Department for Transport

Vehicle Emissions Testing Programme

Moving Britain Ahead

Cm 9259

April 2016

Vehicle Emissions Testing Programme

Presented to Parliament
by the Secretary of State for Transport
by Command of Her Majesty

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Ministerial foreword

We were all shocked when in September last year, Volkswagen confirmed that they had been using software in their cars, which caused the engines to behave differently during emissions tests compared to real world driving. Not only has this caused disruption and distress to the 1.2m Volkswagen users in the UK, it showed a lack of regard for the serious health consequences of nitrogen oxide (NOx) emissions and caused significant damage to the trust consumers have placed in car manufacturers across the country.

It was vital that we immediately started a UK investigation into whether other manufacturers were using equivalent prohibited devices and more broadly to better understand why emissions results in the real world were significantly different from those tested under laboratory conditions. We appointed Professor Ricardo Martinez-Botas, Professor at Imperial College London, to provide independent academic oversight of the Emissions Testing Programme.

Importantly our testing has found no evidence that other manufacturers are using software of the type used by Volkswagen. This finding is a significant step forward in assuring drivers that the serious breach of trust committed by Volkswagen is not more prevalent.

We also wanted to ensure that the actions that the UK and other countries across Europe are taking are going to resolve the longer standing issue here - that emissions of NOx from diesel vehicles are still too high. From next year, the introduction of real driving emissions testing as part of the approval testing will deliver significant improvements in emissions. While the results for some of the newest cars are within the limits of this new test, it is clear that there is still much work to do.

Air quality is a serious health concern and as a Government we are committed to its improvement. The car industry must rise to the challenge to ensure they deliver the emissions reduction I know they are fully capable of. We have a great car industry in the UK that continues to lead the world in innovation and technology. They must use this ability to rapidly cut emissions. We will not reduce the pressure until we see this change.

The UK Government, along with our EU colleagues, is committed to tackling this problem; we need to see the negative impact on health reduced. Whilst there is still a way to go, this report, combined with our other actions, puts us on the right path to significantly cut emissions and to achieve compliance with the required standards for air quality for people across the UK.

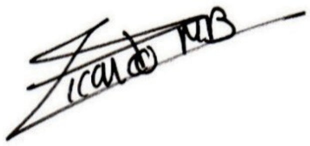
Robert Goodwill MP, Minister of State for Transport

Independent assessment

This program contributes directly to much needed evidence of the emissions of diesel light duty vehicles, particularly focusing on nitrogen oxide emissions. Comparative emission information for representative vehicles on UK roads has been gathered, contributing to restoring public confidence and to providing insights into emissions on the road. A series of tests were devised, both in the controlled environment of a test laboratory and on the test track, with the prime aim to capture actions that lead to the manipulation of the emissions control management system when it recognises the regulatory test cycle. Additionally, tests of all vehicles on the road with the associated variable conditions (traffic, driver behaviour, ambient temperature etc.) were performed. This is crucially important to understand the emissions expected in real world conditions and to quantify the magnitude of the emission gap between the road and the regulated laboratory based values.

I undertook to provide independent oversight of the testing program, confirming the integrity of the processes. This included the selection of a manageable set of representative vehicles sourced independently from the manufacturer. I was given full access, witnessing testing in all three independent test laboratories and assured myself of the appropriateness of the procedures. The testing of vehicles on a test track and public road needed the use of a portable emissions measuring system (PEMS), its installation was considered carefully and it compared well with the large laboratory static measuring equipment. It will be such equipment, and processes, that will form part of future EU regulations from 2017. The process of testing on the road under normal traffic and environmental conditions was planned carefully and it was repeated in a similar manner for each vehicle; again I was given open access and both witnessed a representative test and saw the processing of a set of results.

It is clear from the results that a large gap exists between the regulated nitrogen oxide (NOx) emissions measured under controlled laboratory conditions and on-the-road performance. This is true whether the comparison is made with test track results that followed the profile of the regulatory test cycle (NEDC), or in comparison with real driving emissions (RDE) conditions on the road. Future testing regulations will include a real driving emissions (RDE) testing element as part of the procedure for approval, and the tests in the laboratory setting will be more representative, with the new world-wide harmonized light duty vehicles test procedure (WLTP) replacing the NEDC. Both these measures aim to reduce the emissions gap. Vigilance will be needed to ensure that the gap does not grow again over time, as we know that higher NOx emissions in the real world lead to a substantial health impact to society.



Professor Ricardo Martinez-Botas, Head of Thermofluids Division, Mechanical Engineering Department, Imperial College London

Executive summary

1 On 18 September 2015 the Government became aware that Volkswagen Group had fitted software to their vehicles that distorted emissions test results for nitrogen oxides (NOx). We take these unacceptable actions of Volkswagen extremely seriously and have held discussions with them to ensure that UK customers' vehicles are rectified as soon as possible. But we also wanted to check whether this practice is more widespread, to ensure that it cannot happen again, and to better understand the reported wider discrepancy between tested and real world emissions. To do this, we set up the Emissions Testing Programme to look for “defeat devices” and to understand the real world emissions performance of a broad selection of the best-selling vehicles in the UK.

2 We are very pleased that a range of other countries have also responded decisively and retested vehicles to check for defeat devices and measure real world emissions. This gives us further confidence in our results as the publications so far have come to similar conclusions. We look forward to seeing the results from other countries and institutions that will continue to add to this important body of evidence.

3 Our first step was to engage with industry to secure their commitment that similar devices were not in use. The Vehicle Certification Agency secured assurances from all automotive manufacturers, outside the Volkswagen Group, for whom it had issued emissions type approvals that prohibited defeat devices had not been used. We also wanted to be sure that this was the case by testing the vehicles ourselves.

4 Our tests have not detected evidence of test cycle manipulation strategies as used by the Volkswagen Group. However, tests have found higher levels of nitrogen oxide (NOx) emissions in test track and real world driving conditions than in the laboratory for all manufacturer’s vehicles, with results varying significantly between different makes and models.

5 We discussed the results with manufacturers in order to understand better their emissions control systems. We were told by manufacturers that the emissions control strategy for NOx is less effective at lower temperatures in order to ensure durability and protect the engine from damage. It is clear from our investigation that further improvements to European regulations will help avoid any uncertainty in how the systems are allowed to operate in the future. Manufacturers also explained how other factors relating to the unrepresentative nature of the current laboratory type approval test, the New European Drive Cycle (NEDC) and associated set-up procedures contributed to our findings of higher real world emissions.

6 Improving air quality is a priority for the Government and we are committed to meeting air quality limits for NO_2 in the shortest possible time. In December 2015 Defra published a *National Plan*[1] which sets out a comprehensive approach to meet this goal. The largest source of nitrogen oxide emissions in the areas of greatest concern are diesel vehicles. The UK Government had already been working with the

[1] https://www.gov.uk/government/publications/air-quality-in-the-uk-plan-to-reduce-nitrogen-dioxide-emissions

EU to develop new vehicle emissions tests and to encourage their early introduction to tackle this problem.

7 We have pushed hard to ensure that Real Driving Emissions (RDE) tests will apply to new models that are to be sold from 2017 within the European Union. The RDE agreement makes type approval requirements for vehicles significantly more stringent, with the greatest impact expected for diesel NOx emissions. Manufacturers will continue to have to meet the limits in laboratory tests but will also have to improve their real-world emissions control to meet the RDE requirements. The new European legislation requires manufacturers to ensure real-world emissions are maintained below 2.1 times the lab-testing limit from 2017 and are at or below the limit by 2020 (with a 0.5 margin for measurement uncertainty).

8 We have also been actively supporting the introduction of the new world-wide harmonized light duty vehicles test cycle and procedure (WLTC and WLTP). This is expected to be introduced in 2017 and will address short-comings of the existing laboratory NEDC type approval emissions test. This includes the introduction of some emissions testing at a more representative 14°C, closer to the UK average ambient temperature of 9°C.

9 Whilst our testing results are only a partial cross-section of vehicle emissions across a range of models, they suggest that manufacturers need to work hard to quickly improve the emissions performance of their vehicles ahead of the introduction of WLTP and the first RDE targets in 2017.

10 Even before the introduction of the new requirements, we are urging manufacturers to introduce new technologies to reduce emissions sooner than the new EU regulations require. Some manufacturers have announced that they intend to make changes to vehicles already in use, to improve emissions, and will offer this to customers on a voluntary basis. We welcome this and encourage action from other manufacturers.

1. Introduction

1.1 In September 2015 the United States Environmental Protection Agency (EPA) alleged that diesel passenger cars manufactured by the Volkswagen Group had been fitted with defeat devices. Following this disclosure, Volkswagen announced that 11 million vehicles were affected worldwide with 1.2 million of those in the UK.

1.2 The Secretary of State for Transport ordered an investigation to establish whether the use of these strategies was wider than the Volkswagen Group. This involved the retesting of the most popular diesel vehicles in the UK to allow us to provide clear information to the public and reassure them that we are taking appropriate action.

1.3 In addition, this programme was designed to help quantify the divergence of on-road emissions from those measured in laboratories during the type approval process, and to help understand the variation between the current emissions standard (Euro 6) and its predecessor (Euro 5).

1.4 Other countries also set up programmes to retest diesel vehicles at the same time as the UK. We agreed with Germany that our technical teams would work cooperatively together and we have also been in contact with other EU partners throughout the test programme to discuss our methodology and findings. We look forward to seeing the results of other testing programmes over the coming months.

1.5 This report sets out the context in which testing was undertaken. It then sets out how the tests were undertaken and presents the high level results.

1.6 Whilst the testing was not a comprehensive review of all vehicle emissions, we went to significant lengths to ensure that the sample we tested was representative of the UK car fleet as a whole, that the vehicles were tested using the latest technology for best accuracy, and that the tests took into consideration conditions and environmental factors. We also ensured that testing was carried out completely independently of vehicle manufacturers, and was independently verified.

2. Policy context

2.1 In order to be able to properly interpret the results of this work, it is important to understand the relationship between emissions and ambient air quality at the road side, as well as the existing testing regime being used to enforce emissions standards.

2.2 Poor air quality is detrimental to health and the Government is committed to reducing the levels of pollutants which are causing these health problems. Over recent decades, UK air quality has improved significantly (Figure 2-1). Between 1970 and 2014 sulphur dioxide emissions have decreased by 95%, particulate matter (PM10) by 73%, PM2.5 by 76% and nitrogen oxides (NOx) by 69%. However, meeting the nitrogen dioxide (NO_2) limit values close to busy roads continues to be a significant challenge. In areas where these limits are exceeded, on average transport is responsible for 80% of roadside nitrogen oxides.

