Zemo Partnership

Accelerating Transport to Zero Emissions

The Clean Vehicle Retrofit Technology Guide

Date of Report: March 2021

Acknowledgements

The production of Clean Vehicle Retrofit Guide has been sponsored by the following organisations:

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List of Abbreviations

CVRAS	Clean Vehicle Retrofit Accreditation Scheme
Defra	Department for Environment, Food and Rural Affairs
DfT	Department for Transport
JAQU	Joint Air Quality Unit (Defra + DfT)
TfL	Transport for London
NO_x	Oxides of Nitrogen (NO, NO_2)
PM	Particulate Matter
N_2O	Nitrous Oxide
NO_2	Nitrogen Dioxide
NO	Nitric Oxide
CVTF	Clean Vehicle Technology Fund
CBTF	Clean Bus Technology Fund
ULEZ	Ultra Low Emission Zone
LEZ	Low Emission Zone
HGVs	Heavy Goods Vehicles
RCVs	Refuse Collection Vehicle
GHG	Greenhouse Gas
PEMS	Portable Emissions Measurement System
EST	Energy Savings Trust
Zemo	Zemo Partnership
BEAR 1/2	Bus Emissions Abatement Retrofit (Programme)
HVO	Hydrogenated Vegetable Oil
BioLPG	Bio Liquid Petroleum Gas

1. Introduction

The Clean Vehicle Retrofit Technology Guide aims to provide vehicle operators and local authorities with an understanding of national air quality frameworks for reducing roadside NO_2 concentrations, providing case studies with examples of a range of accredited retrofit technologies that achieve Euro VI equivalent levels of emissions through the Clean Vehicle Retrofit Accreditation Scheme (CVRAS). The Guide covers technologies accredited for bus, coach, truck, refuse collection vehicles and black cabs, with solutions for vans and cars a possibility in the future.

There is a significant air quality challenge currently facing UK cities, towns and the strategic road network, with an estimated 40,000 early deaths caused by poor air quality. The Department for Environment, Food and Rural Affairs (Defra) commissioned research estimated that poor air quality had cost up to £2.7bn in reduced productivity in the UK in 2012 (Ricardo-AEA, 2014).

The two pollutants of most concern are particulate matter (PM) and nitrogen dioxide (NO_2), with local concentration levels of NO_2 exceeding mandated EU limit values. A significant proportion (78%) of roadside NO_x (NO and NO_2) originates directly from road transport, with diesel vehicles responsible for 90+% of NO_x emissions, averaged across the country (Figure 1).

Transport services like buses and taxis are overwhelmingly powered by diesel engines and their high mileage in urban areas often means that non-Euro VI / 6 diesel vehicles can be key contributors to local roadside NO_2 (Figure 2).

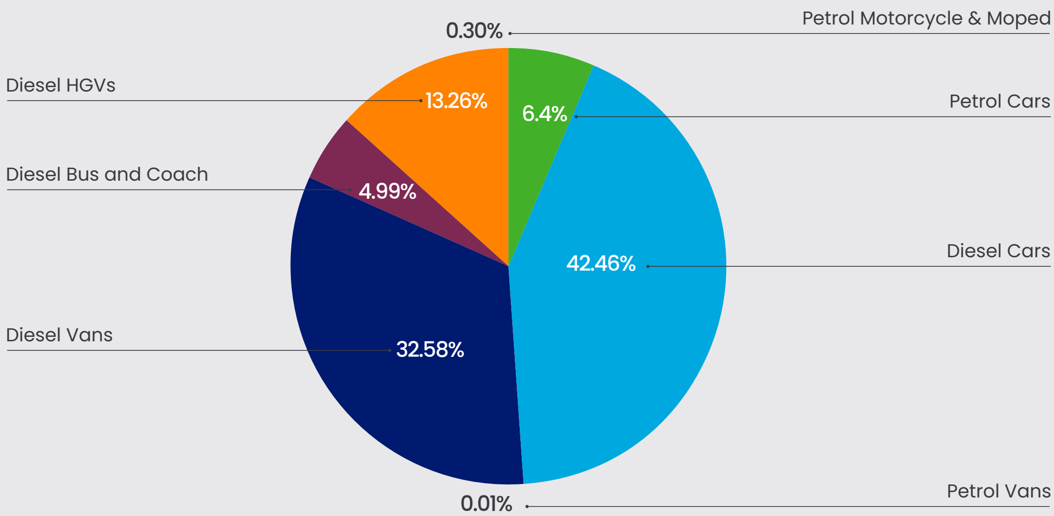
CVRAS accredits retrofit technologies that reduce air pollutants from existing vehicles to levels equivalent to Euro 6 (light duty) or Euro VI (heavy duty) standards.

The purpose of the accreditation scheme is to provide confidence to operators that a system meets set emissions limits and will continue to perform in-service. Only robust, proven retrofit technologies that achieve equivalent emission targets and in- service performance equivalent to Euro VI/6 vehicles will achieve CVRAS accreditation. CVRAS approved companies must also meet set requirements in terms of their legal status, financial stability, quality management, warranty and insurance provision.

1.1 UK Air Quality Policy

The CVRAS accreditation scheme has been incorporated into a range of strategies, policies and funding streams developed across the UK by national and local governments, with approved retrofits already in-service in many cities helping to reduce harmful air pollutants from transport. in a number of areas across the UK. The table below describes the targets for NO_2, which is measured using roadside emissions monitoring stations.

Figure 1: Breakdown of average roadside sources of NO_x emissions by vehicle type. (NAIE, 2018)



Clean Air Zones in England

In July 2017 the Government published the "UK plan for tackling roadside NO_2 concentrations", which originally required local authorities in areas expected to exceed the European Union (EU) NO_2 limit values beyond the next three or four years to develop innovative local plans that will achieve statutory NO_2 limit values within the "shortest possible time". The plan sets out charging Clean Air Zone (CAZ) schemes as one measure to achieve statutory NO_2 limit values in towns and cities in the shortest possible time.

A CAZ defines an area where "targeted action is taken to improve air quality and resources are prioritised and coordinated in order to shape the urban environment in a way that delivers improved health benefits and supports economic growth". There are two types of CAZ:

- Non-charging CAZ: Involves a range of actions to improve air quality including (but not limited to) voluntary targets for fleet renewal and retrofit of non-Euro VI vehicles; measures to encourage the use of public transport; walking and cycling; the uptake of ULEVs or road layout changes at congestion and air pollution 'pinch points'.
- Charging CAZ: In additional to the above, vehicle owners are required to pay a charge to enter or move within a zone if they are driving a vehicle that does not meet the particular standard for their vehicle type in that zone. Under the CAZ Framework for England, charging CAZ are sub-divided into classes A –"\" D on the basis of the types of vehicles to which the charging schemes apply (Table 2)

Vehicles which meet the minimum European emission standards for these zones, including through fitment of approved CVRAS retrofit technologies, will be able to enter or move within the zone without being charged (Table 1). Ultra-Low Emission Vehicles will also be able to enter or move within zones without charge.

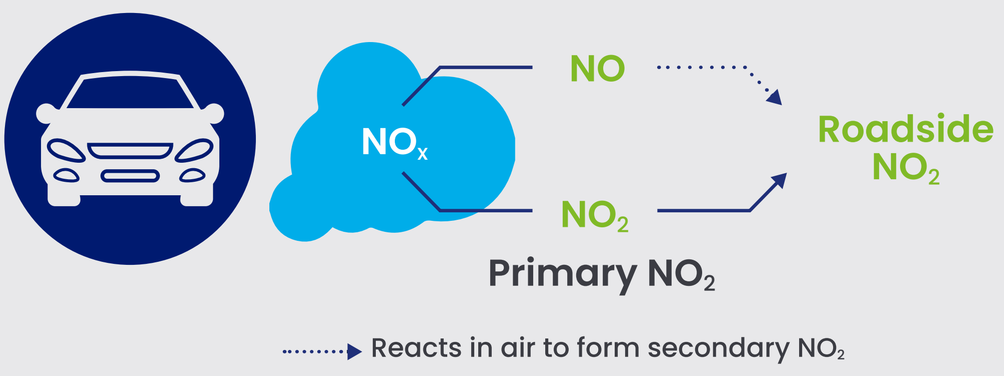
Table 1. The minimum emission standards for charging clean air zones

Vehicle Type	Minimum emission standard
Buses and coaches	Diesel Euro VI
HGVs	Diesel Euro VI
Vans	Euro 6 (diesel) Euro 4 (petrol/LPG)
Taxis and private hire vehicles	Euro 6 (diesel) Euro 4 (petrol/LPG)
Cars	Euro 6 (diesel) Euro 4 (petrol/LPG)
Motorcycles and mopeds	Euro 3

Table 2. Charging clean air zone classes

Charging CAZ Class	Vehicles potentially included
A	Buses, coaches, taxis and private hire vehicles
B	Buses, coaches, heavy goods vehicles (HGVs) taxis and private hire vehicles
C	Buses, coaches, HGVs, large vans, mini buses, small vans/light commercials, taxis and private hire vehicles
D	Buses, coaches, HGVs, large vans, mini buses, small vans/light commercials, taxis and private hire vehicles, cars, motorcycles and mopeds[2] .

Figure 2: Relationship between tailpipe NO_X and roadside NO_2 from internal combustion engines



At the time of publication, Bath and Birmingham will introduce charging Clean Air Zones (CAZ C & D respectively) in 2021, with Manchester, Portsmouth and Newcastle considering the introduction of charging CAZ. Where vehicles do not meet the minimum emissions standards, they will be charged to enter. Charges for access to different CAZs are set at a local level and may differ for the same vehicle class across the country.

A national vehicle checker is being developed to enable drivers to find out if their vehicle will be subject to charge in Clean Air Zones:
www.gov.uk/check-clean-air-zone-charge

Vehicles retrofitted with CVRAS approved technologies will not be subject to charge for entering charging CAZ.

