LowCVP

Low Carbon Vehicle Partnership

THE LOW EMISSION BUS GUIDE

This report is published by The Low Carbon Vehicle Partnership

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Date of Report: 1st November 2016

Acknowledgments

The production of the Low Emission Bus Guide has been sponsored by the following organisations:

ALEXANDER DENNIS
BAE SYSTEMS INSPIRED WORK
BAUMOT innovative exhaust aftertreatment
BYD Build Your Dreams
Eminox
Gas Alliance Group
HJS Emission Technology
Optare
VOLVO
WRIGHTBUS

LowCVP would like to thank members of their Bus Working Group for providing technical information and case study material pertaining to the guide - Argent Energy, BOC, BYD, First Bus JouleVert, Roadgas, Scania, Stagecoach, Transport for London, Volvo, Nottingham City Council, Reading Buses, York City Council.

Executive Summary

Introduction

The Low Emission Bus (LEB) Guide aims to provide bus operators and local authorities with an overview of the benefits of a range of low emission fuels and technologies that reduce both air pollution and greenhouse gas emissions. The guide outlines the emission performance, operational and financial factors, fleet operators should consider when procuring new buses or retrofitting exhaust after treatment technology to existing diesel buses. Real-world bus operator case studies are discussed in the guide to highlight and demonstrate the environmental and business cases for the range of different technologies and fuels.

This guide is intended to equip bus operators and local authorities with relevant information to aid purchasing decisions and encourage the most appropriate low emission bus for a particular route and application.

What does this Guide cover?

The low emission bus technologies and fuels covered in this guide are:

- Alternative Powertrains – electric, hybrid, plug-in hybrid, hydrogen fuel cell
- Spark ignition engines – gas
- Low carbon fuels – biomethane and renewable biodiesel
- Efficient Euro VI diesel buses – electrified ancillaries
- Diesel bus retrofit technology – selective catalytic reduction

Structure of the technology and fuel chapters is as follows:

- Overview of vehicle technology and suitable routes
- Outline of fuel production and supply
- Environmental credentials
- Refuelling/Recharging Infrastructure
- Factors influencing total cost of ownership
- Overview of the current market
- Low Emission Bus accredited models
- Low Carbon Emission Bus models
- Bus operator case study

Why do we need low emission buses?

Buses play a critical role by delivering sustainable transport in our towns and cities and provide rural connectivity to a broad cross section of the UK population. However, existing diesel buses are a source of air pollution and greenhouse gas emissions.

The UK Government is committed to limiting climate change through a package of policy measures aimed at reducing greenhouse gas emissions. Road transport is currently responsible for around quarter of greenhouse gas emissions (GHG) in the UK, of which 4% is attributable to buses[1] . A range of policies have been introduced over the last decade to encourage the take-up of Low Carbon Emission Buses (LCEBs) and more recently Low Emission Buses (LEBs).

Improving local air quality is also extremely high on the Government's environmental agenda. The EU Limit value for nitrogen dioxide (NO2) is currently exceeded in 38 out of the 43 UK air quality monitoring areas. Some 80% of roadside oxides of nitrogen emissions (NOx) in these areas arise from road transport, primarily diesel vehicles. Defra has published an air quality action plan[2] outlining a suite of measures aimed to reduce NO2 levels across cities in the UK. One of the key actions for improving air quality is the establishment of Clean Air Zones (CAZ) in five regions, plus the Ultra Low Emission Zone (ULEZ) in London, by 2020. These 'zones' will discourage older, more polluting buses, taxis, coaches and lorries by charging them to access key areas. It is expected that bus operators will be encouraged to either purchase new Euro VI buses or retrofit existing diesel buses with technology that can achieve NOx emissions equivalent to Euro VI.

A number of local and regional authorities have already introduced policies to help encourage the adoption of clean buses. For example, Oxford City Council and Transport for London have implemented Low Emission Zones, with plans to introduced stricter emissions standards. Various cities have prepared Low Emission Strategies. Some local authorities are using procurement standards, via Bus Quality Partnerships, to set emission standards and thereby increase the adoption of low emission buses.

The purchase of low emission buses can offer fuel costs savings as well as whole life cost/total cost of ownership benefits to bus operators, demonstrating a clear business case for choosing alternative technologies to conventional diesel buses. There is also evidence to suggest that operating low emission technologies and fuels can increase passenger patronage as environmental issues are becoming increasingly important to the travelling public.

Purchasing low emission buses – what to consider?

There are a range of factors that should to be taken into account by bus operators when choosing to purchase a particular type of low emission bus technology. These include total cost of ownership (TCO), route characteristics, maintenance, Government fiscal incentives, infrastructure requirements, technology maturity, operation and environmental performance. Many aspects are difficult to measure in service but are routinely assessed against a representative bus test cycle such as the LowCVP UK LUB cycle. Consideration of local policies such as Clean Air Zones or Low Emission Zones, which specify emission performance standards, should also be taken into account in the fleet renewal process.

The adoption of low emission buses can involve multiple stakeholders and require strong partnership working. It is important to identify relevant stakeholders early on in the procurement process and map out timeframes for vehicle delivery and infrastructure installation with relevant contractors.

The fiscal incentives for low emission buses operating in the UK are currently driven by the Bus Service Operators Grant including the Low Carbon Emission Bus incentive, and in some cases exemption from or a reduction in fuel duty. The incentives vary for different technologies and fuels. The BSOG schemes in England and Scotland are currently under review with changes expected to take place in 2017.

Low Carbon Emission Bus Accreditation Scheme

In order to reduce greenhouse gas emissions arising from buses, the Department for Transport and Transport Scotland have, over the past six years, introduced fiscal incentives to stimulate the take-up of 'Low Carbon Emission Buses'. The incentives include the Green Bus Fund, Scottish Green Bus Fund and the BSOG Low Carbon Emission Bus Incentive. The Low Carbon Vehicle Partnership and its members designed the LCEB accreditation scheme that has served to qualify different low carbon bus models for Government funding. The scheme entails determining Well-to-Wheel greenhouse gas (GHG) emissions of types of low carbon buses. The definition of a Low Carbon Emission Bus is:

> 'A Low Carbon Emission Bus is one that achieves more than 30% Well-To-Wheel greenhouse gas emissions savings compared to an equivalent Euro III diesel bus of similar passenger capacity.'

There are presently 3,760 LCEBs in operation across England, Wales and Scotland covering hybrid, electric, plug-in hybrid, electrified ancillaries, biomethane and hydrogen fuel cell buses.

Low Emission Bus Accreditation Scheme

In 2015 the Office of Low Emission Vehicles introduced the £30million Low Emission Bus (LEB) Scheme, with 326 buses funded alongside £7m towards supporting infrastructure. In 2017, £11m was awarded to five local authorities to support the purchase 153 LEBs and supporting infrastructure. The Scottish Green Bus Fund has also adopted the LEB accreditation criteria for rounds 6 and 7 supporting 93 LEBs with £3.2m. The LowCVP created the definition of a 'Low Emission Bus' and the revised Low Emission Bus Accreditation Scheme to accompany the Low Emission Bus Grant. The LEB accreditation scheme is the new approval process for qualifying different low emission bus models for Government fiscal incentives both in England and Scotland. (The LCEB Accreditation Scheme has been replaced by Low Emission Bus Accreditation Scheme.) The definition of a LEB is:

> 'A Low Emission Bus is a bus that achieves more than 15% WTW GHG emissions savings compared to an equivalent Euro V bus, and meets the Euro VI engine emissions standard or proven equivalent levels'

The LEB accreditation procedure involves determining WTW GHG emissions, energy consumption and compliance with Euro VI engine standard of potential LEBs through measuring NOx and PM emissions. The LowCVP has created a new bus test cycle called the LowCVP UK Bus cycle. Each accredited bus model receives an LEB certificate, showing air pollution and WTW GHG emissions and savings, fuel/electricity consumption and electric range. Data from LEB certified vehicles is presented in this guide. Full details of the scheme and LEB certificates can be found on the LowCVP Low Emission Bus website[3].

