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Clean Vehicle Technology Fund and Clean Bus Technology Fund Programmes

Evaluation Report

Prepared for the DEFRA/DfT Joint Air Quality Unit

Report
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Clean Vehicle Technology Fund and Clean Bus Technology Fund Programmes

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Table of Contents

1 Glossary of Terms

Euro 1 (2, 3, 4, 5,6) - certified Euro Emission level (Chassis dyno method for cars and vans)

Euro I (II, III, IV, V, VI) - certified Euro emission level (Engine test method for bus and truck)

NOx - oxides of nitrogen (NO and NO_2)

NO_2 - nitrogen dioxide

N_2O - nitrous oxide

PM - particulate mass

PN - particle number

CO_2 - carbon dioxide

CH_4 - methane

THC - total hydrocarbons

SCR - Selective Catalytic Reduction

DPF - Diesel Particulate Filter

TMT - Thermal Management Technology

CNG - Compressed Natural Gas

PEMS - Portable Emissions Monitoring System

2 Executive Summary

Improving urban air quality is currently one of the UK's most important environmental goals. The UK is divided into 43 zones and agglomerations for air quality monitoring and reporting purposes. 37[1] zones are currently exceeding the annual mean limit value for NO_2 (Nitrogen Dioxide). Air Quality Management Areas (AQMAs) have been declared for 657[2] local authorities in England for nitrogen dioxide exceedances. Road transport has been identified as one of the main contributors to elevated roadside NO_2 levels, with the highest proportion of NOx emissions (oxides of nitrogen) arising from diesel vehicles[3].

The Clean Bus Technology Fund (CBTF) 2013/2015 and Clean Vehicle Technology Fund (CVTF) 2014 programmes were introduced by the Department of Transport (DfT) to help reduce NOx emissions from diesel vehicles in cities experiencing poor air quality. The total value of the grants was £19 million shared between thirty local and regional authorities. The funding facilitated 2,137 diesel vehicles to be retrofitted with eleven different NOx emission abatement technologies. These have been grouped into three NOx abatement techniques – exhaust after treatment, fuel saving and engine conversions. Ninety percent of the funding was awarded to buses with the remainder allocated to a variety of vehicle types including coaches, black taxis, ambulances, mini-buses, mini-cabs and a fire engine.

NOx emission reduction performance targets were not stipulated in any of the retrofit programmes, however, the CBTF 2015 programme suggested a guidance figure of 50% reduction in NOx emissions supported by vehicle emissions testing. Local Authority grant winners were required to undertake vehicle emission monitoring to demonstrate the NOx reduction achieved by the retrofit technology and to report in service performance. No specific test methodology was prescribed by DfT, consequently local authorities adopted several different approaches to vehicle emission monitoring. These varied between vehicle laboratory testing and on road vehicle emissions monitoring. On road monitoring, undertaken during real world driving conditions, utilised Portable Emission Monitoring Systems (PEMS) and NOx sensors.

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[1] UK plan for tackling roadside nitrogen dioxide concentrations
[2] https://uk-air.defra.gov.uk/aqma/list?la=all&country=england&pollutant=no2
[3] Improving air quality in the UK, Tackling nitrogen dioxide in towns and cities, Defra 2015

The LowCVP has been commissioned by the Joint Air Quality Unit (JAQU) to undertake an evaluation of the CVTF and CBTF programmes, with the objectives of determining the efficacy of different retrofit technologies at reducing tail-pipe NOx emissions and to determine in service performance. An additional task has been to identify the impact of retrofit equipment on other air pollutants (particulate matter and ammonia) and greenhouse gas emissions (methane, nitrous oxide and carbon dioxide). Only projects which supplied good quality vehicle emission monitoring data were included in the analysis, hence the evaluation only covered twenty-five local authority projects and seven technologies, highlighted in Table 1.

Case studies are presented for each retrofit technology and vehicle class – local authority projects include Transport for London, Bradford, Dudley, Transport for Greater Manchester, Brighton and Hove, York, St Albans and Portsmouth and Go North East consortium.

Table 1: Overview of retrofit technologies funded in the CBTF/CVTF programmes and covered in the evaluation study

Retrofit Technology		Vehicle Types	No. of vehicles funded	Euro Standard	Covered in evaluation study	Vehicle emission monitoring data available
Exhaust Gas After Treatment	Selective Catalytic Reduction (SCR) (including alternative ammonia supply)	Bus, coach, fire engine, mini-bus, car	1,594	Pre Euro, Euro II - V Euro 4/5	Yes	Vehicle Lab, PEMS, NOx sensor
	Thermal Management Technology (TMT)	Bus	83	Euro VI	Yes	NOx sensor
Fuel Saving	Flywheel hybrid	Bus	104	Euro III/V	Yes	Vehicle Lab
	Mild Hybrid	Bus	40	Euro III-V	Yes	Vehicle Lab
	Hybrid Assist	Van	18	Euro 4	Yes	Vehicle Lab
	Battery powered ancillaries	Ambulance	109	Euro III	No	Testing planned
Engine Conversion	Battery Electric	Bus	7	Euro II	Yes	N/A
	Range extender battery electric using compressed biomethane gas (CBG)	Bus	1	Euro III	No	Testing planned
	Spark ignition engine powered by CBG	Bus	16	Euro III	No	None
	Duel Fuel Compressed Natural Gas (CNG)	Black Taxi	113	Euro 2,3,4	Yes	Vehicle Lab
	Spark ignition engine powered by LPG	Black Taxi	65	Euro 1,2,3	No	Testing planned

Demonstrating the efficacy of different retrofit technologies at reducing NOx emissions

Table 2 summarises the NOx emission reduction performance of the retrofit technologies assessed in the evaluation study. The retrofit technologies achieving the highest NOx emission reductions are retrofit SCR and diesel bus engine conversion to electric powertrain. Retrofit SCR vehicles delivered very low NOx emissions for both light and heavy-duty vehicles. Where SCR systems have been retrofitted to vehicle classes for the first time (fire engine, mini-bus, car) NOx emission savings are slightly reduced, highlighting the early stages of technology development at the time of the CVTF programme. A new type of ammonia storage system for SCR has been shown to perform as well as conventional aqueous urea, achieving high levels of NOx reduction. Retrofit technologies achieving moderate NOx emission reductions are TMT and flywheel hybrid. Technologies achieving low NOx emission reductions are mild hybrid, hybrid assist and dual fuel CNG conversion.

Table 2: CVTF/CBTF programme retrofit technology NOx emission reduction performance

Retrofit Technology		Vehicle Category	Euro Standard	Average NOx emission reduction	Average tail-pipe NOx emissions
Exhaust After-Treatment Technology	SCR	Bus	Euro III	88%	0.3 g/km
			Euro IV	90%	0.7 g/km
			Euro V	98%	0.8g/km
		Coach	Euro II	86%	1.4 g/km
			Euro III	99%	0.2 g/km
		Fire Engine	Euro III	70%	2.7 g/km
		Mini-bus	Euro 4	77%	0.3g/km
		Car	Euro 4	60%	0.2 g/km
	Ammonia storage for SCR	Bus	Euro V	98%	0.5g/km
	TMT	Bus	Euro IV	29%	11g/km
Fuel Saving	Flywheel Hybrid	Bus	Euro III	26%	6.1 g/km
	Mild Hybrid	Bus	Euro V	5%	6.3 g/km
	Hybrid Assist	Van	Euro 4	6%	0.3 g/km
Engine Conversion	Dual Fuel CNG	Black Taxi	Euro 4	3%	1.1 g/km
	Battery Electric	Bus	Euro III	100%	

Demonstrating in service performance of retrofit technologies

In service performance has only been possible to assess for retrofit SCR, TMT and conversion to flywheel hybrid. In the case of retrofit SCR, in service monitoring performed between six months and two years after retrofit SCR equipment has been fitted to buses, coaches, a fire engine and van derived mini bus, has demonstrated excellent conformity with vehicle emission testing undertaken on fitment of the technology. This highlights that retrofit SCR systems continue work effectively and deliver high NOx reductions when in service. The CVTF programme enabled retrofit SCR to be successfully fitted to light duty vehicles specifically a small number of van derived mini-buses and cars. Initial evidence shows the retrofit SCR mini-buses to be working effectively.

With regards to vehicle operational performance, retrofit flywheel hybrid has experienced the most fitment and operational challenges, as such two out of the three flywheel projects have been terminated and funding re-allocated to alternative technologies.

Impact of retrofit technologies on other air pollutants and greenhouse gas emissions

This assessment has focused on retrofit SCR, hybrid flywheel and dual fuel CNG conversion. Vehicle laboratory testing for a small number buses and a van-derived mini-bus has shown retrofit SCR to achieve high levels of NO_2 emissions reduction (80%) and very low tailpipe NO_2 emissions. The majority of retrofit SCR systems were also fitted with particle filters resulting in high particulate matter reductions (>75%) and exceptionally low tailpipe PM emissions. Ammonia emissions were shown to be below 10ppm post SCR fitment. With regards to greenhouse gas emissions[4] (measured as 'CO_2 equivalent'), these were shown to increase between 3-5% post SCR fitment on buses, primarily due to a rise in the emissions of nitrous oxide.

Vehicle laboratory testing for retrofit hybrid flywheel technology fitted to a Euro III bus revealed a NO_2 emission reduction of 25% and CO_2 emission saving of 30%.

Vehicle laboratory testing results for dual fuel CNG conversion for a Euro 4 black taxi showed very low NO_2 reductions (3%) and an exceptionally high increase in methane (CH_4) emissions (93%).

Vehicle emission testing has revealed that two retrofit fuel savings technologies, mild hybrid and hybrid assist, achieved very low CO_2 emission savings post fitment. The measured changes were well below the suppliers claimed fuel savings.

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[4] Greenhouse gas emission cover methane, nitrous oxide and carbon dioxide

3 Introduction

3.1 Background to the Evaluation Study

The CBTF 2013/2015 and CVTF 2014 programmes[5] were introduced by the Department for Transport to help reduce NOx emissions from diesel vehicles in cities experiencing poor air quality. The total value of the grants was £19 million which was shared between thirty local and regional authorities. The funding facilitated 2,137 diesel vehicles to be retrofitted with eleven different NOx emission abatement technologies. These have been grouped into three NOx abatement techniques – exhaust after-treatment, fuel saving and engine conversion. Ninety percent of the funding was awarded to buses with the remainder allocated to a variety of vehicle types including black taxis, mini-buses, mini-cabs, ambulances and a fire engine; see Table 3.

Specific NOx emission reduction performance targets were not identified in any of the retrofit programmes, however the CBTF 2015 programme suggested a guidance figure of 50% reduction in NOx emissions supported by vehicle emissions testing. A requirement of the local authority grant winners of these programmes was to monitor and report vehicle NOx emissions to demonstrate the performance of the retrofit technology. Two approaches to vehicle emissions monitoring were adopted in the CBTF/CVTF programmes, vehicle laboratory testing and on-road vehicle emissions monitoring; these are discussed in Section 4.

The LowCVP has been commissioned by JAQU to undertake an evaluation of the CVTF and CBTF programmes. The overarching objectives of the CBTF/CVTF evaluation study are:

1) Determine the effectiveness of the different retrofit technologies funded in reducing NOx emissions and impacts on other air pollutants (particulate matter and ammonia) and greenhouse gas emissions (methane, nitrous oxide and carbon dioxide).

2) Determine, where possible, in service performance of different retrofit technologies.

3) Present case studies for the different retrofit technologies across the grant programmes.

[5] https://www.gov.uk/government/collections/clean-vehicle-technology-fund

Table 3: Overview of retrofit technologies funded in the CBTF/CVTF programmes and covered in the evaluation study

Retrofit Technology		Vehicle Types	No. of vehicles funded	Euro Standard	Covered in evaluation study?	Vehicle emission monitoring data available
Exhaust Gas After Treatment	Selective Catalytic Reduction (including alternative ammonia supply)	Bus, coach, fire engine, mini-bus, car	1,594	Pre Euro, Euro II - V Euro 4	Yes	Vehicle Lab, PEMS, NOx sensor
	Thermal Management Technology	Bus	83	Euro VI	Yes	NOx sensor
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	Duel Fuel CNG	Black Taxi	113	Euro 2,3,4	Yes	Vehicle Lab
	Spark ignition engine powered by LPG	Black Taxi	65	Euro 1,2,3	No	Testing planned

3.2 Evaluation Study Methodology

The study methodology entailed analysis of vehicle emissions monitoring data and interviews with local authorities. This evaluation has only covered projects where monitoring data was available and of sufficiently high quality for analysis. The retrofit technologies covered are highlighted in Table 4 and a full list of local authority projects is provided in Appendix 1.

Case studies have been compiled for each type of the retrofit technology and different vehicle classes where relevant. The case studies are as follows:

Table 4: Local authority case studies covered for each retrofit technology

Exhaust After-Treatment	Fuel Saving	Engine Conversion
Selective Catalytic Reduction **Buses**: Transport for London, Bradford City Council, Transport for Greater Manchester **Coaches:** Dudley Council **Fire engine**: Transport for London **Mini-buses**: Brighton City Council **Thermal Management Technology** **Buses:** South Yorkshire PTE	**Flywheel Hybrid – Buses** Go North East Consortium **Mild Hybrid – Buses** St Albans Council **Hybrid Assist – Vans** Portsmouth City Council	**Battery Electric – Buses** York City Council **Dual fuel CNG – Black Taxi** Reading Council

4 Vehicle Emissions Testing Methodologies

The objective of vehicle emissions testing in the CVTF/CBTF programme was to determine a change in tail-pipe NOx (and where possible, NO_2 emissions) of the retrofit technology compared to the unmodified (baseline) vehicle. This would ascertain conformity with retrofit technology suppliers' NOx reduction claims and the scheme's targets (if any). Each local authority has been requested by DfT to report NOx measurements at six and twelve-month intervals after retrofit installation. This data provided evidence of the durability of the retrofit equipment at maintaining claimed NOx emission reduction levels. In some cases NOx emissions testing has been carried out on commissioning of the first retrofitted vehicles.

One of the most important aspects of determining a change in NOx emissions is to ensure a robust comparability exercise is undertaken. This ideally requires the same vehicle to be used for pre and post retrofit testing and adoption of a representative drive cycle. Vehicle lab testing is the most robust testing method. Further in service performance monitoring serves to demonstrate the durability of the retrofit technology after several months or years. Monitoring techniques in the CVTF/CBTF programme have included vehicle lab, PEMS and NOx sensors. For a large number of retrofit SCR projects, only NOx sensor measurements could be exploited to determine retrofit technology performance once the upgraded buses were in service. This was mainly due to the grant streams not funding vehicle emission testing – as such local authorities had to cover this cost themselves and in many cases had limited resources to execute the most robust and highly accurate types of vehicle emission testing.

The CVTF/CBTF programmes entailed local authorities adopting three different methods of vehicle emission testing to determine the performance of retrofit technologies. A summary of each method is provided below.

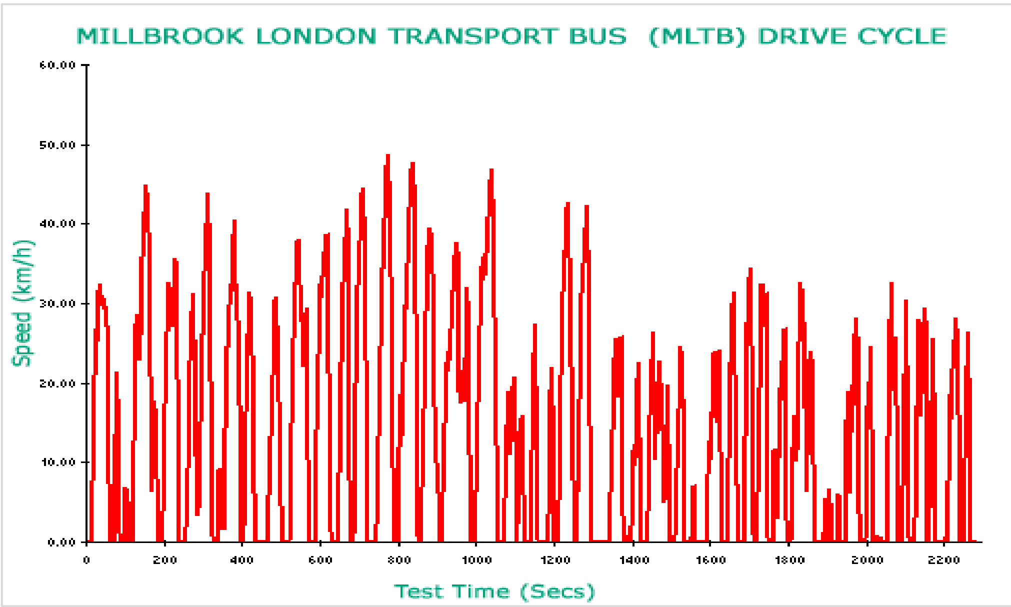
4.1 Laboratory Vehicle Emissions Testing

Vehicle emission testing can be undertaken at several laboratories across the UK. The vehicle is tested on a chassis dynamometer that replicates real world driving conditions by adopting an appropriate vehicle drive cycle and vehicle load, (see Figure 1). A range of drive cycles have been used in lab based vehicle emission testing exercises undertaken under the CBTF/CVTF programmes. These include the Millbrook London Transport Buses Test Cycle (Figure 2), CENEX PCO-taxi cycle, the World Harmonised Light Duty Test Cycle (WLTC) and New European Drive Cycle (NEDC).

Laboratory based vehicle emission testing provides direct emission measurements that are highly accurate, very repeatable using sophisticated analysers. The test procedure maintains tight control on the variables being measured. This type of vehicle emissions testing can measure different species of nitrogen in the exhaust gas stream including NO and NO_2, a range of other air pollutants such as PM and NH_3, greenhouse gas emissions CO_2, CH_4 and N_2O and fuel consumption. Results are reported as mass emissions (g/km).

Figure 1: Bus chassis dynamometer testing

Figure 2: Drive trace for Millbrook London Transport Bus Cycle



4.2 Portable Emissions Monitoring System

Portable Emissions Monitoring System (PEMS) facilitates direct measurements of tail-pipe emissions and fuel consumption when a vehicle is operating during real world driving conditions on the road. The system is fitted to the exhaust system of the vehicle and the sampled exhaust gas is then analysed for various air pollutants using sophisticated analysers, see Figure 3. Test conditions are less controlled than laboratory based vehicle emissions testing – these include ambient climatic conditions, payload and driver behaviour. PEMS has a lower repeatability of measurements encountered when testing, owing to real-world sources of variability. It can therefore be challenging to ensure consistency of measurements between different vehicles tested.

PEMS allows for the following air pollutants and greenhouse gas emissions to be measured as mass emissions (g/km): NOx, NO_2, THC, CO, PN, CO_2.

Figure 3: PEMS fitted to a bus exhaust system

4.3 NOx Sensors

NOx sensors are a simple 'on road', indicative method for monitoring NOx emission levels when the vehicle is operating under real world driving conditions. The sensors typically provide a measure of NOx concentration (ppm). In order to determine mass emissions (g/km), a measure or calculation of exhaust volume flow rate is required. NOx sensors cannot speciate NOx to NO and NO_2, results are therefore reported as NOx.

In the CBTF/CVTF programmes NOx sensors were adopted as a low-cost method of monitoring in service performance of the exhaust after-treatment systems SCR and TMT. Twin sensors were typically fitted, one before the exhaust after-treatment technology, measuring 'engine out' NOx concentrations, and one post after-treatment system, measuring 'tail-pipe' NOx concentrations. The difference between the two measurements gave an indication of performance of the exhaust after-treatment system. This was commonly reported to as '% NOx conversion' by SCR retrofit suppliers. NOx emissions (engine out and tail-pipe) were determined for some projects using NOx sensors.

HJS, Eminox and Proventia have access to the vehicle's engine CAN system making it possible to estimate exhaust volume flow rate and calculate mass NOx emissions. In the case of Green Urban, their NOx sensor measurements are only provided as NOx concentrations (ppm).