Ultra-Low Emission Zone in London

London has introduced the equivalent of a CAZ Class D in the form of the Ultra Low Emission Zone (ULEZ) on 8th April 2019, which will be the same area as the current Congestion Charge zone. There will be a charge to enter the zone of £12.50 per day for non-compliant cars, vans and motorcycles and £100 per day for non-compliant heavy duty vehicles.

On March 1st 2021, ULEZ requirements for Euro VI heavy duty vehicles will expand to cover the existing Low Emission Zone around Greater London, inside the M25. Any heavy duty vehicle entering must be Euro VI compliant or retrofitted with a CVRAS approved technology, or face a £100 daily charge. ULEZ will expand for light duty vehicles including cars in October 2021 to include the area inside the North and South Circular roads (A406, A205).

Despite having a different name, the Ultra Low Emission Zone requires the same emissions standards as Clean Air Zones. Vehicles fitted CVRAS approved technologies will be able to enter ULEZ will not be charged for access. Transport for London has created an online tool to check if a vehicle is compliant with the Ultra Low Emission Zone, accessible via the TfL website.

Clean Air Zones in Wales

The Welsh Government has consulted on its CAZ proposals, which include stopping the most polluting vehicles from entering a CAZ or charging them to enter. In November 2018, the Welsh Government published a supplement to the UK plan for tackling roadside NO_2 concentrations. A £20m air quality fund, which will run until 2021, will be provided to support Cardiff and Caerphilly councils comply with NO_2 concentration limits in the shortest possible time and cover the cost of feasibility studies to assess the impact of introducing Clean Air Zones.

Low Emission Zones in Scotland

The Scottish Government outlined plans for four Low Emission Zones (LEZ) to address air quality issues in the country to be in place by 2020 in the Scottish Governments' Programme for Government 2017/18, with the first LEZ launched in Glasgow at the end of 2018.

A crucial distinction between LEZs in Scotland and CAZ elsewhere is that vehicles cannot pay to access the LEZs. Non-compliant vehicles will receive a penalty charge if they enter the zone, similar to that of a parking fine. Scottish LEZs require the same emission standards for vehicles as Clean Air Zones and London's ULEZ. Vehicles retrofitted with CVRAS approved technologies will not receive a penalty charge for entering LEZs.

In addition to Glasgow, LEZs are also expected to be established in Edinburgh, Aberdeen and Dundee. As part of these plans, Transport Scotland launched a consultation to seek feedback from stakeholders and the general public. Glasgow's LEZ initially only includes buses in the city centre, with a phased introduction until the end of 2022 of all vehicle types, similar to a Clean Air Zone Class D, with some exceptions.

Northern Ireland

An Air Quality Strategy for Northern Ireland is in preparation and will address air quality through measures aimed at sectors such as farming and road transport. A key focus for transport policy in Northern Ireland has been congestion reduction and the encouragement of modal shift away from cars (e.g. Belfast Glider BRT). The final strategy will be published following the public consultation "A Clean Air Strategy for Northern Ireland – Public Discussion Document", which closed in February 2021. To date, there are no specific plans to introduce Clean Air Zones in Northern Ireland.

1.2 National Retrofit Technology Programmes and Funding Streams

There are a range of fiscal and non-fiscal measures that have been introduced by national and local governments to support fleets, businesses and the general public in reducing the impact of their activities on local air quality.

In England, the Department for Transport (DfT) provided funding to local authorities to reduce air pollutants from transport through the Clean Bus Technology Fund (CBTF) in 2013 and 2015 and the Clean Vehicle Technology Fund (CVTF) in 2014. £12m was distributed over 3 years resulting in 2,150 systems being fitted to buses, coaches, fire engines, vans, black cabs and cars. The lessons learnt from these programmes led to the development of CVRAS. The scheme aims to ensure cost-effective NO_x reduction and only funds robust, proven technologies.

Buses have been at the centre of retrofitting programmes as they are diesel powered and have high frequency in densely populated urban areas. Retrofitting buses has been demonstrated as oneof the most cost-effective measures to reduce NO_x from the existing bus fleet, rather than scrappage (Greener Journeys, 2017).
The Clean Bus Technology Fund 2017-2019 was the first funding programme to use CVRAS accreditation with £40m awarded to local authorities to fund the retrofit of 2,768 buses across England. A further £22m has been awarded to local authorities to fund 1,500 more buses in England in 2019. In March 2021, over 3,700 buses have been retrofitted with CVRAS approved systems.

Defra also awarded £1m to retrofit suppliers aimed at supporting the cost of testing for solutions for different vehicle types. This funding has seen a number of new solutions approved, including a number of solutions for trucks and coaches.

In 2018, Transport Scotland allocated £1.6m to local authorities and bus and coach operators through the Bus Emissions Abatement Retrofit (BEAR) programme, delivered by Energy Saving Trust Scotland, to support the purchase of CVRAS approved technologies. Retrofit systems for 42 buses were funded, including the cost of a warranty and Adblue consumption over a five-year period. A further 124 systems were awarded funding under BEAR Phase Two, which could see over 500 systems fitted in Scotland.

1.3 Funding Streams for Retrofit Technologies

There are a number of sources available to fund the retrofitting of existing vehicles in the UK, with availability dependent on vehicle type and an operator's proximity to areas of poor air quality.

England

Support for retrofit measures in England include:

- **Implementation Fund** - £275m - created to support local authorities implement air quality improvement schemes to achieve compliance with legal NO_2 limits, such as through the implementation of a CAZ. Through feasibility studies including modelling of NO_2 emissions specific to their area, local authorities have put forward proposals to improve air quality with supporting business cases for the preferred actions. With approval from JAQU, local authorities are able to access funds to support their chosen measures.
- **Clean Air Fund** - £220m- available to local authorities to help mitigate the impact of air quality improvement measures on local businesses and residents, such as supporting retrofit programmes for fleet operators to help them achieve compliance.
- **Annual Air Quality Grant** - this annual scheme provides funding to local authorities to help improve air quality and to meet statutory duties under the Environment Act 1995. It has awarded over £64 million in funding to a variety of projects since it started in 1997.

Examples of local authority support for retrofit include:

- **Transport for London** has made £5m available for eligible Euro 5 black cab retrofit to LPG. For more details see TfL's Taxi and Private Hire Action Plan and licensing regulations.
- **Leeds City Council** has supported retrofit of non-scheduled buses, coaches and HGVs that operate frequently in the area with funding from the Clean Air Fund. The local grant scheme will provide up to £16,000 for CVRAS approved retrofit or repower solutions, support to purchase a new compliant Euro VI vehicle or contribute towards exiting a non-Euro VI vehicle lease contract so the operator can acquire a compliant vehicle.
- **Birmingham City Council** have been awarded £38m through the Clean Air Fund to support a range of measures including retrofit or repower of black cabs (£5m) and support for HGVs and coaches (£10.05m).

Scotland

A third phase of the BEAR programme has been announced for 2019/20, with a total of £9.75m aimed at supporting over 500 buses and coaches in Scotland.

Wales

In 2018, the Welsh Assembly announced a £20m Air Quality Fund to support local authorities in Wales to reduce emissions and improve the environment. Cardiff City Council has announced that following a detailed feasibility study, a Clean Air Zone will not be implemented to achieve compliance, but a business case for £32m worth of support has been proposed, including £1.8m for a Clean Bus Retrofit Scheme.

Northern Ireland

There are currently no available grants for supporting retrofit activities in Northern Ireland. This may change following consultation on the Air Quality Strategy for Northern Ireland, set to be published in 2021.

2. Clean Vehicle Retrofit Accreditation Scheme

The Clean Vehicle Retrofit Accreditation Scheme (CVRAS) has been developed to accredit retrofit technologies that can reduce NO_x emissions to Euro VI (heavy duty) or Euro 6 standards (light duty), with a focus on legacy diesel vehicles.

The scheme is managed by the Energy Saving Trust with technical support provided by the Zemo Partnership (previously the Low Carbon Vehicle Partnership) on behalf of the Joint Air Quality Unit (JAQU). CVRAS is one part of a range of measures aimed at meeting EU NO_2 limit values in UK towns and cities.

2.1 What is CVRAS and what vehicle types and technologies does it cover?

CVRAS has been developed to accredit technologies that meet the required vehicle emission limits equivalent to Euro VI/6 standards. The scheme ensures the in-service durability of equipment on a day-to-day basis through telematics, as well as auditing and accrediting retrofit supply companies, ensuring required insurance, legal status and warranties are in place. CVRAS covers the following vehicle types:

- Buses
- Coaches
- Trucks
- Refuse Collection Vehicles
- Black Cabs
- Vans
- Passenger Cars

Vehicles retrofitted with CVRAS approved technology will be eligible for charge free access to charging Clean Air Zones (CAZ) across England and Wales, including the Ultra Low Emission Zone in London and Low Emission Zones (LEZ) in Scotland. CVRAS is open to all retrofit technologies that can demonstrate Euro VI equivalent emissions or better. Technologies currently approved under CVRAS are:

- Exhaust aftertreatment: Selective Catalytic Reduction
- Diesel Euro VI System Repower
- Battery Electric Repower
- LPG Conversion and Repower

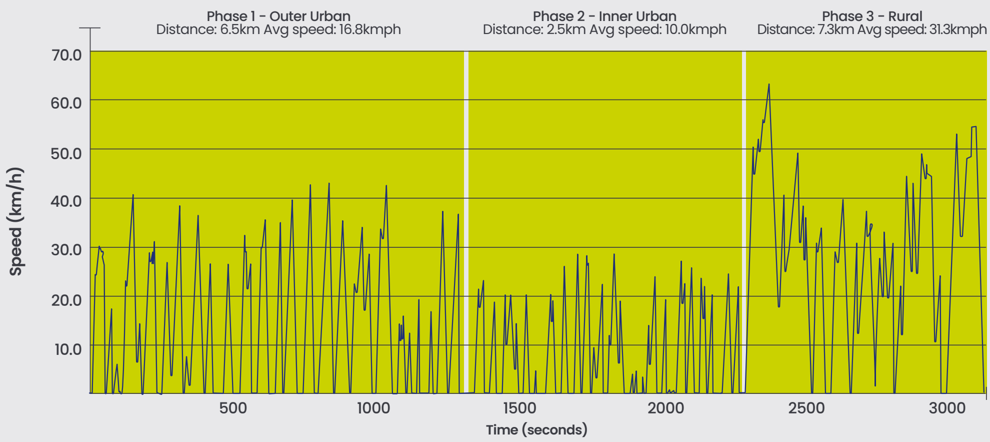
2.2 Technology Accreditation

To become approved under CVRAS, technologies must meet emissions limits over a representative test cycle on a chassis dynamometer (rolling road) or using Portable Emissions Measurement System (PEMS) for larger diesel vehicles equipment on a track course or have a Euro 6/VI certified system. Systems must also report daily average NO_x reduction performance where applicable (i.e. SCR systems). A full list of test procedures and emissions targets are available from the EST CVRAS website (see appendix).