[1] Dft Transport and Environment Statistics, 2016
[2] Air Quality Action Plan for Nitrogen Dioxide in UK, Defra 2015

[3] http://www.lowcvp.org.uk/initiatives/leb/LEBCertificates.htm

Executive Summary

Improving air quality and introduction of Euro VI emissions legislation

Euro VI is the latest engine emissions legislation for heavy-duty vehicles sold within the European Union. From Euro V to Euro VI tail-pipe NOx emissions for diesel buses have reduced by over 75% primarily due to use of sophisticated exhaust emission after treatment technologies - selective catalytic reduction (SCR) and exhaust gas recirculation (EGR). The introduction of the Euro VI regulation in 2014 has seen an improvement in the way truck and bus engines are type approved via the new 'World Heavy Duty Transient Cycle'. This new cycle has been designed to more closely reflect what an engine does during real-world driving conditions. Euro VI vehicles are also equipped with more advanced on-board diagnostic equipment, and are obliged to run sophisticated real world emission tests during certification and in service verification. Independent vehicle emission testing commissioned by Transport for London reveals a significant reduction in NOx emissions is being achieved by Euro VI diesel and hybrid buses.

Comparison Matrix of Different Low Emission Bus Technologies and Fuels

Low Emission Technology/Fuel	Vehicle Capital Cost	Energy Cost Compared to Euro V diesel	Route	Vehicle Options	Infrastructure Requirement	Air Quality Compared to Euro V Diesel	WTW GHG Emissions Compared to Euro V Diesel
Electric	High	Much Better	City, airport express	Single/Double Decker	Low to High	Excellent	Very Good
Hybrid	Medium to High	Better	City, suburban	Single/Double Decker	None	Very Good	Very Good
Plug-in Hybrid	High to Very High (depends on charging technology)	Much Better to Better	City, suburban	Single/Double Decker	Low to High	Excellent - Very Good	Very Good
Hydrogen Fuel Cell	Very High	Higher	City, suburban	Single/Double Decker	High	Escellent	Excellent to Good (depends on pathway)
Gas Buses Fuelled by Biomethane	Medium	Better	City, suburban, rural, airport express	Single/Double Decker	Low to Medium	Very Good	Excellent to Good (depends on pathway)
Renewable Diesel (drop in Biodiesel/HVO)	No Impact to Low	Identical	City, suburban, rural, airport express	Single/Double Decker	None	Very Good	Excellent
Euro VI buses fitted with electrified ancillaries	Low	Slightly Better to Better	City, suburban, rural, airport express	Single/Double Decker	None	Very Good	Good
Retrofit Selective Catalytic Reduction	Low	Identical	City, suburban	Single/Double Decker	None	Very Good	Minor Increase

Contents

1 Introduction

1.1 Aim of this guide

The Low Emission Bus Guide aims to provide bus operators and local authorities with an overview of the benefits of a range of low emission fuels and technologies that reduce both air pollution and greenhouse gas emissions. The guide outlines both the emission performance and the operational and financial factors fleet operators should consider when procuring new buses. The guide additionally demonstrates the role retrofit technology can play in reducing certain air pollution emissions from existing buses. Real-world bus operator case studies are discussed in the guide to highlight and demonstrate the environmental and business cases for the range of different technologies and fuels.

The low emission bus technologies and fuels covered in this guide are: electric, hybrid, plug-in hybrid, electrified ancillaries, hydrogen fuel cell, biomethane, renewable diesel and retrofit selective catalytic reduction.

1.2 Why do we need low emission buses?

Buses play a very important role in delivering sustainable transport in our towns and cities and provide rural connectivity to a broad cross section of the population. However, existing diesel buses are a source of air pollution and greenhouse gas emissions.

The UK Government is committed to limiting climate change through a package of policy measures aimed at reducing greenhouse gas emissions. Road transport is current responsible for around a quarter for greenhouse gas emissions, of which 4% is attributable to buses. A range of policies have been introduced over the last decade to encourage the take-up of Low Carbon Emission Buses (LCEBs) and more recently Low Emission Buses (LEBs).

Improving local air quality is high on the Government's environmental agenda. The EU Limit Value for nitrogen dioxide (NO2) currently exceeds 38 out of 43 UK areas. Some 80% of oxide of nitrogen emissions (NOx) in these areas arise from road transport, primarily with diesel vehicles. Defra has published an air quality action plan[2] outlining a suite of measures aimed to reduce NO_2 levels across cities in the UK, with particular focus on road transport emission reduction. One of the key actions for improving air quality is the establishment of Clean Air Zones (CAZ) in five regions, plus the Ultra Low Emission Zone (ULEZ) in London, by 2020. The regions are Birmingham, Leeds, Nottingham, Derby and Southampton. York City Council will be independently introducing a Clean Air Zone over the next few years. These 'zones' will discourage older, more polluting buses, taxis, coaches and lorries by charging them to access key areas. In the case of buses, it is expected that operators will therefore be encouraged to either purchase new Euro VI buses or retrofit existing diesel buses with technology that can achieve NOx emissions equivalent to Euro VI. A number of local and regional authorities have already introduced policies to help encourage the adoption of clean buses. For example, Oxford City Council and Transport for London have implemented Low Emission Zones, with plans to introduce stricter emissions standards. Various cities have prepared Low Emission Strategies, such as Manchester and York, which cover a range of interventions to encourage cleaner and greener buses. Some local authorities are using procurement standards, via Bus Quality Partnerships, to set emission standards and thereby increase the adoption of low emission buses. The forthcoming Buses Bill makes reference to local authorities encouraging the take-up of low emission buses. Bus operators are therefore coming under increasing pressure to take into account the environmental performance of their existing bus fleet and to review new fleet purchases.

The purchase of low emission buses can offer life-cycle cost/ total cost of ownership benefits to bus operators, demonstrating a clear business case for choosing alternative technologies to conventional diesel buses. There is evidence to suggest that operating low emission technologies and fuels can increase passenger patronage as environmental issues are becoming increasingly important to the travelling public.

1.3 Low Carbon Emission Bus (LCEB) Accreditation Scheme

In order to reduce greenhouse gas emissions arising from buses, the Department of Transport and Transport Scotland have, over the past six years, introduced fiscal incentives to stimulate the take-up of 'Low Carbon Emission Buses'.

The definition of a Low Carbon Emission Bus is:

'A bus that achieves more than 30% Well-To-Wheel greenhouse gas emissions savings compared to an equivalent Euro III diesel bus of similar passenger capacity.'

[1] DFT Transport and Environment Statistics, 2016
[2] Air Quality Action Plan for Nitrogen Dioxide in UK, Defra 2015

'Well-to-Wheel' (WTW) is a value that includes all the emissions involved in the process of extraction/creation, processing and use of a fuel in a vehicle to gauge the total carbon impact of that vehicle in operation. 'Well-to-Tank' (WTT) only includes all the emissions associated with a fuel up to the point that it enters a vehicle's fuel tank or energy storage device. 'Tank to Wheel' (TTW) covers the emissions associated with fuel combustion in the vehicle, i.e. from the tail-pipe.