Figure 4: Illustration of a NOx sensor

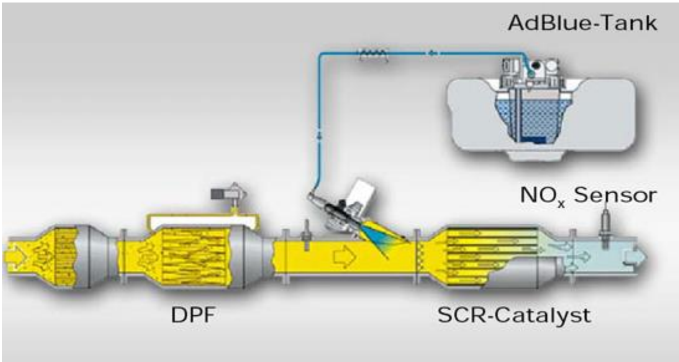
5 Exhaust Gas Treatment Technologies

5.1 Selective Catalytic Reduction

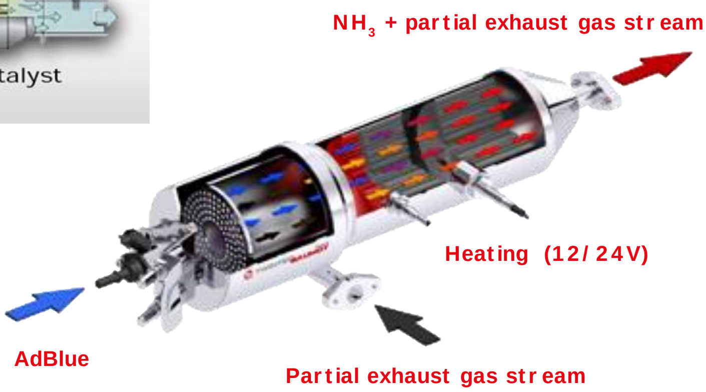
Selective Catalytic Reduction (SCR) is an exhaust after treatment emissions control technology. The system injects a reductant agent, typically ammonia, through a special catalyst into the exhaust stream of a diesel engine. The ammonia initiates a chemical reaction that converts nitrogen oxides into nitrogen, water vapour and carbon dioxide which are then expelled through the vehicle tail-pipe. There are different approaches to ammonia storage and dosing. Wet SCR dosing systems use aqueous urea as the source of ammonia; this is purchased as 'AdBlue'. This is stored in a urea tank on board the vehicles. Four companies involved in the CVTF/CBTF programmes currently offer these types of SCR systems in the UK – Eminox, HJS, Green Urban and Proventia. An alternatively designed system comprises of an ammonia generator that doses ammonia gas directly into the exhaust line. An example is the BNOx System supplied by Twin Tech Baumot and featured in the CBTF 2015 programme.

Figure 5: Illustrations of different SCR systems

Wet SCR system



BNOx system



The temperature window for urea injection in the SCR system is typically 250-450°C. Temperature, the amount of urea, ammonia injection design and the type of catalyst are the main factors that determine actual NOx removal efficiency. Ammonia emissions (ammonia slip) can result from incomplete reaction of NOx and urea. This can occur due to over-injection into the gas stream, temperatures too low for ammonia to react, or catalyst degradation. The SCR system should be designed to keep ammonia emissions to very low levels, typically less than 10ppm at any time.

The SCR system is commonly fitted after a Diesel Particulate Filter (DPF) that reduces particulate matter emissions. Continuously Regenerating Trap technology (CRT) is the most widely adopted type of DPF. This uses an oxidation catalyst in front of the filter to generate the NO_2 required to keep the filter clean. Increased primary NO_2 emissions have been an issue with installation of CRT. The latest generation of SCR catalysts (3rd generation) utilise copper zeolite catalysts that have the benefit of lowering direct NO_2 emissions. In addition, they can reduce NOx emissions at lower exhaust temperatures, and achieve very low exhaust emissions. The systems are more compact in size enabling buses with larger engine and reduced spacing to achieve high NOx reductions.

Amminex Emissions Technology has introduced an innovative type of ammonia storage system named the Ammonia Storage and Delivery System. Amminex system involves removing the current urea based dosing system and replacing this with an ammonia salt dosing system. The ammonia is activated by heating coils which can be mixed with the exhaust gases at a lower exhaust temperature (c200 °C) allowing an earlier emissions treatment. The ammonia is stored in cylindrical cartridges, of which two are on board the vehicle but only a single cartridge is in use at any one time, the second only being used once the initial is empty. This technology has been adopted by TfL.

Figure 6: Ammonia Storage and Delivery System

The majority of CVTF/CBTF retrofit SCR projects entailed equipment suppliers fitting on and off board monitoring systems to ensure the continued and effective performance of the SCR system. These included warning lights on the dashboard of the bus driver cabin to indicate low NOx conversion rates and urea levels. Offboard devices included telematic systems that provided the bus operators with real time diagnostic data, received via their mobile phone and/or a PC at their depot. These systems can quickly identify system faults and maintenance issues.

5.1.1 CBTF and CVTF SCR Retrofit Projects

The most extensive application of retrofit SCR has been with buses. The CBTF and CVTF programmes funded 1,553 diesel buses to be fitted with this technology, covering 37 local authority projects. The majority of retrofits have involved Euro III buses, however Euro II, Euro VI and V buses have also been successfully converted. Euro III, II and pre-Euro Standard buses were also fitted with particle filters. A list of the local authority bus SCR retrofit projects covered in this evaluation study are listed below.

Table 5: Retrofit SCR bus projects covered in the evaluation study

Programme	Local Authority	No of vehicles funded	Euro Standard	Retrofit Technology Supplier
CBTF 2015	Blackpool City Council	30	Euro III	Eminox
CVTF 2014	Bradford Metropolitan District Council	27	Euro III	Eminox
CBTF 2013	Brighton & Hove City Council	50	Euro III	Eminox
CBTF 2015	Brighton & Hove City Council	23	Euro IV	Eminox
CBTF 2015	Centro (Birmingham)	5	Euro IV	Green Urban
CVTF 2014	Cheshire West Borough Council	2	Euro III	Green Urban
CBTF 2013	Chiltern District Council	15	Euro III	Green Urban
CBTF 2013	City of York	2	Euro II	Green Urban
CVTF 2014	Colchester Council	10	Euro III	Eminox
CVTF 2014	Coventry City Council	21	Euro III	Eminox
CBTF 2013	Gateshead/Sunderland (Go North East)	40	Euro III	Eminox
CBTF 2015	Harrogate Borough Council	10	Euro III	Eminox
CBTF 2013	Leicester City Council	32	Euro IV	HJS
CVTF 2014	Leicester City Council	5	Euro III	HJS
CBTF 2015	Leeds City Council	23	Euro IV	Eminox
CBTF 2013	Merseytravel - Liverpool City Region	29	Euro III	Eminox
CVTF 2014	Merseytravel - Liverpool City Region	12	Euro III	Green Urban
CBTF 2015	Norfolk County Council	2	Euro III	HJS
CBTF 2013	Oxford City Council	8	Euro II	HJS
CBTF 2015	Rossendale Borough Council	35	Euro III	Eminox
CBTF 2015	Sheffield City Region	25	Euro IV	Eminox
CVTF 2014	Suffolk County Council	26	Euro III	HJS
CBTF 2013	Suffolk County Council, Ipswich Council	15	Euro II	Green Urban
CBTF 2015	Sunderland City Council	14	Euro V	Eminox
CVTF 2014	Transport for London	400	Euro III	Proventia, Eminox, HJS
CBTF 2015	Transport for London	30	Euro V	HJS
CBTF 2015	Transport for London	55	Euro V	Amminex *
CBTF 2013	Transport for Greater Manchester	34	Euro III/IV	HJS
CBTF 2013	West Yorkshire Combined Authority	119	Euro III	Eminox
CVTF 2014	West Yorkshire Combined Authority	46	Euro IV	Eminox

* *Ammonia storage system combined with existing SCR*

Table 6: Retrofit SCR other vehicle projects covered in the evaluation study

Vehicle Class	Local Authority	No of vehicle funded	Euro Standard	Retrofit Technology Supplier
Mini-bus & cars	Brighton & Hove City Council	17	Euro 4	Green Urban
Coaches	Dudley Council	10	Euro II/III	Eminox
Fire Engine	Transport for London	1	Euro III	Proventia
Mini-bus	Merseyside	6	Euro III	Green Urban

The subsequent section of this chapter focuses on demonstrating the NOx emission reduction performance of retrofit SCR. Commentary is additionally given to other air pollutants and greenhouse gas emissions where robust vehicle emission monitoring data was available. The largest analysis has been devoted to buses as a result of the significant amount of Government funding allocated to these vehicles.

5.1.2 Retrofit SCR Application in Buses

Retrofit SCR was fitted to a wide variety of bus models and engine variants funded through the CBTF and CVTF programmes. In the majority of cases a diesel particulate trap was also fitted to control particulate matter emissions. Projects included single and double-decker public buses, school buses and open topped tourist buses. The largest programmes have been run by Transport for London, West Yorkshire Combined Authority, Go North East, Brighton and Hove City Council and Sunderland City Council.

Various challenges were experienced by retrofit suppliers in terms of fitting their SCR systems. A common problem was that the incumbent diesel bus had been poorly maintained, meaning the vehicles required improvement work before the SCR could be fitted. This revealed the importance of appropriately inspecting buses prior to committing them for a retrofit project. Engine checks are additionally important prior to the SCR system being fitted to prevent engine failure, especially for older engines. Other challenges included sizing the SCR to achieve high NOx reduction within the constraints of available engine spacing. This was a particular issue for buses equipped with large engines. Overall these challenges were overcome with retrofit SCR technology demonstrated to be a highly effective exhaust after treatment technology.

Vehicle emissions monitoring results for retrofit SCR projects have been derived from both on road and vehicle lab testing. This data has predominately been from testing a single bus in a bus operator's fleet on fitment of the SCR system. In service monitoring results for two retrofit buses have been also been included – notably PEMS monitoring for Bradford and Leicester.

Several projects in the CBTF 2015 programme which entailed fitting the Eminox 'SCRT System', were able to provide on-road NOx emissions for their entire retrofit SCR bus fleet. This involved the use NOx sensors combined with exhaust flow rate measurements. For these projects, an average NOx emission and NOx emission reduction has been calculated for each bus model in the bus operator's fleet. The projects are Rossendale Borough Council, Brighton and Hove Council, Leeds City Council, Harrogate Borough Council.

A large number of retrofit SCR bus projects deployed NOx sensors to measure daily NOx concentration reduction to demonstrate the in service performance of the SCR system. A review of this data has been provided for thirty-three bus models. The measurements relate to six months in service data.

Figure 7 shows NOx emissions for retrofit SCR Euro III, IV and V buses. For Euro III retrofitted bus tail-pipe NOx emissions range from 0.2g/km – 4.7g/km, with the majority of these buses achieving NOx emissions below 0.5g/km. Figure 8 illustrates the NOx emission reduction for the same buses. The results range from 75%-99%, the majority of projects achieving over 90% reduction in engine out NOx emissions. Euro IV retrofit SCR buses achieve very low NOx emissions between 0.3 and 1.4 g/km. The retrofit SCR systems demonstrate a 93%-97% drop in NOx emissions. Euro V retrofit SCR buses follow identical performance. Tail-pipe NOx emissions measure between 0.3g/km and 1.43g/km. The SCR systems lower engine out NOx emission between 93% and 98%.

A large number of retrofit SCR bus projects involved the use of NOx sensors to provide in service vehicle emissions monitoring and evidence of SCR performance. Most of the data is reported as NOx concentration, indicating the NOx conversion efficiency of the SCR equipment. Figure 9 shows the six-month daily average NOx concentration reduction for pre-Euro Standard to Euro V retrofitted buses, this ranges from 60%-95%. The majority of the projects demonstrate a NOx concentration reduction of more than 80% in service, indicating very good NOx conversion efficacies of the SCR systems. This corresponds to the high NOx emission reduction performance revealed by more robust monitoring techniques (Figure 8).

The results above demonstrate that retrofit SCR system are highly effective at reducing NOx emissions when fitted to Euro III, IV and V buses, and continue to perform to a high standard of NOx reduction when in service. In service NOx sensor measurements from Euro III and pre-Euro Standard buses reveal the technology can perform equally well for much older buses.

Figure 7: NOx emissions retrofit SCR buses - on road and vehicle lab monitoring

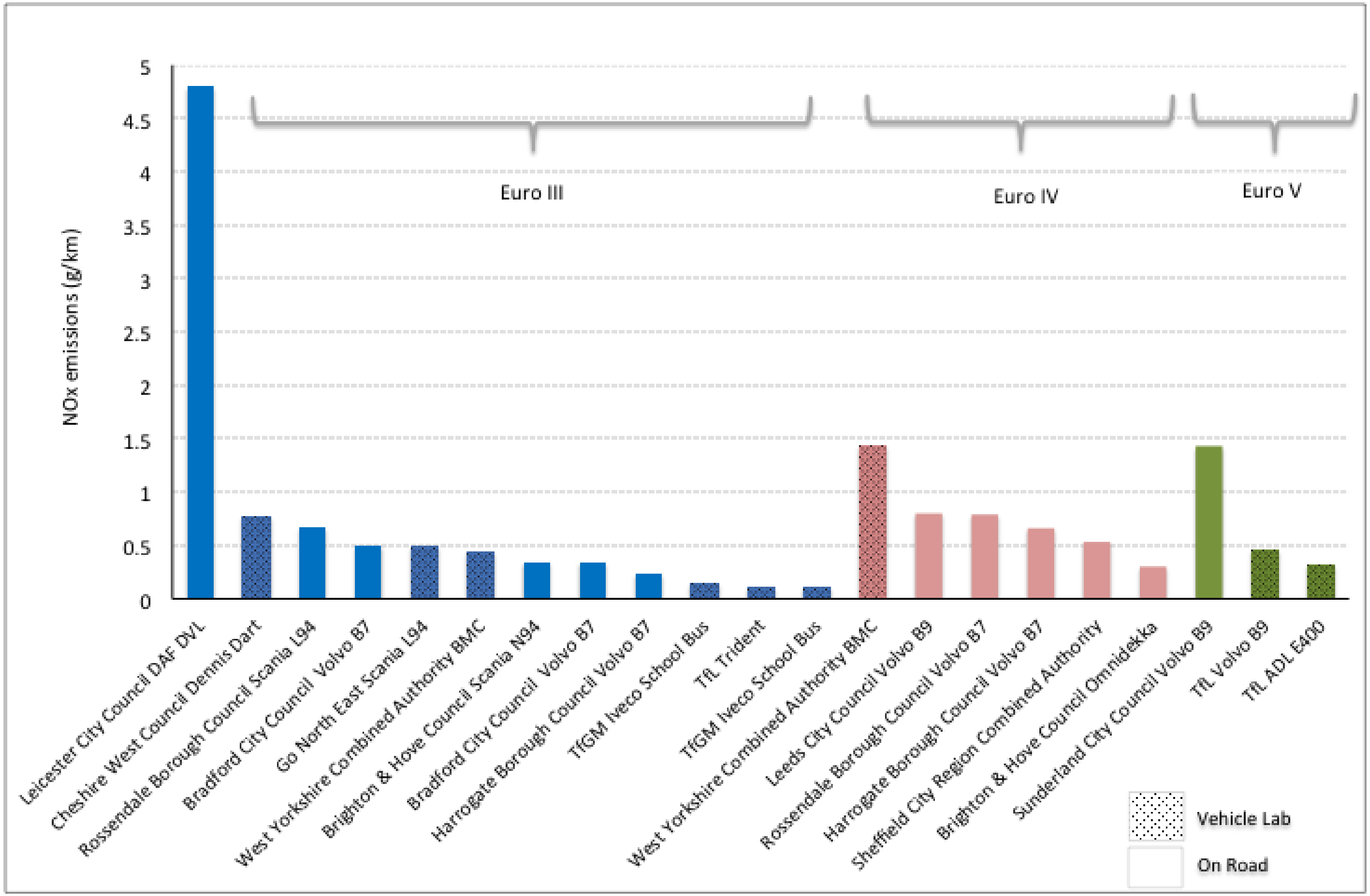


Figure 8: NOx emission reduction retrofit SCR buses - on road and vehicle lab monitoring

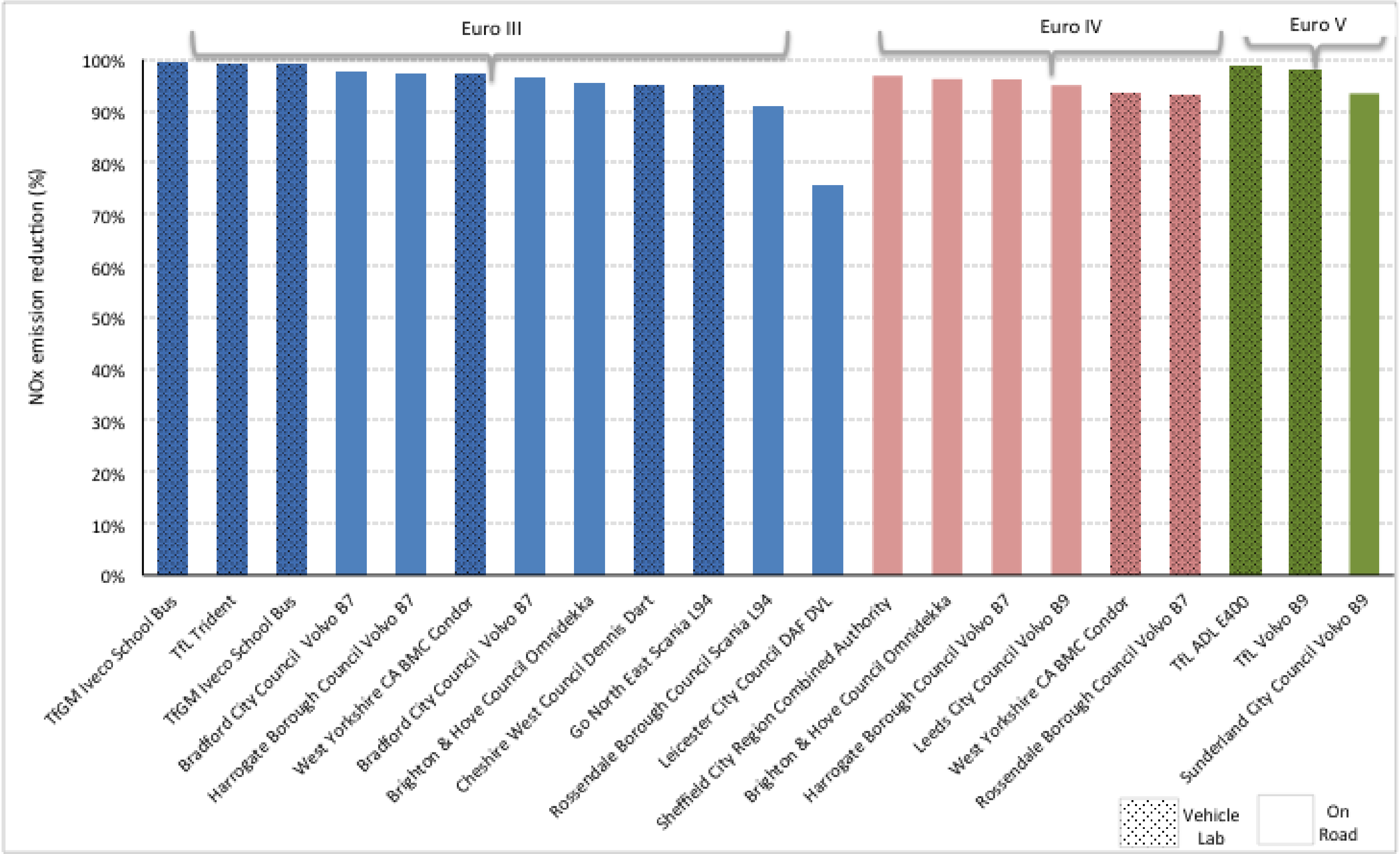


Figure 9: On road in service monitoring SCR retrofit buses - six-month NOx sensor data