For selective catalytic reduction (SCR) exhaust aftertreatment systems are tested and approved for specific engine models, weight class (e.g. single/double deck) and Euro standard as systems require complex calibration to achieve Euro VI equivalent emissions. For repower options certified as Euro 6/VI, suppliers will be able to size the system appropriately for the vehicle type and size and are not required to be model specific as the old engine is being replaced/converted.

By working closely with vehicle test houses, bodies such as Transport for London and the Confederation of Passenger Transport, the Zemo Parternship has developed a host of representative test cycles for each vehicle category covered by CVRAS where existing cycles were not available or appropriate. Examples include WLTP, the UK Bus Cycle (Figure 3), Zemo's UK Coach and HGV cycles.

Figure 3: The UK Bus Cycle used to compare emissions before and after the fitment of retrofit technologies seeking CVRAS approval.



A retrofit supplier will first test a vehicle over the appropriate test cycle to understand the baseline emissions performance of the vehicle. The retrofit system will then be fitted and calibrated to achieve Euro VI equivalent emissions, as well as ensuring no significant increase in greenhouse gas emissions.

2.3 Vehicle Emissions Limits

Retrofit systems must meet emissions limits for both air pollutants and greenhouse gas emissions. These include NO_x, NO_2, PM, Particulate Number (PN), Ammonia (NH_3), CO_2, methane and nitrous oxide measured as CO_2 equivalent (see appendix).

Equivalent emission limits for NO_x are 0.5 g/km for heavy duty vehicles and 0.25 g/km for light duty vehicles. Vehicles are tested with additional weight on board to simulate representative real- world operations such as passengers or a payload. A full set of test protocols for CVRAS approval is available to download alongside other supporting documents from the Energy Saving Trust's CVRAS webpage.

2.4 In-Service Monitoring

In-service monitoring is required to ensure that the daily average NO_x reduction of 80% is met throughout the lifetime of the system. On-board NO_x sensors measure NO_x reduction levels and the data is recorded, logged and reported via on-board data loggers and telematic systems. This gives suppliers the ability to inform operators if systems are dropping below 80% and quickly identify why the system is not performing as required. For Euro 6/VI certified repowers, daily reporting is not required as certified on-board diagnostic systems monitor exhaust emissions to ensure emissions standards are met and the vehicle cannot be operated in a non-compliant mode.

Different suppliers will provide alert systems for drivers and operators to suit, such as warning messages or lights on driver dashboards. The minimum performance parameters that must be reported by telematics systems are shown in Table 3.

Table 3. Telematic reporting requirements for NO_x tailpipe emissions

Vehicle Registration	24h average NO_x (g/km)	Live NO_x reduction (%)	Live Tailpipe NO_x (ppm)	Urea Level	Tailpipe NO_x below 100ppm	DPF backpressure below 20 KPa
e.g. HG58 GHR	0.5	98	20			

2.5 Company Approval

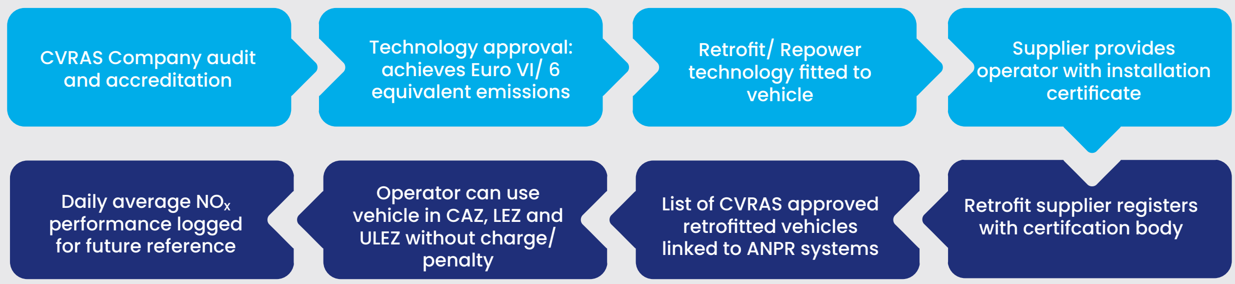
Companies supplying CVRAS approved systems are audited to ensure aftermarket support is available and that systems are maintained throughout the warranty period/lifetime of the system, typically five years. Companies must prove they are an identifiably legal entity and provide balance sheets for the previous two years or supporting evidence for new companies.

Companies are required to operate a certified Quality Management System (QMS) the ISO 9001:2015 standard. Manufacturers of systems must ensure that any external organisations involved in the production, fitment or maintenance of systems meet these quality processes. Company approval is reviewed annually and may be withdrawn should all the requirements of the CVRAS not be met.

2.6 Registering a Retrofit System

Once a vehicle is retrofitted with a CVRAS approved system, the retrofit supplier will issue an installation certificate and complete an entry on their retrofitted vehicle installation log. The CVRAS approved supplier will inform the CVRAS certification body and register the vehicle as retrofitted with the appointed body hosting the vehicle data. A list of CVRAS approved retrofitted vehicles will be linked to the central CAZ charging databases used by the ANPR camera systems to identify the emissions standards of a vehicle entering a charging CAZ and enable correct charging decisions.

Figure 4: CVRAS Accreditation, Registration and In-Service Compliance for Retrofit Technologies



3. Vehicle Retrofit Technologies

There are a range of factors to consider when choosing which retrofit technology is suitable for vehicle fleet and/or operation types beyond CAZ, LEZ or ULEZ compliance. These include the total cost of ownership, duty cycle or route characteristics, maintenance, local and national financial incentives, infrastructure requirements, expected vehicle lifetime, aftermarket support, operational impacts and additional environmental performance.

For fleet operators it is important to engage with the local authority to identify potential fiscal support and understanding the long-term ambition of the town or city. For example, Leeds City Council is offering support to local bus, coach and HGV operators in the form of grant and Birmingham is supporting the repower of black cabs to run on LPG.

It is also worth considering the long-term goal of reducing greenhouse gas emissions to combat climate change. Retrofit technologies can also be combined with fuel saving devices and/ or low carbon, sustainable and renewable fuels which can benefit greenhouse gas emissions and, in some cases, deliver fuel cost savings (see chapter 4).

3.1 Selective Catalytic Reduction

Selective Catalytic Reduction is an exhaust after-treatment technology targeting NO_x emissions in diesel vehicles. The technology has been used for several years by the automotive industry to meet Euro IV, V and VI NO_x engine emission standards for heavy duty vehicles, and more recently Euro 6 light duty vehicles. There are currently SCR retrofit systems available for buses, coaches and refuse collection vehicles, with truck solutions under development. There are approximately 8000 diesel buses fitted with retrofit SCR system in England. Retrofit suppliers including HJS Emission Technology are assessing the potential for SCR systems for vans and black cabs.

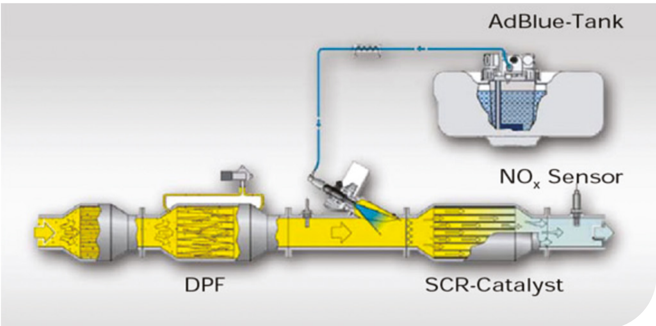
The system injects urea (AdBlue©) into the exhaust stream of a diesel engine which passes through a special catalyst (Figure 5). The urea sets off a chemical reaction that converts oxides of nitrogen (NO_x) into nitrogen and water vapour that are then expelled through the vehicle tailpipe, with some small amounts of Nitrous Oxide (N_2O) produced. The SCR system is commonly fitted after a Diesel Particulate Filter (DPF) that traps particulate matter emissions. The effective operation of SCR systems is highly dependent by exhaust gas temperature.

The temperature window for urea injection in the SCR system is typically 200- 450°C but can be as low as 150°C. There are also alternative dry systems that convert urea into an ammonia gas prior to injection into the exhaust. The production of ammonia gas takes place in a separate generator thus enabling the direct dosing of NH3 at temperatures down as low as 150°C.

An alternative delivery mechanism for ammonia has been developed which uses ammonia absorbed into a complex salt rather than urea liquid. Heating coils are used to generate the ammonia allowing for NO_x conversions at lower exhaust gas temperatures. An innovative feature of this system is that the ammonia is stored in cylinders which can be easily replaced when depleted and refilled by the supplier.

Temperature, the amount of urea, injection design and catalyst activity are the main factors that determine actual NO_x reduction. Control systems are built into the SCR system to ensure ammonia emissions from incomplete reactions (ammonia slip) is minimised. SCR technology has been developed over many decades, with over 8,000 buses operating in the UK with retrofit SCR systems.