Greenhouse Gas (GHG) emissions covered are: carbon dioxide, methane and nitrous oxide. All are considered as Carbon Dioxide equivalent (CO_2 eq) using a 100yr assessment of the global warming potential. (GWP)

The Low Carbon Vehicle Partnership and its members designed the accreditation scheme that has served to qualify different LCEBs for Government funding – the LCEB Accreditation Scheme. The procedure for testing and accrediting LCEBs was based upon previous work by Transport for London to create an approval process encompassing a whole vehicle emission test over a representative bus driving cycle. As of January 2016, the LCEB scheme has been superseded by the Low Emission Bus Accreditation Scheme, explained below.

The fiscal incentives introduced by the Government were aimed at kick-starting the LCEB market by lowering both the purchase and operational costs of new and innovative low carbon bus technologies. The two vehicle capital grant schemes were the Green Bus Fund and the Scottish Green Bus Fund. The Low Carbon Emission Bus Incentive was subsequently introduced in England and Scotland, to encourage a level playing field with the Bus Service Operators Grant (BSOG) rebate for conventional vehicles and help reduce running costs for bus operators adopting new technologies. (See section 1.5)

As a result of these incentive schemes there are presently 3,760 LCEBs in operation across England, Wales and Scotland covering six technologies and twenty bus models. The technologies and fuels adopted through these schemes are: hybrid, electric, plug-in hybrid, electrified ancillaries, biomethane and hydrogen fuel cell. A map showing the location of the different types of LCEB can be seen on LowCVP's Low Emission Bus website[3].

[3] http://www.lowcvp.org.uk/initiatives/leb/Home.htm

1 Introduction

1.4 Low Emission Buses (LEBs) Accreditation Scheme

In 2015 the Office of Low Emission Vehicles (OLEV) launched the Low Emission Bus Grant, a £30 million funding package to support the purchase of 'low emission buses' and accompanying infrastructure. The Low Emission Bus Scheme placed more emphasis on combining air pollution and greenhouse gas emissions reduction from buses and was designed to also encourage elements of zero emission running in city centres. The funding has been awarded to twelve local and regional transport authorities in England and Wales and will see the roll-out of 326 Low Emission Buses (LEB) between 2017-2020. Funding has been awarded to the following types of LEBs: electric, hybrid, hydrogen fuel cell and biomethane buses. In 2017, £11m was awarded to five local authorities to support the purchase 153 LEBs and supporting infrastructure. In February 2018, £40m was awarded to local authorities to support the clean-up of 2786 older diesel buses through retrofit technologies through the Clean Bus Technology Fund. A further £50m has been allocated for new buses for 2018-2021.

'A Low Emission Bus is a bus that achieves more than 15% WTW GHG emissions savings compared to an equivalent Euro V bus, and meets the Euro VI engine emissions standard or proven equivalent levels'

The LowCVP created the definition of a 'Low Emission Bus' and the Low Emission Bus Accreditation Scheme to accompany the Low Emission Bus Grant. The LEB accreditation scheme is the new approval processes for qualifying different low emission bus models for Government funding; both in England and Scotland.

The LEB accreditation procedure involves a whole-vehicle test to measure the Tank-to-Wheel GHG emissions (reported as CO2e) and energy consumption of the potential LEB, as well as NOx and Particulate Matter (PM) emissions (to determine compliance with Euro VI engine standard). A bus is placed on a chassis dynamometer and run over a series of simulations that replicate real world operating conditions for buses, with the exhaust emissions collected and analysed. The test uses the new LowCVP UK Bus Test Cycle, which incorporates the Millbrook London Transport Bus (MLTB) test cycle and a rural section to reflect rural driving conditions. Full details of the scheme and process can be found on the LowCVP Low Emission Bus website.

In order to calculate WTW GHG emissions, the WTT GHG emissions of the vehicle fuel are assessed either from established government databases (DEFRA) or through independent verification of the fuel production pathway. These CO2 figures are

then added to the Tank-to-Wheel GHG emissions measured during the independent vehicle test. The Well-to-Tank GHG emissions reflect a specific fuel production pathway. In the case of electricity, hydrogen, renewable diesel, hydrogen and biomethane there are potentially numerous production pathways. Evidence of the GHG emissions associated with the fuel pathway is required as part of the LEB accreditation process. The adoption of lower carbon fuels will reduce the overall WTW carbon footprint of a low emission bus. In the case of biofuels, tail-pipe CO2 emissions may be discounted as any CO2 expelled during the combustion of the fuel is cancelled out by the CO2 absorbed by the feedstock used to produce the fuel during growth.

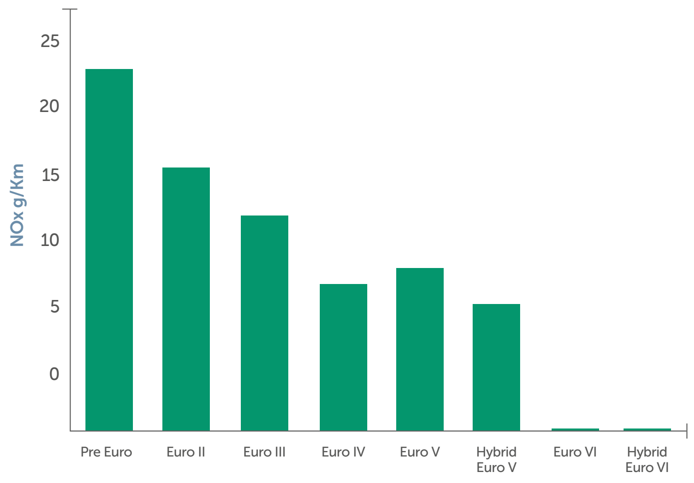
Once an LEB has passed the LEB accreditation procedure, a Low Emission Bus Certificate is given to the vehicle manufacturer for the particular bus model. The certificate provides air pollution and GHG emissions data pertaining to the LEB. Key information shown on the certificate is: Tailpipe emissions, WTW GHG emissions, WTW GHG emissions saving compared to a Euro V bus, fuel and/or electricity consumption and, where applicable, the electric range. The LEB certificates of bus models that have been approved under the LEB accreditation scheme are presented on LowCVP's Low Emission Bus website. The information is also provided in this guide under each technology chapter to enable bus operators and local authorities to have robust evidence on the performance of LEBs.

1.5 Air pollution emission reduction and Euro VI diesel buses

Euro VI is the latest engine emission legislation for heavy-duty vehicles sold within the European Union. Since 1993, when the 'Euro I' legislation was introduced for trucks and buses, the European Commission has regulated the amount of pollutants emitted from the tail-pipe of diesel engines. In particular, the Commission identified two key constituents within the exhaust stream – Oxides of Nitrogen (NOx) and Particulate Matter (PM) which needed to be controlled and reduced.

As a result, over the past 20 years, European engine makers have invested heavily in developing new technology that has seen the levels of NOx and PM (as well as other elements such as unburnt hydrocarbons) in the exhaust of all new diesel engine trucks and buses falling dramatically.