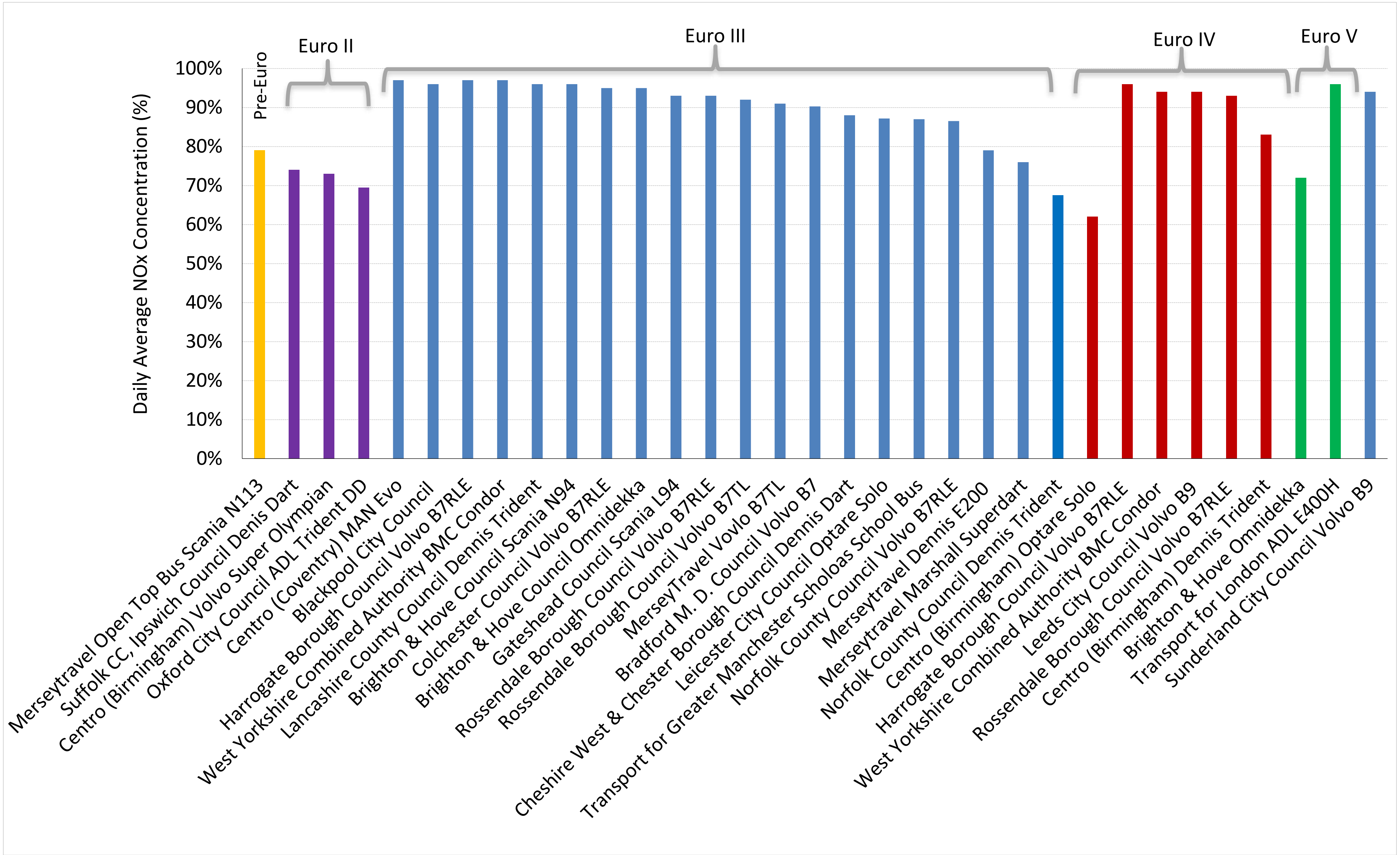


Figure 10 illustrates the performance of retrofit SCR with regards to reducing NO_2 emissions. Only a few projects measured NO_2 emissions as part of PEMS and vehicle lab monitoring. Measured NO_2 emissions are exceptionally low ranging from 0.03g/km to 0.32 g/km. High levels of NO_2 emission reduction are evident, Figure 11, with retrofit SCR systems achieving 55% to 97% NO_2 emission reduction for Euro III buses, 58% for Euro IV and 99% for Euro V.

Figure 10: NO_2 emissions retrofit SCR buses – on road and vehicle emissions monitoring

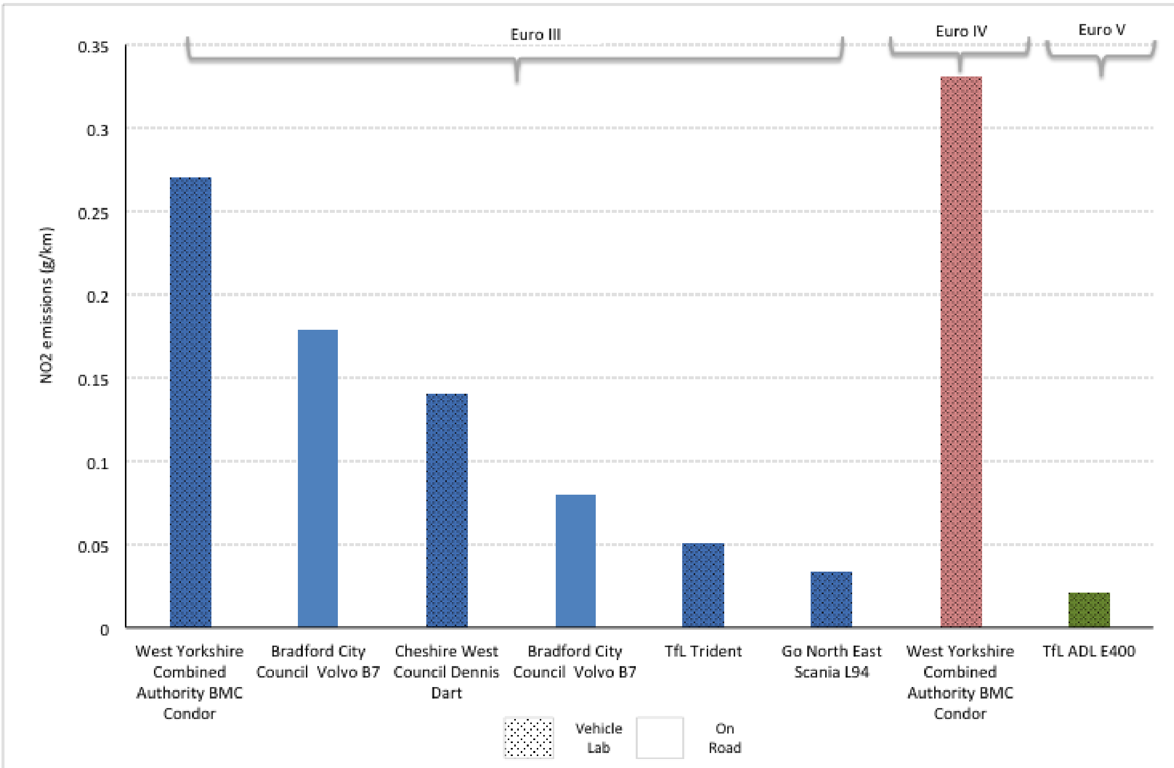
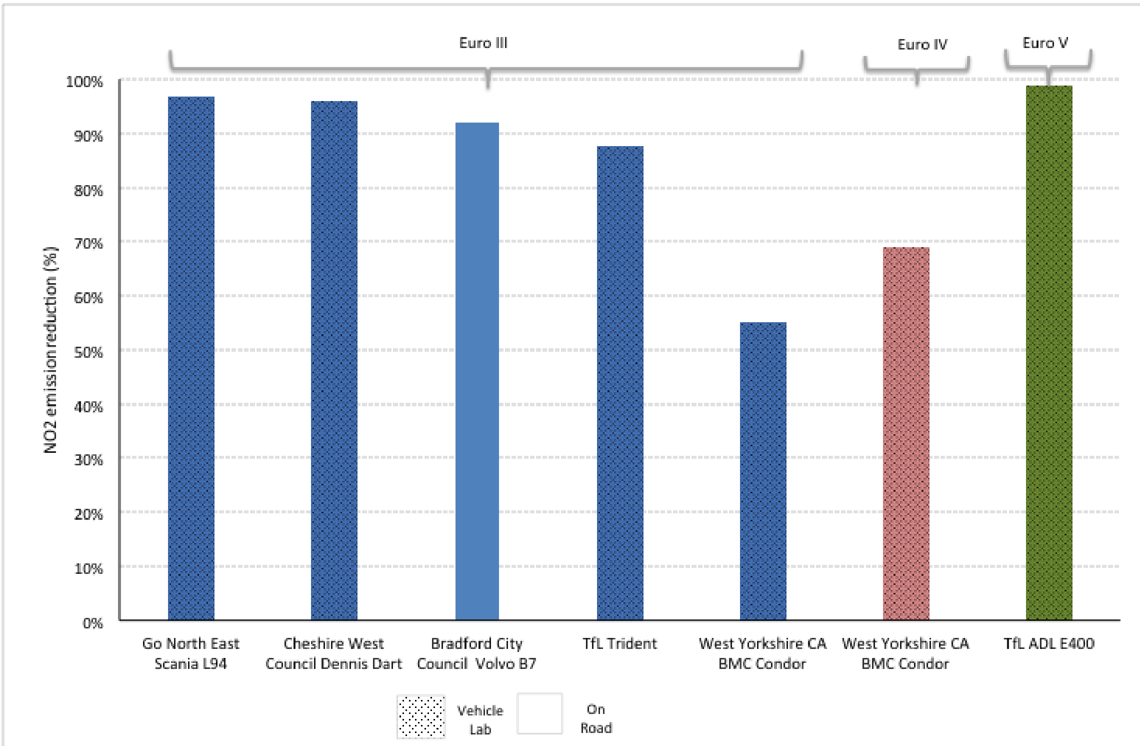


Figure 11: NO_2 emission reduction retrofit SCR buses – on road and vehicle emissions monitoring



The NO:NO_2 ratio of diesel vehicle exhaust emissions has been of interest in recent years due to evidence of increased primary NO_2 emissions. The NO:NO2 ratio of retrofit SCR system will be influenced by the SCR catalyst specification, with the most recent designs (3rd generation) achieving lower NO_2 emissions. Given the significant NOx emission reduction demonstrated by retrofit SCR buses in the CVTF/CBTF programmes, the NO:NO2 ratio becomes less important.

Ammonia emissions were measured as part of vehicle lab testing for four of the retrofit SCR buses. The results were well below 10pmm, the ammonia emission limit for certified Euro VI diesel vehicles.

Figure 12 shows Euro III retrofitted buses PM (particulate matter) emissions range from 0.005 g/km – 0.25 g/km, the majority have PM emissions below 0.03 g/km. The PM emission result for Bradford is markedly higher than the other four retrofitted buses, this could be an artefact of PEMs testing as accurate PM measurement is highly challenging.

Figure 12: PM emissions retrofit SCR buses – on road and vehicle emissions monitoring

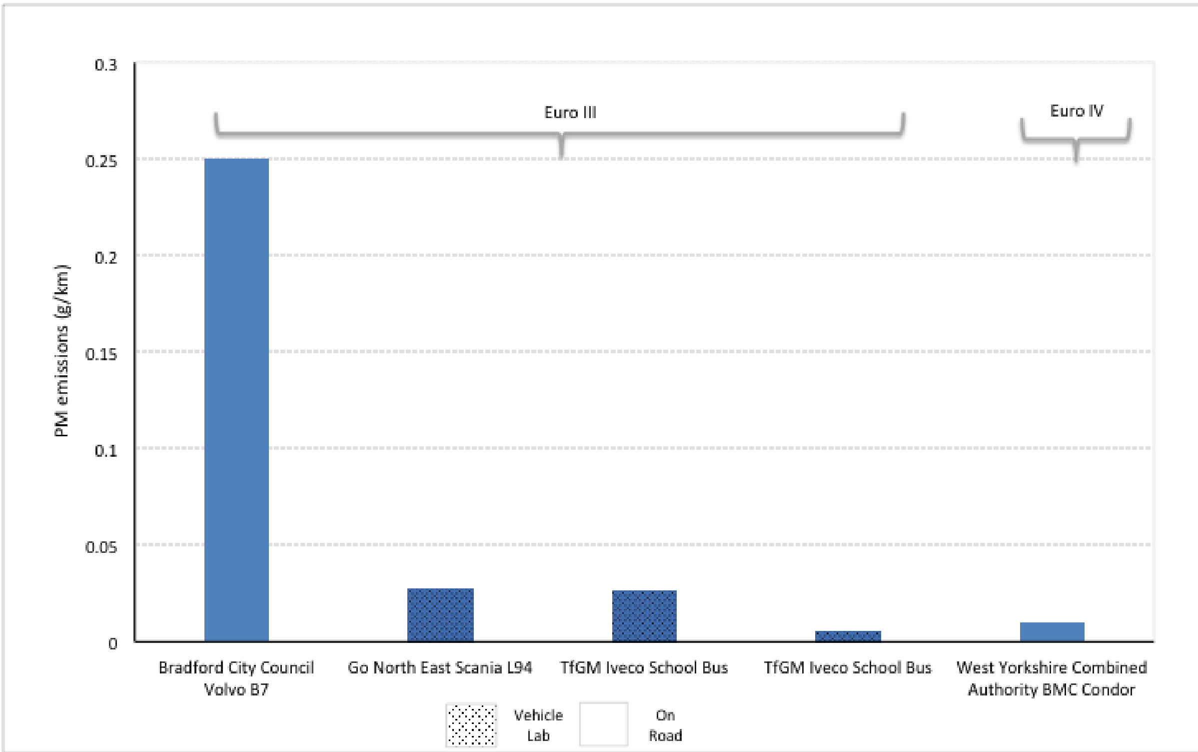


Figure 13 reveals very high PM emission reduction for the retrofit SCR buses ranging from 82%-99%. It should be highlighted that the Euro III SCR systems have been fitted with diesel particle filters.

Figure 13: PM emission reduction retrofit SCR buses – on road and vehicle emissions monitoring

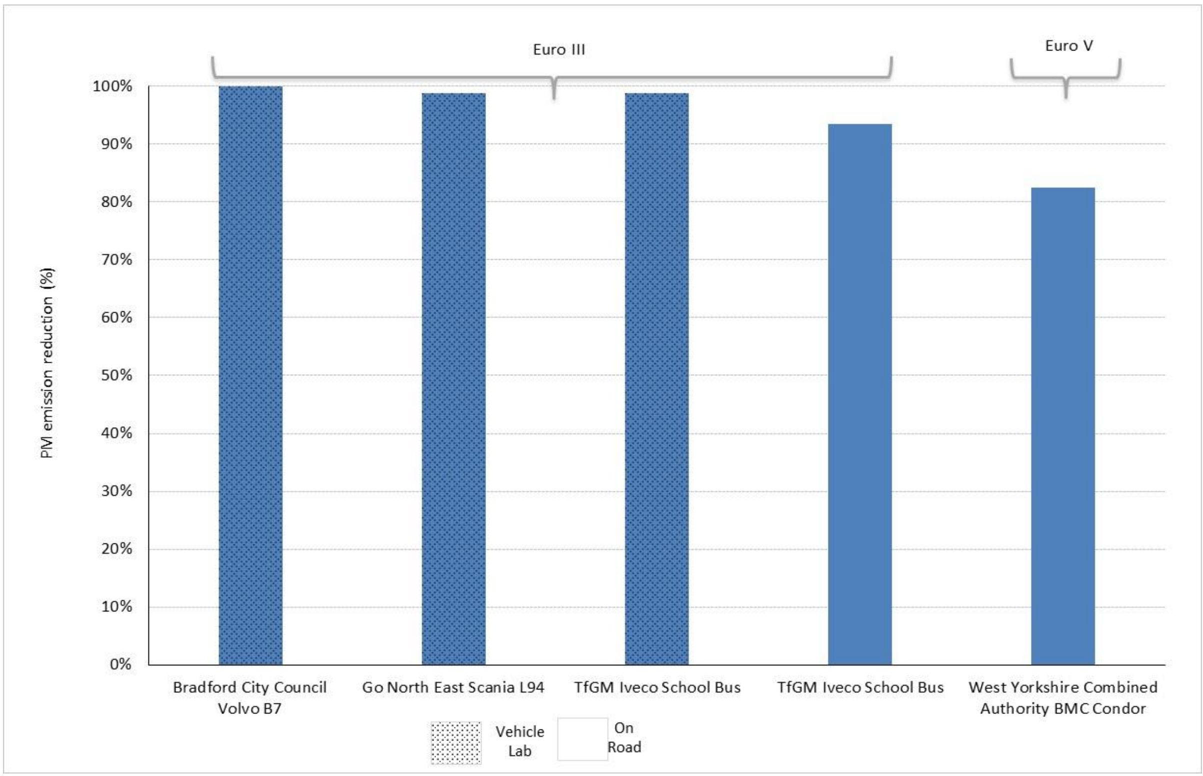
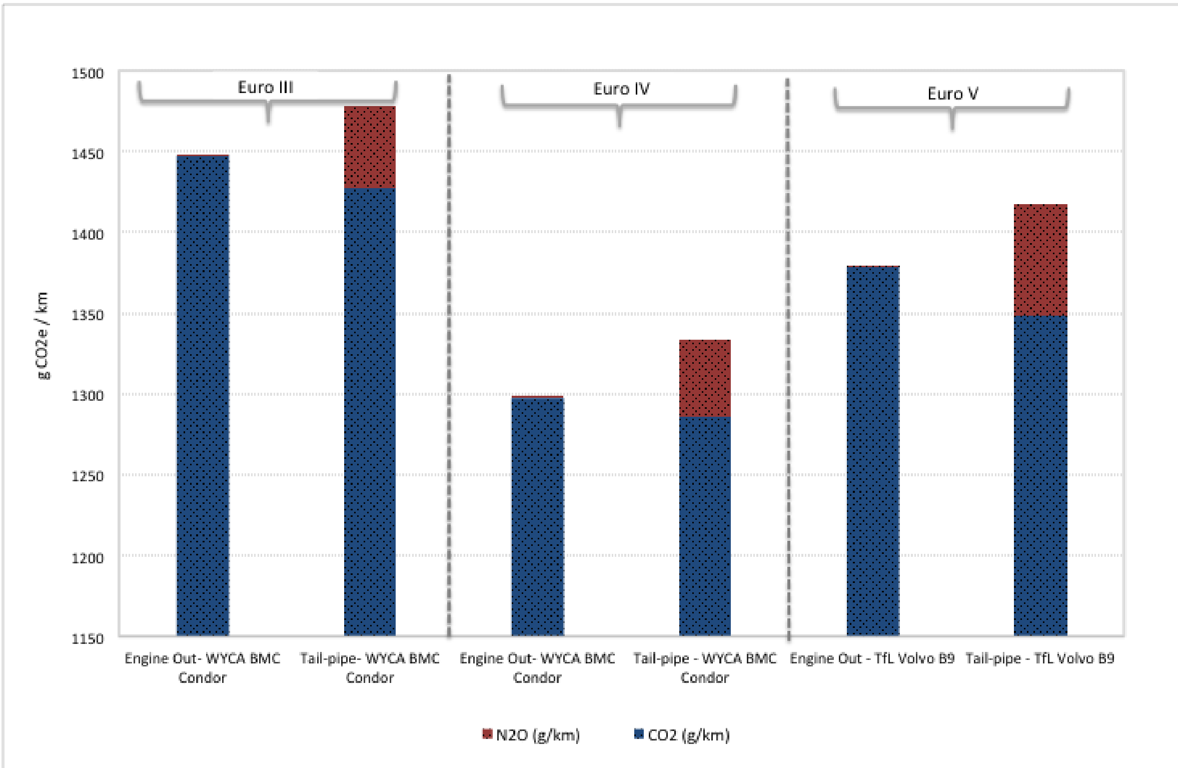


Figure 14 shows the CO_2e emissions for three buses before and after SCR fitment. CO_2 equivalent describes how much global warming a given type and amount of greenhouse gas may cause, using the functionally equivalent amount or concentration of carbon dioxide as the reference. The greenhouse gas covered are nitrous oxide (N_2O), methane (CH4) and carbon dioxide (CO_2). In the case of exhaust emission from retrofit SCR buses nitrous oxide and carbon dioxide are of relevance.

A 3-5% increase in CO_2e emission arises following SCR fitment to Euro III, IV and V buses. This is primarily due to a higher proportion of N_2O emissions. The chemical conversion of NOx emissions over the SCR catalyst with ammonia results in the generation of N_2O which is release in tail-pipe emissions. Catalyst formations and engine operating conditions influence N_2O emissions.

Vehicle N_2O emissions are currently unregulated in Europe and unmeasured in vehicle certification. Euro VI/6 vehicles, when fitted with SCR for NOx abatement, will have higher N_20 emission than previous Euro Standards. Evidence is very limited at the present time, however vehicle emission testing evidence from bus engines operating to bus duty cycles indicate that N_2O emissions add in the order of 5 – 8% to their overall GHG impacts (LowCVP Low Emission Bus Certification Scheme).[6]

Figure 14: CO_2e emissions retrofit SCR buses – vehicle lab monitoring



Note: N_2O global warming potential of 298 used to calculate CO_2e.