Figure 5: Illustration of Wet SCR System where urea (Ad Blue) is mixed with exhaust gases over a catalyst to convert NO_x to inert nitrogen



CVRAS Approved SCR Systems to date

Visit the EST CVRAS webpages for the most up-to-date list of approved systems.

Table 4: Approved Systems for Selective Catalytic Reduction to date

Vehicle	Retrofit Technology	Retrofit Companies	Applicable Models
Coach	Exhaust after- treatment system	Eminox Ltd Proventia / Excalibre Technologies Ltd HJS Emission Technology	Several models – see full list on EST CVRAS webpages
Bus	Exhaust after- treatment system	Eminox Ltd HJS Emission Technology Proventia / Excalibre Technologies Ltd	Several models – see full list on EST CVRAS webpages
Refuse Collection Vehicle	Exhaust after- treatment system	Eminox Ltd	Dennis Eagle Elite with Volvo D7E 7.1 Litre Euro V Mercedes-Benz Econic 6.3 Litre Euro V
Trucks	Exhaust after- treatment system	Proventia / Excalibre Technologies Ltd	Several models – see full list on EST CVRAS webpages

System Installation and Maintenance

Before testing, a pre-fitment inspection is carried out to ensure the vehicle is ready for fitment, including inspecting the engine condition through a smoke test of tailpipe exhaust gases. Systems are then designed to be fitted within the available chassis space as many vehicles of the same model will have variations in their assembly.

SCR systems can be fitted at the operator's depot or at the supplier's workshop, providing vehicle lifts, power and air supplies are available. Fitment time can vary depending on the vehicle, but one system can be typically fitted in one day.

SCR systems utilise urea which is widely available. This is already common place for operators of Euro IV, V and VI vehicles, however engine systems that have Exhaust Gas Recirculation (EGR) instead of original SCR systems will need a urea tank combined and urea injection system.

Figure 6: Proventia/Excalibre Technologies NO_XBUSTER™ SCR System fitted to ADL E200 Euro V Bus

Figure 7: Technician creating 3D digital image of internal body of a coach using a laser system to identify available space for SCR system (courtesy of Eminox)

In-Service Monitoring

Monitoring and reporting of in-service NO_x performance is a mandatory requirement of any CVRAS approved SCR system. On-board diagnostic system monitors the NO_x performance in real-time and reports are logged on a database using telematics systems connected via mobile phone networks. Data is also stored on-board to enable direct download of system performance. A Malfunction Indicator Light (MIL), which is usually installed on the dashboard, can be used as a visual indication that there is an issue with the SCR system and the supplier should be contacted.

Some systems will offer digital dashboard displays for the driver to observe the performance of the retrofit SCR system in real- time. System features can include in-service NO_x alarms, urea level gauge, summary screen showing back pressure and NO_x reduction performance and has a service indicator.

Suppliers can provide operators with access to online portals, with live data displayed for each individual vehicle system installed. This real-time data can be displayed on mobile devices using apps and enables operators to identify performance issues. Data displayed can include NO_x reduction percentage, urea tank, DPF backpressure and more.

Environmental Credentials

Retrofit SCR systems can lower tail-pipe NO_x emissions by more than 90% when retrofitted to Euro III, IV and V diesel buses. Systems fitted with an additional DPF also ensure very low levels of particulate matter emissions. The CVRAS standards also limit any increase in greenhouse gas emissions.

Total Cost of Ownership

The total cost of ownership associated with upgrading with retrofit SCR technology should take into account a number of factors: the purchase cost of the technology, including fitting, telemetry charges, the cost of urea and annual maintenance.

Table 5 below provides and indicative cost of a SCR system for a Euro V bus over a 5-year period. The cost of a system will depend on whether a system has already been developed for the specific type and Euro standard of the bus, as well as the number of vehicles to be fitted. The amount of urea required for the SCR system is related to annual mileage of the bus. Maintenance includes cleaning of DPF filters with suppliers typically offer an annual service package to support operators.

Table 5: Total cost of ownership of SCR Retrofit system for a EURO V Bus over 5 years (assumptions in appendix).

Item	Cost
Retrofit SCR system & installation	£ 17,000
Annual Ad Blue consumption	£2,500
Maintenance (inc. DPF clean)	£ 3,000
Extended warranty	£ 2,000
Fuel Costs	£ 116,573
BSOG payments	£ 40,706
Telematics	£750
Total Cost of Ownership	**£101,117**

Bus Retrofit SCR case study – Transport for London

TfL has been managing the largest SCR retrofit programme for Euro III, IV and VI buses since 2011 to help reduce NO_2 concentrations London. The first retrofit programme saw 2,000 Euro III buses retrofitted with SCR technology supplied by Eminox, HJS and Proventia. TfL have allocated over £80m to retrofit over 4,000 Euro IV and V diesel and diesel-electric hybrid buses with SCR technology by the end of 2020, with £3m coming from the Clean Bus Technology Fund 2017-19 programme to support the programme. Models being retrofitted include, but is not limited to, the ADL Enviro 400, Volvo B5LH and Wrightbus Gemini. Suppliers of SCR systems included Eminox, HJS, Amminex, Proventia (Excalibre Tech). This programme will enable the entire TfL fleet of 9,500 buses to be either Euro VI certified, retrofitted to Euro VI equivalence or be fully zero emission by the end of 2020.

Putney High street was used as a key case study in the justification for continued rollout of retrofit for buses. In 2011 a NO_x source apportionment study was conducted by TRL and identified buses as the key contributor of NO_x emissions, with 27 scheduled buses stopping across a 30-minute window at peak hours and the majority of the fleet being Euro III or IV. Air quality monitoring indicated that following the retrofit of 93 Euro III double decker's, NO_x concentrations reduced by 9% and NO_2 concentrations reduced by 14% and the number of hourly NO_2 exceedances dropped by 40%. In 2017, Putney High Street was chosen to be a Low Emission Bus Zone, with only Euro VI buses operating on the high street. Provisional results indicate a 40% reduction in annual mean NO_2 concentrations, demonstrating the low levels produced by Euro VI vehicles.

Figure 8 shows the results of NO_x emissions testing undertaking at Millbrook Proving Ground for TfL Euro V buses over the TfL MLTB drive cycle, retrofitted with SCR equipment supplied by HJS and Eminox. Testing demonstrated that NO_x emissions were reduced by more than 95% from both Euro V buses below the 0.5g NO_x/km Euro VI equivalent limit following SCR retrofit. Retrofitted buses are equipped with telematic systems to report daily performance which will be monitored by TfL.

Figure 8: NO_x Emissions for TfL Euro V Buses before and after SCR retrofit from lab tests.

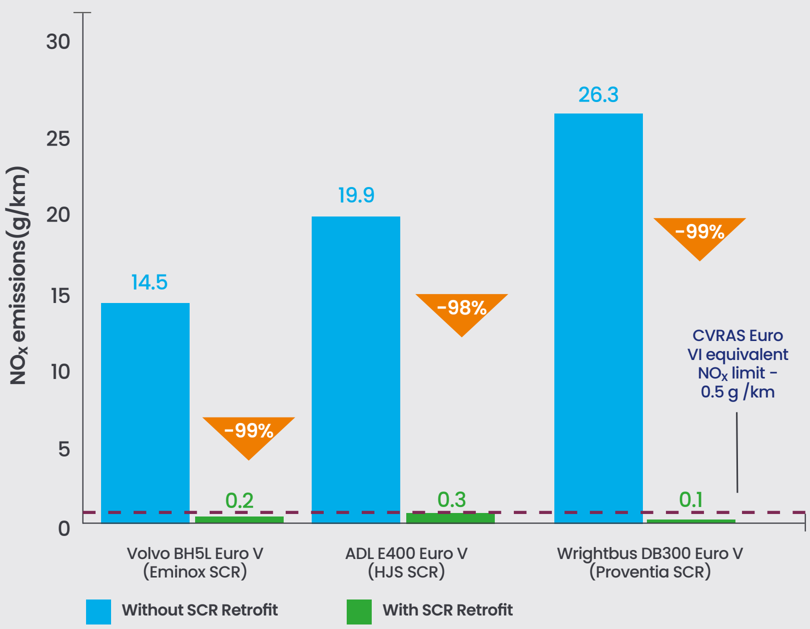
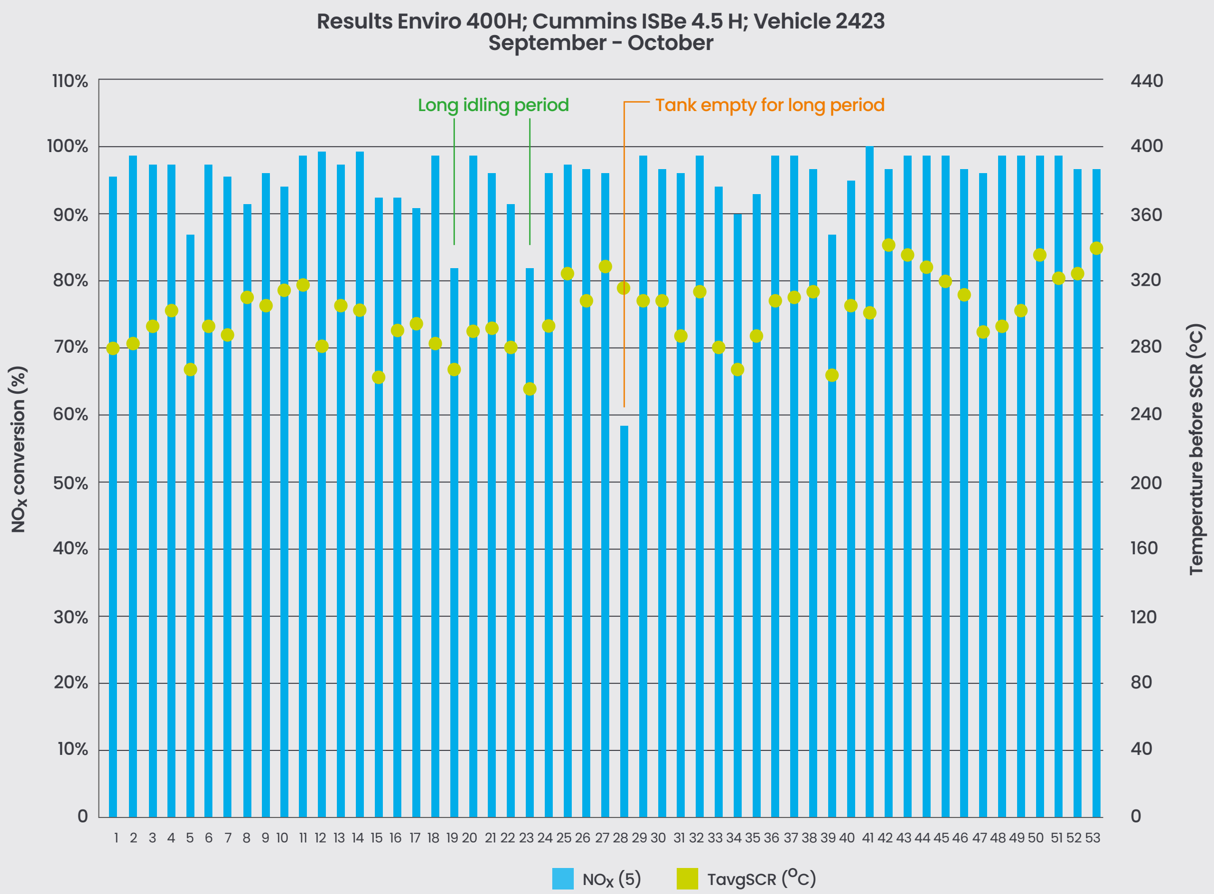