Diagram 1: In Service NOx Emissions (g/km) from TfL Buses



Source: independent test data for double decker bus on London 159 test route

From Euro V to Euro VI tail-pipe NOx emissions for diesel buses have reduced by over 75% primarily due to the use of sophisticated exhaust emission after treatment technologies - selective catalytic reduction (SCR) and exhaust gas recirculation (EGR). Particulate matter emissions have lowered by 66% primarily through the use of diesel oxidation catalysts and particle traps. The introduction of the Euro VI regulation in 2014 has seen an improvement in the way truck and bus engines are type approved via the new 'World Heavy Duty Transient Cycle'. This new cycle has been designed to more closely reflect what an engine does during real-world driving conditions. Euro VI vehicles are also equipped with more advanced on-board diagnostic equipment. Diagram 1 shows independent vehicle emission testing commissioned by Transport for London for different Euro standard buses over a representative drive cycle (MLTB). The chart reveals a significant reduction in NOx emissions is being achieved by Euro VI diesel and hybrid buses – measuring below 0.5g/km.

1.6 Fiscal incentives for low emission buses

A number of Government fiscal incentives exist that offer further cost savings to bus operators. These tax incentives and subsides vary for different low emission fuels and technologies

Bus Service Operators Grant Rebate
The Bus Service Operators Grant (BSOG) is a grant paid to operators of eligible bus services and community transport organisations to help them recover some fuel duty costs. BSOG is only paid on public routes with bus stops. The BSOG rebate scheme is different in England and Scotland.

Table 1: BSOG Rates in England and Scotland

BSOG Rates - England	BSOG Rates – Scotland
The amount each bus operator receives is based on their annual fuel consumption.	The amount each bus operator receives is based on eligible kilometre run on local bus services and the total volume of fuel used
Diesel - 34.57 pence per litre **Biodiesel** - 34.57 pence per litre **Biomethane** - 18.88 pence per kilo	**Diesel** - 14.4 pence per kilometre **Biodiesel** - 17 pence per kilometre - Only mixes of B15 or above are eligible with rates calculated on a pro-rata basis. **Biomethane** – no declared rate but will support should operators wish to run gas buses

Bus Services Support Grant
The BSSG is the bus operator diesel rebate scheme in Wales. Funding is provided to five lead local authorities throughout Wales at a level to each lead as agreed by all local authorities from the total allocation available to provide:

- Direct supported bus services secured through their own procurement mechanisms;
- A payment per kilometre made to operators for each live commercial kilometre operated through commercially registered bus services;

It is up to the local authority to determine the level of funding provided per litre commercial kilometre operated based upon the size of vehicle that is used. The figure will generally range between 8p and 13p, but not consistent across all authorities.

Low Carbon Emission Bus Incentive
New buses that have been accredited under the Low Carbon Emission Bus Accreditation Scheme, and the Low Emission Bus Accreditation Scheme, are eligible for the Low Carbon Emission Bus BSOG Incentive. The LCEB incentive is different in England and Scotland; it is not available in Wales.

- LCEB Incentive England - 6 pence/kilometre
- LCEB Incentive Scotland - 10.1 pence/kilometre

The Department for Transport and Transport Scotland are currently reviewing BSOG and the LCEB incentive. The structure of both schemes is expected to be reformed to encourage greenhouse gas savings and more zero emission mileage.

1 Introduction

Fuel Taxation

Fuel duty discounts and exemptions apply to certain types of low emission buses. Electricity and hydrogen are exempt from fuel duty. Fuel duty for biomethane (and fossil) gas is 24.9p/kg compared to 57.9p/l for diesel. This price differential compared to diesel is frozen until 2024.

1.7 Purchasing low emission buses – what to consider?

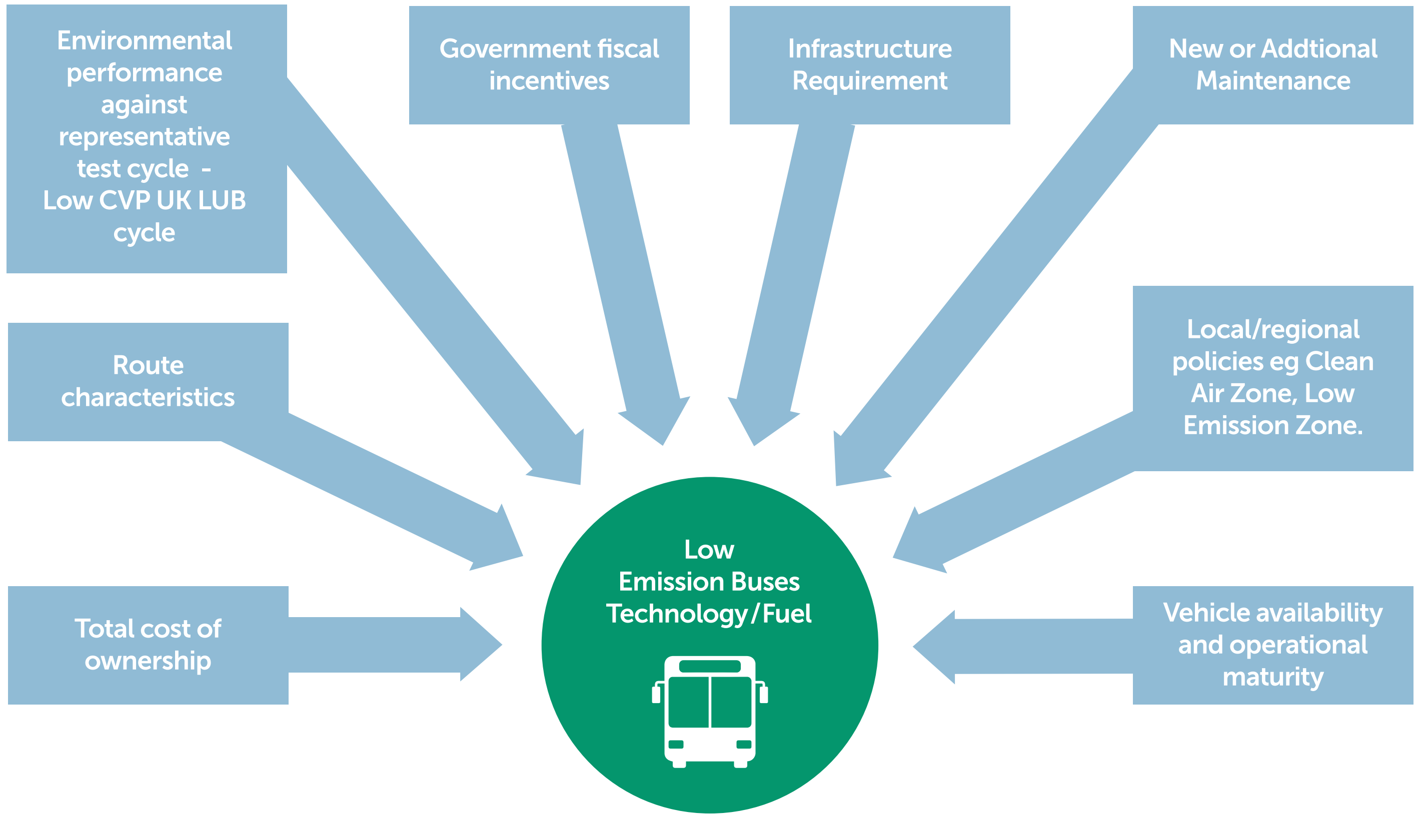
There are a range of factors that should to be taken into account when choosing to purchase a particular type of low emission bus technology. Diagram 2 highlights the most essential parameters. This guide is intended to equip bus operators and local authorities with relevant information to aid purchasing decisions and encourage the most appropriate low emission bus for a particular route and application. Consideration of local policies such as Clean Air Zones or Low Emission Zones, which specify emission performance standards, should also be taken into account in the fleet renewal process. .