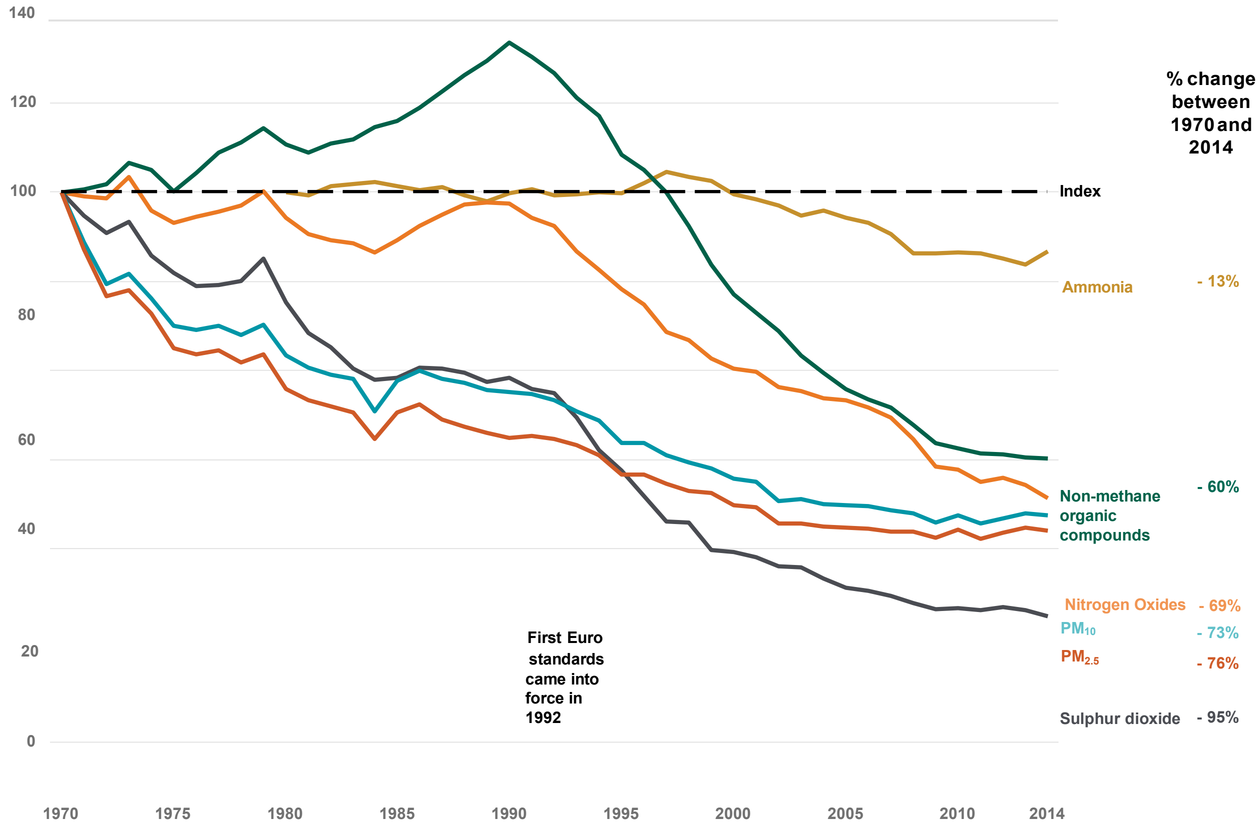


Figure 2-1 UK National emissions of air pollutants

2.3 This Government is committed to improving air quality. Our plans to do this, published last December, set out a comprehensive approach for meeting EU legal limits. This includes a new programme of Clean Air Zones, which aims to tackle the most polluting vehicles in the cities where we have the greatest air quality problems, alongside national action and continued investment in clean technologies.

2.4 Diesel engines play a significant role in causing poor air quality at the road side. The diesel engine combustion process is more fuel efficient and typically results in low emissions of carbon monoxide and hydrocarbons. However, a diesel engine, by its nature, tends to produce higher emissions of NOx and particulate matter than a petrol engine. These two emissions are the most important in relation to health.

2.5 Diesels make up 38% of the British licensed car fleet. This has grown from only 7% in 1994 due to a number of factors including the better fuel efficiency, lower CO_2, and greater choice of diesel car models. Diesel is also the only widely available fuel for larger vehicles including buses and HGVs.

2.6 The effectiveness of emissions reduction standards in relation to diesel is a key part of work to tackle poor air quality at the road side. The first 'Euro' emission standard, Euro 1, was introduced in 1992. The NOx limit in the current Euro 6 standard, introduced in 2014, is over 90% lower. However emerging evidence has shown that the main reason that air quality standards have not improved, despite these increasingly stringent regulatory standards, is that vehicles in the 'real world' are not performing as well as when tested in the laboratory (Figure 2-2). This is now recognised across Europe and we have led action and helped secure agreement at European level to introduce real driving emissions testing in 2017 so that diesel vehicles deliver the expected emission reductions on the road as well as in the laboratory. The success of the new testing regime is key for all the countries in the EU to see the improvements in air quality so urgently needed.

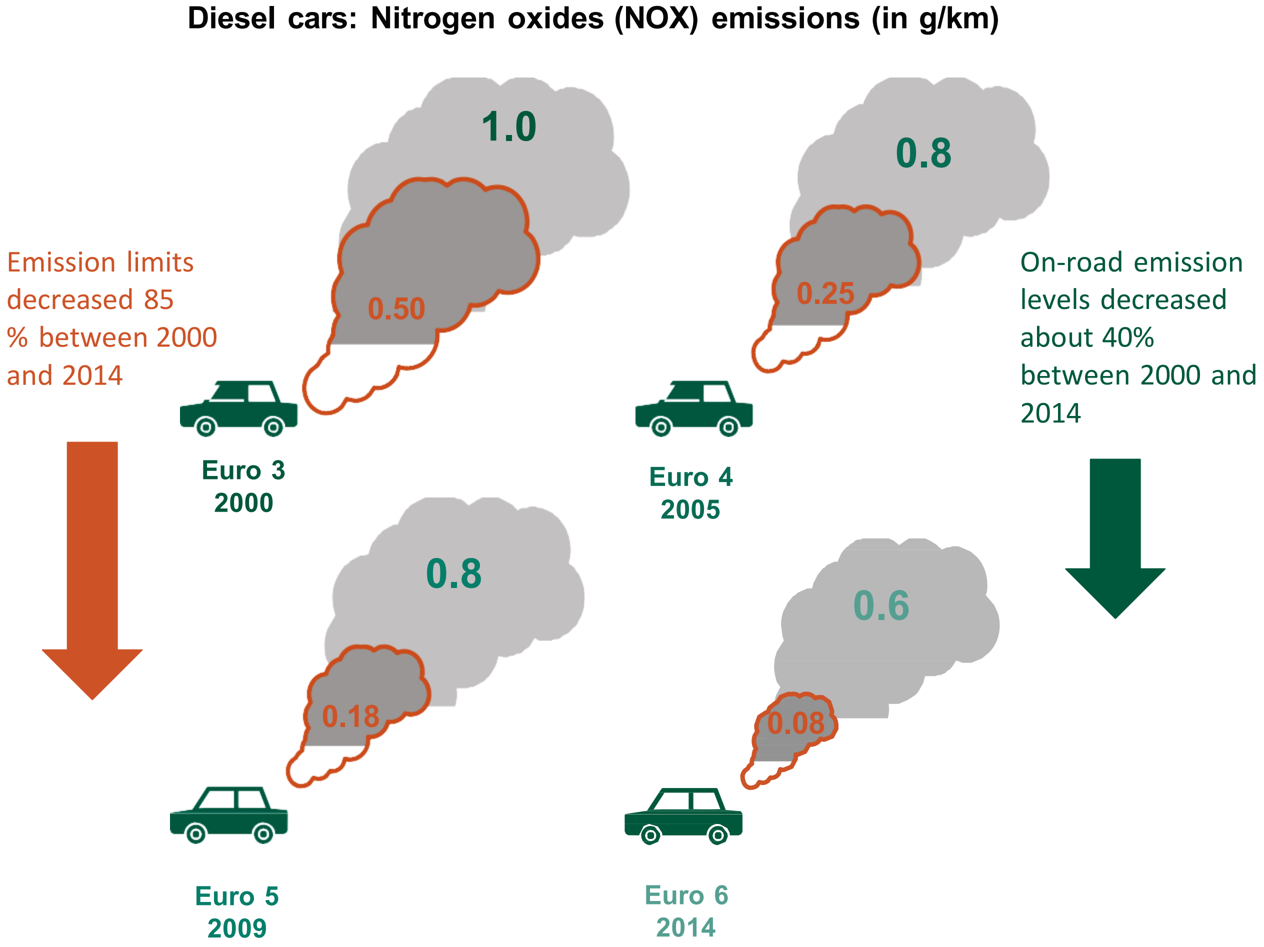


Figure 2-2 Difference between emissions limits and on-road measured values (sources: Carslaw 2011, ICCT, 2014)

The current new vehicle approval regime

2.7 New vehicles must be designed to comply with a comprehensive set of legislative requirements. These are designed to ensure that vehicles are safe and their environmental impacts are controlled. Before placing a new vehicle design on the EU market a manufacturer needs to secure type approval to demonstrate that it conforms to the relevant safety and environmental standards.

Type Approval

2.8 Type approval is the process by which new vehicles are assessed. A vehicle is currently tested against around 60 different standards or regulations before approval is granted. The tests are carried out by technical service organisations on behalf of Type Approval Authorities. Once proof that the vehicle complies with the necessary requirements has been submitted to the Type Approval Authority, it will issue a Type Approval Certificate to the manufacturer. Only then can the manufacturer start selling the vehicle.

2.9 The current emissions related type approval requirements in Europe are covered by Regulation (EC) N°. 715/2007[2] and several supporting technical European Commission regulations. The regulated emissions are carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NOx) and particulate matter. Particulate matter is regulated both in terms of total particle mass (PM) and also as a count of the number of solid particles (PN).

2.10 The main type approval emissions test is the New European Drive Cycle (NEDC) test which is run on a chassis dynamometer (or 'rolling road') in a laboratory. The test cycle is over 20 years old and has been criticised as not representative of real-world driving. It is planned to be replaced by the world-wide harmonized light duty vehicles test procedure (WLTP) in 2017.

2.11 Alongside the laboratory emissions test, a new Real Driving Emissions (RDE) test is also being introduced in 2017 as part of the type approval requirement. This test will be conducted on public roads using a portable emissions measuring system (PEMS),

2.12 The automotive industry has developed a range of technologies to meet the increasingly stringent and challenging emissions limit for NOx. These technologies, often used in combination with each other, can significantly reduce the NOx emissions of a diesel vehicle. A list of the various technologies that are used to meet the legislative limits is set out in Annex B.

Defeat device regulations

2.13 In broad terms, a defeat device is a system which results in a vehicle producing significantly higher emissions in normal use than it does when being subjected to the official laboratory emissions test. Authorities across the globe have specifically identified those technologies, known as 'defeat devices', and set out when they are prohibited and a few specific circumstances when their use is considered acceptable. Importantly, defeat devices are defined as reducing the effectiveness of the vehicle's emissions control, therefore resulting in higher exhaust emissions. In other words, a

[2] Regulation (EC) No 715/2007 of the European Parliament and of the Council of 20 June 2007 on type approval of motor vehicles with respect to emissions from light passenger and commercial vehicles (Euro 5 and Euro 6) and on access to vehicle repair and maintenance information.

defeat device would not operate during the official laboratory test, but would become 'active' in specific real-world use conditions.

2.14 The United Nations Economic Commission for Europe (which develops global vehicle regulations), the European Commission and the US Environmental Protection Agency all have similar definitions of what constitutes a defeat device, and requirements prohibiting their use. However each also specifies certain situations in which this prohibition does not apply. For example, it is permissible to reduce the effectiveness of a vehicle's emissions control system under certain conditions if this is necessary to prevent engine damage, or to ensure that the vehicle can still be operated safely. The full text of the regulations is included at Annex A.

3. Establishing the testing programme

3.1 This testing programme was designed to test a range of the best-selling passenger cars in order to ascertain whether there was evidence of systematic use of defeat devices and to inform policy makers on the general trends in vehicle emissions. The programme selected an independent and representative sample of vehicles to test in a variety of conditions using the latest technology.

3.2 The programme was not designed to be a comprehensive study of the entire vehicle fleet. For example it did not include tests on vans, trucks or buses. Whilst we are confident of the indication of real world emissions it shows us for cars, it cannot be used to conclude outcomes for the full fleet.

Choosing our sample of vehicles

3.3 We undertook a study of buying preferences over each of the years 2010 – 2015 and aggregated the findings to establish the list of the 100 top selling diesel vehicles. Our aim was to capture 75% of sales of the top 70 vehicles, representing more than 50% of all diesel passenger cars licensed and in use on UK roads. Our final selection had to consider vehicle availability and timing constraints however we ensured that all major manufacturers were represented in our vehicle selection.