[6] http://www.lowcvp.org.uk/Hubs/leb/TestingandAccreditation.htm

5.1.3 Bus Case Studies

Transport for London

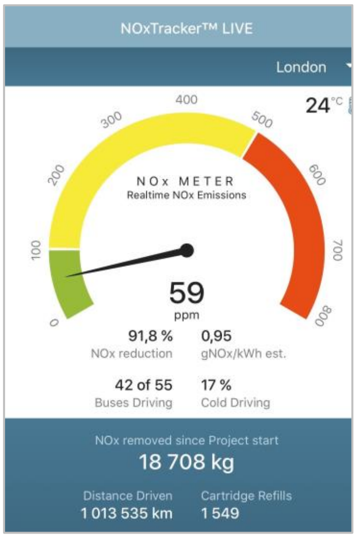
TfL successfully completed the world's largest SCR retrofit programme in 2012, retrofitting 1,015 older diesel buses operating on more than 50 routes across London. The £10m retrofit programme funded by TfL and the DfT has delivered air quality benefits to 102 of the 187 NO_2 focus areas identified by the Mayor of London.

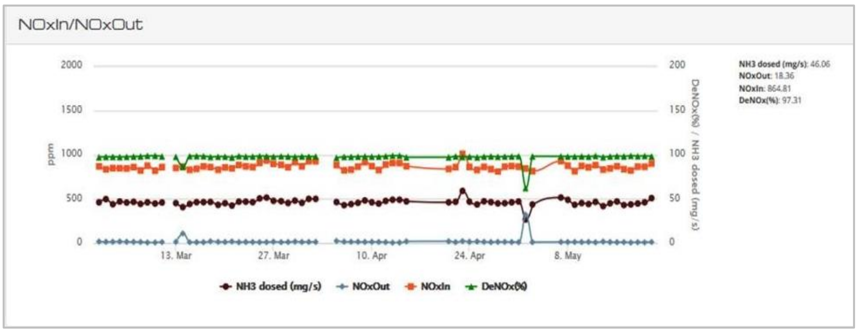
TfL won funding under the CVTF 2014 programme to retrofit 400 Euro III buses including Volvo B7, Dennis Trident, Scania and Series II Mercedes with SCR systems equipped with new third generation catalysts. The SCR systems were supplied by three manufacturers; Eminox, HJS and Proventia. TfL was awarded further funding under the CBTF 2015 programme to retrofit the HJS system to 35 Volvo B9 Euro V buses and install the Amminex Ammonia Storage system in place of urea in 55 Enviro 400 Euro V buses. TfL set their own performance criteria of 70% reduction in NOx emissions.

TfL worked in partnership with several bus operators including Metroline, Stagecoach, Abellio and Go-Ahead on the CVTF and CBTF retrofit projects. TfL's contractors are responsible for undertaking basic maintenance work such as replenishing AdBlue and changing particulate filters. TfL has a maintenance contract with each retrofit supplier who carries out annual service checks and repairs to the SCR system. Overall TfL has found the retrofit systems to be reliable with limited issues experience by their contractors.

TfL's contractor Metroline has been running their Euro V buses with the Ammonia Storage and Delivery System since mid-2016. The company have found this alternative method of ammonia storage to be successful and experienced no issues. Amminex have fitted NOx sensors to all of Metroline's buses in order to provide real time performance data of the retrofit SCR system. Metroline staff can receive this via an Amminex phone app NOx Tracker Live – see Figure 15. The parameters measured include ammonia dosing, SCR inlet temperature and NOx conversion. Warning lights have been installed on the buses to alert the drivers when one or both cartridges are empty. The cartridges are typically replaced every three to four days. The empty cartridges are returned to Amminex for refilling.

Figure 15: Amminex 'NOxTracker Live'

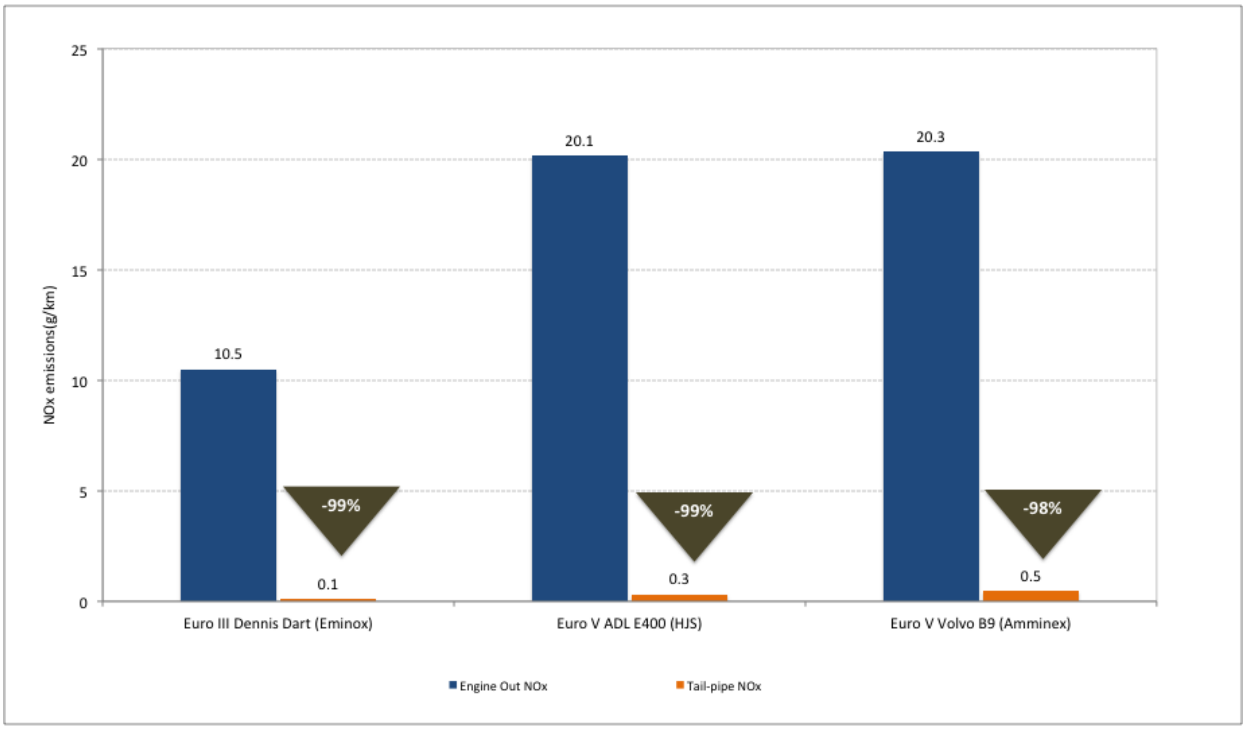




TfL has undertaken vehicle emission lab testing at Millbrook Proving Grounds to demonstrate the emission reduction performance of the retrofit SCR and Amminex Storage and Delivery System. The buses have been tested over the Millbrook London Transport Buses Test Cycle. Measurements were taken from engine out and tail-pipe to determine the emission reduction. A selection of buses have been equipped with NOx sensors to demonstrate the in service performance of the SCR technology. In the case of the Amminex system all 55 retrofitted Euro V buses have been fitted with NOx sensors.

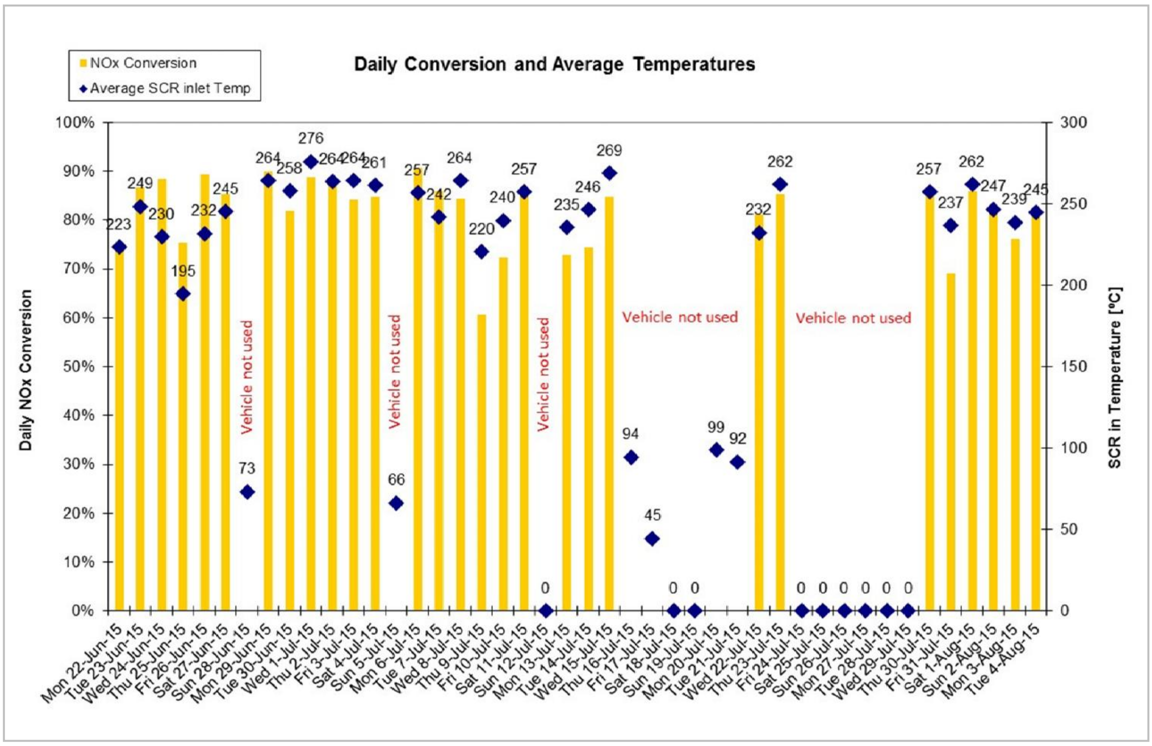
Figure 16 shows the NOx emissions for TfL's Euro III and V retrofitted buses. The Euro III bus was fitted with the Eminox 'SCRT System' achieved a NOx emission reduction of 99%. NOx emissions are exceptionally low measuring 0.1g/km. For the CBTF 2015, results for the Euro V retrofitted with the HJS SCR system are very good showing a 98% NOx emission reduction. The Amminex ammonia storage and delivery also performs very well achieving 98% NOx emissions reduction. This demonstrates that the Amminex system works as effectively as conventional aqueous urea. All three retrofit systems exceed TfL's NOx emission reduction target. NO_2 emissions were also shown to significantly reduce post SCR fitment for the Euro III and V, results are shown in Figures 10 and 11.

Figure 16: NOx emissions TfL retrofit SCR buses on fitment – vehicle lab testing



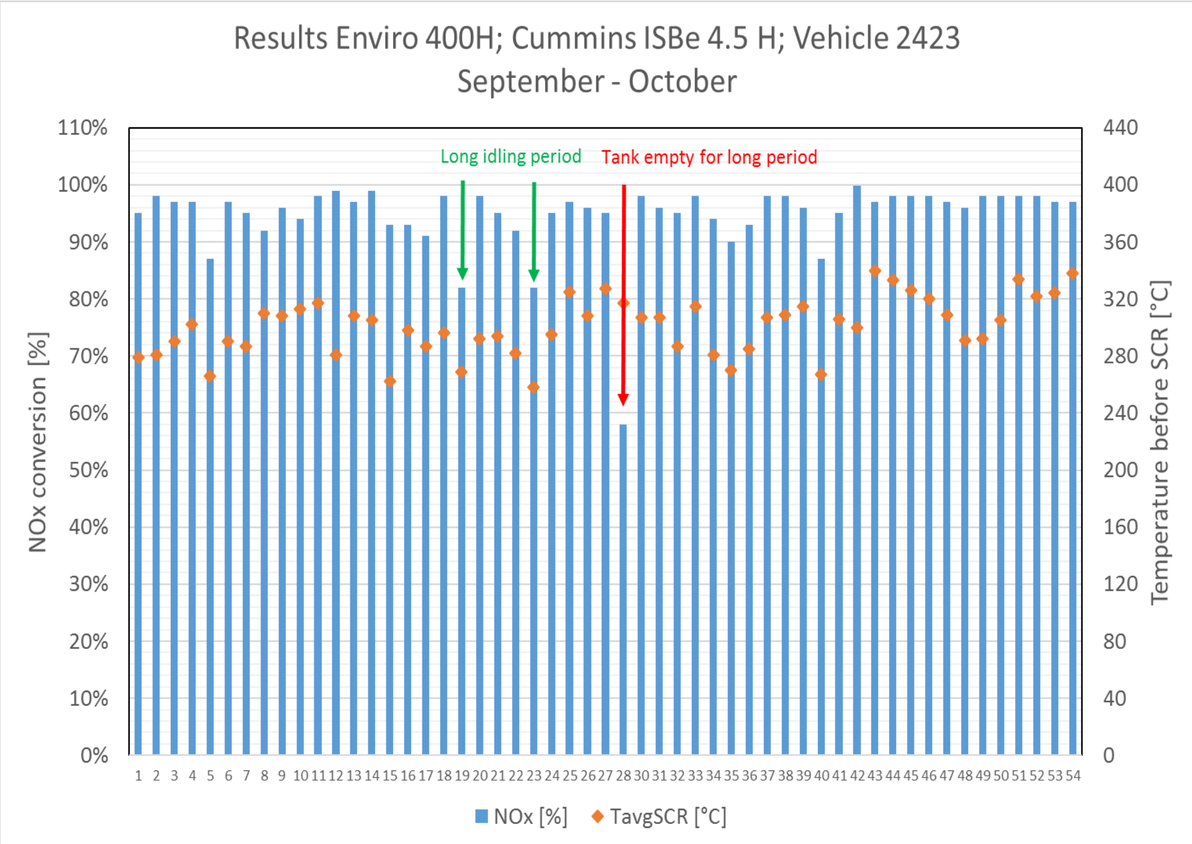
NOx sensor measurements for the Dennis Trident Euro III fitted with the Eminox SCR were undertaken between 22 June and 4 August 2015, see Figure 17. The bus was operating on a typical inner London bus route. The results show a consistently high level of daily NOx conversion ranging from 75% to 91% within the optimal exhaust temperature window, indicating effective operation of the SCR system.

Figure 17: Three month in service monitoring TfL retrofit SCR Euro III bus – on road (NOx sensor)



Daily NOx concentration reduction results for two months in 2016 for the Volvo B9 Euro V bus refitted with the HJS SCR system are shown in Figure 18. This reveals excellent in service daily NOx conversion, averaging at 96% over this period. The SCR catalyst temperature remains high throughout the two-month monitoring period, averaging at 300°C. This clearly demonstrates the system continues to perform well in service and correlates with the Millbrook testing results. The SCR system performance drops on a few occasions over this monitoring period. These occur during vehicle idling which reduces the exhaust gas temperate. Low Ad Blue levels give rise to a drop in NOx reduction, see day 28 in Figure 18.

Figure 18: Two month in service monitoring TfL retrofit SCR Euro V bus – on road (NOx sensor)



Note: NOx conversion refers to NOx concentration reduction

Six-month NOx sensor results for the 55 ADL 400H buses fitted with the Amminex system revealed a daily average NOx concentration reduction of 90% for the whole fleet. This is sound evidence that the SCR system and ammonia storage system continue to achieve a high level of NOx emission reduction in service.

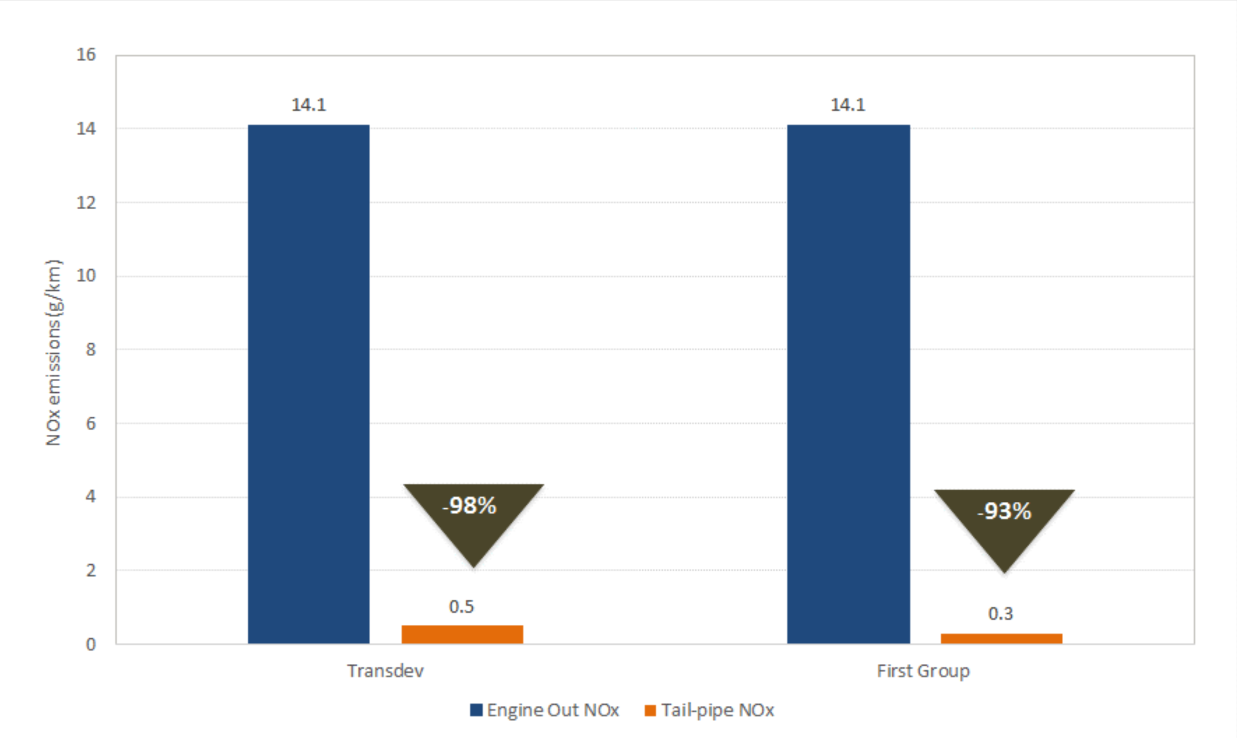
Bradford City Council

Bradford City Council retrofit SCR bus project entailed installing the Eminox 'SCRT System' to 11 Euro III double deck Volvo B7 buses in First Group's fleet, and 14 Euro III single deck Volvo B7 buses in Transdev fleet. Eminox claimed to achieve an 80% reduction in NOx emissions. The fitments were completed in December 2015. In advance of the SCR system being fitted to the First Group buses, the vehicles were inspected and found they had to undergo maintenance work to get these up to an appropriate standard for the SCR system to be installed. Both First Group and Transdev have an annual maintenance contract with Eminox, and carry out in house maintenance work such as cleaning particle filters and regularly topping up of AdBlue.

Bradford City Council deployed on road testing, both PEMS and NOx sensors, on a retrofit Volvo bus from each operators' fleet to determine the performance of the Eminox SCRT system. PEMS testing was undertaken by Emissions Analytics. The First Group retrofitted Volvo bus test programme was conducted between 29 September and 29 October 2015. The vehicle was tested before and after the SCRT system was installed. A bus route in Bradford city centre was chosen for the test run. It was 4.3 miles long, takes approximately 24 minutes to drive at an average speed of 10.6 mph.

PEMS testing was carried for the Transdev retrofitted Volvo bus in July 2016. In this test programme, no baseline measurements were undertaken. Route 662 running from Keighley to Bradford was used for the testing exercise. The route was 9.2 miles long and took approximately 47 minutes to drive at an average speed of 12.0 mph. The baseline PEMS results for the First Group bus have been used for illustrative purposes to demonstrate the NOx emission reduction performance of the retrofit SCR on the Transdev bus.

