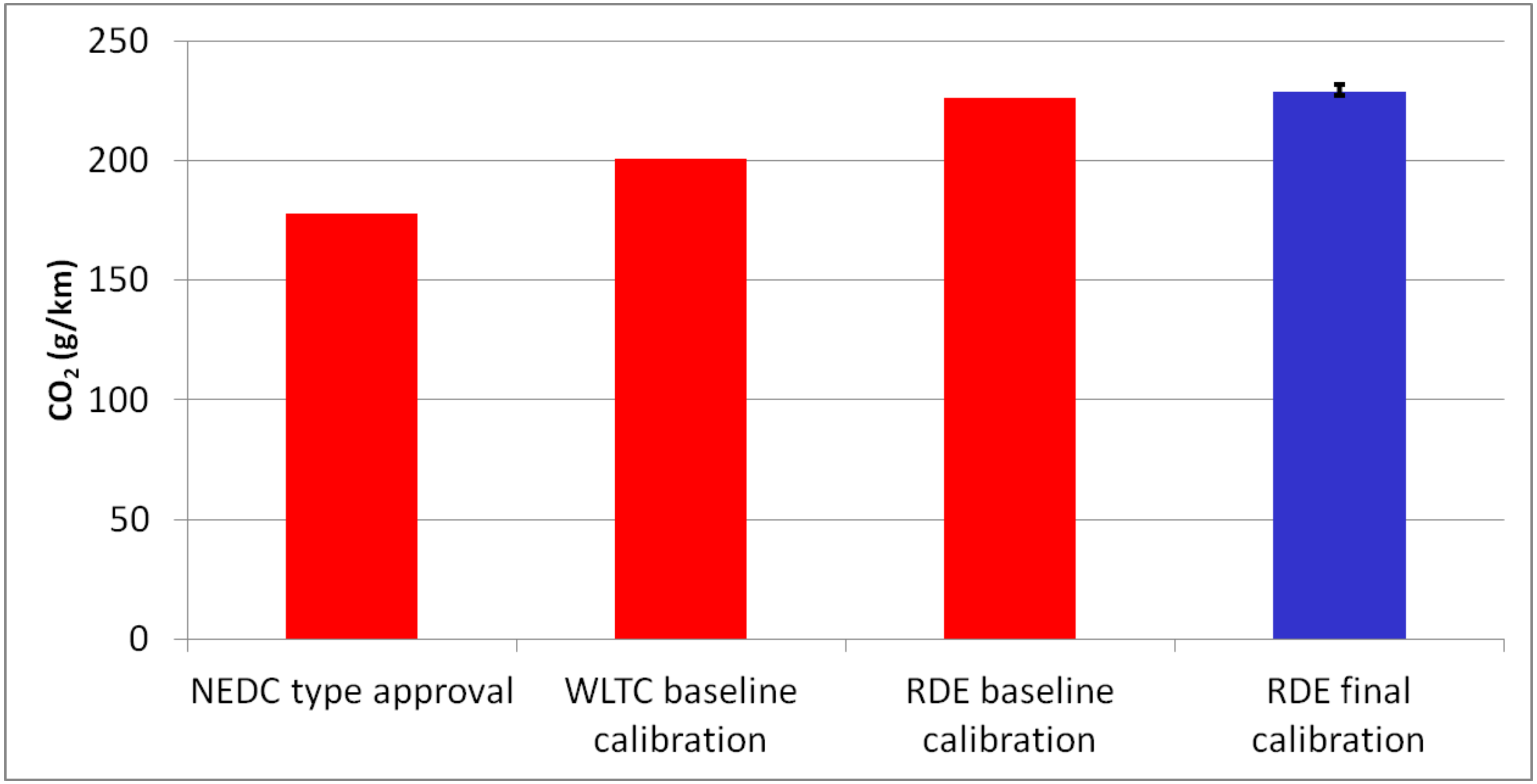


NOx emissions summary



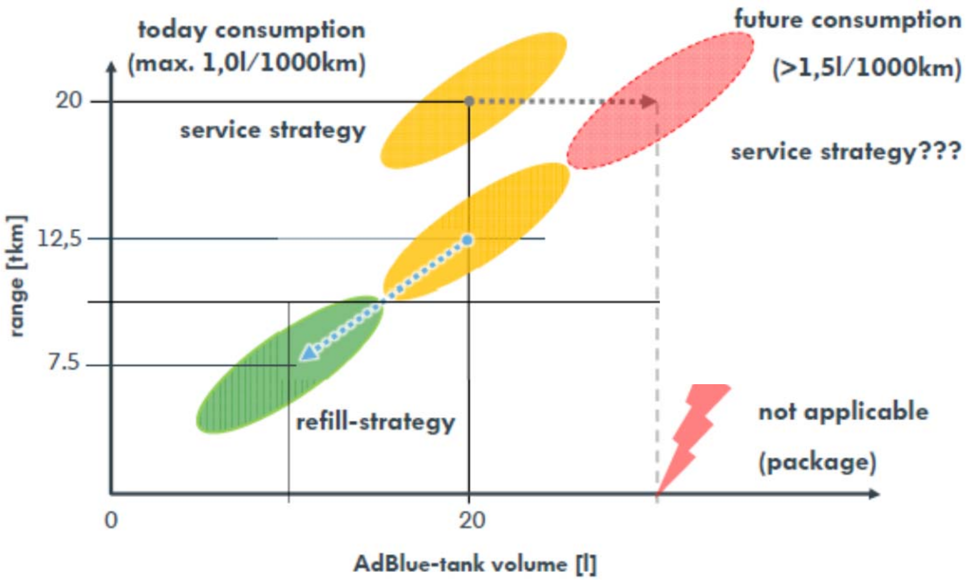
RDE CO_2 emissions

- CO_2 emissions over the RDE were slightly increased with modified calibration (0.5% to 2.6%; average 1.4%).



Urea consumption

- The modified calibrations confirm that as a result of full control to meet RDE requirements, urea consumption will increase,
- OEMs are understood to be planning for customer refill.