3.4 Further consideration of the vehicle list identified a degree of engine sharing across a manufacturer’s model range and between brands. While it could not be concluded that engine calibration or exhaust after treatment would necessarily be common it was considered that it would be reasonable to rationalise the programme by testing a single application of a particular engine type.

3.5 We are satisfied that we have tested a representative selection of the vehicles used on UK roads, including a sample of the newest and the UK’s top selling vehicles. The vehicles were close to evenly split between those produced to conform to Euro 5 emissions limits and Euro 6 limits.

3.6 A list of the specifications of the vehicles we tested is included at Annex C.

Selecting suitable vehicles

3.7 We were clear that the testing needed to be independent of the manufacturers to make sure that the vehicles were representative of those in use on our roads and that they had not been subject to any interference or modification. For this reason we sourced the vehicles from car hire fleets.

3.8 Vehicles assessed in the programme were required to have completed no more than 30,000 miles and were checked for defects before being introduced into the programme. The fuel was replaced with a typical winter grade diesel[3], and this fuel

[3] In the winter, UK garages stock winter grade diesel which has been treated with additives to prevent gelling in cold temperatures.

was kept consistent across all tests. They were then put through the New European Drive Cycle (NEDC) test which is the current official legislative test used in the laboratory to establish compliance with the regulated emission requirements.

Number of tests

3.9 The small sample size means that our results show a snapshot of the emissions picture from the vehicles, rather than providing a definitive value of performance for each model. However we have seen results of the same magnitude from testing programmes in other countries and across the range of vehicles that we have tested.

Testing locations

3.10 As with the vehicles, we made sure that the laboratories were independent of the vehicle manufacturers. The testing was undertaken at a selection of commercial laboratories across the UK, following an open procurement competition.

3.11 The Real Driving Emissions testing was undertaken from the Vehicle Certification Agency's site in Nuneaton, using Portable Emissions Measuring System (PEMS) equipment that had been procured for this programme or were owned by the commercial laboratories.

4. Undertaking the testing

4.1 The principal aim of our testing programme was to understand whether there is evidence of use of defeat devices or cycle recognition strategies by manufacturers other than the Volkswagen Group. For this reason, much of the testing revolved around the use of the New European Driving Cycle (NEDC), which is the current emission test for vehicles in type approval and therefore the cycle that such strategies would be designed to recognise.

4.2 The test programme was constructed around variations of this cycle with testing being undertaken both in emissions laboratories and on test tracks. Further tests were conducted on public roads to establish the emissions performance of the vehicles in typical real-world use conditions.

Laboratory testing

4.3 We first carried out the official legislative NEDC test for each vehicle as part of our initial check that its emissions system was functioning as it had been when that model was presented for type-approval. This test is known officially as the "Type I" test but we have referred to it as the "cold" NEDC as the engine is not warmed up prior to the test. The vehicle is given a standard pre-conditioning test, then left in a temperature controlled room so that the whole vehicle including engine oil and coolant is 'soaked' to a temperature between 20 and 30°C as specified in the regulations. Following that the official test is run with emissions recorded from engine start.

4.4 We then ran a series of variations of the NEDC test. These tests aimed to ensure that if a vehicle was able to detect the official NEDC test, it would no longer recognise that it was being tested and would start to show a different emissions profile. These variations consisted of:

- A hot NEDC test - the same test cycle, but starting with a fully warmed up engine.
- A hot double NEDC test - running two consecutive NEDC tests, recording emissions for both, to assess the consistency of the results.
- A hot 'reversed' NEDC test - in which the higher speed section of the test, which usually takes place at the end, was conducted at the beginning of the test.

4.5 In the laboratory we attached Portable Emissions Measurement System (PEMS) equipment to each vehicle (Figure 4-1) and used this alongside the laboratory emissions measurement system of Constant Volume Sampling. This was to check that the PEMS equipment was accurately calibrated for when we used it for the later track and road testing.

Track testing

4.6 The track test element of the programme was designed to replicate, as far as practicable, testing in the laboratory. We conducted tests on a track measuring emissions using the PEMS equipment fitted to each of the vehicles. We recreated the hot NEDC tests which had been run in the laboratory by providing the driver with a screen showing a trace of the speed that they needed to maintain for each section (as is done in the laboratory test). In addition we ran a hot NEDC + 10% test in which the speeds of the test cycle were increased by 10% compared to the standard test. The track tests were designed to check that the vehicle was not set up to recognise when it is being driven on a chassis dynamometer or 'rolling-road'. While there are legitimate reasons for a vehicle to recognise that it is being used on a dynamometer, such as to deactivate certain safety systems when only two of its wheels are turning, the track testing allowed us to check whether this affected the performance of the emissions system.

Figure 4-1 Portable emissions measurement system (PEMS) installed in a test vehicle

On road testing

4.7 The final part of our testing of a vehicle was to use it on the road in an approximation of a Real Driving Emissions (RDE) test. The RDE requirements have not yet been fully defined so this was only indicative of the test that new vehicles will take from 2017, but it allowed us to estimate the current gap between how vehicles perform in the laboratory and their emissions in the real world. This element involved driving the vehicle for approximately 1.5 hours over a test route on public roads. The route included urban, rural and motorway driving and tests were carried out during the day in normal traffic conditions.

Manufacturer meetings

4.8 During our testing programme whenever we recorded notably high emissions results for a given vehicle we contacted the manufacturer. We invited them to meet with us to discuss the results. We asked them to explain the results we had measured and describe the emission control strategies used in their vehicles.

4.9 These discussions provided insight into the various reasons why a vehicle may achieve the legal emissions limit when tested on the official test cycle, but may emit significantly higher emissions in other situations. In the following chapter we summarise these reasons.

5. Results and analysis

5.1 In this chapter we present the key results from our test programme. We also present an analysis of the reasons for the results we found.

5.2 For each vehicle, the results from the laboratory, track and road tests were collated. These were reviewed to check for missing data and ensure no errors had been made during testing. Emissions were calculated using the procedure specified by the regulations.

5.3 We have summarised our results into three main sections:

- Cycle recognition - checking whether vehicles were equipped to detect the official legislative test cycle and adopt a different emissions control strategy.
- Laboratory and track test emissions - summarising the results of the various NEDC tests carried out both in the laboratory and on the test track.
- On road emissions - examining what levels of NOx emissions are typically produced during real driving on public roads in the UK, covering urban, rural and motorway use.

Cycle recognition

5.4 Our testing has not found any evidence of the use of cycle recognition strategies in any of the vehicles tested, except those of the Volkswagen Group. Other manufacturer's vehicles did not appear to be able to recognise when they were being tested in the laboratory and so change the emissions strategy of the engine.

5.5 Before starting our programme we conducted initial tests on Skoda vehicles. Skoda are part of the Volkswagen Group and the UK's Vehicle Certification Agency had issued the emissions type approval for them. These vehicles were ones which Volkswagen had identified as having the cycle detection software.

5.6 Figure 5-1 shows two NEDC tests conducted on the same Skoda vehicle. In the first, a standard NEDC test was run and the measured NOx emissions are shown by the orange line. In the second test, the higher speed section of the test, which usually takes place at the end, was conducted at the beginning of the test. The emissions for this test are shown by the green line.

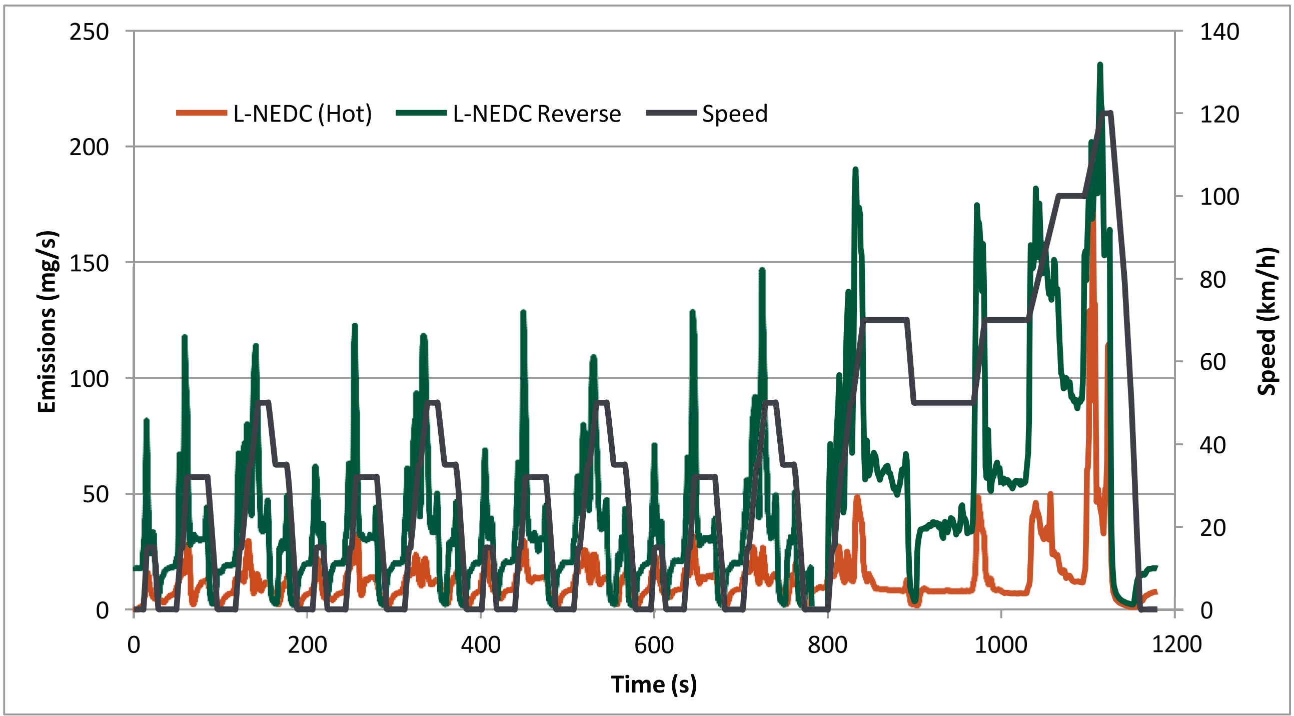


Figure 5-1 Comparison of NOx emissions on NEDC tests showing impact of Volkswagen Group cycle recognition software

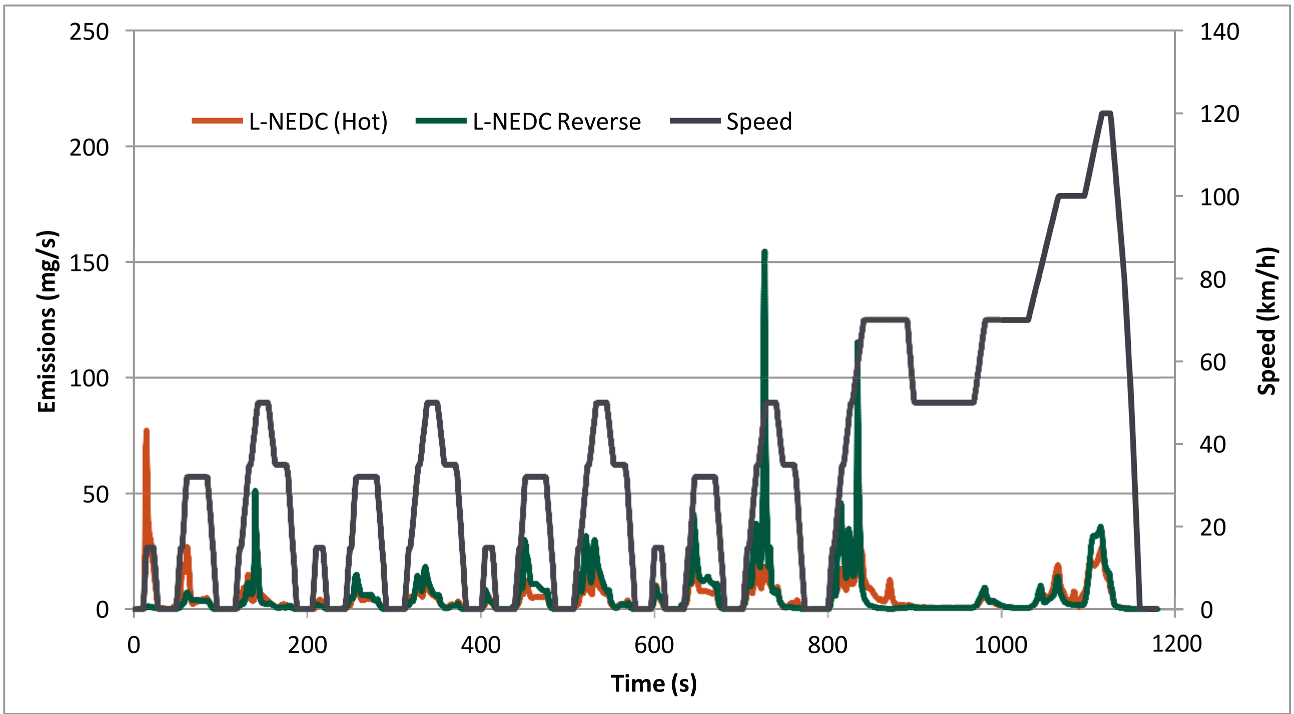


Figure 5-2 Comparison of NOx emissions on NEDC tests showing vehicle which does not appear to vary emissions behaviour.