Figure 9 shows the daily NO_x conversion rates for two months in 2016 for the ADL Enviro400H Euro V bus retrofitted with the HJS SCR system. This reveals excellent in-service daily NO_x conversion, averaging at 96% over this period. The SCR catalyst temperature remains high throughout the two-month monitoring 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 temperature. Low urea levels give rise to a drop in NO_x reduction, see day 28 in Figure 9.

TfL worked in partnership with several bus operators including Arriva, Stagecoach, Abellio and Go-Ahead on the retrofit programme. Operators are responsible for undertaking basic maintenance work such as replenishing urea tanks and cleaning particulate filters. Overall TfL has found the retrofit systems to be reliable with limited issues experience by their contractors.

Figure 9: two months NO_x sensor data from in service monitoring of TfL Retrofit SCR Euro V Bus Note: NO_x conversion (%) refers to NOx concentration reduction (courtesy of HJS)



Coach SCR Retrofit Case Study – Luckett's Travel

Luckett's Travel has a fleet of around 100 coaches' operating in the south of England, including National Express routes with journeys to London, Southampton and Portsmouth. Luckett's chose to retrofit a Volvo B9R with a CVRAS approved Eminox SCR system to ensure they met the emissions regulations for London's ULEZ and growing number of CAZs around the UK, instead of buying a new vehicle.

Coaches tend to have a longer life cycle to buses, HGV's and cars, and fleets have very low rates of turnover. Operators will tend to buy 1 or 2 new coaches every year, using the new vehicles on premium services and cascading older vehicles onto less valuable operations such as school run contracts. The introduction of charging CAZs is affecting the value of non- Euro VI coaches and with currently no grant schemes in place, operators are looking at SCR retrofit as a viable option to achieve Euro VI equivalence.

The Volvo B9R coach with 56 passengers has an annual mileage of 70,000kms operating on a range of different services include ad-hoc private hire and school contracts. Prior to fitment, Eminox developed CAN integration software to enable the SCR system to integrate with the OEM ECU, ensuring the SCR performance relates to the demand put on the engine. The system was fitted and validated over 8 days and then calibrated over Zemo's UK Coach cycle to meet the CVRAS emissions limits and is now in-service with Luckett's. On-board diagnostics systems and telemetry provide Luckett's with minute-by-minute information on how the system is performing with the driver receiving dashboard notifications.

3.2 Repower: Euro VI System

Instead of improving the emissions of an existing system to Euro VI equivalence, operators of heavy-duty vehicles have the choice of completely repowering their vehicle with a new Euro VI certified engine, complete with a new exhaust aftertreatment. This enables operators to have Euro VI emissions alongside the advantages of a new engine such as improved fuel consumption compared to the original system. Currently repower to Euro VI is only available for buses.

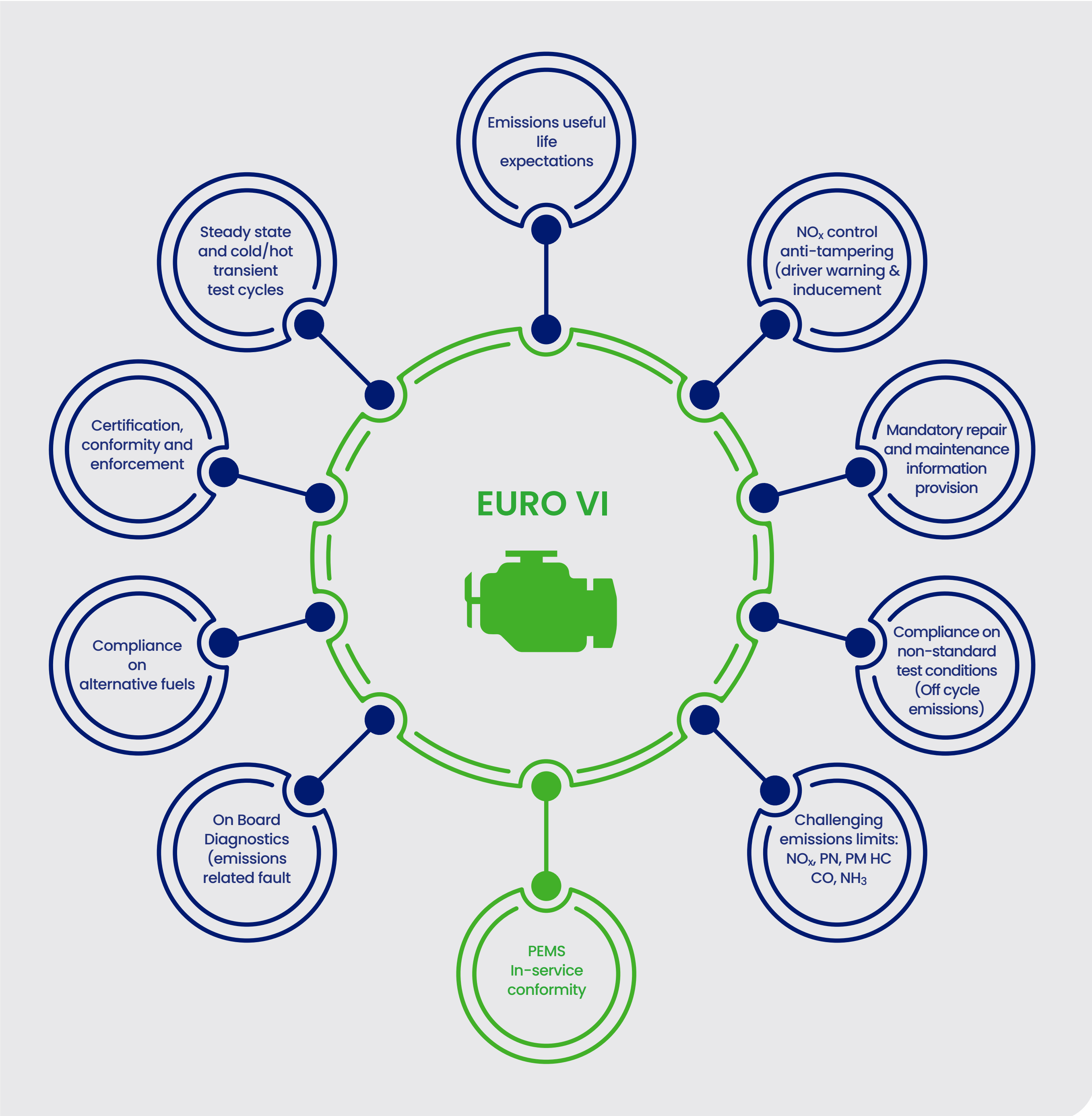
The Euro VI standard was first introduced in 2013 across the EU, with a number of iterations coming forward since, described as Euro VI Phase A, B, C, with D arriving in 2019 and E to follow. Euro VI engine families for repower are subject to in-service PEMS testing to ensure emissions on road are comparable with those measured under lab conditions.

Euro VI certified systems comprise of an engine system and accompanying exhaust aftertreatment system, typically using SCR technology and DPFs, that have been developed in tandem to achieve Euro VI emissions regulations, alongside a wide range of other standards such as safety and quality assurance.
Euro VI systems also have mandatory on-board diagnostic and anti-tampering systems which, after a timed sequence of warning levels, will force the engine to run on low power, known as engine de-rate, if no service intervention takes place. This provides system protection against any potential progressive faults and also ensures the engine will not exceed emissions levels.

Buses that are around 4-8 years old which have a Euro IV or V engine are ideal candidates for repowering as the vehicle is expected to last another 7-10 years depending on operation. Currently Cummins are looking to supply Euro VI systems for bus only.

Figure 10: Euro VI Cummins Repower fitted to an ADL E400 bus by Millbrook Special Vehicle

Figure 11: Benefits of Euro VI Certified Engine



CVRAS Approved Euro VI Repower Systems

Visit the EST CVRAS webpages for the most up-to-date list of approved systems.