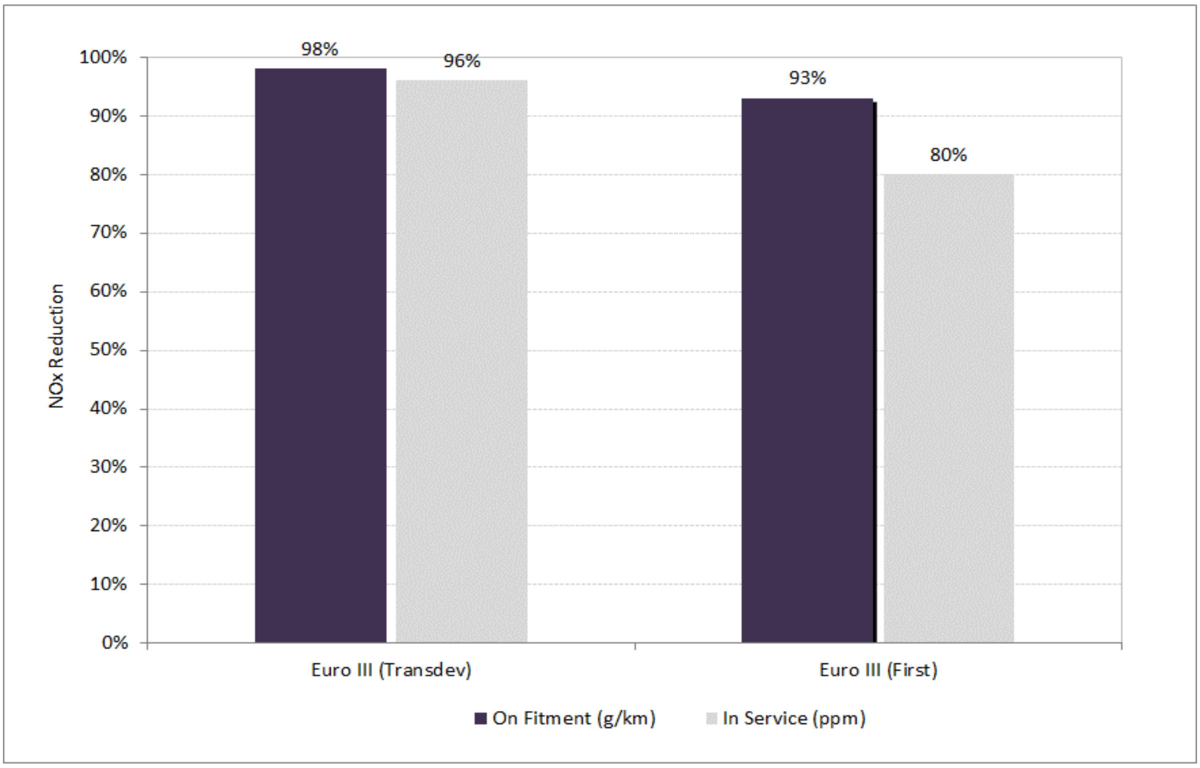
Figure 19: NOx emissions Bradford retrofit SCR Euro III buses – on road (PEMS)



The results of the PEMS testing, Figure 19 reveal very low NOx emissions for SCR retrofitted buses measuring between 0.3 and 0.5g/km, achieving in the order of 98% reduction in NOx emissions post fitment. This demonstrates the SCR system is achieving equipment suppliers' performance target on fitment and in service. PEMS testing also revealed high NO_2 and PM reduction on fitment and in service for the retrofitted buses.

Eminox installed NOx sensors on the two retrofitted buses to enable the in service performance of the SCR system to be demonstrated. The daily NOx conversion was measured after six months after the SCR fitments. Figure 20 reveals the high NOx conversion rate of both SCR systems in service (80%-96%). This is in line with the NOx emission reduction shown by the PEMS testing for both retrofitted Volvo buses. These results provide good evidence that the Eminox 'SCRT System' is performing well at reducing NOx emissions under day-to-day driving conditions.

Figure 20: In service monitoring of Bradford retrofit SCR Euro III bus – on road



Transport for Greater Manchester Case Study – School Buses

Transport for Greater Manchester (TfGM) were awarded funding under the CBTF 2013 and CBTF 2015 programme to retrofit SCR to 41 Euro III and IV Iveco buses, as part of their fleet of 93 Yellow School buses. These vehicles operate on dedicated school services across Greater Manchester, which covers their AQMA. Two suppliers were chosen for these projects; Twintech Baumot and HJS.

Stagecoach are one of TfGM's contracted school bus operators. The company provided two Iveco Scolabuses to serve as 'prototypes' as the vehicles frequently run with low exhaust temperatures. Exhaust gas temperature measuring equipment was installed to monitor the temperature profile of the school buses and allow the suppliers to develop a bespoke solution**.** Each prototype bus was fitted the HJS and Twintech Baumot SCR system and taken to Millbrook Proving Grounds for vehicle emission lab testing in 2015. This provided a NOx emission benchmark that the suppliers had to ensure their system could continue to perform against. The Scolabus bus fitted with the Twintech Baumot system was retested at Millbrook after two years in service.

Figure 21: NOx emissions TfGM retrofit SCR Euro III buses, on fitment & in service – vehicle lab testing

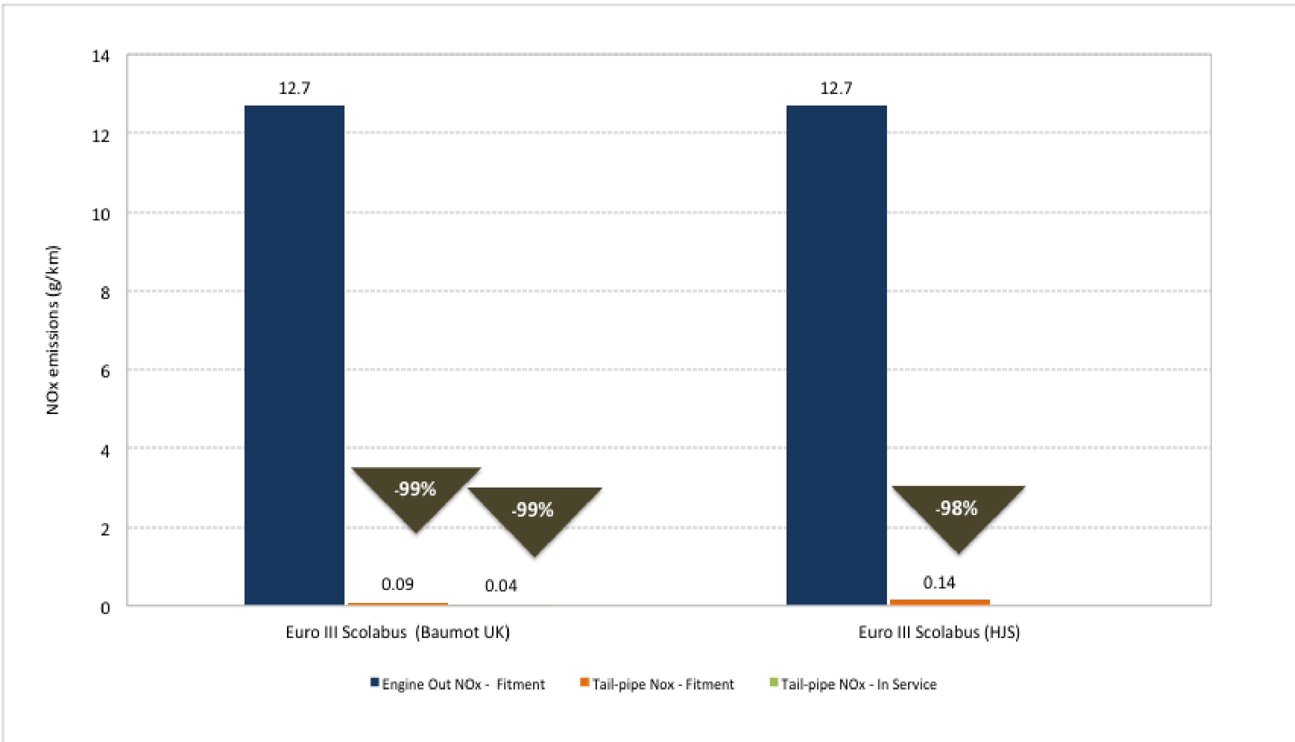


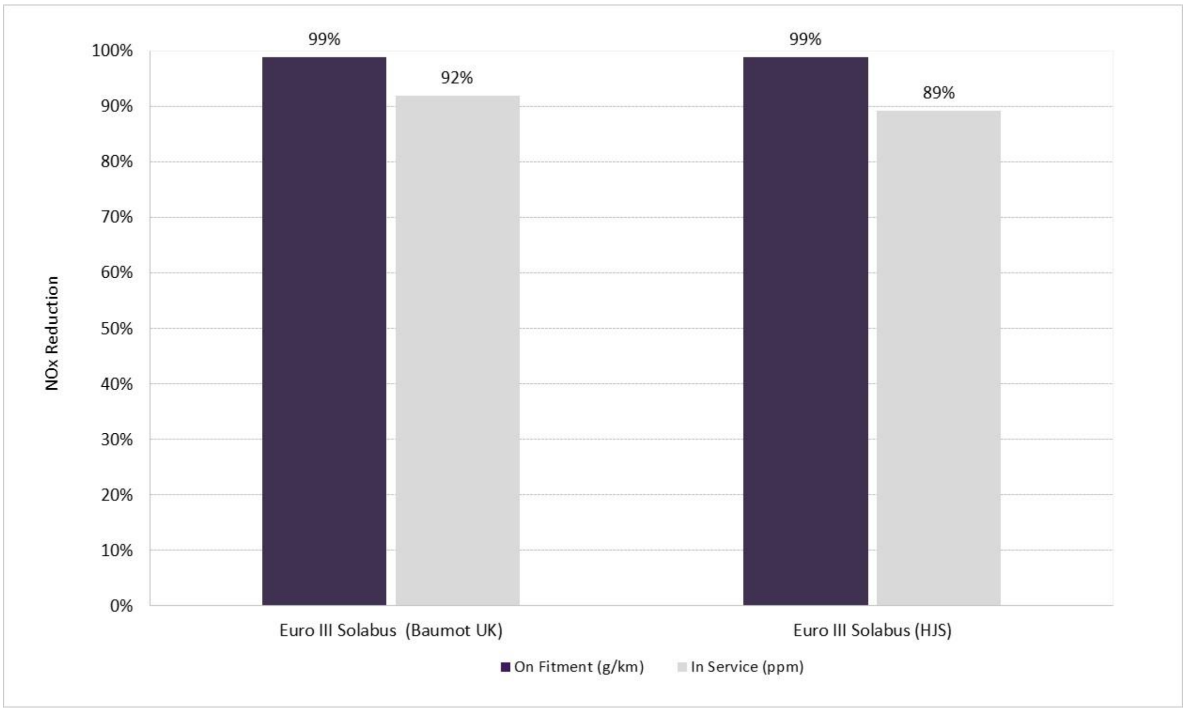
Figure 21 shows the HJS and Twintech Baumot SCR system achieved very high NOx emission reductions of 99%. The Twintech Baumot system continues to perform successfully after two years in service, achieving 92% NOx emission reduction. Tail-pipe NOx emission remain exceptionally low. Table 7 shows that NO_2 and PM emissions continue to be at low levels following two years in service, again demonstrating that the SCR system continues to perform successfully.

Table 7: Vehicle emissions testing results Twintech Baumot SCR system on fitment and in service

	NOx (g/km)	PM (g/km)	CO_2 (g/km)
On Fitment	0.09	0.03	1288
In Service	0.04	0.02	1309

Further evidence of the in service performance of the HJS and Twintech retrofit SCR systems is demonstrated by NOx sensor readings. Figure 22 compares the NOx emission reduction measured at Millbrook Proving Grounds with the six-month daily average NOx concentration for Scolabuses fitted with the HJS and Twintech Baumot systems. The in service measurements reveal excellent comparability to the vehicle lab testing results, demonstrating the on-going effective operational of both retrofit SCR systems.

Figure 22: In service performance TfGM retrofit SCR Euro III buses - on road (NOx sensor)



A number of challenges were experienced following the fitment of the initial SCR systems on the Scolabuses. These included problems mounting SCR components (AdBlue tank and exhaust system) due to variations in the age and chassis layout of TfGM's bus fleet, and component ECU failures. This meant more development work was required to resolve these problems. Various adaptations were undertaken to adequately fit components onto the chassis. A saloon heater was also installed on the buses to help increase engine temperature and urea dosing in the mornings and the Twintech Baumot B-NOx system was upgraded from a 12v to a 24v system which greatly improved the system reliability. TfGM has undertaken a number of measures to help ensure the effective performance of the SCR systems, and further reduce exhaust emissions:

- In service monitoring of emissions performance data and system reliability. The 41 retrofitted school buses are fitted with NOx sensors. Telematics will be fitted to the Twintech Baumot retrofitted buses to enable real time SCR performance monitoring and fault detection.
- Installation of idle limiters, to help reduce engine idling time, conserve fuel and reduce harmful emissions.
- Installation of fast acting windscreen de-misting equipment to reduce the need to operate engines prior to commencing the journey.

Maintenance of the buses is undertaken by HJS and TwinTech Baumot. Stagecoach will be taking over maintenance arrangements from TwinTech Baumot and are arranging training courses for their staff. Stagecoach and TfGM carry out basic maintenance work to ensure the continued high performance of the SCR systems which includes inspecting and cleaning DPFs every 28 days. AdBlue is topped up weekly; the annual cost of urea is not considered significant. Engine maintenance is regarded by TfGM as essential. Engine faults can damage the SCR system and also result in higher than expected emission levels. TfGM intend to build a maintenance regime into the contract agreement for operation of their school buses to ensure correct maintenance of the SCR systems is maintained.

The HJS and Twintech Baumot SCR systems have not caused any changes to the normal maintenance regime of the Scolabuses. TfGM has not seen any change in the fuel consumption of their school buses post SCR fitment. Encouragingly TfGM have not observed a drop in performance in the two SCR systems over the last two years; this is demonstrated in the in-service monitoring data presented for this case study.

5.1.4 Retrofit SCR Application – Coaches

Dudley Metropolitan Council where awarded funding under the CVTF 2014 programme to retrofit the Eminox 'SCRT System' to 10 coaches, 7 Euro II and 3 Euro II, operated by Prospect Coaches (West) Ltd. The coaches transport students to college and school children to swimming lessons and other curricular activities. The SCR fitments were completed in August 2015. Eminox claimed their 'SCRT System' could achieve a NOx reduction of 94% for the Euro III and the Euro II coaches.

The performance of the retrofit SCR coaches has been determined using NOx sensors in conjunction with exhaust flow rate and odometer readings. NOx sensors were fitted to two Euro II and two Euro III retrofitted coaches. NOx emission monitoring was conducted on commissioning of the retrofitted coaches, six and twelve months after fitment. The monitoring exercises were undertaken on a coach route in Dudley specified by Prospect (West) Coaches Ltd. With an average speed of 13mph - 15mph.

Figure 23 shows NOx emissions at engine out and tail-pipe for one Euro III coach on SCRT fitment then at six and twelve months in service. The Euro III coach demonstrates a 99% NOx emission reduction on SCRT fitment, this lowers marginally to 97% at six and twelve months in service. This aligns with Eminox's claimed NOx emission reduction target. A noticeable increase in engine out NOx emissions arises after one year in service; nevertheless tail-pipe NOx emissions maintain a very low level. These results demonstrate the Eminox 'SCRT System' remains to be consistent and effective in abating NOx emissions.

Figure 23: NOx emissions Dudley retrofit SCRT Euro III coach – on fitment and in service (NOx sensor)

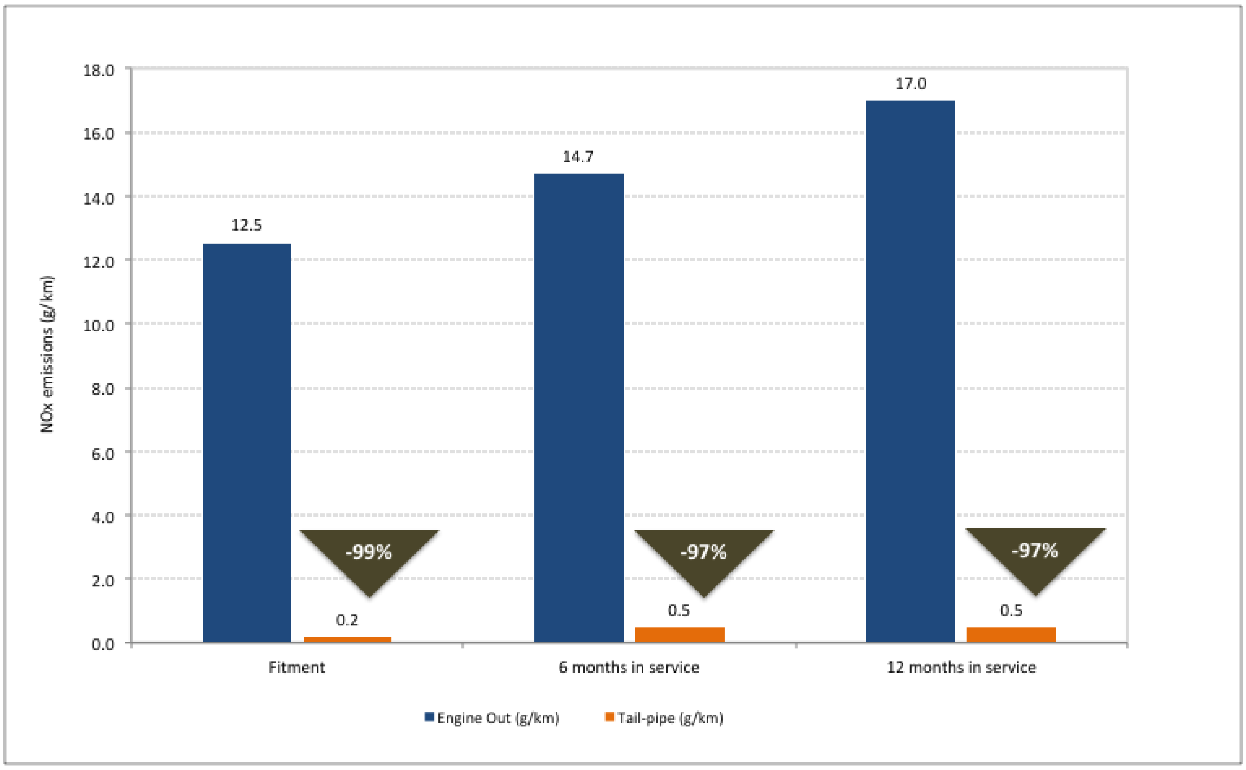


Figure 24: NOx emissions Dudley retrofit SCRT Euro II coach – on fitment and in service (NOx sensor)