5.7 In the first test, the vehicle has detected the official test cycle and the emissions shown by the orange line are relatively low, but in the second test, the vehicle has not recognised that it is being tested, and its emissions are much higher - as shown by the green line. (Note that in order to make this comparison the results of this test have been switched round again so that the high speed section is at the end).

5.8 An example of the same comparison for a vehicle which does not show significant variation in emissions behaviour is shown in Figure 5-2. This was another Volkswagen Group vehicle, but this time the latest Euro 6 VW Golf. The results indicate that this vehicle does not have the cycle recognition software.

5.9 These results demonstrate that the series of tests being used was appropriate to detect that a vehicle was recognising when it was being tested and was adjusting its emissions strategy accordingly.

5.10 The results of the hot double NEDC, the hot reversed NEDC, and the NEDC+10% tests for all other vehicles showed no evidence of cycle recognition software being used by other manufacturers.

Laboratory and track test emissions

5.11 The next stage of our test programme was to compare and examine in more detail the differences between the emissions results from the official legislated 'cold' NEDC laboratory test and those generated in other conditions.

Cold versus 'hot' NEDC - laboratory results

5.12 The first step was to compare the 'cold' and 'hot' NEDC test results in the laboratory. All the Euro 5 vehicles tested met the legislated 180 mg/km limit on the 'cold' NEDC (allowing a 5% tolerance to take into account mileage and service history). However on the 'hot' test, with a fully warm engine, our results show a significantly greater spread - while some vehicles continue to meet the limit, the highest was 2.4 times higher. On average the results were 21% higher than the limit (Figure 5-3 left hand side).

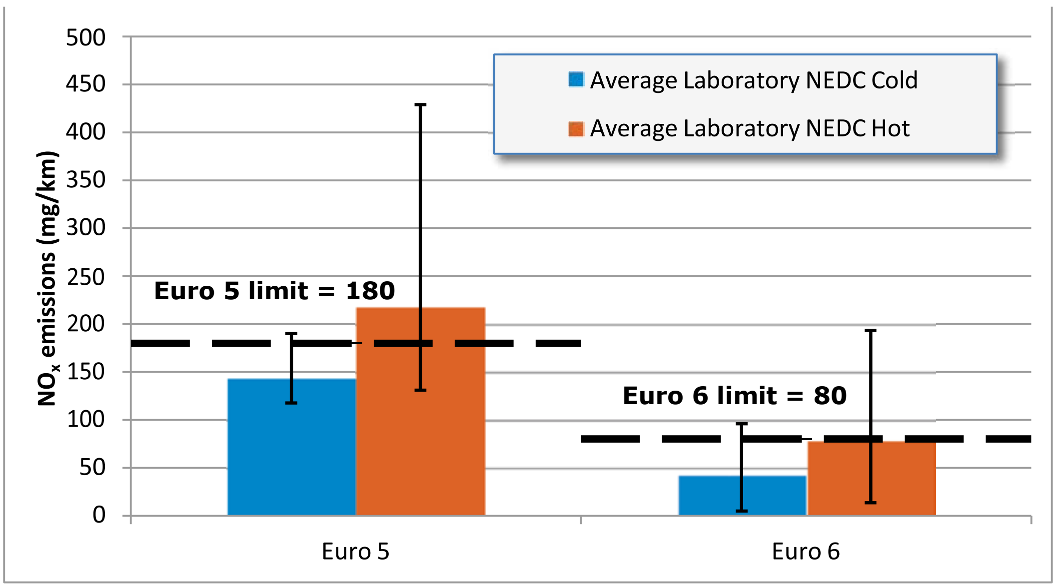


Figure 5-3 'Cold' versus 'hot' NEDC NOx emissions - lab results

5.13 The results of Euro 6 vehicles are shown on the right in the same figure. On average the Euro 6 vehicles tested achieved 41 mg/km on the official 'cold' NEDC test. The 'hot' NEDC results again showed significantly higher emissions, although the average of the results was 78 mg/km - still within the legislated limit. Again there was a greater spread in the results, with some vehicles well below the limit, while the highest was 2.4 times above.

5.14 Details of individual vehicle results are available in annex D.

'Hot' NEDC in the laboratory versus 'hot' NEDC on the track

5.15 In the test track environment it is not possible to 'soak' the whole vehicle including engine oil and coolant to the specified 20-30°C temperature for the official 'cold' NEDC test. For this reason, all track test work was conducted with a fully warmed engine.

5.16 A comparison can therefore be made between the 'hot' NEDC test run in the laboratory to a 'hot' NEDC test on the test track. Figure 5-4 shows the lab versus track results for the Euro 5 and 6 vehicles.

5.17 It is immediately obvious that emissions on the test track are much higher than those from the laboratory. For Euro 5 vehicles they are on average over five times higher. For Euro 6 vehicles, the track results are on average four and a half times higher than for the laboratory. However it is notable that our results show that the track test emissions from the Euro 6 vehicles are over 70% lower than those for Euro 5.

5.18 Details of individual vehicle results are available in annex D.

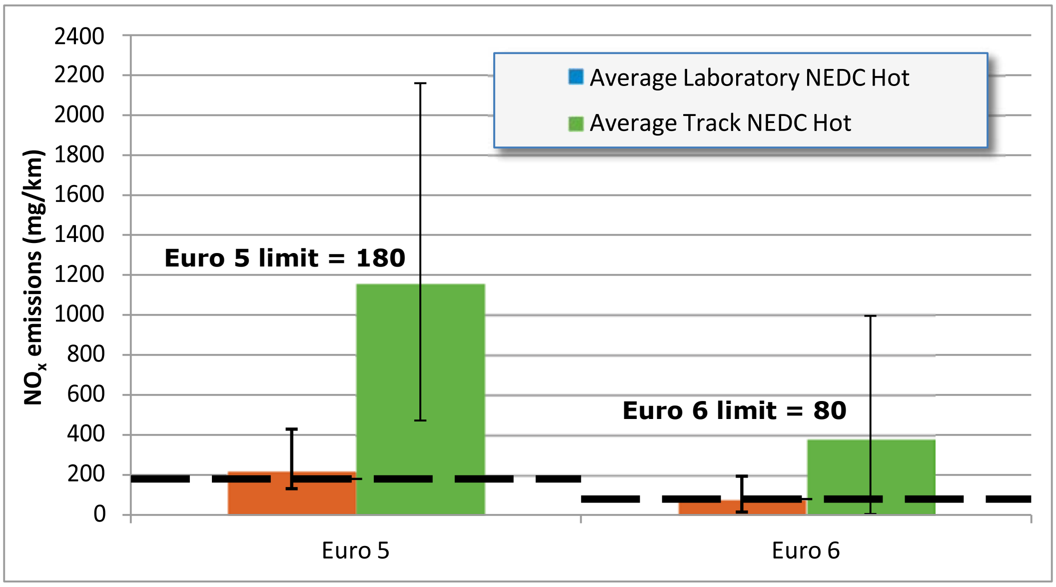


Figure 5-4 Comparison of 'hot' NEDC in lab and on the track

On road emissions

5.19 By its nature, conducting emissions tests on public roads means that there will be test to test variability. There are a number of factors which may have affected results:

- Traffic conditions - while a set route was used, traffic conditions and congestion will inevitably have varied between tests.

- Driving style - wherever possible, differences in driving style were minimised, however this may still have had an impact.
- Weather conditions - ambient temperature and pressure varies from day to day and the road surface may have been wet or dry.

5.20 Figure 5-5 shows the overall NOx emissions from the on road tests for the Euro 5 cars. The average NOx emissions of all vehicles tested is shown by the horizontal red line, while the horizontal dotted black line is the 180 mg/km type approval limit. It can be seen that all of the results are substantially higher than this limit, with the best results being about three times higher, and the worst about ten times higher. However it is important to note that these results are not directly comparable to each other as the exact test conditions varied from test to test.

5.21 On average our measured road test NOx emissions from Euro 5 vehicles were 1135 mg/km - over six times higher than the 180 mg/km official legislative NEDC laboratory test limit.

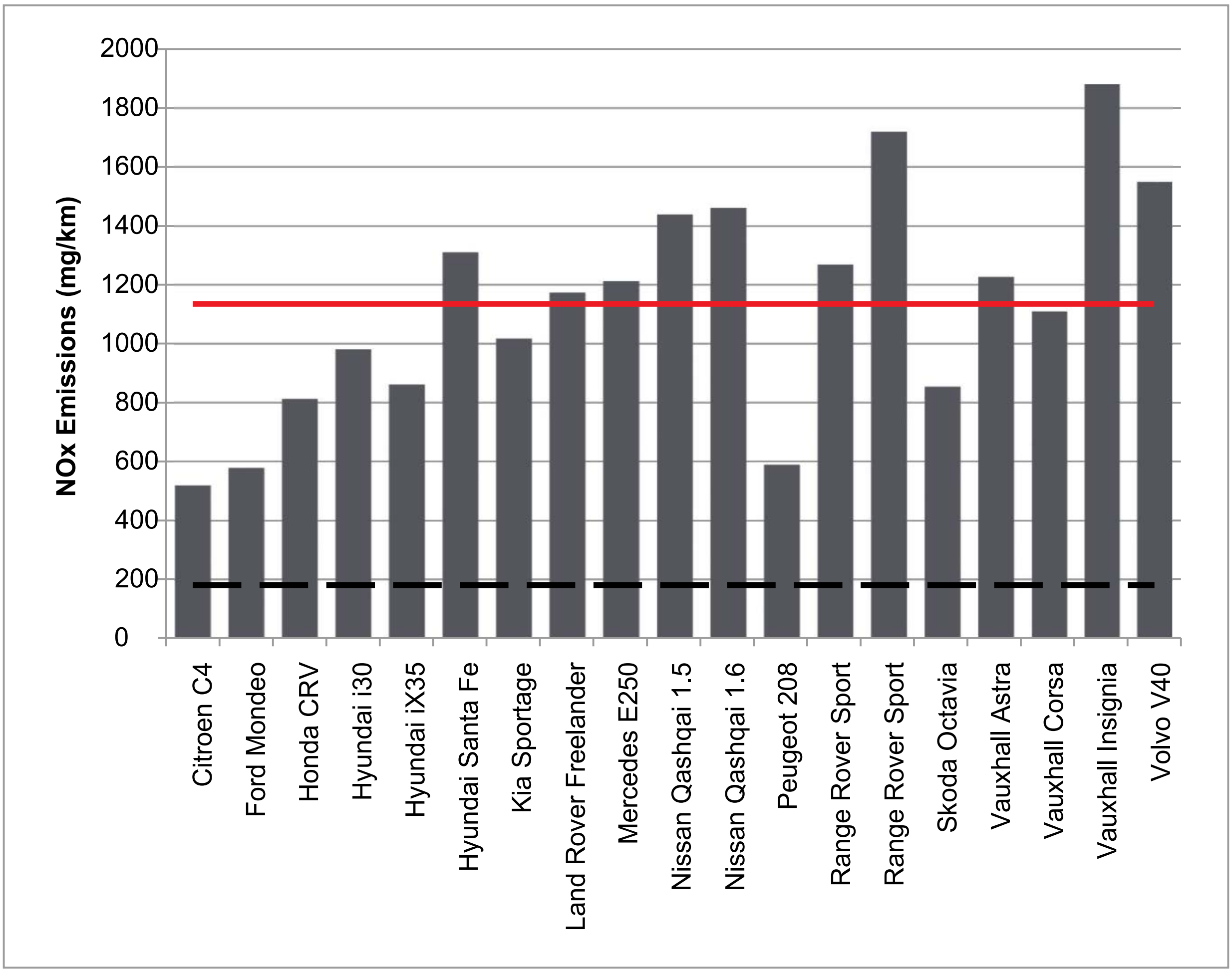


Figure 5-5 Real driving NOx emissions - Euro 5 vehicles (note: direct comparisons should not be made between vehicles as test conditions varied).