Table 6: Approved Systems for Euro VI Engine Repower

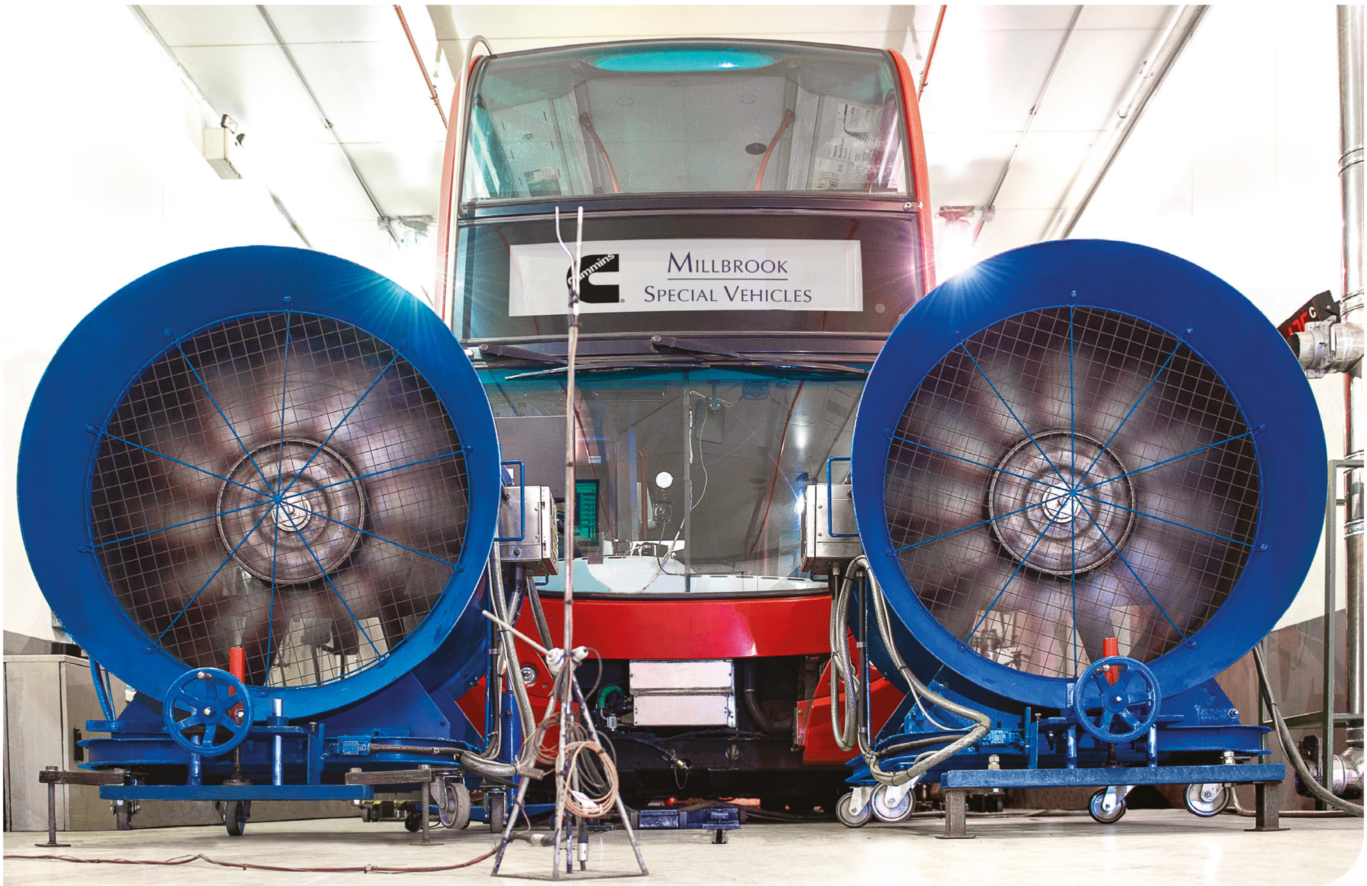
Vehicle	Retrofit Technology	Retrofit Companies	Applicable Models
Bus	Diesel Euro VI repower	Millbrook Special Vehicles	Wide range of Euro III, IV and V single and double deck buses
Bus	Diesel Euro VI repower	Cummins Ltd	Wide range of Euro III, IV and V single and double deck buses

System Installation and Maintenance

Depending on bus age and condition, the repower can range in scope from an engine and exhaust replacement to a full removal of the original powertrain. A full vehicle inspection will take place prior to installation to identify any parts that can be reused to reduce cost, though most elements will be new. A repower of a bus will take typically 2 weeks from engine removal to be ready for on-road service. The Euro VI repower will extend the usable life of a bus by 7 to 8 years, as well as improved engine performance with higher low-end and peak torque and extended oil service intervals.

System fitters will need to demonstrate that their installations meet the required standards of the engine manufacturer, typically through a prototype system. Millbrook Special Vehicles have repowered a 2009 ADL E400 Euro V with a Cummins ISB 6.7 Euro VI Phase C diesel engine (Figure 10), including a new transmission, which has been through rigorous durability and structural integrity testing on tracks to the same standard as a new vehicle.

Figure 12: An ADL E400 undergoing testing following Repower with a Cummins Euro VI Phase C 6.7 litre engine by Millbrook Special Vehicles



Prior to achieving CVRAS certification, the repower technology supplier must prove that the fitter can meet their standards for installation and will be capable of providing full in-service support for vehicles within the agreed warranty period. Cummins and Millbrook Special Vehicles are offering a two-year, unlimited mileage warranty on the engine and supporting systems (Extended Warranty Coverage options up to 5 years are also available). In- service conformity checks on the engine family are required to ensure Euro VI Phase C emission levels are maintained for regulated emissions throughout the system lifetime.

Euro VI maintenance practices have been developed by engine manufacturers to help fleet operators ensure vehicles perform with maximum in-service efficiency over their lifetime. Most fleet operators will have some experience with Euro VI vehicles to date and understand the required maintenance regime, though information and training is available from manufacturers. A repower system is designed to the same standards as a new vehicle and should be subject to the same maintenance regimes.

In-Service Monitoring

A Euro VI repower is designed to be exactly the same as a new Euro VI vehicle for NO_x and particulate matter emissions performance. Several NO_x sensors are fitted into the system that monitor NO_x levels as they leave the engine and use urea to convert the NO_x to non-harmful emissions through the SCR system, as described in Chapter 3.1. Repower systems will include on-board notifications systems, such as MIL lights, to notify drivers and engineers of any systems faults or low urea levels. Ensuring systems are filled with urea regularly is crucial to ensuring Euro VI systems perform during operations.

Environmental Credentials

Repowering with a new engine and aftertreatment system provides Euro VI emission standards and will also increase the usable life of the vehicle, providing an 90+% reduction in NO_x and 50% reduction particulate matter when replacing a Euro V system.

The repower enables operators to take advantage of new technologies like Cummins' stop/start engine option, which can reduce emissions, lower noise and save fuel. Stop/start technologies will shut down the engine when the vehicle comes to a stop and can provide up to 8% fuel savings, based on 15-20 stops per operating hour. Over the course of a year this could reduce fuel consumption by over 2,000 litres and lower the carbon footprint by over 5 tonnes for a bus with annual mileage of 90-100,000kms.

Total Cost of Ownership

An engine repower will extend the life of the vehicle and have an improved residual value for having a Euro VI Phase C engine. The TCO of the system will depend on how many systems are ordered initially as well as where the vehicle is operating and the annual mileage. Table 8 provides an indicative cost price for a new Euro VI engine system for a double deck bus over 5 years.

Table 7: Total cost of ownership over 5 years for a Euro VI Repower of a double deck bus (Assumptions listed in appendix).

Item	Cost
Cummins Euro VI Repower & installation	£40,000
Annual Ad Blue consumption	£2,500
Maintenance (inc. DPF clean)	£3,000
Fuel Costs (add up to 25% fuel saving with engine repower)	£87,429.75
BSOG payments (£0.3457/litre)	£30,529.50
Total Cost of Ownership (over 5 years)	**£121,367 - £156,367**

Case Study:
Sir Peter Hendy's Routemaster Bus

To demonstrate the proof of concept for engine repower, a London Routemaster which first entered service in 1962 was repowered with a 150 HP ISB 4.5 litre four-cylinder engine and integrated SCR and DPF exhaust aftertreatment system. Repowering the Routemaster was considered to be the most challenging due to the very limited space available in the engine bay.

The vehicle was tested over the UK Bus Cycle used for accrediting buses for the Low Emission Bus scheme 2015-17 and demonstrated 97% NO_x reduction and excellent fuel efficiency of 26 litres/100km or 10.6 mpg. Since its Repower, the RM1005 has at times been operating on London's heritage Route 15 which runs through the ULEZ in central London.

System status, performance and diagnostics are remotely monitored over-the-air using Cummins connected telematics technology, advising the bus owner, Sir Peter Hendy, via email about preventative maintenance and service requirements.

3.3 Repower: Battery Electric Powertrain

Electric vehicles operate using a battery powered electric motor powered by a battery for propulsion rather than a petrol or diesel internal combustion engine. Electricity is used to recharge the battery, with various strategies in existence for recharging, most typically overnight, depot-based charging drawing power from the national electricity grid. Vehicles with at least 5 years lifetime remaining are suitable for conversion to electric. Magtec and Astra Vehicle Technologies are approved for repowering electric vehicles, focusing on heavy duty trucks, buses and RCVs. There are a small number of electric repowers in operation currently in the UK, 6 double deck sightseeing buses in York, 2 singled deck buses in Brighton and one electric RCV and an electric 18 tonne repower.

Battery technology has focused on lithium ion chemistry, such as lithium iron phosphate. Progress in energy density has been substantial over the last decade, with 200 kWh in 2019 being offered for the same weight and cost as 133kwh was in 2015.