Source: Development of the AdBlue infrastructure for passenger cars, Garbe (VW), 6th International Conference SCR, Stuttgart, 28-29 April 2014

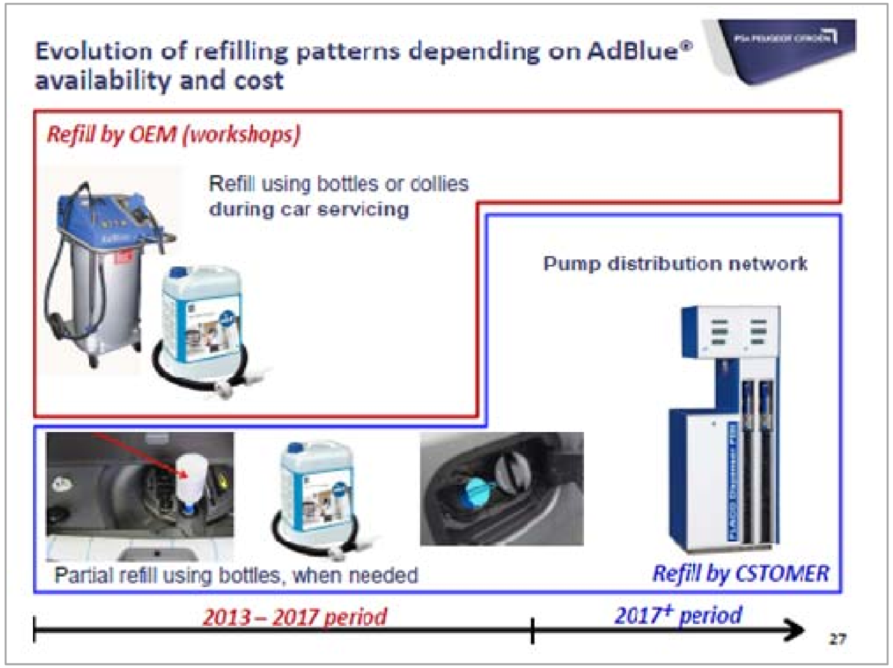
	Low Hypothesis	High Hypothesis
Annual Diesel car sales (PC + LDT) in Europe	7 350 000	7 350 000
SCR penetration	70%	90%
Average AdBlue® consumption (in liter for 1000 km)	1.35	2.5
CO_2 benefit	Limited	High
Refilling rate outside OEM network	< 60%	> 75%