There are multiple stakeholders involved in establishing and operating a low emission bus fleet. These can vary depending on the technology chosen. Stakeholder include bus manufacturer, bus operator, local planning authority, local transport authority, infrastructure supplier, fuel supplier, local gas or electricity network operator and technology provider, On-going partnership work with the local authority and contractors will be beneficial in ensuring the effective and successful operation of a low emission bus fleet. Bus operators should identify relevant partners early on in the procurement process and ensure advice is obtained on low emission buses, and where relevant, infrastructure options.

Table 2: A summary of fiscal incentives for different types of low emission bus

Technology/Fuel	Government Fiscal Incentives
Electric	LCEB incentive England and Scotland, requires LEB accreditation. No fuel duty on electricity.
Hybrid	LCEB incentive England and Scotland, requires LEB accreditation. BSOG payment for diesel England and Scotland, possibly Wales.
Plug-in Hybrid	LCEB incentive, requires LEB accreditation. BSOG payment for diesel England and Scotland, possibly Wales. No fuel duty on electricity.
Hydrogen fuel cell	LCEB incentive, requires LEB accreditation. No fuel duty on hydrogen.
Biomethane	BSOG payment for biomethane England and Scotland. LCEB incentive, requires LEB accreditation. Reduced fuel duty.
Biodiesel	BSOG Biodiesel Incentive in Scotland. BSOG payment of diesel England.
Electrified Ancillaries	LCEB incentive England, requires LEB accreditation. BSOG payment for diesel England and Scotland.

Diagram 2 - Factors to Consider When Choosing Low Emission Bus Technologies and Fuels



2 Electric Buses

2.1 Vehicle technology overview

Electric buses operate using an electric motor powered by a battery for propulsion rather than a diesel internal combustion engine. Electricity from the grid is used to recharge the battery, with various strategies in existence for recharging. Electric buses are designed with regenerative braking, enabling a proportion of the energy that would otherwise have been lost when the vehicle is decelerating to be recovered back to the batteries and stored to power the vehicle. Electric buses are ideally suited for city centre routes due to their electric operating capabilities and zero tail-pipe emission operation. Automotive manufacturers supplying electric buses are Optare, Wrightbus, Volvo, BYD-ADL and Irizar.

The operating range of an electric bus is influenced by its battery capacity and charging strategy. Electric bus manufacturers choose battery capacities that provide a compromise between range and passenger capacity (weight). Battery capacities currently vary from 76-340 kWh. The electric range of current electric buses vary between from 30-300km. The range of an electric bus will be influenced by route topography, in particular hills, and ancillaries such as heating and cooling systems, as well as driving style. Manufacturers are able to provide predictions of the energy consumption and any cell deterioration rate for their batteries so that their suitability for a particular route operation can be assessed throughout the life of the vehicle. Electric buses can be fitted with an on-board data logger to enable monitoring of electricity consumption and range.

Electric bus battery technology has focused on lithium ion chemistry such as lithium iron phosphate. Advancement in battery chemistry is expected to show battery capacity increasing with a concurrent reduction in size. A recent evolution in battery chemistry has been the advent of lithium titanate batteries in the automotive sector. Manufacturers currently propose a battery 'life' of seven years and over for an electric bus.

Currently the UK legal weight limit for 2 axle buses is 18000kg, but this will soon be relaxed to 19500kg for alternative fuel vehicles. This will make large battery electric buses much more practical, with little or no loss of passenger capacity compared to diesel buses, except on routes with local weight limits (such as weight limited bridges). In the meantime, the Department for Transport has granted special dispensation for some electric bus trials to exceed the current 18000kg road limit.

2.2 Environmental credentials

Electric buses produce zero tail-pipe air pollution emissions. If diesel powered cabin heaters are fitted these can be a source of air pollution and CO2 emissions on electric buses. Consideration could be given to electric heating; however this may result in a reduction in electric range.

Some manufacturers are equipping electric buses with diesel heaters that can achieve very low emissions levels and can be powered by renewable diesel (biodiesel/HVO). This will take into account the carbon footprint of electricity production, transmission and the efficiency of the charging infrastructure. The WTW GHG emission savings for electric buses using current UK grid electricity, certified under the LEB accreditation, range from 62% to 68% compared to an equivalent Euro V diesel bus.

In the UK electricity is produced using both fossil fuels and renewable energy. Operators may be able to select a 'green' tariff from their electricity supplier to ensure maximum use of low carbon energy sources or if possible generate renewable electricity on site.

Electric buses are quiet and very smooth in operation, offering benefits to noise reduction in city centres and passenger comfort.

2.3 Charging infrastructure overview

There are three types infrastructure for charging electric buses: plug-in systems and 'opportunity charging' covering inductive charging and conductive pantograph charging. Bus manufacturers have chosen different different infrastructure strategies.

2.3.1 Connecting to the electricity supply

Plug-In systems

Plug-in charging is simple, cost effective and efficient and is one of the most common choices for charging an electric bus overnight or during a daytime layover. This can take place using a slow (15kw) charging unit, with charging time being up to 10 hours. Slow chargers are typically integrated on-board the bus.

Stages of plug-in charging unit installation

- **Stage 1** — Site survey by infrastructure company engineer includes looking at power supply on site and determining the availability of three-phase capacity.
- **Stage 2** — If power capacity is insffucient either a power supply upgrade or a new power supply from DNO will be suggested. New connection can take 6-12 months. Energy supplier is responsible for meter installation - takes a few weeks.
- **Stage 3** — Civil work such as trenching, ducting, trunking are usually performed by the same team which does charge point installation.
- **Stage 4** — Charge point installation. The IET COP and BS7671 guidelines are followed, with the installer generating a test certificate provided to infrastructure provider and operator.
- **Stage 5** — Infrastrucuture provider sends commissioning engineer to install a SIM card and run a test charge with the electric bus.

Fast (22kw) and rapid (50kw) charging units are off-board. These connect to a three-phase power supply and facilitate quicker charge times between 1.5-4 hours. Most plug-in buses must perform a balance charge overnight every few days to ensure battery stability and durability. Plug-in charger suppliers include APT (EVolt), Siemens and ABB. These are commonly used for charging Optare electric buses at the bus depot and Park and Ride sites. Examples of fleet operators include Arriva in London, First Bus in York and Nottingham City Council.

BYD provides 80 kW chargers (using two charging plugs, option to use a single plug which gives a rate of 40kW). These rapid chargers enable the high capacity bus to be charged up in four hours after a full day's operation and this can be completed within off-peak hours. Go-Ahead in London and Nottingham City Council operate BYD buses and charging systems.

Inductive charging

Inductive charging uses coils installed under the road surface that can transfer energy to matching coils fitted beneath the floor of the bus. On arrival, the driver has to position the vehicle over the roadway coils and then activate the charging system. There is no direct electrical contact with the charging station – energy is transmitted through the air gap via magnetic fields. Some systems are capable of energy transfer to moving vehicles, but most practical implementations are installed at end-of-route sites where the bus is stationary. Power capabilities of up to 200kW are possible with currently available equipment. This type of 'opportunity' charging can take less than ten minutes to "top up" the batteries.