A key aspect to repowering to zero emission battery electric is to understand the daily operation cycle of the vehicle in order to size the battery capacity appropriately, without impeding on the existing passenger or load capacity. Battery capacities currently vary from 72-420 kWh. The electric range of current electric vehicles can vary between from 100-300km depending on weather and loads. Ensuring that enough power can be provided via a charger to the vehicle within the available period between services must also be considered.

CVRAS Approved Battery Electric Repower Systems

Visit the EST CVRAS webpages for the most up-to-date list of approved systems.

Table 8: Approved models for Repower with Battery Electric Powertrain

Vehicle	Retrofit Technology	Retrofit Companies	Applicable Models
Bus	Electric re-power	Magnetic Systems Technology Ltd	Several models – see full list on EST CVRAS webpages
Refuse Collection Vehicle	Electric re-power	Magnetic Systems Technology Ltd	Several models – see full list on EST CVRAS webpages
HGV	Electric re-power	Astra Vehicle Technologies Magnetic Systems Technology Ltd	Several models – see full list on EST CVRAS webpages

System Installation and Maintenance

System fitment and installation can take between 2-8 weeks per vehicle depending on the type of vehicle and will require the vehicle to be taken to the retrofit supplier factory, as on-site fitment is not possible. Once the vehicle has been fitted and test runs conducted the vehicle can return to its depot using its new powertrain, or on a low-loader if the return distance is too great.

The maintenance of a battery electric system is typically 20% less than a conventional combustion engine as there are no oil changes required and less moving parts. Modern battery systems have been designed to monitor the health of individual cells within the battery packs which can be individually replaced if showing signs of failure.

Battery and full system warranties will depend on the battery supplier and required operational duty of the vehicle. Warranties can range from 2 years up to 7 years and batteries may need replaced more than once during the life of the vehicle. This replacement can cost between £20,000 -£80,000 depending on the battery system.

The newly retrofitted vehicle will require charging infrastructure. The number of vehicles, battery capacity, charging window and rate of charger will all affect the required electricity supply equipment that will need to be installed. The existing electrical supply may be sufficient for slow charging (3-7kW) vehicles, but converting large depots to all electric may require significant investment in new substations and transformers depending on the local network. Early engagement with the local District Network Operator (DNO) is recommended and conversion to electric will require a range of project partners to ensure the successful deployment of vehicles and supporting infrastructure. Currently only plug-in conductive charging using CCS Combo 1 or 2 is available for retrofit systems.

In-Service Monitoring

Electric vehicles can be fitted with an on-board data logger to enable monitoring of electricity consumption and range and be constantly monitored remotely using telematics. This is particularly useful during the winter to ensure the vehicle can return to the depot when cold conditions will impact the battery capacity and heating may be needed to keep passengers warm. Manufacturers will recommend battery health checks and monitoring procedures to ensure the lifetime of the battery is maximised.

Environmental Credentials

Zero emission technologies such as battery electric powertrains produce no harmful tailpipe emissions from vehicle operation and use less energy per kilometre travelled than conventional petrol and diesel vehicles. There are still greenhouse gas emissions produced when electricity is generated via the national grid, but this has reduced by over 50% since 2012 in the UK due to the integration of renewables. These emissions can be offset by the installation of renewable sources such as solar PV which can be stored in batteries during the day and used to charge vehicles overnight.

Total Cost of Ownership

The total cost of ownership will depend on a range of factors including the vehicle type, daily operational mileage and service time, battery capacity and charging infrastructure. Charging infrastructure can range from £250 - £20,000 depending on rated power of the charger, ranging from 3-150kW per vehicle, with higher rated chargers able to fast (4-6 hours) or rapid charge (1-3 hours). The total cost of ownership of an electric repower bus is show below:

Table 9: Total cost of ownership of an Electric Repower of a double deck bus over 5 years (Assumptions in appendix)

Item	Electric Repower Bus (200kWh)
Retrofit Battery System & installation	£95,000
Maintenance	£2,800
Telematics	£750
Infrastructure (80 kW fast charger)	£20,000
Fuel Costs	£33,000
BSOG LCEB	£15,000
Total Cost of Ownership	**£136,550**

Case Study:
York City Council

York City Council have converted six diesel powered sightseeing buses to battery electric using funding from the Clean Bus Technology Fund in 2013. 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 with 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 utilised a Lithium Iron Phosphate battery pack with a design capacity of 133kWh in two modules. 200 kWh can now be offered today for the same weight and cost as 133kWh. 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, Transdev undertake annual maintenance checks that involve limited work and the battery is expected to have a life of around seven years. Transdev are experiencing lower fuel costs running the converted electric bus compared to the original diesel.

Figure 13: York sightseeing bus Repowered to Battery Electric

Case Study:
Big Lemon

Big Lemon is a bus and coach operator based in Brighton, with a long term aim of operating a community owned zero- emission bus fleet powered by renewable energy by 2030. This is in line with Brighton and Hove City Councils ambition for a zero-emission bus fleet by 2030.

In 2016, Big Lemon raised £250,000 through a bond offer open to the public and to retrofit and refurbish two second-hand single deck diesel buses with Magtec's Repower battery electric system. The repower system comprised of 132kWh battery capacity with a range of 100 miles, with an operational window of around 10 hours on one charge.

A further £25,000 was raised through crowd funding and M&S Energy Awards to install a 120 panel (21kW) solar PV array to generate renewable energy to offset the electricity used to charge the bus overnight. 'Om Shanti', the UK's first solar powered bus went into service in April 2017 and is now operating with 6 other single deck EVs in the Brighton and Hove region.

RCV Repower Magtec Greenwich

In 2017, the Royal Borough of Greenwich (RBG) undertook a project with Magtec to create the UK's first 26 tonne battery electric refuse collection vehicle (RCV). The eRCV project, funded in part by Innovate UK, was aimed at demonstrating the reduction of local impacts from refuse collection operations such as air pollutants and noise, as well as using energy from renewable sources. The project partners include Innovate UK, Magtec, Veolia, Sheffield City Council and Westminster City Council, Microlise (telematics) and DG Cities.

The project included the electrification of the powertrain and the electrification of actuators used to control the hydraulics systems used to compact collected refuse. RCVs are suited to electrification as they do frequent stop/start operations with low speeds in urban and often residential areas, which provides little opportunity for the engine to clean the DPF filter through regeneration.

The vehicle, a seven-year-old Mercedes Benz Econic Euro V was chosen as it was close to the end of life, was supplied by RBG to Magtec for retrofit as part of 'DG (Digital Greenwich): Cities' eRCV project. The vehicle has been in operation since July 2018, operating as part of a normal duty cycle of 14 hours a day, without needing to recharge.

The vehicle covers between 30-60 miles a day on a single shift and consumes approximately 150 kWh of energy giving an average energy consumption of 3.5kWh/mile. This compares to 2.5-4.5 mpg (18.1-10.1 kWh/mile) typical performance for a diesel RCV. The eRCV is charged overnight for 6 hours using a 40kW charger, with a total battery capacity of 300 kWh.

The total cost of the eRCV over a 7-year period is £299,000, compared with £366,000 for a Euro VI diesel, with significant savings arising due to the lower cost of electricity compared to the cost of diesel. Further Innovate UK funding has been awarded to the eRCV II project, which will see the retrofit of a further four diesel RCVs for operation in two contrasting environments, the dense urban area of Westminster in London and the hilly rural and urban roads of Sheffield.

3.4 Euro 6 system and LPG conversion

Liquified Petroleum Gas (LPG) has been in use as a transport fuel for many years with over 12 million LPG vehicles operating within the European Union and 35 million globally. An LPG repower replaces the existing diesel engine with a Euro 6 engine or converts the existing petrol engine to run on LPG. For repowering a diesel vehicle, the original engine is replaced with a petrol engine adapted to run on LPG.

A CVRAS approved system is available for repowering 'Black Cabs' models TX1, TX2 and TX4 to run on LPG. It is possible to repower other vehicles such as vans and cars but currently no CVRAS approved models are available.

The 'GasCab' repowering comprises of a 2.0L engine adapted for running on LPG. The engine control unit (ECU) is optimised to work with a LPG system to achieve optimal power and emissions performance. The engine is mapped to follow the original diesel power output as closely as possible and produces 80 – 100 HP depending on the diesel engine being replaced. The original output of the engine is 280HP, therefore it is operating well within its capabilities which should mean a long service life.

The original fuel tank is replaced by a 100 litre LPG tank and a 12-litre petrol tank for cold starting and as a reserve. For a petrol vehicle conversion, a gas injection system, a controller and a pressurised LPG tank is fitted to the vehicle. The tank is often located in the spare wheel well.

Refuelling at an LPG pump is straightforward; the refuelling nozzle is locked into place to create a sealed pressurised system. Refuelling takes around the same time as refuelling with petrol or diesel. There are over 1,300 outlets selling LPG across the UK. For locations of LPG refuelling points in the UK view the DriveLPG refuelling map online. Autogas Ltd, the country's largest supplier of automotive LPG, has a search function for their refuelling sites on their website.

Cities including London, Birmingham, Glasgow and Edinburgh have approved LPG conversions and repowers as part approved technologies under taxi licensing, with around 100 LPG black cabs already in operation.

CVRAS Approved LPG Repower and Conversion Systems

Visit the EST CVRAS webpages for the most up-to-date list of approved systems.

Table 10: Approved Models for LPG Repower & Conversion Systems

Vehicle	Retrofit Technology	Retrofit Companies	Applicable Models
Black Cab	Repower and LPG conversion	Vehicle Repowering Solutions Ltd	TX1, TX2 and TX4

System Installation and Maintenance

An approved LPG installer should be used for repower and conversions. It will take one technician around 8 working days to fully repower a diesel taxi, including inspections and paperwork. LPG vehicles must have an annual gas check alongside their MOT. A certificate is provided following a short 15-minute inspection of vehicle for a small fee and is typically conducted separately as not all MOT centres offer this service. Currently Vehicle Repowering Solutions offer 2 years warranty on the system or 80,000 miles, whichever comes first.