5.22 Note that two Euro 5 Range Rover Sport vehicles were tested. This was because this vehicle was first tested early in the programme on a day with a low ambient temperature. It was decided to test a second vehicle at a higher ambient temperature to understand better any temperature influences. The influence of temperature on emissions performance can be seen in Figure 5-8.

5.23 Figure 5-6 shows the equivalent NOx emissions results for the Euro 6 cars during the on road test. Again the average NOx emissions of all vehicles tested is shown by the horizontal red line, while the horizontal black line is the type approval limit, but for Euro 6 this is much lower, at 80 mg/km. This time, the best results are less than twice this limit, while the worst are more than 12 times higher. As for the Euro 5 results, it is not appropriate to make comparisons between individual vehicles as conditions varied from test to test.

5.24 On average our measured road test NOx emissions from Euro 6 vehicles were 500 mg/km - over six times higher than the 80 mg/km official legislative NEDC laboratory test limit. However this average is less than half the figure for the Euro 5 vehicles.

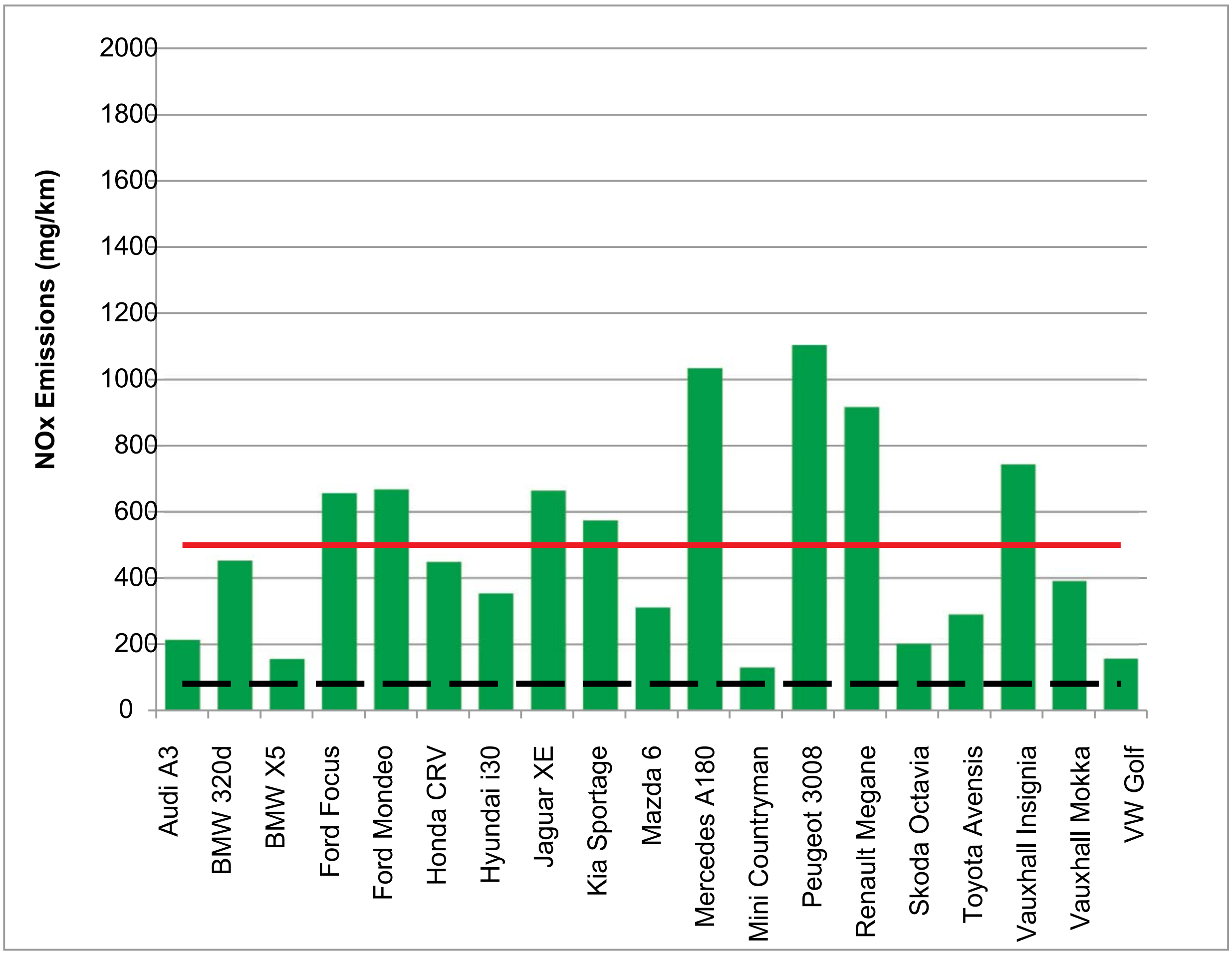


Figure 5-6 Real driving NOx emissions - Euro 6 vehicles (note: direct comparisons should not be made between vehicles as test conditions varied).

Analysis

5.25 During our test programme, a number of meetings were held with manufacturers to better understand the reasons behind the emissions results presented here. There are several broad themes which emerged from these discussions. These are presented here:

Reasons for differences between 'cold' and 'hot' NEDC laboratory tests

5.26 For the majority of vehicles tested, the NOx emissions measured for the 'hot' NEDC laboratory test were higher than those for the 'cold' test. NOx emissions are generated by high peak temperatures and pressures during the engine's combustion process. A fully warm engine might therefore be expected to generate higher NOx emissions during an NEDC test than an engine which has started from 25°C.

5.27 The official legislated 'cold' NEDC test procedure specifies a vehicle pre-conditioning procedure prior to test. This is designed to ensure that test results are consistent. Our testing programme did not use a set pre-conditioning procedure when running 'hot' tests as we wanted to simulate the variations which might be seen in real world use. This may account for the greater spread in the hot test results.

Influence of ambient temperature

5.28 Ambient temperature appears to be a significant factor influencing the emissions results obtained in both track and on-road testing. This influence of temperature is more immediately obvious when looking at the track test NOx emissions results plotted in order of temperature (see Figure 5-8). As can be seen, in general, vehicles that were tested at lower ambient temperatures tended to produce higher NOx emissions than those which were tested at higher ambient temperatures.

5.29 One of the most widely used technologies for control of NOx emissions generated during combustion is exhaust gas recirculation (EGR). Manufacturers explained that the amount of EGR which can be used is dependent on ambient temperature. Problems occur at low temperatures when moisture condenses on to the EGR valve and pipes and traps soot from the exhaust gas, leading to a build-up of deposits. Low intake air temperatures can also result in higher engine-out soot levels, exacerbating the problem. Eventually these deposits can lead to clogging, preventing the EGR valve from operating correctly and blocking the EGR cooler and pipes. This in turn can prevent proper control of EGR flows, leading to driveability problems and possibly affecting the safe operation of the vehicle. At very low temperatures, problems of moisture freezing can also occur.

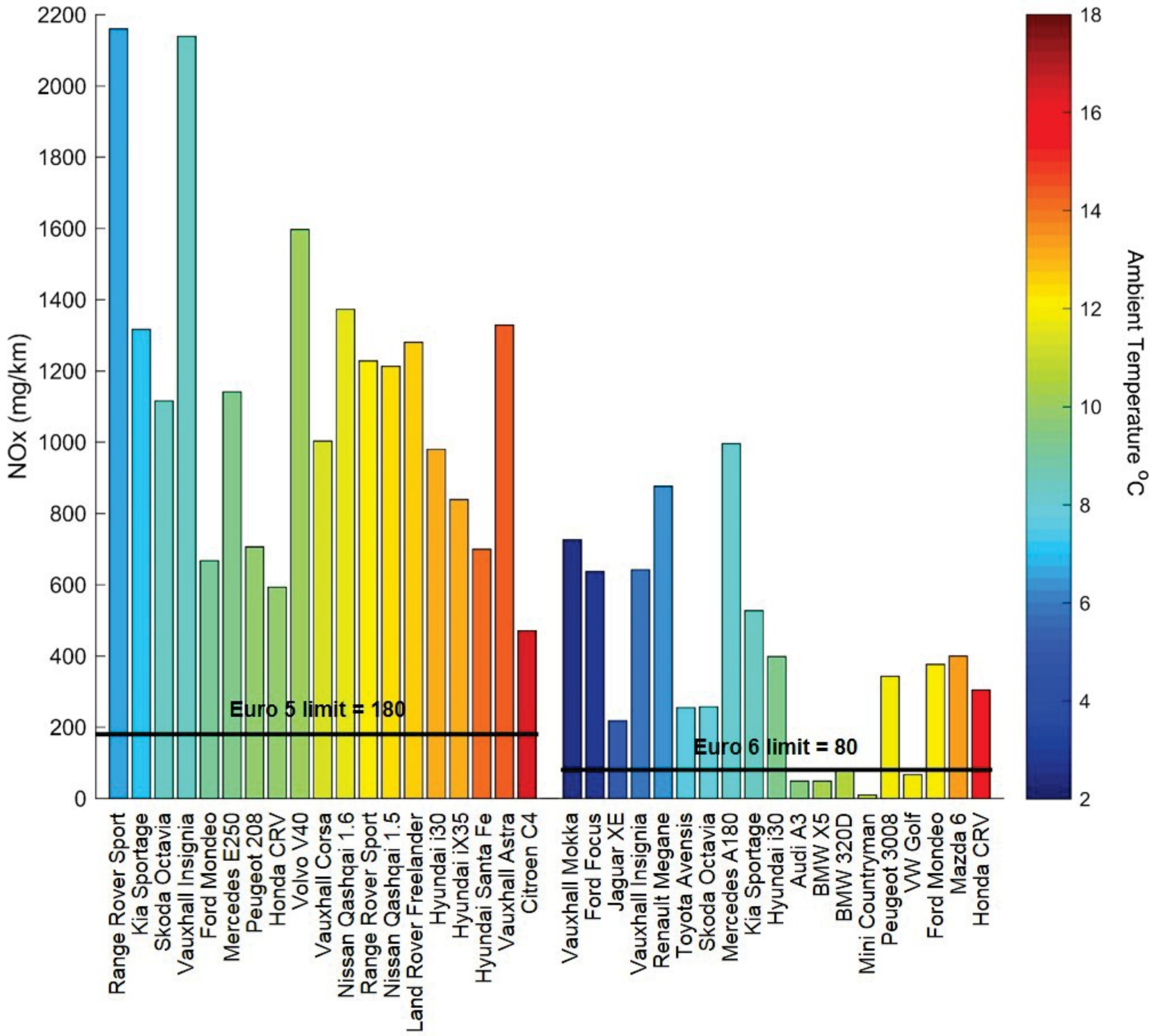


Figure 5-7 Track test results plotted in ambient temperature order

5.30 State of the art technology for NOx control on Euro 5 diesel vehicles is a combination of EGR with control of the fuel injection to influence the combustion process. For Euro 6 vehicles additional exhaust aftertreatment is used - either a lean NOx trap (LNT) or selective catalytic reduction (SCR). For more information on these technologies see Annex B: Emissions reduction technologies.