Since 2012 Arriva has been operating eight Wrightbus Streetlite electric buses on Route 7 in Milton Keynes as part of the UK's first wireless charging electric bus project. The project is a collaboration between Mitsui subsidiary eFleet Integrated Service Ltd, Milton Keynes Council, Arriva, Wrightbus Limited, inductive charging supplier Conductix-Wampfler and Western Power Distribution. The charging coils are positioned at three locations (Wolverton, Bletchley and Central Milton Keynes) to enable charging during the day whilst on the route. It takes ten minutes parked over a coil to replenish two thirds of the energy consumed by the bus's route during the daytime. The buses are charged in the layover time at the ends of the route using inductive chargers and overnight in the depot using conventional plug-in charging.

2 Electric Buses

Conductive Pantograph Charging

Conductive pantograph systems use roof-mounted equipment to make an electrical connection between the bus and an overhead power supply. The equipment can be installed at the ends of the route or at intermediate bus stops. An extendable pantograph – similar to those used on some electric trains – is fitted either to the roof of the bus, or to the overhead mast. When the bus arrives the pantograph is extended to make electrical contact; the process is automated and provides a very efficient power transfer. Pantograph systems are capable of very high power transfer. Power capacity of the charger is typically 150-300kw with a charge time of 5-6 minutes. Pantograph charging units can be installed indoors or outdoors providing more flexibility in terms of charging sites in cities. ABB and Siemens are supplying conductive pantograph charging systems and working in partnership with Volvo internationally.

European bus manufacturers Irizar, Solaris, VDL and Volvo have agreed to ensure the interoperability of electric buses with charging infrastructure provided by ABB, Heliox and Siemens. The objective is to ensure an open interface between electric buses and charging infrastructure. This will facilitate the transition to electric public transport in cities to ensure reliability and compatibility across different bus brands and charging systems.

There are currently no electric bus fleets using pantograph charging in the UK, however several cities in Europe are exploiting this type of infrastructure. One example is Route 55 in Gothenburg, where bus company Keolis operate three electric and seven plug-in hybrid Volvo buses charged by pantograph. The route was funded by Volvo, Energimyndigheten, Västra Götalandsregionen, Västtrafik, Chalmers and the City of Gothenburg. Recharging is carried out using pantographs, which are located at Campus Lindholmen and Campus Chalmers. The pantograph technology type was selected due to the fact that opportunity charging is a cost effective solution and assessed by the stakeholders to be the future solution for highly demanding and constant-operation city bus traffic.

The key objective of the project was the implementation of a complete electro-mobility solution in an urban environment which involves electric buses, charging stations, outdoor and indoor bus stops and infotainment solutions. The project was started in April 2013. The commercial operation started June 15th 2015 and will continue until June 2018. Electricity phase two is now in scoping and will run from 2018 to 2021.

Early results from the project reveal the energy consumption of the electric bus to be 1.1kWh/km. The energy consumption of a Euro VI diesel bus on this route is 0.41 litres/km. Route 55 is a particularly high intensity route. The energy saving is approximately 73% in this case. Feedback from passengers regarding the new electric routes is very positive. 73% say they are very pleased with their trip compared to 57% for ordinary bus lines.

2.3.2 Installing and operating charging infrastructure

When planning an electric bus deployment, it is important to consider the charging strategy at an early stage. Depending on the route and the type of bus, charging may be required once, twice or many times per day and may involve several charging units.

The large energy capacity of batteries on electric buses means that charging power requirements are higher than for cars. Practical deployments of electric buses require high power charging – power levels of 40-100kW per bus are typical.

The power supply capacity is an important factor to consider when electric buses are charged using high power charging stations. This can be particularly challenging when many buses need to be charged simultaneously at one location – for example, a fleet of electric buses will all require charging overnight at the same bus garage. The peak power requirement may exceed the power capacity of a typical local electricity distribution network(DNO). It is important to discuss power availability with local DNO at the earliest possible stage of introducing an electric bus fleet. The site survey undertaken by charging infrastructure providers will assist in determining whether the local supply network will need upgrading. The cost of this work will vary enormously according to local circumstances. Upgrading work can vary from simply connecting to a phase 3 power supply to more complex work involving installing a new electricity substation, trenching work to lay long cables and road closures.

An example of the upgrading work undertaken by a bus operator is the Go-Ahead electric bus depot in central London. The bus depot runs 46 BYD buses and using 43 plug-in BYD rapid chargers. A power supply of 2MW was required to accommodate rapid charging of this large electric bus fleet, this high power demand required upgrading of the local electricity network. This involved

the installation of two new substations carried out by infrastructure partner Scottish and Southern Energy.

Bus fleet operators should take into consideration ways in which the peak demand can be reduced and explore options for load management. Usually it will not be necessary to charge all the buses simultaneously at full power – a bus returning to the garage at, say, 9.00pm and plugged in immediately may be fully charged before the last bus of the day returns to the garage. Some buses will arrive back with only partially depleted batteries, reducing their required charging time. Careful planning and analysis could identify opportunities to reduce the peak power demand by 50% or more.

Factors To Consider When Upgrading Local Electricity Network.

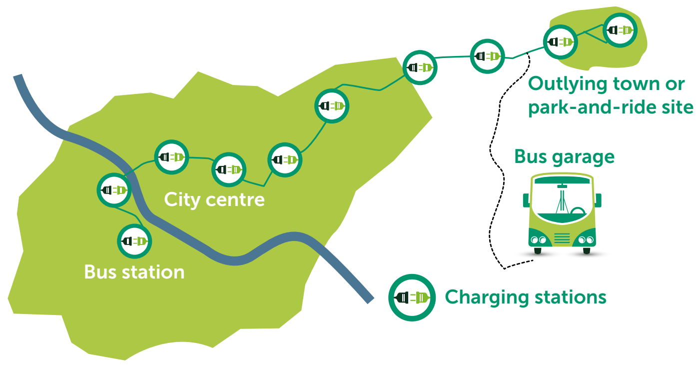
- Distance to the nearest sub-station, cabling may need to be upgraded
- Capacity of the sub-station, additional transformers may need to be installed
- Whether the sub-station itself has a sufficient power supply to support the increased output load
- Timeframe for upgrading work and new connection, preparing legal contracts and negotiations with DNO – lead times can be lengthy

2.3.3 Charging strategies for electric buses

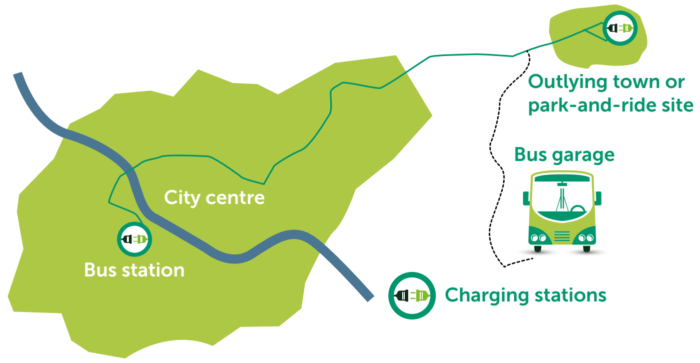
Depending on the route and the electric bus battery capacity, a spectrum of different operating strategies can be considered. The operational strategy needs to be planned so that there is some reserve battery capacity on every bus. Outlined below are scenarios for 'on route' and 'overnight charging'. Manufacturers will be able to model bus route profiles to determine the suitability of battery capacity and charging requirements.

On route charging

Buses get short top-up charges when they pause at bus stops or the end terminuses.
This minimises the battery capacity required on the bus, however it requires investment in infrastructure that is dedicated to a single route. Charging stations need high power capability such as inductive or pantograph. Opportunity charging can offer 24-hour operation of electric buses.