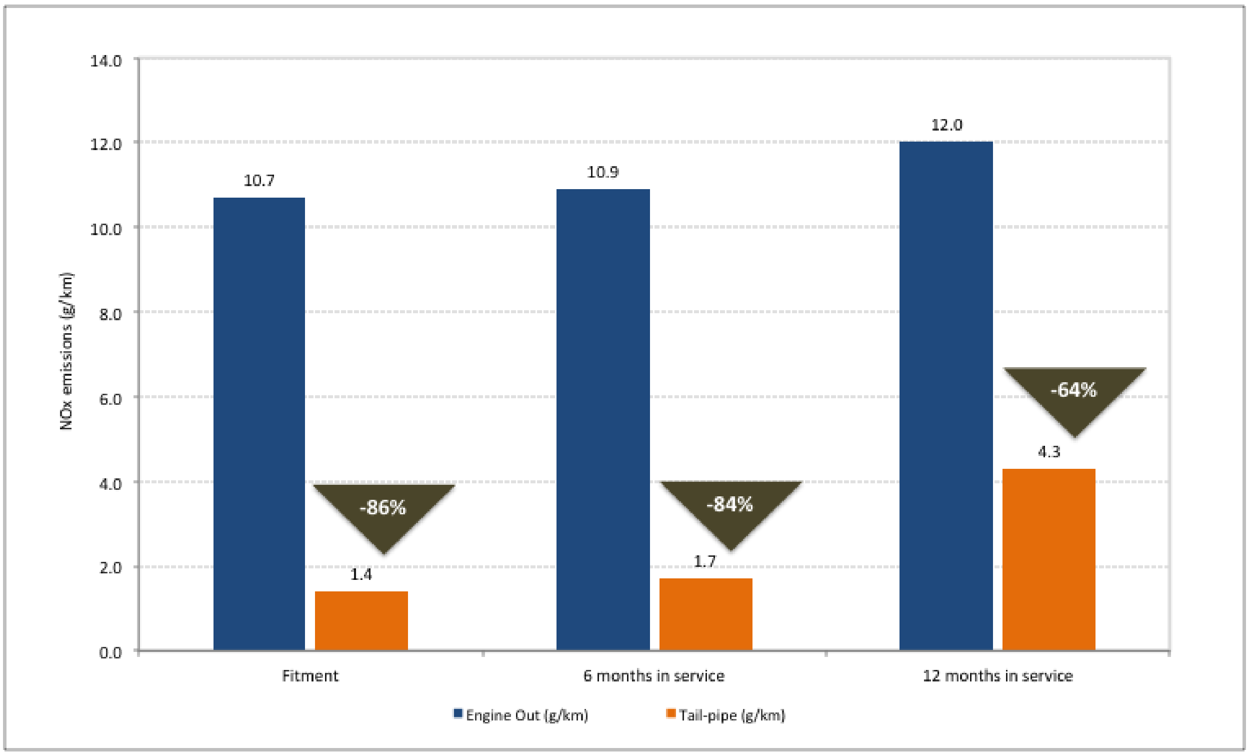
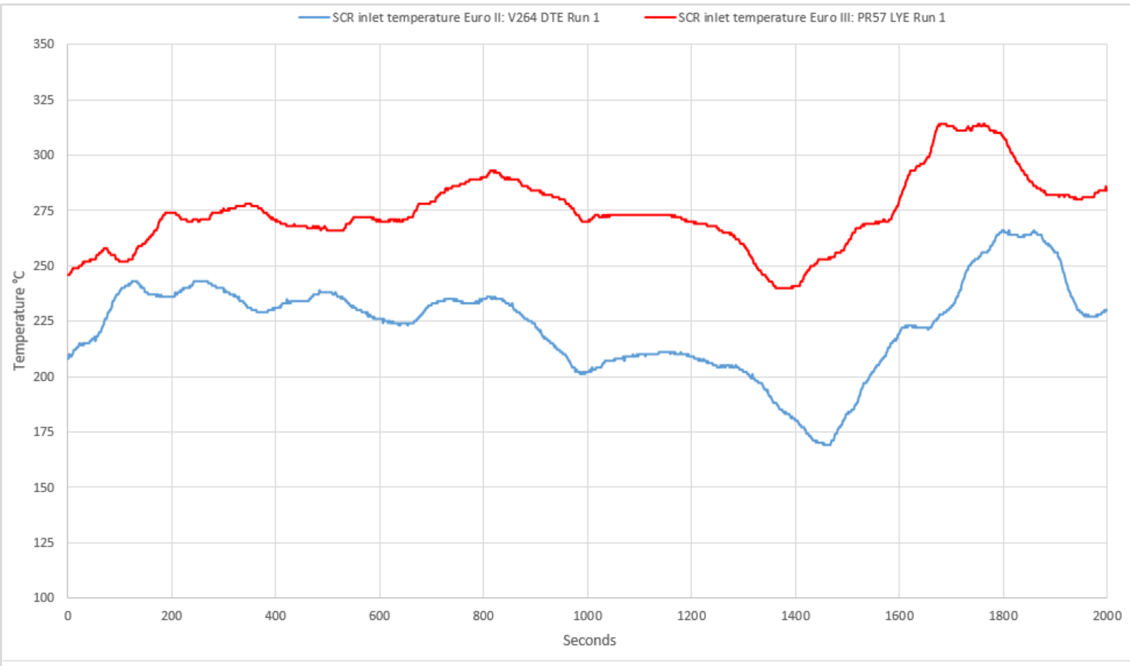


Figure 24 shows the retrofit SCR Euro II coach achieves a good level of NOx reduction, albeit lower than the retrofitted Euro III coach. The performance of the SCR system falls by around 20% after the first year in operation. The retrofitted Euro II coach does not meet Eminox's original NOx reduction claim of 94%. This has been attributed to the lower exhaust gas temperature of the Euro II coach, this was observed to drop below the SCR system's injection temperature during the vehicle emission testing exercises. The temperature monitoring data in Figure 25 illustrates the difference in exhaust gas temperature between the Euro II and Euro III coach.

Figure 25: SCR temperature profile Euro II and III coach at 6 months in service monitoring

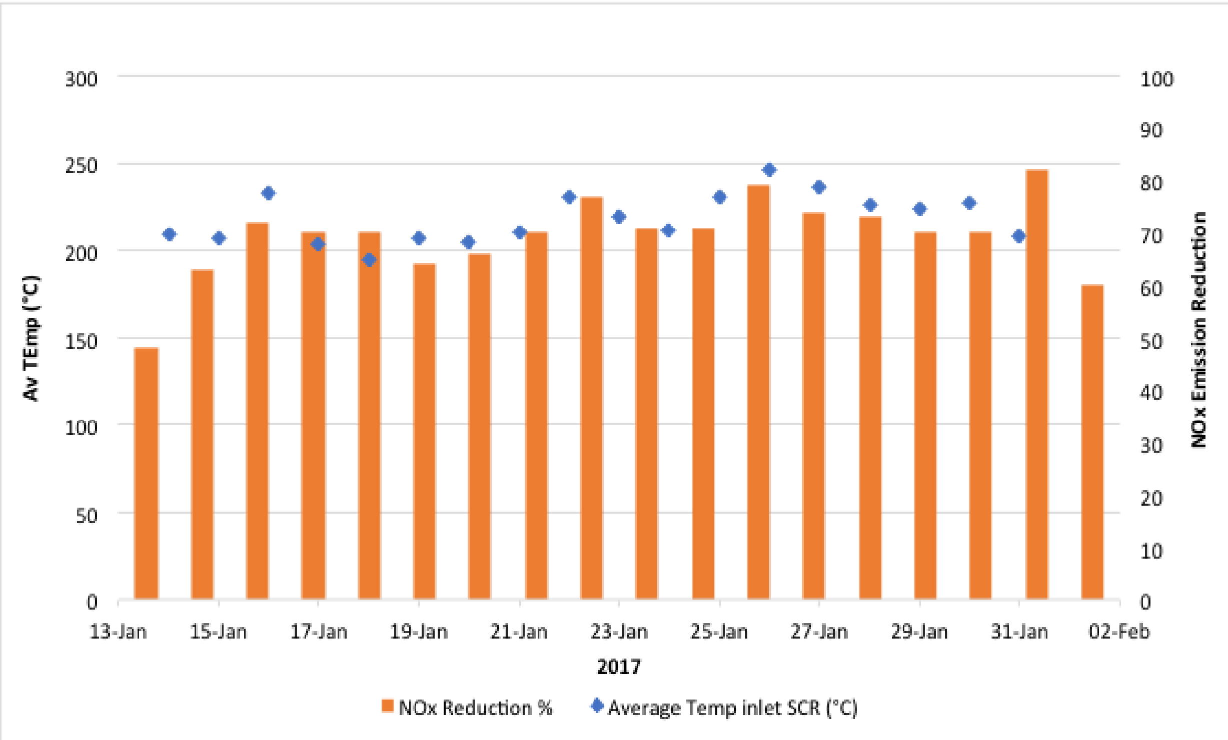


5.1.5 Retrofit SCR Application - Fire Engine

TfL was awarded funding in the CVTF programme to run a trial with the London Fire Brigade to retrofit SCR to a Euro III fire engine. The SCR system was supplied by Proventia who claimed a NOx emission reduction target of 70%.

The SCR system was installed in the fire engine in 2015. This was an ambitious project due to the short daily duty cycle (20-60 minutes) and mileage of the fire engine and the ability of the SCR system to perform within a lower exhaust temperature profile. Proventia has fitted the fire engine with NOx sensors and telemetry, proving real time performance of the SCR to London Fire Brigade staff via a phone app. The real-time monitoring system measures a variety of parameters including NOx conversion, NOx emissions, SCR inlet temperature and urea dosing. The fire engine has been operating successful and demonstrated an average daily NOx emission reduction of 72% during January 2017, operating at an average temperature of 220°C, see Figure 26. On a few occasions, the SCR performance drops below 70%. Tail-pipe NOx emission ranged from 0.4g/km to 3.8g/km, with the average over the month of January at 2.7 g/km.

Figure 26: In service performance retrofit SCR Euro III fire engine 2017 – NOx sensor



5.1.6 Retrofit SCR Application – Van Based Mini-Buses and Cars

Two CVTF 2014 projects entailed retrofitting SCR system to light duty vehicles in Merseyside Travel and Brighton and City Council. In both cases the SCR systems were supplied by Green Urban with a NOx emission reduction claim of 75%.

The Merseyside Travel project involved retrofitting seven mini-buses operated by Halton Borough Council. The NOx concentration for one retrofit mini-buses was measured after six months in service using NOx sensors. This achieved an 84% reduction in NOx concentration, demonstrating the effective functionality of the SCR system during every day driving conditions.

Brighton and Hove City Council programme entailed fitting the Green Urban 'ecoNOxT' SCR technology to 17 mini-cabs comprising of eleven Euro 4 and 5 van based mini-buses (Ford Transit, Fiat Scudo, VW Transporter, Renault Traffic, Peugeot Expert) and six Euro 4 cars (Skoda Octavia). Green Urban claimed an 75% reduction in NOx emissions could be achieved from their SCR system.

This project involves the innovative application of SCR technology to light duty vehicles that experience significant frequencies of low temperature exhaust gas on their daily driving routes in Brighton. Normally this would reduce dosing of AdBlue and lower the operational performance of SCR. Bespoke and compact SCR systems were designed by Green Urban that had added insulation to accommodate the lower exhaust operating temperatures of the minibuses and cars. Prototype SCR systems were first produced and trialled before the final designed systems were fitted to all the vehicles. One of the main technical challenges with installing the SCR system in a Skoda Octavia was locating space to fit the AdBlue tank. The limited engine space in cars makes the application of SCR difficult, hence why this exhaust after treatment system is typically adopted in medium and large sized cars to achieve the Euro 6 emission standard. In the case of the Octavia Skoda, an estate car, the AdBlue tank was positioned under the bonnet, next to the battery. This made refilling the tank relatively straightforward for the driver. The mini-cabs are all fitted with on-board diagnostics systems that are linked to warning lights on the driver's vehicle dashboard to alert when AdBlue requires topping up or if there is a fault of the SCR system.

Brighton and Hove City Council worked in partnership with local taxi firm, CityCabs, to deliver the retrofit project. The mini-cabs are predominantly used for community transport services that cover a variety routes in Brighton including city, dual carriage and rural routes. A few challenges encountered by the Council and Green Urban were the time taken to get the vehicles released by the local taxi drivers for installing the SCR system, and addressing concerns from the drivers that the retrofit SCR might damage their vehicles. Brighton City Council and Green Urban successfully overcame these issues and the majority of mini-cabs are now in service.

Brighton and Hove City Council commissioned vehicle lab testing for two mini-cabs to demonstrate the performance of the Green Urban ecoNOxT SCR system - a Euro 4 VW Transporter and the Euro 4 Skoda car. Both vehicles were tested at MIRA using World Harmonised Light Duty Test Cycle (WLTC). The VW Transporter was tested in January 2016 and the Skoda car in June 2017. The results for the VW Transporter are presented in Figure 27 and Table 8.

The Green Urban ecoNOxT SCR system achieved a 74% reduction in NOx emissions, with tail-pipe NOx emissions measuring 0.3g/km. Whilst this is below the supplier's original claim of 80% reduction, this takes into account the unexpectedly high baseline NOx emissions for the VW Transporter. These are well above the NOx emission limit for Euro 4 vans, with a baseline of 1300mg. It is well known that the Euro 4 and 5 diesel vehicles have not performed under real world driving conditions in terms of achieving the regulated NOx emission limits. This is evident from the VW Transport vehicle emission test results. With regards to other air pollutants, see Table 7, NO_2 emissions reduced by 100% and PM emissions by 22% post SCR fitment. There has been no change in CO_2 emissions.

Figure 27: NOx emissions Brighton and Hove retrofit SCR Euro 4 mini-bus taxi – vehicle lab testing

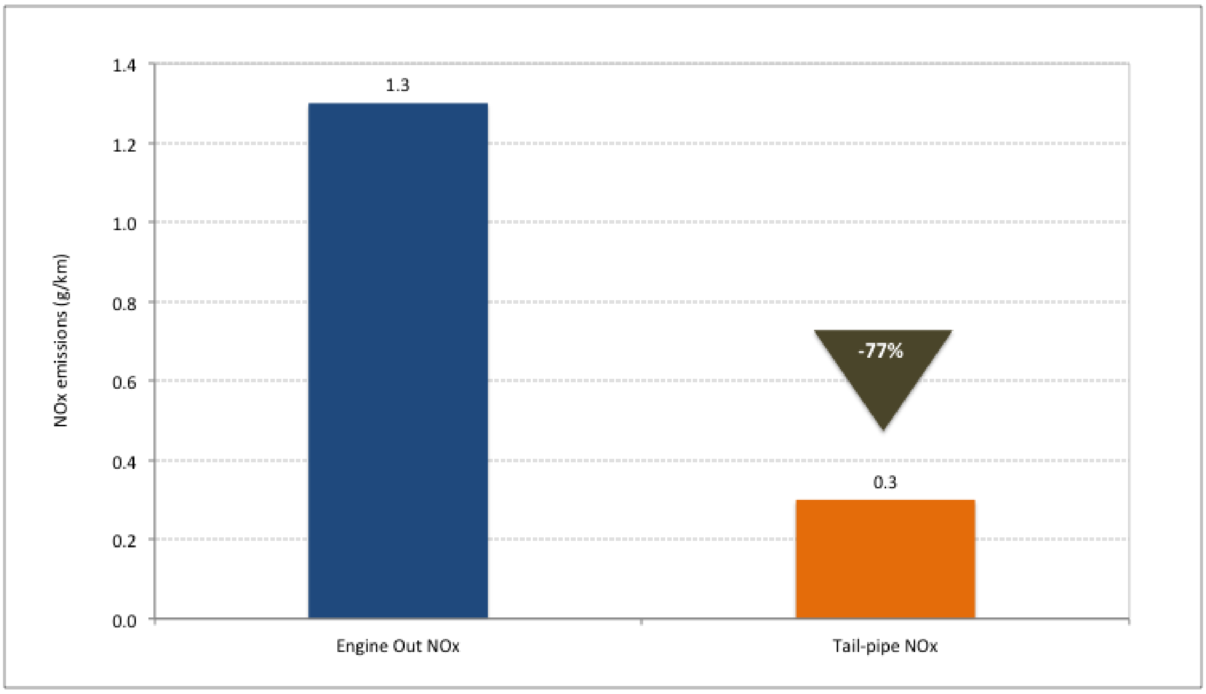
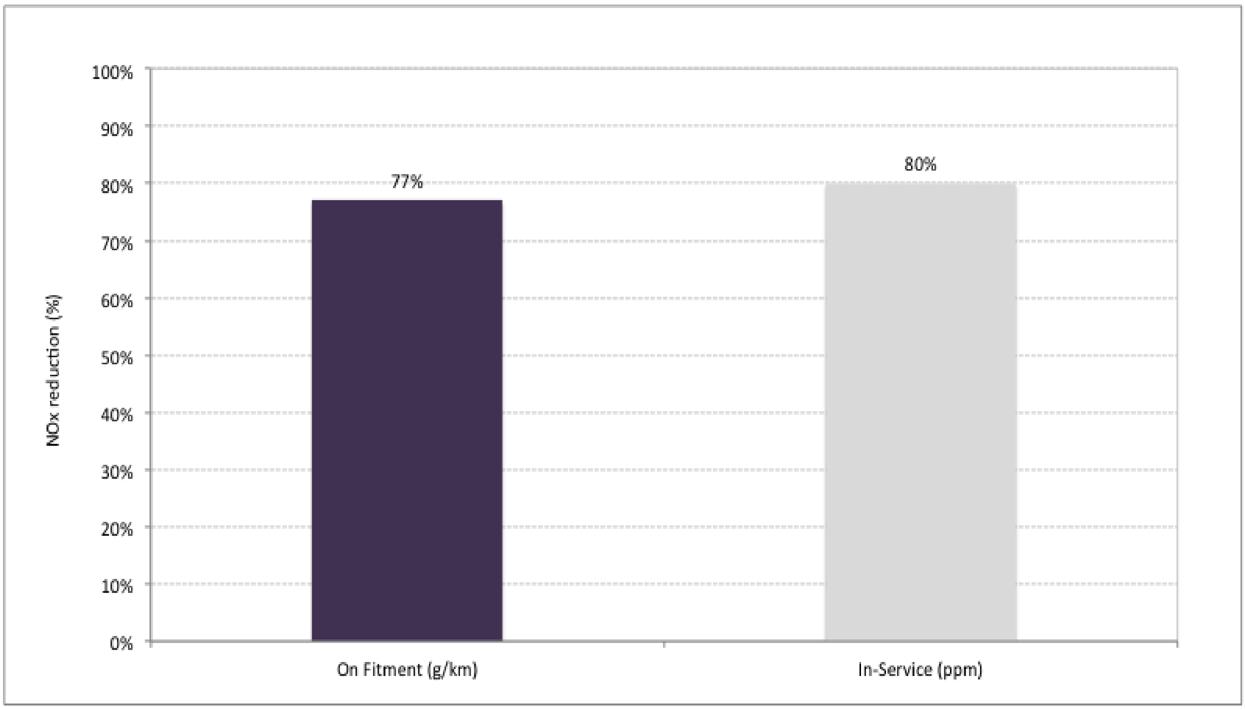


Table 8: Brighton and Hove retrofit SCR Euro 4 mini-bus taxi vehicle lab testing results

	NO_2 (g/km)	PM (g/km)	CO_2 (g/km)
Engine Out	1.01	0.02	198
Tail-pipe	0.001	0.01	198
% change(+/-)	- 100%	- 22%	0

Green Urban fitted NOx sensors to several of the mini-cabs measuring NOx concentration. Figure 28 compares the six month daily average NOx concentration reduction for the VW Transport, and the NOx emission reduction measured by vehicle lab testing. The NOx sensor data reveals the Green Urban SCR system is performing well under real world driving conditions, achieving an 80% NOx conversion rate.

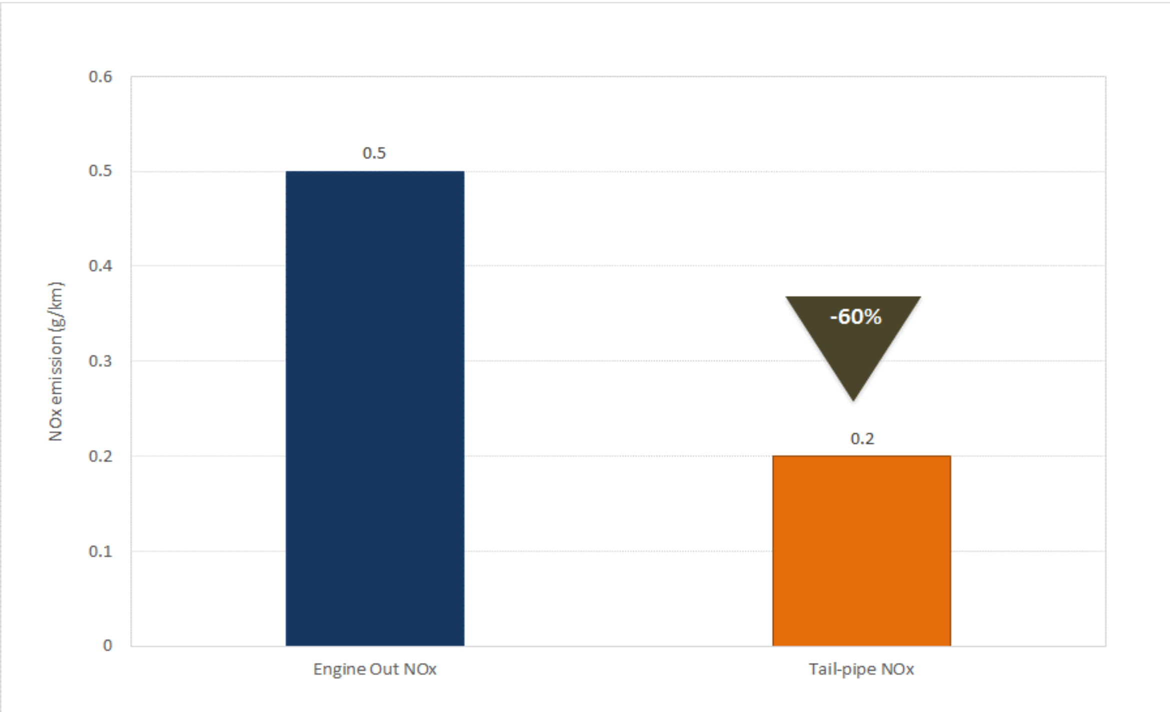
Figure 28: In service SCR performance Brighton and Hove retrofit SCR Euro 4 mini-bus taxi



The NOx emission testing results for the retrofit SCR Euro 4 car are shown in Figure 29. The SCR system gives rise to a 65% reduction in NOx emissions, with tail-pipe emission measuring 0.2 g/km. Whilst this is below Green Urban's target of 75% NOx reduction, the achievement is encouraging given that this is a prototype retrofit SCR system for cars. Green Urban has made various design improvements to their ecoNOxT SCR for cars over the last twelve months including improved injectors and adoption of a catalyst that performs better under lower engine temperature conditions. The company have suggested an increase in NOx emission reduction of 85-95%, vehicle emission testing is required to demonstrate this enhancement in SCR performance. In service NOx sensor data has yet to be made available for this vehicle.