5.31 Ambient temperature can also impact the efficiency with which LNT and SCR exhaust NOx after treatment control can work. Both technologies have 'optimum temperature windows' for effective operation.

5.32 An important point to bear in mind is that all the vehicles in our test programme will have been designed and engineered several years ago. For some Euro 5 vehicles, initial designs may have started a decade ago. Our conversations with manufacturers made clear that there has been a substantial amount of learning regarding how to effectively control NOx emissions from diesel vehicles in the past 10 years.

Influence of chassis dynamometer settings for laboratory tests

5.33 A further major factor contributing to differences between laboratory and real-world emissions is the methodology used for chassis dynamometer settings in the official laboratory NEDC test.

5.34 The chassis dynamometer (or 'rolling road') must be set up to provide resistance forces that are representative of those the vehicle would experience in real world operation. These settings are established separately, by dynamic vehicle assessments known as "coast down" tests. There are various factors which can affect the results of this test, such as ambient temperature and pressure, road surface, and vehicle mass.

5.35 The chassis dynamometer is set up with an inertia weight representative of the vehicle with just the driver. For this programme, the track and road tests were carried out with the additional weight of the PEMS equipment plus a passenger - approximately an extra 220kg.

5.36 This extra weight could increase the emissions of the vehicle. We modelled the potential effect of this increase on NOx emissions and found it to be 10% or less.

6. Conclusions

6.1 The investigation led by the Department’s engineers and managed by the Vehicle Certification Agency has assessed the emissions of a large number of diesel cars typically found on UK roads. The oversight of Professor Martinez-Botas has ensured the testing was relevant, the evidence produced was robust and the analysis by TRL Ltd. of the highest quality.

6.2 The tests on the Skoda showed how effective Volkswagen Group's cycle recognition strategy was in detecting the laboratory conditions and altering the emissions so as to pass the test. The evidence collected during this programme has not found any similar systems being used by any other manufacturers outside the Volkswagen Group. The Government is satisfied that the first objective of the investigation has been answered.

6.3 The emissions of NOx from the other tested vehicles, whether in the Euro 5 or Euro 6 technology levels, are surprisingly different when tested on a test-track or on-road under real driving conditions compared to those recorded in the laboratory.

6.4 We have learned through this investigation that manufacturers are using a temperature dependent strategy to regulate the amount of Exhaust Gas Recirculation (EGR) as part of their emissions control. These temperature based systems are used in both the older Euro 5 designs and the very latest Euro 6 engines. Manufacturers argue that temperature based control of the EGR system is essential to ensure the emissions control works reliably during normal vehicle use and over the extended conditions of 100,000 miles.

6.5 The systems work by controlling the mass flow (and hence concentration) of EGR entering the engine as the ambient temperature rises or falls. Manufacturers optimise their EGR calibration to suit each model and engine configuration, and it is not possible to draw any conclusion from the test programme on the effectiveness of a particular manufacturer’s system in ensuring high levels of durability while also maximising the emissions reducing potential of the EGR system in normal use.

6.6 The investigation team has seen evidence from manufacturers to support their justification that without such a temperature dependant control, the EGR components and some of the fundamental elements within the engine would be materially damaged and cease to operate in the designed condition. The consequences of such damage could be a significant cost to the consumer for major repair work.

6.7 It is clear from our investigation that further improvements to European regulations will help avoid any uncertainty in how the systems are allowed to operate in the future. It is noted that the European legislation was recently updated to align it more closely with the USA obligations for these systems. In future this will require manufacturers presenting a vehicle for type approval to declare the presence of any aspect of the emissions control system (for example the EGR control strategy) which might reduce its effectiveness during real world use. The Government will be writing to the European Commission seeking further improvements so as to provide the clarity needed for regulators and manufacturers, while also ensuring the highest levels of environmental performance from vehicles.

6.8 In addition two further important changes to the emissions tests will be introduced in the next two years. The UK has played an active role in helping to develop new tests that will make it very difficult, if not impossible for a vehicle manufacturer to manipulate type approval emissions testing in the future - either through the use of cycle recognition or prohibited defeat devices. This legislation, known as the Real Driving Emissions (RDE) test has been developed at a European level and the UK has pushed strongly for its earliest possible introduction, now scheduled as September 2017.

6.9 The RDE test will be run on real roads, in real traffic, making Europe the first region in the world to introduce regulatory emissions tests on public roads. As the test procedure does not prescribe a set vehicle speed profile it will not be possible for a vehicle to detect that it is on test in the way which the Volkswagen Group software appears to have done. Instead the RDE test procedure allows a wide range of variation in the way in which the vehicle is driven, the terrain and the weather. This is intended to capture over 90% of all typical European driving.

6.10 Importantly, once manufacturers have put vehicles on the market, the legislation will also allow independent, third party organisations to conduct their own RDE tests, to verify that vehicles conform to requirements. If a vehicle is found not to comply with the emissions requirements, then the validity of type approval will be open to challenge.

6.11 Separately a new laboratory test cycle is being finalised that is tougher than the current one. The new test is known as WLTP and is a more demanding assessment with many more periods of acceleration and higher speeds which tend to generate pollutants such as NOx. Flexibilities in the current test, often seen as loopholes, have been removed.

6.12 Despite the new test being more representative of real-world driving, and therefore more demanding, the regulatory emission limits will stay the same and manufacturers will have to improve the way they control emissions to make sure they continue to comply on the new cycle. In general WLTP is expected to more than double the stringency of the NOx emissions limit.[4]

6.13 The UK is pressing for the implementation of WLTP as soon as possible and we expect that it will be mandatory for new cars from after September 2017.

The approval of new vehicles for environment and for safety sits within an EU framework of regulations known as EU type approval. This framework is currently being revised in the European Council and the Government will be pressing not only for appropriate measures to improve the supervision of the testing and assessment of new vehicles, but also to ensure vehicles leaving the production line and those coming into the UK from wider markets are also compliant.

[4] 'Comparison of US and EU programs to control light duty vehicle emissions' ICCT, 2015 - slide 11. Available at: http://www.theicct.org/sites/default/files/ICCT_comparison%20Euro%20v%20US.pdf

Annex A: Defeat device legislation

A.1 Regulators across the globe have long been aware of the potential for vehicle manufacturers to try to design a vehicle such that it meets the official emissions test, while emitting significantly higher emissions in normal use. As a result, legislation has been introduced defining what is meant by 'defeat device', and prohibiting their use. The rules also set out a few specific circumstances when their use is considered acceptable.

A.2 The term defeat device was first used in the US, in the Clean Air Act. European and UN-ECE regulations are closely aligned to the US requirements, but with some important differences.

US defeat device regulations

A.3 US regulations define an "auxiliary emission control device" (AECD) as *"any element of design which senses temperature, vehicle speed, engine RPM, transmission gear, manifold vacuum, or any other parameter for the purpose of activating, modulating, delaying, or deactivating the operation of any part of the emission control system."*

A.4 They then go on to define a defeat device with reference to an AECD:

"Defeat device means an auxiliary emission control device (AECD) that reduces the effectiveness of the emission control system under conditions which may reasonably be expected to be encountered in normal vehicle operation and use, unless:

(1) Such conditions are substantially included in the Federal emission test procedure;

(2) The need for the AECD is justified in terms of protecting the vehicle against damage or accident;

(3) The AECD does not go beyond the requirements of engine starting; or

(4) The AECD applies only for emergency vehicles and the need is justified in terms of preventing the vehicle from losing speed, torque, or power due to abnormal conditions of the emission control system, or in terms of preventing such abnormal conditions from occurring, during operation related to emergency response. Examples of such abnormal conditions may include excessive exhaust backpressure from an overloaded particulate trap, and running out of diesel exhaust fluid for engines that rely on urea-based selective catalytic reduction."

A.5 Importantly the US regulation requires manufacturers to declare all AECDs at the time of their application for a certificate of conformity by listing them, stating what they sense, and providing a justification and rationale for why each one is not a defeat device.

European defeat device regulations

A.6 The European Regulation (EC) 715/2007 does not make reference to AECDs. Instead it combines the two definitions contained in the US regulations into a single, longer defeat device definition which uses almost identical language:

'defeat device' means any element of design which senses temperature, vehicle speed, engine speed (RPM), transmission gear, manifold vacuum or any other parameter for the purpose of activating, modulating, delaying or deactivating the operation of any part of the emission control system, that reduces the effectiveness of the emission control system under conditions which may reasonably be expected to be encountered in normal vehicle operation and use;

Article 5 of (EC) 715/2007 goes on to make clear that defeat devices are prohibited, except in certain situations:

1. The manufacturer shall equip vehicles so that the components likely to affect emissions are designed, constructed and assembled so as to enable the vehicle, in normal use, to comply with this Regulation and its implementing measures.

2. The use of defeat devices that reduce the effectiveness of emission control systems shall be prohibited. The prohibition shall not apply where:

(a) the need for the device is justified in terms of protecting the engine against damage or accident and for safe operation of the vehicle;

(b) the device does not function beyond the requirements of engine starting;

or

(c) the conditions are substantially included in the test procedures for verifying evaporative emissions and average tailpipe emissions.

A.7 The third of these exceptions essentially means that if the defeat device operates during the official emissions test (and the vehicle is still able to meet the required emissions limits) then this can be deemed acceptable.

A.8 Unlike the US regulation, the European regulation does not set out in detail how the exceptions to the prohibition on defeat devices should apply, whether or how manufacturers should apply these exemptions, or how a type approval authority should evaluate the validity of their use.

UN-ECE defeat device regulation

A.9 Manufacturers wishing to type approve vehicles for sale in Europe can choose whether to approve emissions to EC or to UN-ECE regulations. The UN-ECE definition of a defeat device is found in UN-ECE Regulation 83 and is almost identical to (EC) 715/2007:

2.16. "Defeat device" means any element of design which senses temperature, vehicle speed, engine rotational speed, transmission gear, manifold vacuum or any other parameter for the purpose of activating, modulating, delaying or deactivating the operation of any part of the emission control system, that reduces the effectiveness of the emission control system under conditions which may reasonably be expected to be encountered in normal vehicle operation and use.

Such an element of design may not be considered a defeat device if:

2.16.1. The need for the device is justified in terms of protecting the engine against damage or accident and for safe operation of the vehicle; or

2.16.2. The device does not function beyond the requirements of engine starting; or

2.16.3. Conditions are substantially included in the Type I or Type VI test procedures.

A.10 UN-ECE Regulation 83 states that the use of a defeat device is prohibited[5]. The Regulation sets out essentially the same 3 exceptions as set out in (EC) 715/2007, however there is an important difference in the wording of each Regulation that leads to different conclusions as to whether a system is a defeat device:

EC 715/2007 states *"The prohibition* (on defeat devices) *shall not apply where"* any of the exceptions apply; whereas

UN-ECE Regulation 83 states that a system *"may not be considered a defeat device if"* any of the exceptions apply.

A.11 As a result, under EC 715/2007 there are effectively 'legal' defeat devices - those for which the prohibition on defeat devices does not apply due to one of the 3 exceptions applying - whereas under UN-ECE Regulation 83, the same system would not be considered a defeat device at all.