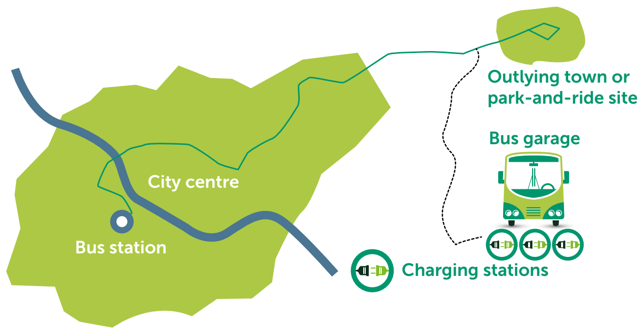
Buses get a partial charge at the end of the route.
This takes advantage of the dwell time that is typically scheduled at the end of the route to allow partial top-up charging. It may be combined with a longer period of overnight charging. The bus should have sufficient battery capacity to allow a few charging opportunities to be missed, for example as a result of traffic delays, but the capacity can still be much smaller than an 'all-day' electric bus. Attention needs to be given to the scheduling of the bus timetable and charging times; extra time may need to be built into the schedule to accommodate charging.



Overnight charging

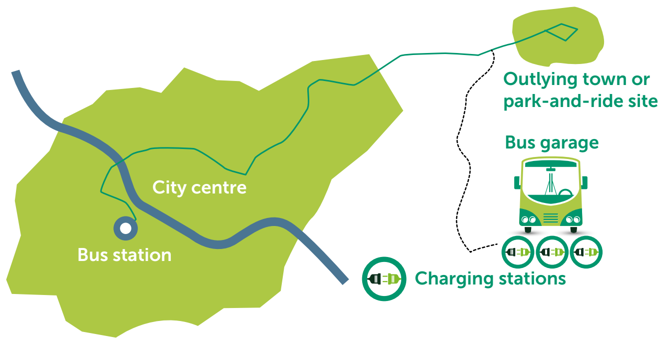
Buses are charged overnight at the depot, returning for a top-up charge in the middle of the day.
This may require somewhat greater battery capacity than end-of-route charging but avoids the need for installing charging equipment in already congested and space-constrained bus stands. The strategy is very attractive on routes where the mid-day vehicle requirements are lower than the morning and evening peak requirements, creating a natural charging opportunity.
In cases where the bus garage is a long way from the bus route, rather than driving back to the bus garage in the middle of the day, it may be preferable to install some additional charging stations at a bus stand on or close to the bus route.

2 Electric Buses



The layover charging approach can also be used on routes where the number of buses required for service is steady through the day. In this case there needs to be sufficient additional buses available so that, for each bus that is taken out of service for charging, a freshly charged replacement is available. This can allow an intensive service to be operated using buses with smaller battery capacities than would otherwise be the case.

Buses are charged overnight at the depot, capable of completing a full day's duty.
This requires buses with a large battery capacity but, for many routes, electric buses can operate throughout the entire daily schedule with no changes from a 'diesel timetable'.
Overnight charging depends on the vehicle type but four hours is typical, allowing operation up to theoretically twenty hours per day. Installing the charging stations at the bus garage is often easier than at bus stations, however, for large fleet implementation the provision of sufficient electrical power to charge many buses simultaneously can be challenging.



2.4 Factors to consider when purchasing and operating electric buses

Total cost of ownership is a key factor to be assessed when considering purchasing an electric bus fleet. Parameters that need to be reviewed include: electric bus annual mileage, electricity consumption, ownership period, capital cost of the electric bus, Government financial incentives for supporting vehicle capital and operational costs, capital and installation cost of infrastructure, maintenance and electricity costs, requirement for spare diesel or electric buses to cover electric bus downtime.

Electric buses currently have a much higher capital cost than a conventional diesel bus and the price of electric charging infrastructure can vary broadly, both in terms of type of charging system deployed and installation. The site survey for electric bus charging infrastructure will provide more detailed information to inform the cost of installation works. Requirements for local electricity supply upgrade will increase the cost of installation. Financial savings can be gained operating electric buses through lower fuel costs and some degree of lower maintenance costs. The cost of replacing more expensive electrical components, such as the lithium ion battery, will need to be factored in once the vehicle is out of warranty.

A summary of the practical and financial factors that should be considered when purchasing and operating an electric bus fleet are outlined below.

Table 3: Key factors to consider when purchasing and operating electric buses

Operation	Charging Infrastructure	Maintenance
• Route length, topography & electric range • Passenger capacity • Operation day length of the bus • Flexibility of operational base/term of contract • Depot space – to facilitate charging at night • Driver training to optimise energy efficiency and range • Fuel cost savings • Awareness raising - integration of e-buses across the whole organisation • Requirement for additional buses to cover e-bus downtime	• Number, type of charger & locations • Peak vehicle requirement • Availability of 3-phase power • Power capacity at charging site, possible upgrading of local power supply • Managing peak demand • Optimising route scheduling with bus charging • Maintenance contract for infrastructure and telemetry	• Lower frequency in brake pad replacement, no requirement for engine oil filter changes • Components likely to require replacement: lithium battery, traction motor and power electrics. • Manufacturers typically offer five-year warranty periods. Once out of warranty there will be a cost for extension. • Tailored packages to support the vehicle life are available

2.5 Electric bus market and models

There are 175 electric buses operating across eight cities in the UK, with the first electric buses coming into service in 2012. The largest electric bus fleets are run by Nottingham City Council, Go-Ahead Group, Arriva and First Bus. Cities operating the highest number of electric buses are London, Nottingham and York.
The electric bus market has been dominated by midi and single decker models, however in 2016 Metroline, on behalf of Transport for London, commenced trialling five double decker electric buses supplied by BYD.

The OLEV LEB Grant Scheme has awarded funding for 86 electric buses with accompanying recharging infrastructure. The winners are Nottinghamshire County Council (2), Transport for London (34), Merseyside Travel (12), Transdev Blazefield (8), West Midlands Travel Limited (19) and Milton Keynes Borough Transport (11).

2.5.1 LEB accredited electric bus models

Electric bus models that have been accredited under the Low Emission Bus Accreditation Scheme are shown in Table 4 below . Performance data has been obtained from the vehicle's LEB certificate[4].

2.5.2 LCEB accredited electric buses

The following electric bus models are currently LCEB accredited.

Manufacturer	Model
Irizar	I2
Wrightbus	Streetlite EV
Optare	Versa EV, Metrocity EV
BYD	K9 (eBus)

Table 4: LEB accredited electric bus models

	Electric Bus Models	Energy Consumption and Electric Range	WTW GHG and Air Pollution Emissions
	**Volvo 7900 Electric** Single Decker Length: 12m Passenger capacity: 83 GVW: 18,000 kg	84.7 kWh/100km Up to 39.3 km	WTW GHG Emissions: 447.3 gCO2e /km 5.3 gCO2e/passenger km WTW GHG savings: 65% Zero emission
	**Optare Solo EV** Single Decker Length: 9.2-9.9m Passenger capacity: 55 GVW: 11,300 kg	51.0 kWh/100 Up to 208km	WTW GHG Emissions: 307 gCO2e/km 5.6 gCO2e/passenger km WTW GHG savings: 69% Zero emission
	**BYD eBus** Single Decker Length: 12m Passenger capacity: 70 GVW: 18,700 kg	83.1 kWh/100km Up to 452.7 km	WTW GHG Emissions: 429.6 gCO2e/km 6.1 gCO2e/passenger km WTW GHG savings: 62% Zero emission
	**BYD-ADL Enviro200EV** Single Decker Length: 12m Passenger Capacity: 90 GVW: 18,600 kg	83.1 kWh/100km Up to 425.1 km	WTW GHG Emissions: 429.6 gCO2e/km 4.8 gCO2 e/passenger km WTW GHG Savings: 68% Zero emission

Notes: Electricity consumption and electric range will vary under real-world driving conditions, charging via UK electricity grid. The BYD eBus and BYD-ADL Enviro 200EV have received a GVW dispensation from the Government.