Regarding other air pollutant emissions, NO_2 was not measured, PM emission results showed no change post SCR fitment. This is likely to be due to the fact that a particle filter was not fitted with the SCR system.

Figure 29: NOx emissions Brighton and Hove retrofit SCR Euro 4 car – vehicle lab testing



5.2 Thermal Management Technology

Euro IV and V buses have experienced challenges with reducing NOx emissions under real world driving conditions. Although these vehicles have often been fitted with SCR technology, early incarnations of this after treatment technology have not performed effectively in inner city locations. This is because buses are frequently caught up in traffic and spend a large proportion of their operating time standing at bus stops with their engine idling. This can result in higher NOx emissions is due to the lower catalyst temperature and AdBlue dosing. A way to overcome this problem is to retrofit thermal management technology to Euro IV and V buses.

The Thermal Management Technology (TMT) comprises of a control unit that measures the temperature and pressure of the exhaust upstream and the temperature downstream of the SCR catalyst. If the control unit determines that the exhaust temperature is too low, it actuates an exhaust flap integrated into the TMT system. By changing the position of this flap, the backpressure of the exhaust is increased and this in turn causes the temperature of these gases to increase significantly. This effect is further aided by additional insulation material that is wrapped around the SCR catalyst. Overall, the TMT system is able to increase the exhaust-gas temperature by up to 50°C. The one supplier of TMT funded through the CVTF 2014 programmes was HJS; the retrofit bus projects adopting this technology were South Yorkshire PTE and Bristol City Council.

South Yorkshire PTE was awarded funding to retrofit the HJS TMT to 41 Euro IV Volvo B9 buses operated by First Group. The claimed NOx emission reduction by HJS was 40%.

In service performance monitoring of one retrofit TMT bus are available for July to September 2015 and October to November 2016. The vehicle emissions monitoring has been undertaken using NOx sensors combined with exhaust flow rate and odometer measurements. Figure 30 shows NOx emissions with and without the TMT system activated over difference speeds for the 2015 period. The highest NOx emission reduction is experienced at very low speeds, achieving approximately 40% at 1-5 km/hr. NOx emissions across all vehicle velocities reduce from 16g/km to 11g/km with the TMT system fitted, averaging at 29% NOx reduction.

Figure 31 shows NOx emissions with and without the TMT system activated over difference speeds for the following year. The highest NOx emission reduction continues to occur at very low vehicle speeds. Across all speeds NOx emissions reduce from 15.5g/km to 11g/km equating to an average 26% reduction.

The in service monitoring data for the retrofit TMT system does not meet HJS's original claim of 40% NOx emission reduction across all driving speeds. The system only achieves the 40% reduction target during very slow driving conditions.

Figure 30: In service Performance South Yorkshire PTE Retrofit TMT Euro IV bus 2015 – NOx sensor

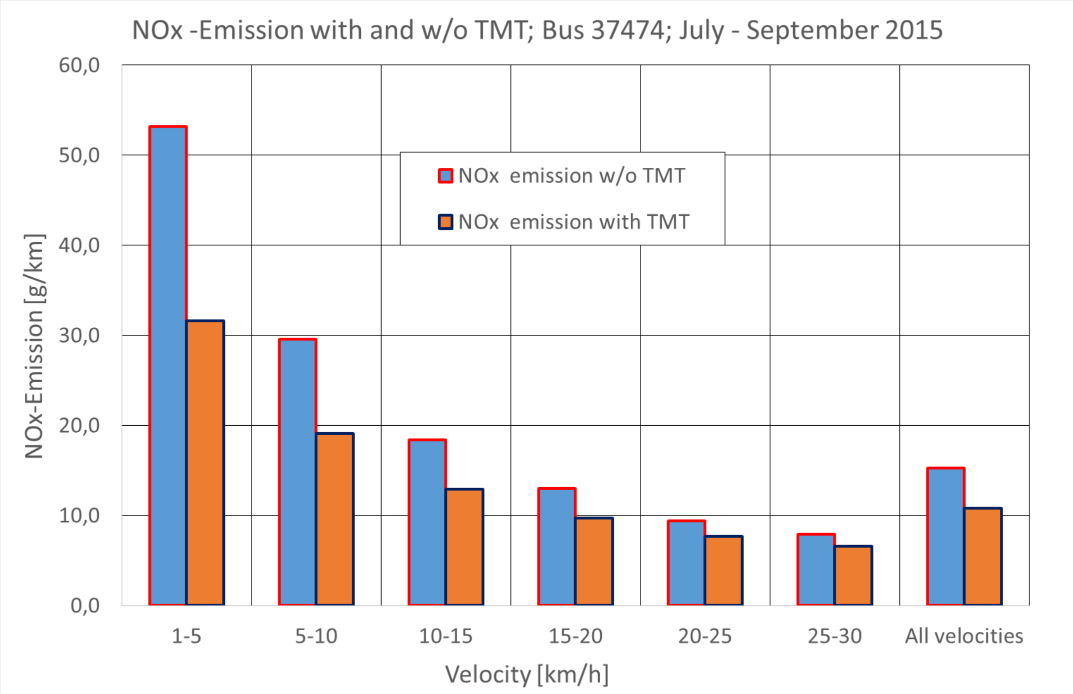
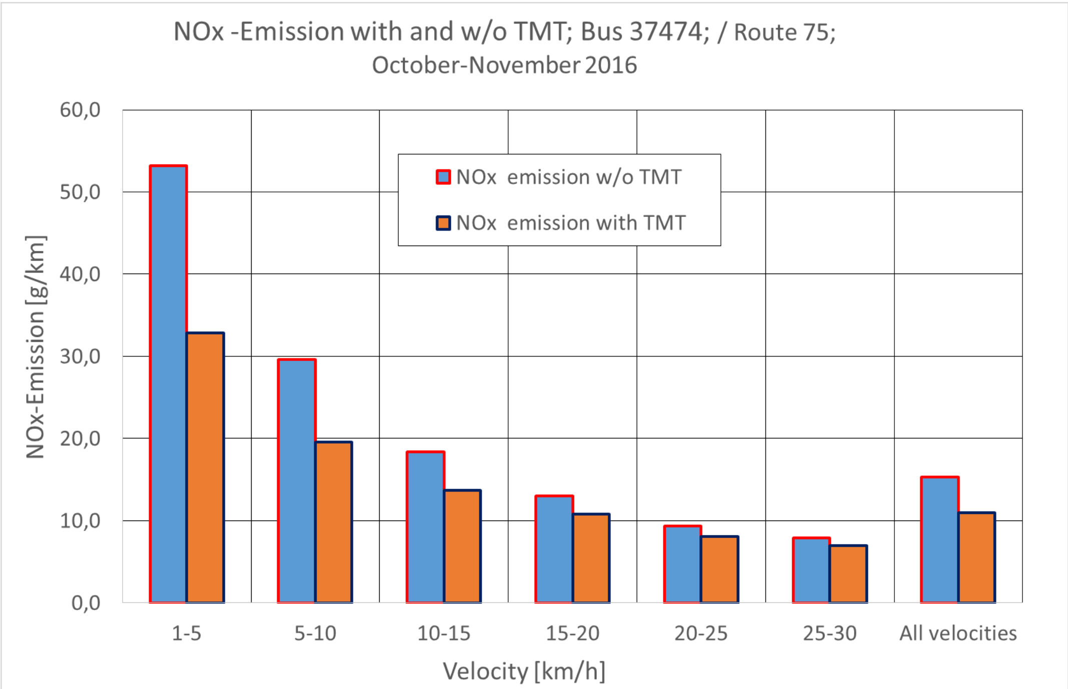


Figure 31: In service Performance South Yorkshire PTE retrofit TMT Euro IV bus 2016 – NOx sensor



6 Fuel Saving Technologies

6.1 Flywheel Hybrid

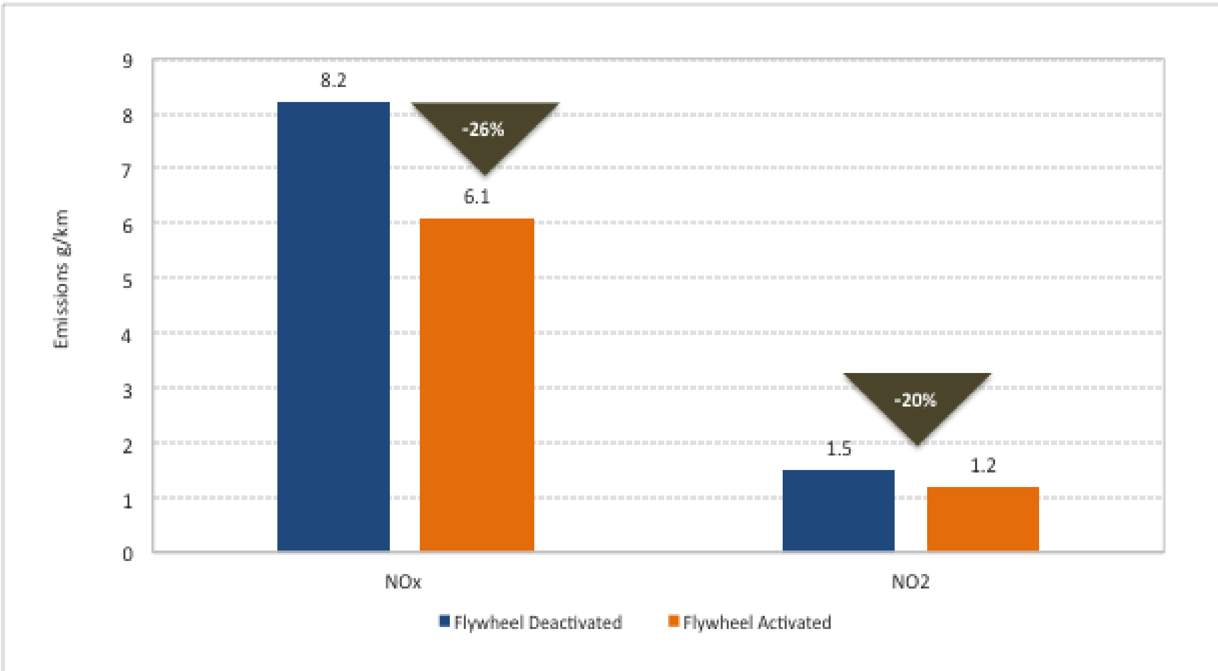
Electric flywheel technology is based on the principle of a Kinetic Energy Recovery System (KERS). When a bus brakes, it harvests the energy normally lost as heat. The flywheel stores the energy and returns it to the wheels on demand, boosting power, saving fuel and reducing emissions. When the driver brakes, a traction motor within the drivetrain slows the vehicle, generating electricity. This electricity is used to charge the flywheel, spinning it up to 36,000rpm. When the driver accelerates, the system works in reverse. The energy is drawn from the flywheel and converted back into electricity to power the traction motor. This reduces the work done by the internal combustion engine, leading to an improvement in fuel economy and a reduction in emissions.

The CBTF 2013 and CVTF2014 supported three projects entailing the retrofitting buses with the Williams GKN Flywheel hybrid system. These were the Go North East Consortium (Sunderland, Newcastle, Durham and Gateshead City Councils), Wiltshire Council and Sheffield City Council. The GKN flywheel claimed a NOx emission reduction of 25%, with an improvement in fuel efficiency of 30%.

None of these projects entailed vehicle emissions testing. However, Williams GKN provided the Go North East consortium with vehicle lab testing results for a Euro III Volvo B9 retrofitted with their flywheel hybrid system. As Go North East project involved the same bus model, this data could serve a proxy test data for the performance of the flywheel hybrid technology. The vehicle emissions testing was undertaken at Millbrook Proving Ground using the MLTB cycle. The bus was tested with the hybrid system activated and deactivated. Figure 32 shows NOx emissions reduced by 25% and NO_2 emissions by 24%. Fuel consumption improved by 30%.

The Go North East consortium project involved retrofitting the Williams GKN flywheel hybrid technology to 58 Euro III buses and 28 Euro V buses operating in Go North East's bus fleet operating between Durham, Gateshead and Newcastle. In order to provide the performance of GKN flywheel system (both in terms of reliability and fuel efficiency) two Volvo B9 Go North East's fleet were first used as trial vehicles. The trial buses experienced numerous technical problems over an eight-month period following fitment of the GKN flywheel system. These related to poor quality fitment and unreliable components. The trial buses were taken off the road on several occasions and after many attempts to resolve the technical issues the buses were deemed unroadworthy.

Figure 32: NOx and NO_2 emissions Go N.East retrofit flywheel Euro III bus – vehicle lab monitoring



The rationale for the flywheel system was a reduction in NOx emissions as a result of an improvement in fuel consumption. Fuel consumption data was monitored by Go North East for the trial buses before and after the flywheel system was fitted, see Table 9. The average mile per gallon decreased for both buses following fitment of the GKN flywheel hybrid technology, compared with claims of 30% improvement in MPG, this deterioration in fuel usage demonstrates the poor performance of the flywheel system when in service.

Table 9: Fuel consumption for Go North East retrofit flywheel hybrid Euro III buses

Service	Trial Bus	Fuel Consumption Before Fitment (MPG)	Fuel Consumption After Fitment (MPG)	% Change in MPG
Cobalt Clipper	Volvo B9	6.8	6.7	-2.4%
Fab 56	Volo B9	6.3	5.9	-5.5%

Given the plethora of technical challenges experience with the two trial buses and the lack of improvement in fuel efficiency, Go North East decided to terminate the retrofit flywheel projects. The funding awarded to Newcastle and Durham has now been reallocated to retrofit SCR supplied by Eminox.

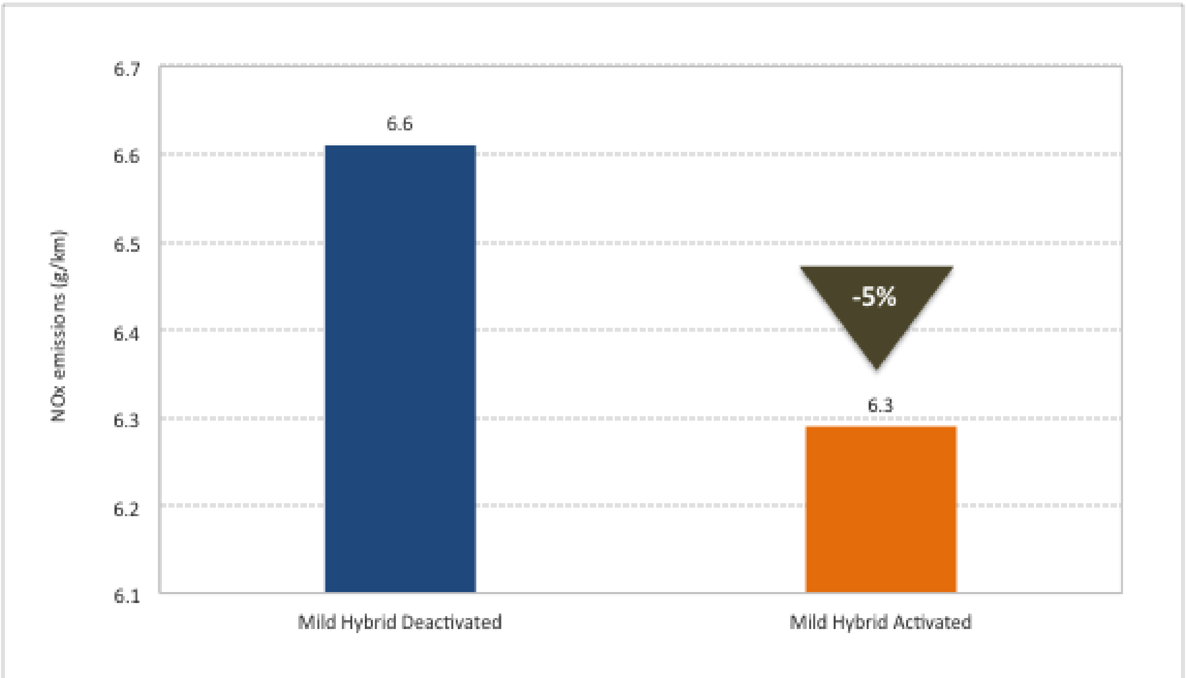
Similar problems were also experienced by Wiltshire Council who were also awarded funding for the GKN flywheel technology; an alternative retrofit programme is currently being explored. Sheffield City Council was the only project that has not faced any problems with fitting the GKN flywheel system, the retrofitted buses are reported to be operating reliably. No fuel consumption data is available to analyse. However, the bus operator reports a 10% fuel savings in the retrofitted flywheel buses. (This is still far short of GKN's original claim of 30% improvement in fuel efficiency).

6.2 Mild-Hybrid

One bus retrofit project run by St Albans District Council involved the use of the 'Sigma System' mild hybrid. This was a prototype technology that achieves fuel savings by intelligent control of engine ancillary systems such as the gearbox fans, compressor and alternator. The mild hybrid system was fitted to 40 Euro III, IV and V buses including Dennis Trident, Mercedes Citaro and ADL Enviro 200. This mild hybrid technology was considered highly suitable for the start-stop duty cycle of the St Albans bus routes. The system was marketed as achieving a 25% reduction in NOx emissions and 30% reduction in fuel consumption.

Vehicle emission testing was undertaken at Millbrook Proving Grounds for a Euro V Mercedes Citaro bus, retrofitted with the mild hybrid system, to demonstrate NOx emission reduction performance. The bus was tested over the MLTB cycle. The mild hybrid system was deactivated to provide the baseline measurement and then activated, results are presented in Figure 33. When activated NOx emissions reduced by 5% and CO_2 emissions by 10%. Both results are well below the manufacturer's claim.

Figure 33: NOx emissions St Albans retrofit mild hybrid Euro III bus – vehicle lab testing

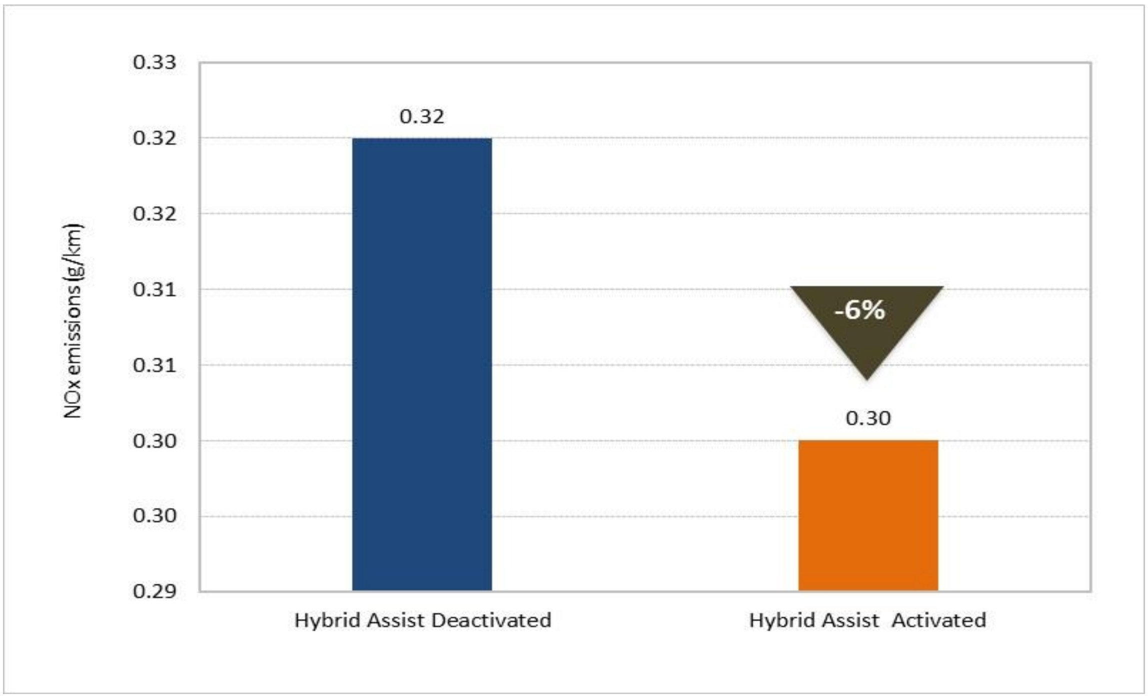


6.3 Hybrid Assist

Hybrid assist technology has been predominantly adopted in large panel vans in the UK as a fuel saving technology supplied by Ashwoods Automotive Limited. The technology is similar in principle to the flywheel hybrid, but stores the electrical energy in a battery pack rather than a mechanical flywheel.