[5] 5.1.2.1 of Regulation 83

Annex B: Emissions reduction technologies

Exhaust Gas Recirculation (EGR)

A.1 EGR displaces intake air with inert exhaust gas. The presence of inert exhaust gas in the combustion chamber reduces both peak combustion temperatures and the amount of oxygen available. This in turn reduces formation of NOx, but can also cause an increase in the emissions of particulate matter (soot).

A.2 There are a number of types of EGR available to the engine designer:

- Internal EGR – this occurs within the combustion chamber/exhaust manifold interface, and is set by the timing of the closing of the exhaust valve. Following the completion of the exhaust stroke, the exhaust valve remains open during the start on the induction stroke, causing some of the exhaust in the exhaust manifold to be drawn back into the combustion chamber. As there is no additional control over this, the amount of EGR that occurs is generally kept low.
- External EGR – some of the exhaust gas is directed through a pipe from the exhaust system back into the inlet manifold. The EGR flow is controlled by an EGR valve and is set according to a range of engine operating conditions and parameters. 'High pressure' EGR systems take exhaust gas from before the turbocharger. For Euro 6, 'low pressure' EGR systems are also being introduced, which take exhaust gas from after the diesel particulate filter.
- Cooled EGR – as per external EGR, but the recirculated exhaust gases pass through a cooler before re-entering the engine. This provides a further reduction in the combustion temperature.

A.3 EGR has been around for many years on both light-duty and heavy-duty engines. Use of EGR may lead to compromises on other vehicle characteristics, for example particulate emissions, driveability, fuel economy or performance. However a well-designed and calibrated EGR system will minimise any negative impacts.

Diesel oxidation catalyst (DOC)

A.4 A diesel oxidation catalyst promotes the oxidation of several of the exhaust components. These are oxidised using oxygen, which is present in the diesel exhaust, in the presence of a catalyst. The components include:

- Carbon monoxide (forms carbon dioxide)
- Hydrocarbon (oxidised to carbon dioxide and water)
- Organic fraction of particulate matter (SOF)

A.5 In addition to targeting regulated pollutants, a DOC can also control several non-regulated HC species such as aldehydes and PAHs as well as reducing the odour of the exhaust.

A.6 The disadvantage of DOCs when used on their own is that they might increase the emissions of NO_2, due to the oxidation of NO. However, this may prove to be a benefit when used prior to a DPF or SCR, by helping regeneration in the former and enhancing the performance of the latter.

Diesel particulate filter (DPF)

A.7 A diesel particulate filter is a device to remove the particulate matter from the exhaust gas of a diesel engine. They generally consist of some form of filter material which traps the particles as the exhaust flows through it. During use, soot will accumulate on the filter, increasing the back pressure in the exhaust. To allow continued efficient operation, this accumulated soot needs to be regularly removed. This can be achieved on the vehicle by regeneration – the soot is burned off. There are a number of ways to achieve this, including:

- Increase the exhaust temperature through engine management (late fuel injection or injection during the exhaust stroke). Diesel particulate burns at about 600 °C, so this temperature needs to be maintained for the regeneration period (i.e. a period of high engine load needs to be sustained).
- The addition of a fuel borne catalyst, which reduces the combustion temperature of the particulate from 600 °C down to 350-450 °C. This requires a small additional tank to hold additive, plus the associated plumbing, but this is more energy efficient.
- Passive regeneration – the presence of NO_2, generated in the DOC, can also reduce the combustion temperature allowing the DPF to regenerate continuously, avoiding the fuel penalties associated with raising the exhaust temperature to initiate regeneration.

A.8 The alternative to on-board regeneration is to remove the DPF from the vehicle, though this is often impractical and is not a common solution.

Lean NOx Trap (LNT)

A.9 Unlike a petrol engine, a diesel engine's exhaust is 'lean' – a term meaning it has excess oxygen present. As a result, a standard catalyst cannot convert NOx emissions. A lean NOx trap is a device which looks similar to a standard catalyst, but which acts as a molecular sponge, chemically trapping NOx emissions (by adsorption) rather than converting them. The amount of NOx a trap can hold is dependent on its temperature. The optimum temperature window is typically around 250-450°C. However, once the trap is full, it can't adsorb any more NOx. The trap must therefore be periodically 'purged' by briefly creating 'rich' conditions (excess fuel) in the exhaust. When this happens the trap releases and simultaneously converts the NOx to nitrogen and water vapour. The frequency with which this happens will depend on the system and the driving conditions, but it is typically several times an hour.

Selective Catalytic Reduction (SCR)

A.10 SCR is an alternative catalyst system that is able to convert NOx even under 'lean' exhaust gas conditions. The reaction takes place with ammonia (typically supplied as AdBlue) in the presence of a catalyst, either oxides of base metals (such as vanadium, molybdenum and tungsten), zeolites, or various precious metals. To be efficient, the SCR must be at its nominal operating temperature (350-450 °C) and it can reduce NOx emissions by up to 95%. Critically, unlike the other systems described here SCR relies on a consumable reagent (to provide the ammonia) and only reduces emissions whilst the catalyst is being supplied or "dosed" with this reagent. As a result, regulations require a visible and audible driver warning when reagent levels are low and that vehicle performance is restricted, or engine restart is prevented if the driver fails to refill the system.

A.11 The temperature of the SCR is determined primarily by the exhaust gas. Therefore, the placement of the SCR in relation to the engine and the engine's duty cycle are critical with respect to the SCR's performance. The SCR canister is relatively large. In addition to the SCR, the following are also required:

- AdBlue tank – the AdBlue dosing rate will vary by engine and vehicle but this tank will be sized to avoid vehicle owners having to refill too frequently. The tank also contains heaters and sensors.
- A dosing pump – to pump the AdBlue from the tank into the exhaust pipe just before the SCR.
- A control module – to control the amount of AdBlue added.
- Pre and post SCR NOx sensors – to ensure that the SCR system is operating correctly.

A.12 Although readily available, the main design constraint is the amount of space needed for the installation.

Ammonia catalyst

A.13 SCR requires ammonia, derived from the AdBlue. The ideal ratio of ammonia to NOx is 1:1. However, under certain conditions, the SCR efficiency might be low (e.g. low temperatures, high exhaust flow rates etc.). Under these conditions, the ammonia might not be all used and some of it may exit the SCR – known as ammonia slip.

A.14 To prevent the release of ammonia, an additional catalyst is placed immediately after the SCR. There are various terms for these devices, including:

- AOC: ammonia oxidation catalyst
- ASC: ammonia slip catalyst
- CUC: clean up catalyst

A.15 Any ammonia can either be oxidised to NOx (not really desirable) or it can be selectively oxidised to produce water and nitrogen. The ammonia catalyst is often packaged in the same can as the SCR.

Combinations of devices

A.16 Almost all diesel engines these days are turbocharged. The resulting emissions will be dealt with using a combination of techniques. This commonly includes:

- EGR + DOC + DPF
- EGR + DOC + LNT + DPF
- EGR + DOC + SCR + DPF

A.17 In the future, the introduction of Real Driving Emissions regulations may result in manufacturers using EGR + DOC + LNT + SCR + DPF. The combination of LNT and SCR technologies can provide improved NOx control over a wider temperature range and has already been introduced for diesel vehicles in the US market.

Annex C: Specifications of test vehicles

Manufacturer	Model	Engine	Euro Level	Type Approval Authority	EGR	DOC	LNT	SCR	DPF
Citroen	C4	1569	5	e2	Y	Y			Y
Ford	Mondeo	2000	5	e11	Y	Y			Y
Honda	CRV*	2200	5	e11	Y	Y			Y
Hyundai	iX35	1685	5	e11	Y	Y			Y
Hyundai	i30 (Auto)	1582	5	e11	Y	Y			Y
Hyundai	Santa Fe*	2199	5	e11	Y	Y			Y
Kia	Sportage*	1995	5	e11	Y	Y			Y
Land Rover	Freelander*	2179	5	e11	Y	Y			Y
Mercedes	E 250	2100	5	e1	Y	Y			Y
Nissan	Qashqai	1461	5	e9	Y	Y			Y
Nissan	Qashqai	1598	5	e2	Y	Y			Y
Peugeot	208	1398	5	e2	Y	Y			Y
Range Rover	Sport*	2993	5	e11	Y	Y			Y
Skoda	Octavia	1600	5	e11	Y	Y			Y
Vauxhall	Insignia	1956	5	e1	Y	Y			Y
Vauxhall	Astra	1686	5	e1	Y	Y			Y
Vauxhall	Corsa	1300	5	e1	Y	Y			Y
Volvo	V40	1560	5	e4	Y	Y			Y

Table 1 Euro 5 vehicles tested (* = 4 wheel drive)

Manufacturer	Model	Engine	Euro Level	Type Approval Authority	EGR	DOC	LNT	SCR	DPF
Audi	A3	1598	6	e13	Y	Y	Y		Y
BMW	X5*	2993	6	e24	Y	Y		Y	Y
BMW	320d*	1995	6	e24	Y	Y	Y		Y
Ford	Mondeo	2000	6	e11	Y	Y	Y		Y
Ford	Focus	1499	6	e11	Y	Y	Y		Y
Honda	CRV*	1600	6	e11	Y	Y	Y		Y
Hyundai	i30	1582	6	e11	Y	Y	Y		Y
Jaguar	XE	1999	6	e11	Y	Y		Y	Y
Kia	Sportage	1685	6	e11	Y	Y	Y		Y
Mazda	6	2191	6	e11	Y	Y			Y
Mercedes	A180	1461	6	e1	Y	Y	Y		Y
Mini	Countryman	1598	6	e24	Y	Y	Y		Y
Peugeot	3008	1560	6	e2	Y	Y		Y	Y
Renault	Megane	1461	6	e2	Y	Y	Y		Y
Skoda	Octavia	1600	6	e1	Y	Y	Y		Y
Toyota	Avensis	1998	6	e11	Y	Y	Y		Y
Vauxhall	Insignia	2000	6	e1	Y	Y		Y	Y
Vauxhall	Mokka	1589	6	e4	Y	Y	Y		Y
Volkswagen	Golf	2000	6	e1	Y	Y	Y		Y

Table 2 Euro 6 vehicles tested (* = 4 wheel drive)

Key for Type Approval Authorities:

e1 = Germany

e2 = France

e4 = Netherlands

e9 = Spain

e11 = UK

e13 = Luxembourg

e24 = Ireland

Annex D: Laboratory and track test results

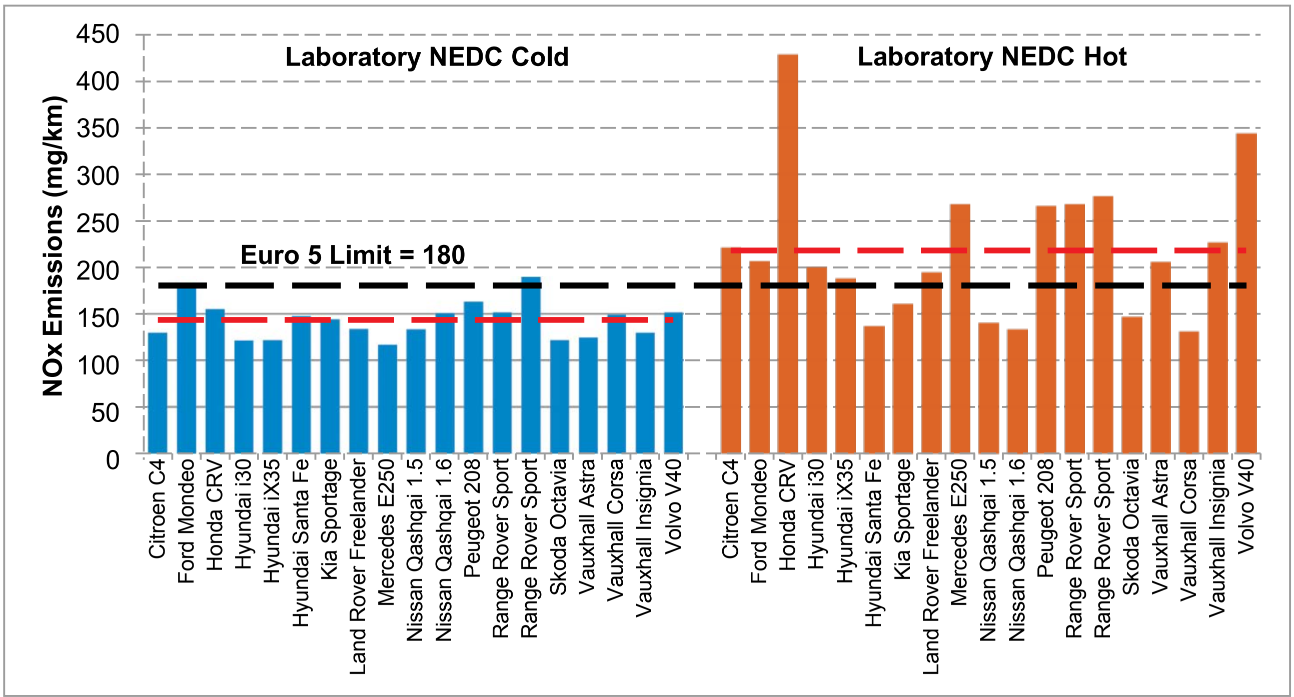


Figure D-1 Laboratory - NEDC cold versus NEDC hot - Euro 5 vehicles

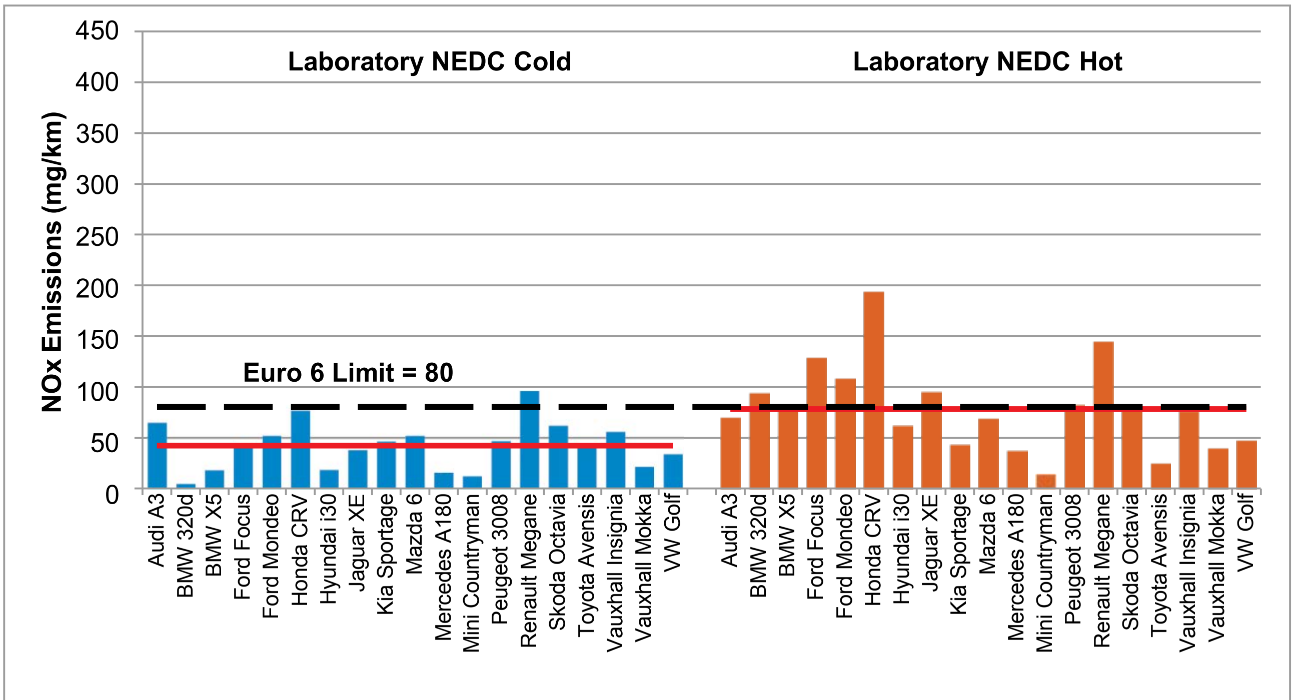


Figure D-2 Laboratory - NEDC cold versus NEDC hot - Euro 6 vehicles

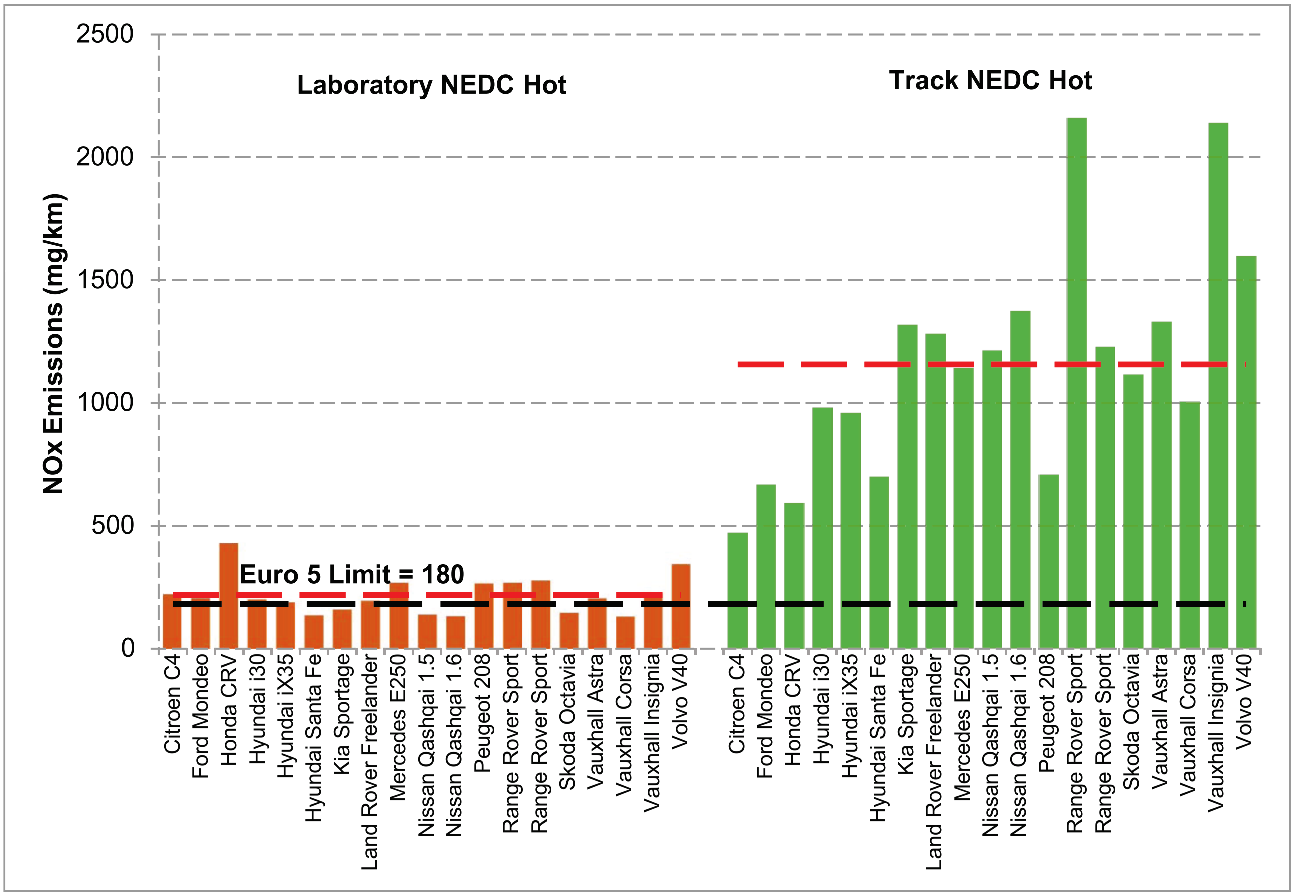


Figure D-3 Laboratory NEDC hot versus track NEDC hot - Euro 5 vehicles

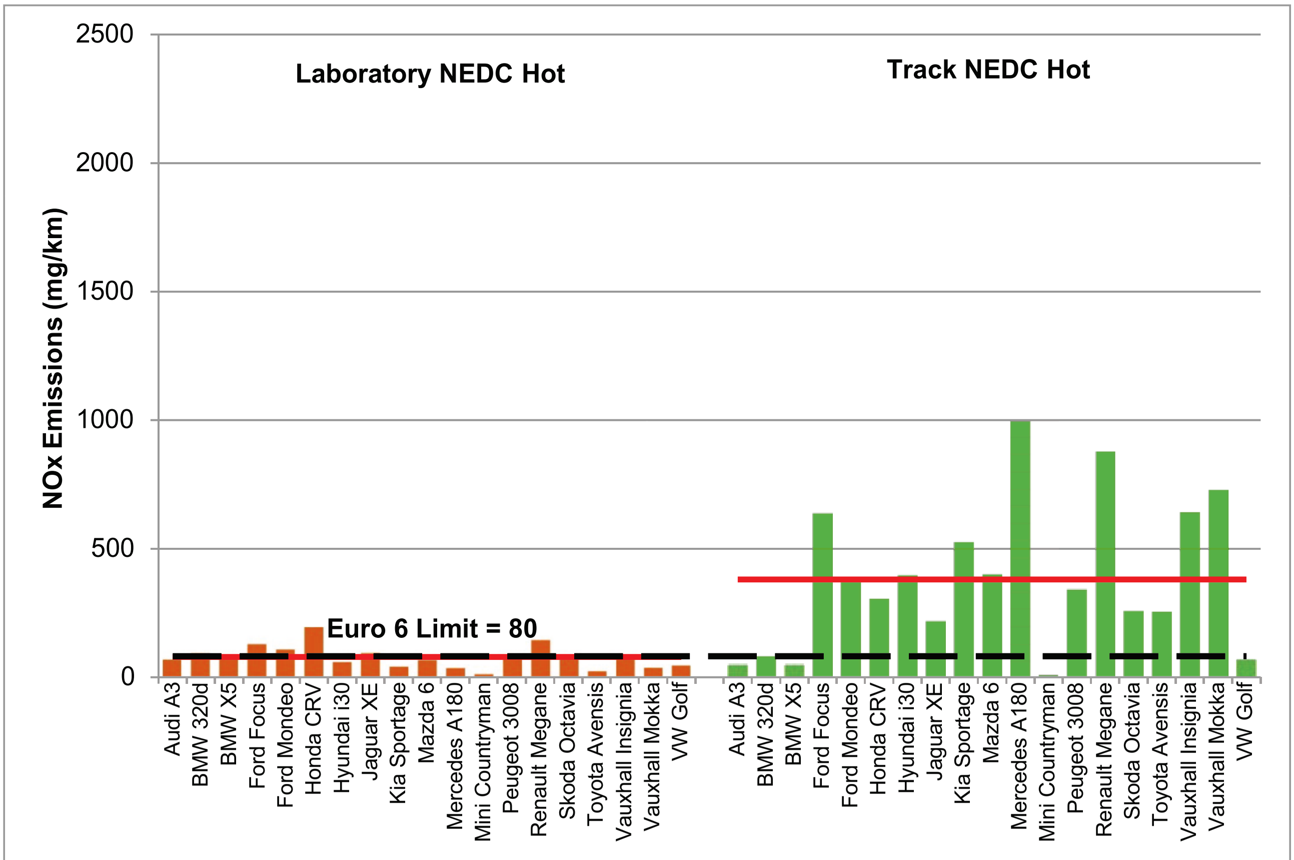


Figure D-4 Laboratory NEDC hot versus track NEDC hot - Euro 6 vehicles