In-service monitoring

The engine and aftertreatment systems used in repowered LPG vehicles have been certified as Euro 6 and are not required to report daily average NO_x reduction through telematics systems.

Environmental credentials

An LPG repower or conversion to will achieve Euro 6 emissions standards, delivering a 90%+ reduction in NO_x as well as reduced PM compared to previous diesel Euro standards. LPG produces less greenhouse gas emissions per litre but has a slightly higher fuel consumption when compared to diesel.

Total Cost of Ownership

Running vehicles on LPG enables drivers to benefit from the lower rate of fuel duty applied to LPG making it almost half the cost of petrol or diesel. The cost of the repowering technology on the TX diesel taxi is between £9,800 and £10,400 ex VAT, dependant on model and options on the vehicle i.e. air conditioning. The total cost of ownership over 5 years is show in Table 11.

Table 11: Total cost of ownership for an LPG Repower Taxi with new Euro VI LPG Engine System over 5 years (Assumptions in appendix)

Item	LTC TX4 Repowered LPG
Repower & installation	£10,400.00
Adblue consumption	Not required
Maintenance	£2,625
Fuel cost	£30,114
Total Cost of Ownership	**£43,169**

Case Study:
Birmingham City Council

In September 2014, Birmingham City Council (BCC) received £500,000 from DfT's Clean Vehicle Technology Fund to repower 65 diesel TX1 and TX2 black taxis with petrol engines using LPG. The funds also provided training for eight technicians to carry out LPG repowers and assisted in creating a new supply chain which previously did not exist within the city.

The work is part of BCC's NO_x Reduction Champion project, a partnership between approved converter Harborne Garage in Selly Oak, engine manufacturer Kronenberg Management Systems (KMS), European LPG conversion kit experts Vogels Autogas Systems and BCC. The partnership is further supported through collaboration with LPG supplier Autogas Ltd.

There are approximately 1,200 taxis and 4,000 private hire vehicles licensed by BCC. Birmingham has an ageing fleet of taxis that means the provision of cleaner vehicle in the city is a priority for BCC addressing air quality, whilst delivering a CAZ compliant taxi fleet.

A crucial element for success was continuous engagement with taxi drivers (i.e. end users) in Birmingham throughout the project. A series of workshops were held to engage with drivers, operators and union representatives to educate about the technology and expected operational performance, from pre-grant application to in-use following a number of months after systems had been in-service.

This engagement ensured there was a high level of satisfaction with the technology, its servicing, performance and the conversion procedure, with 97% of drivers recommending a conversion. Passengers were surveyed alongside drivers and a reduced engine noise was a key feature of the feedback.

BCC is offering financial support for LPG conversion and repower as part of a package of support measures to help local businesses affected by the introduction of a CAZ, drawing down £38m from the Clean Air Fund.

4. Reducing Greenhouse Gas Emissions

Alongside reducing harmful air pollutants, renewable fuels and other fuel reduction technologies can be used in tandem with a retrofit solution to reduce greenhouse gas emissions that are contributing to climate change.

Renewable Fuels

Biodiesel is a renewable alternative to standard diesel. It is produced via the process of esterification using straight vegetable oil and waste materials such as used cooking oil (UCO), fat and tallow from animal rendering processes and grease from waste water systems.

Fleet operators can purchase biodiesel either as a blend of biodiesel and standard diesel, typically B20 and B30, or as 100% biodiesel, known as B100. High blends of B100 will require vehicle modification. Well-to-wheel (WTW) GHG emissions of biodiesel are highly influenced by the feedstock used to produce the fuel; waste derived feedstocks are associated with the lowest carbon footprint. WTW GHG emissions will vary depend on the finished biodiesel blend, for example B20 from UCO would offer a 13% CO_2 eq. saving in comparison to standard diesel, B100 would offer 85% CO_2 eq. saving. A number of bus operators in the UK are using biodiesel in retrofitted vehicles e.g. Stagecoach and Metroline in London.

HVO

Hydrotreated vegetable oil (HVO) a renewable paraffinic fuel that can replace diesel, produced by hydrotreating vegetable oils or animal fats in oil refinery type equipment. It can be produced from vegetable or waste oil products. HVO is the same fuel chemically as paraffinic diesel e.g. Shell GTL (Gas to Liquid), which is produced from fossil fuels.

There are currently no fleets operating on HVO in the UK although several trials have been conducted in truck and coach fleets, such as Luckett's Travel with Scania. HVO requires no engine modification or changes to maintenance schedules and it can be used as a 100% drop-in fuel in diesel vehicles. There are no vehicle warranty issues with using HVO. HVO produced from UCO achieves a 90% GHG emissions saving compared to standard diesel based on the DfT reporting for the Renewable Transport Fuel Obligation scheme.

BioLPG

LPG vehicles can use BioLPG produced from wastes, residues and renewable vegetable oils. It can be blended and used for all existing LPG applications reducing lifecycle CO_2 emissions by up to 80%.

Renewable Electricity

Using a renewable electricity tariff can reduce the associated GHG emissions produced during electricity generation. WTW GHG emissions can be reduced by as much as 90% depending on the supplier.

Fuel Saving Technologies

Telematics can be used to provide real time information on vehicles as they carry out their daily operations, providing a useful tool for driver training and incident evaluation. Good driver behaviour can lead to significant fuel savings and thus greenhouse gas savings. Telematics systems have GPS capabilities and can report 1000s of lines of data per second, including location, speed, acceleration, breaking and fuel consumption. Some vehicle manufacturers offer telematics systems pre-installed on vehicles, while there are a range of third party providers who can retrospectively install systems. This information can be packed and allocated to driver profiles enabling operators to reward good drivers and provide targeted training.

Appendix

References and Further information

Energy Saving Trust - CVRAS Website
www.energysavingtrust.org.uk/transport/clean-vehicle-retrofit-accreditation-scheme-cvras

Zemo Partnership
www.zemo.org.uk

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www.lowemissionzones.scot

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www.uk-air.defra.gov.uk/assets/documents/reports/cat19/1511251135_140610_Valuing_the_impacts_of_air_quality_ on_productivity_Final_Report_3_0.pdf

NAEI, 2018:
"Breakdown of average roadside sources of NO_x emissions by vehicle type" [Online] Available at: http://naei.beis.gov.uk/

Greener Journeys, 2017:
"Improving Air Quality in Towns and Cities" [Online] Available at: https://greenerjourneys.com/

DG Cities, 2019:
"The Case for Repowering Refuse Collection Vehicles from Diesel to Electric" [Online] Available at: https://www.dgcities.com/#publications-section

Clean Air Zone Vehicle Checker:
www.gov.uk/check-clean-air-zone-charge

CVRAS Vehicle Emissions Limits

Emission	Emission Limit over test cycle for HDVs (Truck, Bus, Coach)	Emission Limit over test cycle for LDVs (Vans, Cars)	Emission Limit over test cycle for Black Cab
Oxides of Nitrogen, NO_x ($NO + NO_2$)	0.5 g /km	0.25g /km	WLTP: 0.125 g/km PCO-Cenex: 0.25 g/km
Nitrogen Dioxide, NO_2	0.1 g /km	0.1 g /km	0.1 g /km
Particulate Matter, PM	0.01g /km Coach: 0.025 g/km	0.01g /km	0.01g /km
Number of Particles, PN	6 x 10^{11} /km Coach: 6 x 10^{12} /km	6 x 10^{11} /km	6 x 10^{11} /km
Nitrous Oxide + Methane, N_2O + CH_4 (CO_2 equivalent or CO_2e)	Less than 5% increase in CO_2e from baseline	Less than 3% increase in CO_2e from baseline	Less than 3% increase in CO_2e from baseline
Carbon Dioxide, CO_2	Less than 1% increase from baseline	Less than 1% increase from baseline	Less than 1% increase from baseline
Ammonia, NH3	10 parts per million (ppm) average over test cycle and cannot exceed 25ppm throughout test	10 ppm average 25 ppm peak	10 ppm average 25 ppm peak

CVRAS Approved Technology Suppliers

Retrofit Supplier	Contact Details
Amminex Emissions Technology A/S (Soborg, Denmark)	**info@amminex.com**
Cummins Distribution UK (Wellingborough, UK)	**jacob.harling@cummins.com**
Driveline Emissions Technologies Ltd (Penrith, Cumbria UK)	**www.drivelineemissions.com**
Eminox Ltd (Gainsborough, UK)	**enquiries@eminox.com**
HJS Emission Technology GmbH & Co KG (Menden, Germany) UK Representation: HJS UK Ltd (Swindon)	**www.hjs.com/en/uk**
Magnetic Systems Technology Ltd (Sheffield, UK)	**info@magtec.co.uk**
Millbrook Special Vehicles (Bedford, UK)	**info@millbrooksv.co.uk**
Proventia Oy (Oulunsalo, Finland) UK Representation: Excalibre Technologies Ltd (Gloucestershire	**sales@excalibretech.com**
Vehicle Repowering Solutions Ltd (VRS) (Alcester, UK)	**info@vehiclerepowering.com**

Assumptions for Total Cost of Ownership Calculations

Bus

- Annual Mileage: 50,000 kms
- Annual AdBlue© consumption: £500/bus
- Annual Maintenance, including DPF clean: £600/bus
- Double Deck Bus – 6 MPG (47.1 litres/100km)
- Battery Electric Energy Consumption: 1.2 kWh/km
- Price of Electricity: £0.11/kWh
- Wholesale price of diesel (Large Fleet Operator): £0.99/ litre
- Cost of DPF annual clean: £150/bus
- Annual Telematics subscription: £150/bus
- BSOG rate England - £0.34/litre

Black Cab

- Annual Mileage: 64,000 kms
- Price of LPG: 0.60/litre
- LPG Taxi MPG – 18 MPG (15.7 litres/100km)

Zemo Partnership
Accelerating Transport to Zero Emissions

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