Portsmouth City Council was awarded funding to install the Ashwoods hybrid assist system to 14 vans comprising of Euro 4 and Euro 5 vehicles. The claimed NOx emission reduction was 26% and CO_2 emission 15-20%. Laboratory vehicle emissions testing was undertaken at MIRA (January 2016) to demonstrate the NOx emission reduction performance of the hybrid assist technology. The vehicle was tested over the New European Drive Cycle. The results presented in Figure 34 reveal that the retrofit hybrid assist Ford Transit van only achieves a 6% NOx emission reduction. CO_2 emissions, and fuel saving, measured a 4% reduction when the hybrid assist was activated. Both results are markedly lower than the supplier's emission reduction claims.

Figure 34: NOx emissions Portsmouth retrofit hybrid assist Euro 4 van – vehicle lab testing



7 Engine Conversions

7.1 Battery Electric

There are currently 178 battery electric buses operating across the UK. The compression engine of a diesel bus can be completely removed and replaced with a battery-powered electric motor for propulsion. This provides an alternative solution to purchasing new electric buses. The conversion to electric powertrain results in zero tail-pipe emissions.

Two local authorities won funding under the CBTF 2013 programme to convert diesel buses to electric – York City Council and Brighton and Hove Council.

York City Council have converted six diesel powered sightseeing buses to battery electric. The sightseeing buses are operated in York's City Centre, which has been declared by the authority as a Clean Air Zone. The retrofit project has been developed by Transdev who operate the sightseeing bus service for the City of York. The bus used for the prototype project forms part of Transdev's York fleet and a Euro II Dennis Trident. The technology for the retrofit was supplied by Magtec.

The first prototype electric bus was completed in 2015 and the bus has been running for two years; the other five electric bus conversions went into service in June 2017. The first converted electric bus took some time to develop due to the bespoke nature of the conversion, and the fact it was a prototype. The conversion utilises a Lithium Iron Phosphate battery pack with a design capacity of 133kWh in two modules. The batteries power a 150kW electric motor that delivers 3,000Nm torque.

Charging takes place overnight at Transdev's York depot with full charge taking eight hours, and is timed to take advantage of the off-peak period when low carbon generated electricity is available. Transdev reports that prototype bus has performed very well and achieves an electricity consumption of 0.67 miles per kWh. The practical maximum daily range has been set at 76 miles which is sufficient to cover the 55-65 mile duty cycles of the York City Sightseeing vehicles.

Magtec warranty repair and replacement parts for the electric sight-seeing buses, Trans Dev undertake annual maintenance checks that involve limited work. The battery is expected to have a life of seven years. Trans Dev are experiencing lower fuel costs running the converted electric bus compared to the original diesel bus.

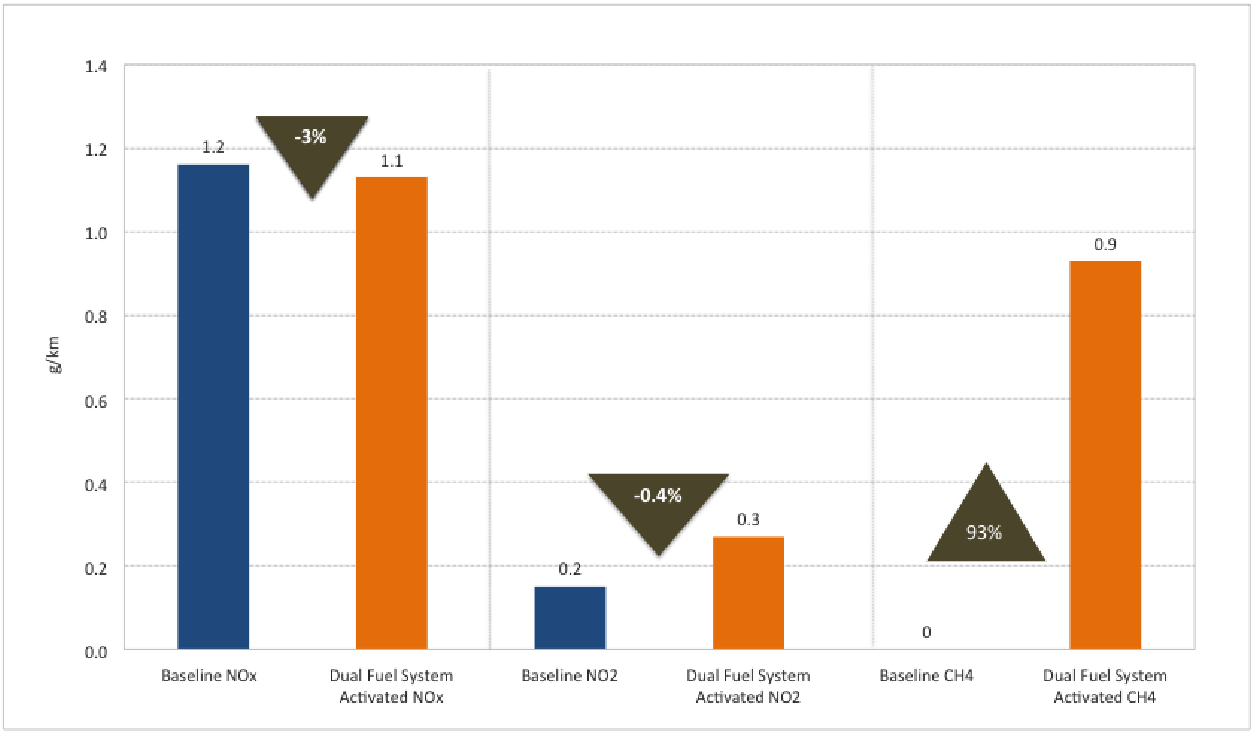
7.2 Duel Fuel CNG Conversion

Dual fuel is a retrofit technology that enables a vehicle to be powered by two fuels, in this case compressed natural gas (CNG) and diesel. Dual fuel CNG retrofit technology has over recent years been exploited by the heavy-duty vehicle market in the UK, especially for long haul freight operators. Dual fuel technology is optimised under steady state, high speed driving conditions i.e. motorway driving. This allows for a higher substitution of natural gas over diesel. Natural gas typically burns cleaner than diesel resulting in lower NOx and PM emissions; however recent vehicle emission testing evidence has revealed that Euro VI gas and diesel heavy-duty vehicles show limited difference in air pollutants emissions. Vehicles powered by natural gas, dedicated or dual fuel, can emit methane emissions; a powerful greenhouse gas.

Reading Borough Council won funding through the CVTF 2014, to retrofit dual fuel CNG technology to 113 Euro 2,3 and 4 black taxis. The company supplying the equipment was CRD Technology. The claimed reduction in NOx emissions was between 28-52%.

Reading Borough Council commissioned vehicle laboratory testing to evaluate to performance of the dual fuel CNG technology. A retrofitted TX4 black taxi was tested over the New European Drive Cycle at Millbrook Proving Grounds. Four separate test runs were undertaken, one to determine baseline diesel emissions and three tests where the CNG and diesel mix was modified by CRD Technology. Vehicle emission testing results in Figure 35 are for the taxi running on diesel (baseline) then with the dual fuel system operating at a 35% CNG substitution rate.

Figure 35: Reading retrofit duel fuel CNG Euro 4 black taxi vehicle lab testing results



The 35% CNG substitution achieved the highest NOx emissions saving compared to the diesel baseline. However, this was only a 3% reduction in NOx emissions. This is in the order of 50-70% lower than the NOx emission reduction claimed by CRD Technology. The dual fuel CNG system demonstrated no beneficial impact on NO_2 emissions.

The vehicle emission testing revealed elevated methane (CH_4) emissions for all the tests with the taxi running on CNG. Methane has a global warming potential 25 times that of carbon dioxide, when taking this to account the carbon impact of the dual fuel technology is significant. The dual fuel system at a 35% CNG substitution rate resulted in a 93% increase in methane emissions. A methane catalyst could have been fitted to control methane emissions, however this would have made the retrofit dual fuel CNG system financially unviable.

Given the poor performance of the retrofitted CNG dual fuel taxi, the project was terminated and the funding diverted to local bus operator Reading Bus Company. Reading Bus Company has converted one of their old hybrid buses to battery electric fitted with a gas turbine serving as a range extender. The gas turbine will be powered by biomethane, a renewable form of natural gas produced from organic waste. The retrofit technology has been supplied and installed by Magtec. Reading Bus Company current operate a fleet of biomethane buses and have a biomethane refuelling station at their depot. Vehicle emission testing results will be available in the summer of 2017.

8 Conclusion

This evaluation study covered twenty-five local authority projects comprising of seven vehicle classes – buses, coaches, a fire engine, van derived mini-buses, black taxis and cars and seven retrofit technologies:

- Exhaust after treatment – SCR and TMT
- Fuel savings – Mild hybrid, flywheel hybrid and hybrid assist
- Engine conversion – Electric powertrain and dual fuel CNG

Vehicle emissions monitoring data analysed consisted of vehicle laboratory and on road monitoring (PEMS and NOx sensor). This covered vehicle emission testing undertaken on retrofit equipment fitment and after six months to two years in service. Interviews have been carried out with a number of local authorities to ascertain operational performance of retrofitted vehicles once in service and any challenges experienced with fitment of retrofit technology.

Demonstrating the efficacy of different retrofit technologies at reducing NOx emissions

The retrofit technologies achieving the highest NOx emission reductions (80%-100%) are retrofit SCR and diesel bus engine conversion to electric powertrain. Retrofit SCR vehicles funded in the CVTF/CBTF programmes reveal on average very low NOx emissions (<1g/km) for both light and heavy-duty vehicles. Where SCR systems have been retrofitted to vehicle classes for the first time (fire engine, mini-bus, car) NOx emission savings are slightly lower than buses, highlighting the early stages of technology development at the time of the CVTF programme. A new type of ammonia storage and delivery system for SCR equipment, has been shown to perform as well as conventional aqueous urea, achieving high levels of NOx reduction.

Retrofit technologies achieving moderate NOx emission reductions (25%-29%) are TMT and flywheel hybrid.

Retrofit technologies achieving low NOx emission reductions (3%-6%) are mild hybrid, hybrid assist and dual fuel CNG conversion.

Demonstrating in service performance of retrofit technologies

In service vehicle emission performance has only been possible to assess for retrofit SCR and TMT. In the case of retrofit SCR, in service monitoring performed between six months and two years after retrofit SCR equipment has been fitted to buses, coaches, a fire engine and van derived mini bus, has demonstrated excellent conformity with vehicle emission testing undertaken on fitment of the technology. This highlights that retrofit SCR systems continue to operate effectively and deliver high NOx reductions when in service. The CVTF programme enabled retrofit SCR to be successfully fitted to light duty vehicles, specifically a small number of van derived mini-buses and cars. Initial evidence shows the retrofit SCR mini-buses to be working effectively.

The prototype electric bus conversion has been operating reliably for the last two years.

With regards to vehicle operational performance retrofit flywheel hybrid has experienced the most fitment and operational challenges, as such two out of the three flywheel projects have been terminated and funding re-allocated to alternative technologies.

Impact of retrofit technologies on other air pollutants and greenhouse gas emissions

This assessment focused on retrofit SCR, hybrid flywheel and dual fuel CNG conversion.

Vehicle laboratory testing for a small number buses (Euro III, IV and V) and a van-derived mini-bus (Euro 4) has shown retrofit SCR to achieve high levels of NO_2 emissions reduction (>80%) and very low tailpipe NO_2 emissions. The majority of retrofit SCR systems were fitted with particle filters resulting in high PM reductions (>75%) and exceptionally low PM emissions. Ammonia emissions where shown to be below 10ppm post-SCR fitment. With regards to greenhouse gas emissions (measured as CO_2 equivalent), this was shown to increase between 3-5% post-SCR fitment on buses, primarily due to a rise in the proportion of nitrous oxide emissions.

Vehicle laboratory testing for retrofit hybrid flywheel technology fitted to a Euro III revealed a NO_2 emission reduction of 25% and CO_2 emission saving of 30%.

Vehicle laboratory testing results for dual fuel CNG conversion for a Euro 4 black taxi showed very low NO_2 reductions (3%) and an exceptional high increase in methane emissions (93%).

Vehicle emission testing has revealed that two retrofit fuel savings technologies, mild hybrid and hybrid assist achieved very low CO_2 emission savings post fitment. The measurements were well below the suppliers claimed fuel savings.

9 Appendix 1 – CBTF/CVTF individual project details and results

Bus Projects

Grant Programme	Local Authority	Number of vehicles funded	Euro Standard	Model	Retrofit Technology	Supplier	Claimed NOx emission reduction	Measured NOx Emission Reduction %	Tail-pipe NOx emissions (g/km)	NOx concentration reduction in service	Vehicle Emission Testing Method
CVTF 2014	Blackpool City Council	30	Euro III	Dennis Trident	SCR	Eminox	85%		0.19	96%	NOx Sensor
CVTF 2014	Bradford Metropolitan District Counci	25	Euro III	Volvo B7TL	SCR	Eminox	80%	98%	0.34		PEMS
			Euro III	Volvo B7RLE	SCR	Eminox		96%	0.50	80%	
CBTF 2015	Brighton & Hove City Council	23	Euro III	Omnidekka	SCR	Eminox	95%	96%	0.30	95%	NOx Sensor
			Euro IV	Omnidekka	SCR	Eminox		95%	0.35	72%	NOx Sensor
CBTF 2015	Brighton & Hove City Council	2			E Conversion	Magtec	100%				n/a
CBTF 2013	Brighton & Hove City Council	50	Euro III	Scania N94UD	SCR	Eminox	87%			96%	NOx Sensor
CBTF 2015	Centro (Birmingham)	27	Euro IV	Dennis Trident DD	SCR	Green Urban	80%			95%	NOx Sensor
			Euro III	Dennis Trident DD	SCR	Green Urban				94%	NOx Sensor
			Euro II	Volvo Super Olympian DD	SCR	Green Urban				87%	NOx Sensor
CVTF 2014	Chester West and Chester Borough Council	2	Euro III	Dennis Dart	SCR	Green Urban	80%	95%	0.77	88%	Vehicle Lab
CBTF 2013	Chiltern District Council	15	Euro III	MAN 14.220 LF	SCR	Green Urban	60%			77%	NOx Sensor
CVTF 2014	City of York Council	6	Euro II	ADL Trident	E Conversion	Magtec					n/a
CBTF 2013	City of York Council	2	Euro II	Volvo B6	SCR	Green Urban	72%			76%	NOx Sensor
CVTF 2014	Colchester Borough Council	10	Euro III	Volvo B7RLE	SCR	Eminox	75%			95%	NOx Sensor
CBTF 2013	Go North East (Gateshead/Sunderland)	40	Euro III	Scania L94	SCR	Eminox	87%	95%	0.50	93%	Vehicle Lab
CBTF 2015	Harrogate Borough Council	10	Euro IV	B10BLE	SCR	Eminox	96%	96%	0.66		NOx Sensor
			Euro III	Volvo B7RLE	SCR	Eminox	96%	97%	0.24	97%	NOx Sensor
CBTF 2015	Leeds City Council	32	Euro IV	Volvo B9	SCR	Eminox	69%	95%	0.80	94%	NOx Sensor
CBTF 2013	Leicester City Council	32	Euro III	DAF DB250	SCR	HJS	72%	76%	4.80		PEMS
CVTF 2014	Leicester City Council	5	Euro III	Optare Solo	SCR+eFan	HJS	75%	76%		87%	NOx Sensor
CBTF 2013	Merseytravel - Liverpool City Region	59	Euro III	Dennis Marshall Superdart	SCR	Green Urban	80%	76%			NOx Sensor
			pre- Euro	Scania N113 (Open Top Bus)	SCR	Green Urban		85%		79%	NOx Sensor
CBTF 2013	Merseytravel - Liverpool City Region	7	Euro III	Dennis Marshall SuperDart	SCR	Green Urban	80%	76%		76%	NOx Sensor
		20	Euro III	Vovlo B7TL	SCR	Green Urban	80%			91%	NOx Sensor
CVTF 2014	Merseytravel - Liverpool City Region	30	Euro III	BMC Condor	SCR	Green Urban	80%			76%	NOx Sensor
			Euro III	Dennis E200	SCR	Green Urban				82%	NOx Sensor
			Euro III	Dennis Dart	SCR	Green Urban		82%		85%	NOx Sensor

Grant Programme	Local Authority	Number of vehicles funded	Euro Standard	Model	Retrofit Technology	Supplier	Claimed NOx emission reduction	Measured NOx Emission Reduction %	Tail-pipe NOx emissions (g/km)	NOx concentration reduction in service	Vehicle Emission Testing Method
CVTF 2014	Newcastle City Council	57	Euro V	Volvo B9	Flywheel Hybrid	Williams GKN	25%	26%	6.10		NOx Sensor
CBTF 2015	Norfolk County Council	24	Euro III	Volvo B7RLE	SCR	HJS	99%	87%		87%	NOx Sensor
CBTF 2013	Oxford City Council	11	Euro II	ADL Trident DD	SCR	HJS	75%	70%		70%	NOx Sensor
CBTF 2015	Rossendale Borough Council	38	Euro IV	Scania K230 + Volvo B7RL	SCR	Eminox	85%	93%	0.79	93%	NOx Sensor
			Euro III	Scania L94 + Volvo B7RLE	SCR	Eminox	85%	92%	0.74	93%	NOx Sensor
CBTF 2015	Sheffield City Region Combined Autho	25	Euro IV	B9	SCR	Eminox	95%	97%	0.53		NOx Sensor
CVTF 2014	South Yorkshire Passenger Transport	41	Euro IV	B9TLs	TMT	HJS	40%				NOx Sensor
CBTF 2013	St Albans City and District Council	2	Euro IV	Mercedes	Mild Hybrid	Fugence - SIGMA	25%	5%	6.29		Vehicle Lab
CVTF 2014	Suffolk County Council	26	Euro III	Dennis Dart / Optare Solo	SCR	HJS	99%	87%		85%	NOx Sensor
CBTF 2013	Suffolk County Council, Ipswich Council	47	Euro II	Dennis Dart SD	SCR	Green Urban	65%			91%	NOx Sensor
CBTF 2015	Sunderland City Council	14	Euro V	Volvo B9	SCR	Eminox	90%	98%	1.40	94%	Vehicle Lab
CBTF 2013	Transport for Greater Manchester	34	Euro III/IV	Iveco School Bus	SCR	HJS	80%	99%	0.14	87%	Vehicle Lab
				Iveco School Bus	SCR	Twintech Baumot					Vehicle Lab
CBTF 2015	Transport for London	55	Euro V	Volvo Trident	SCR/Ammonia storage	Amminex	90%	98%	0.50		Vehicle Lab
		30	Euro V	ADL E400H DD	SCR	HJS	90%	98%	0.30	96%	Vehicle Lab
CVTF 2014	Transport for London	400	Euro III	Volvo B7/ Denis Trident	SCR	Proventia	90%	99%	0.10		Vehicle Lab
CBTF 2013	West Yorkshire Combined Authority	119	Euro III	BMC Condor	SCR	Eminox	87%	93%	1.40	94%	Vehicle Lab
CVTF 2014	West Yorkshire Combined Authority	46	Euro IV	BMC Condor	SCR	Eminox	94%	97%	0.43	97%	Vehicle Lab

Other Vehicle Types

Local Authority	Number of vehicles funded	Vehicle Type	Euro Standard	Model	Retrofit Technology	Supplier	NOx emission reduction	Tail-pipe NOx emissions (g/km)	NOx concentration reduction in service	Vehicle Emission Testing Method
Portsmouth City Council	18	Van	Euro 4	Ford Transit	Hybrid Assist	Ashwoods	26%	0.3		Vehicle Lab
Brighton & Hove City Council	22	Mini-Bus (cab)	Euro 4	VW Transport	SCR	Green Urban	74%	0.36		Vehicle Lab
Reading Borough Council	113	Black Taxi	Euro II/III	Black Cab	Dual fuel CNG		3%	1.13		Vehicle Lab
Transport for London	1	Fire Engine	Euro III	Fire Engine	SCR	Proventia	70%	2.7	70%	NOx sensor
Dudley Metropolitan Borough Council	10	Coach	Euro II	V264 DTE	SCR	Eminox	76%	3.3	70%	NOx sensor
			Euro III				99%	0.18	97%	NOx sensor
Merserytravel - Liverpool City Region	5	Mini-bus	Euro III	Mercedes Sprinter	SCR	Green Urban			84%	NOx sensor

Low Carbon Vehicle Partnership

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