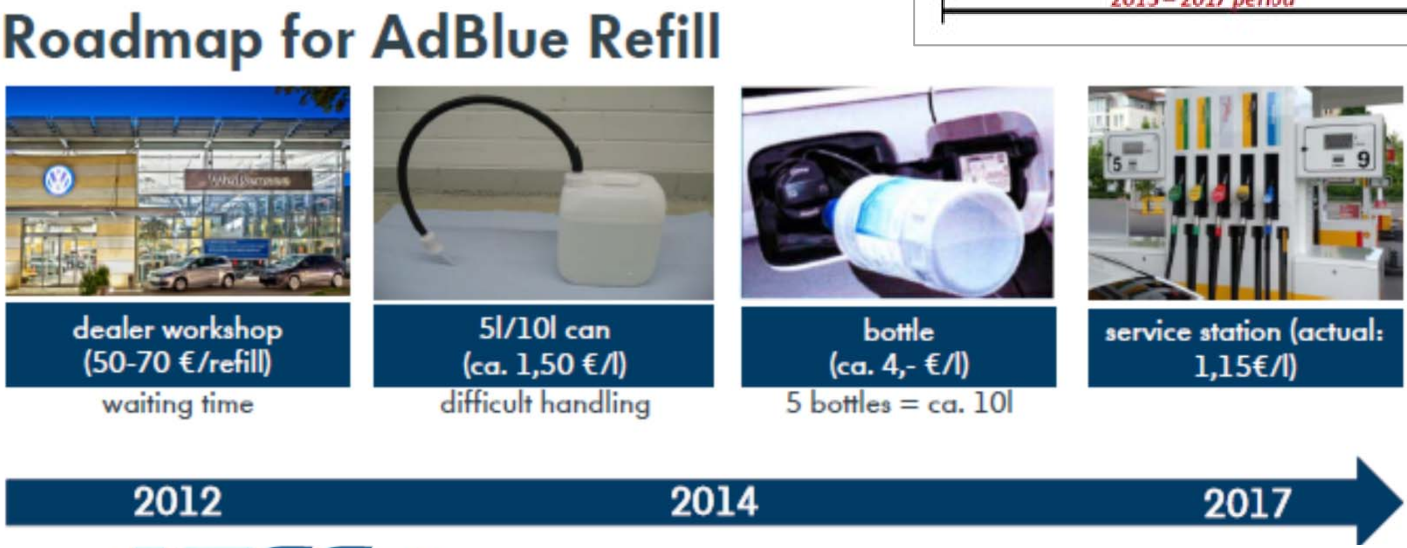
Source: Macaudière (PSA), SIA Diesel Conference, Rouen, May 2014

OEM planning for urea refill

- Urea tanks designed to accept bottles as an interim solution as well as pump distribution in filling station.

Source: Macaudière (PSA), SIA Diesel Conference, Rouen, May 2014





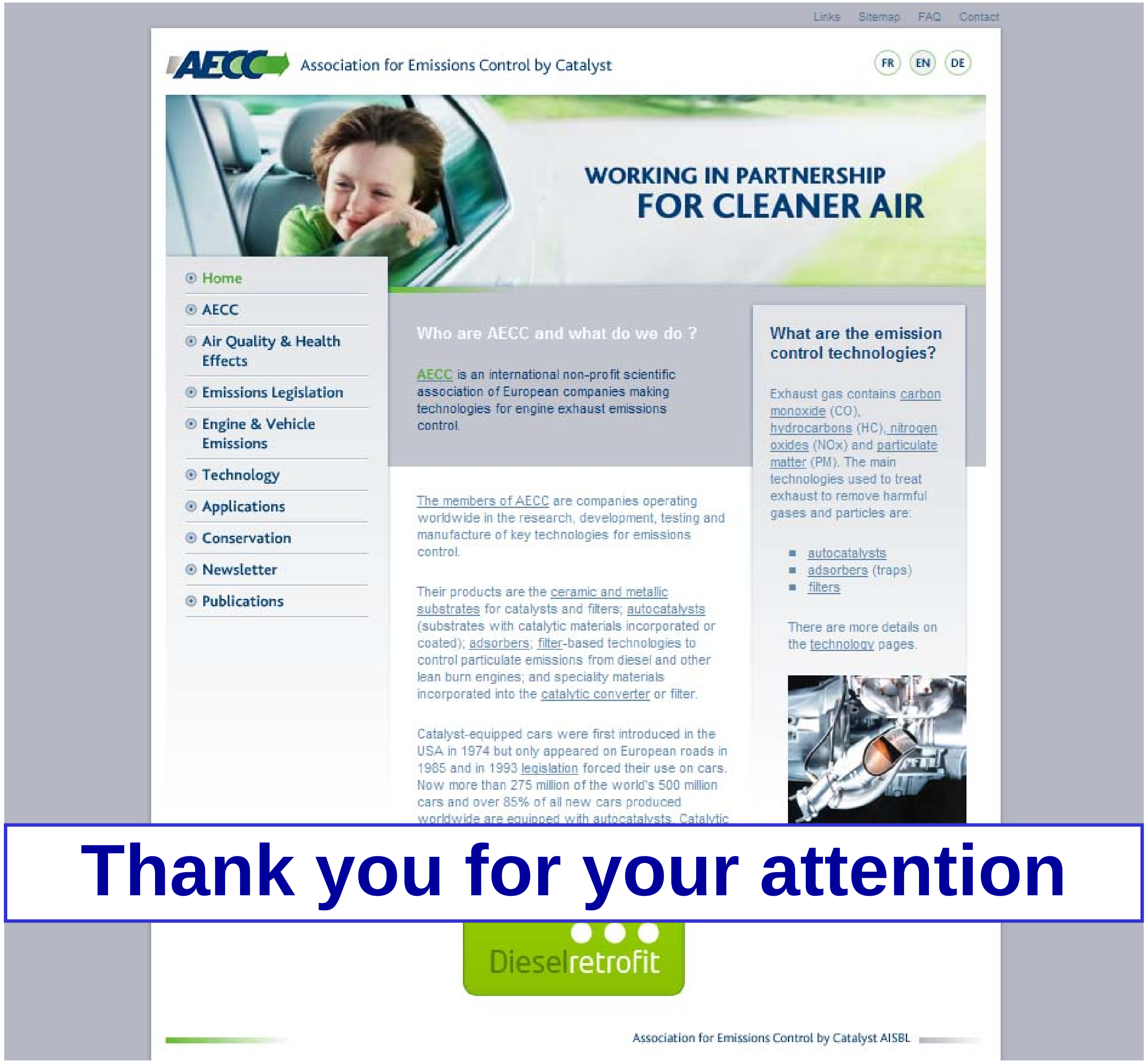
Source: Development of the AdBlue infrastructure for passenger cars, Garbe (VW), 6th International Conference SCR, Stuttgart, 28-29 April 2014

RDE testing

- RDE routes need to achieve a realistic balance of driving conditions.
- Neither routes nor analysis methods should exclude appropriate coverage of higher load points.
- Procedures and legislated Conformity Factors will be key to ensuring low emissions that can contribute to Member States meeting air quality targets.

AECC project on RDE NOx improvement: Conclusion

- To meet RDE requirements revised calibrations will be required using a combination of NOx control technologies.
- The Euro 6 test vehicle achieved a Conformity Factor for NOx of 1.1 to 1.6 with average 1.4% fuel economy penalty by combining the vehicle’s existing aftertreatment system with calibration adjustments.
- The final calibration gave good emissions and fuel economy performance without significantly deteriorating drivability.



Thank you for your attention