[4] http://www.lowcvp.org.uk/initiatives/leb/LEBCertificates.htm

2 Electric Buses

2.6 Electric bus fleet case studies

Nottingham City Council
Nottingham City Council operates 45 Optare Solo and Versa electric buses on city routes such as Medilink, a fifteen-mile round trip that links the Park and Ride to the local hospitals and the tram network. Improving local air quality and reducing road transport CO2 emissions were the Council's main reasons for choosing electric buses.

The Optare electric buses have a maximum range of 95 miles, with drivers achieving up to 80 miles in real driving. Driver training has played an important role in optimising electric bus range and improving the efficiency of their electric bus fleet. Monitoring the bus's range, electricity consumption and the charging in real-time has been important and only recently has an effective telemetry system been found to do this in the ViriCity system. Nottingham City Council has found their electric buses to be reliable and cost effective. The Council identifies that running costs are significantly cheaper, around half of the cost of a diesel bus.

In addition, Nottingham has experienced lower servicing for the electric buses and an improvement in the reliability over the last few years. The Optare electric bus lithium batteries have 240 individual cells. Nottingham has only been required to change four battery cells in their whole electric bus fleet.

The Council has given much attention to route planning and scheduling to accommodate electric bus charging and maintain service performance. In order to accommodate electric bus downtime additional electric buses have been purchased, one spare electric is required for every two on duty. Embedding awareness about electric buses across their organisation has been pivotal in effectively integrating electric buses into their fleet. The Green Bus Fund was critical in Nottingham's decision to invest in electric buses and helped cover a large proportion of the £100,000 or so premium of electric buses over diesel vehicles.

Nottingham City Council has recently ordered 13 BYD electric buses supported by Green Bus Fund 4, the vehicles will come into service towards the end of 2016.

The Council has installed both slow and rapid chargers at four locations in Nottingham. Nottingham City Council has funded the purchase and installation of the charging units via several routes - the 'Plugged-in Places' Midlands grant, the Local Transport Strategy and revenue from the Nottingham's Workplace Parking Levy. One of the main challenges experienced by Nottingham City Council has been requiring extra capacity of the local electricity network to cope with the power demand of the charging infrastructure. Expensive and lengthy upgrading work was required at several locations. Examples of the infrastructure costs of Nottingham's electric bus infrastructure are as follows:

— Queen's Drive has 24 slow chargers and 3 rapid chargers supplied by Evolt. The purchase and installation cost for the slow chargers was £121,000 and the rapid chargers - £176,000. The cost included a new 440kva sub required to increase the electricity capacity of this site. The rapid chargers cost approximately £18,000.

— Broad Marsh Bus Station has one rapid charger and 19 slow chargers. The first 13 trickle chargers that were installed cost £30,000 covering capital and installation costs. In order to accommodate the rapid charging unit, costing £18,000, a new 1 kva grid connection was required; this cost £7,145. Two years later this was upgraded to 270kva that cost £4,000, this provided sufficient capacity to install six more slow charge points totalling £16,840.

Go-Ahead London
By the end of 2016, the Go-Ahead Waterloo Bus Garage in London will have the largest fleet of electric buses to run out of a single depot in Europe following the introduction of 46 BYD-ADL Enviro 200 buses (as part of a fleet of 51). This builds on a successful trial that saw Go-Ahead operate two BYD electric buses on routes 507 and 521 since December 2013. The buses are able to complete 16 hours of service consistently with no charging required during the day .Overnight charging is utilised using an 80kw AC charger per bus, which costs a fraction of a DC rapid charger.

3 Hybrid Buses

3.1 Vehicle technology overview

A hybrid bus typically retains a diesel engine but uses additional equipment to drive the bus when needed. There are many types of hybrid system currently in operation. On a conventional bus, when the driver brakes, the kinetic energy of the moving bus is dissipated as heat in the brakes or retarder. The bus slows down, but the energy is lost. On a hybrid bus when the driver brakes, the hybrid system captures kinetic energy and stores for use later when it is required for propulsion. The next time the bus accelerates, the stored energy is fed back to the driving wheels, reducing the load on the engine thereby saving fuel and reducing CO2 emissions. The fuel efficiency of a hybrid bus is influenced by the route characteristics such as topography, in particular hills, and speed. City and suburban routes, characterised by slow speed and frequent start-stop traffic, favour hybrid technology.

Provided there is sufficient energy storage, and a powerful enough motor, hybrid buses can provide a modest amount of zero-emissions driving. Typically, this is limited to low speed driving when approaching or departing from bus stops.

A number of manufacturers now integrate stop-start technology as a design feature in hybrid buses. Switching off the engine when a bus is stationary provides an opportunity for fuel and emissions savings, this can be achieved via automatic engine stop-start systems.

Lithium batteries are the most established form of energy storage in hybrid buses, but more recent developments have included super-capacitors, flywheels and hydraulic accumulators. Flywheels are the most recent alternative energy storage devices introduced into hybrid buses in the UK.

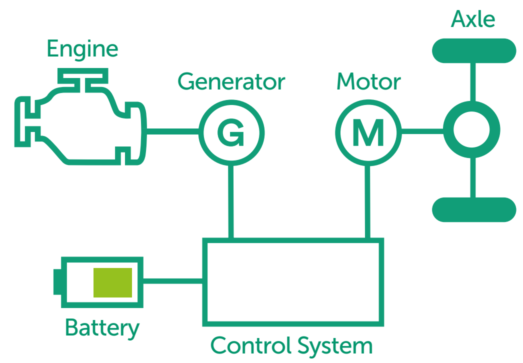
Series and Parallel Hybrids
Hybrids are classified as either 'series' or 'parallel' exploiting different drivetrain architectures.

In a series hybrid, there is no mechanical drive between the engine and the axle, the vehicle is exclusively propelled by the electric motor. Typically, the engine is connected to a generator that can either charge the battery or provide power to a traction motor. The control system determines the most efficient use of energy at any time. The series architecture allows complete freedom for the control system to manage energy in the most efficient way. The ADL Enviro 400 using the BAE hybrid system and the Wrightbus New Routemaster using the Siemens hybrid system are examples of series hybrids.

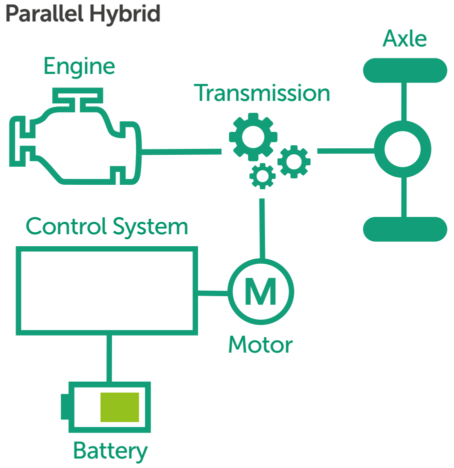
In a parallel hybrid, a mechanical drive between the engine and the axle is retained, with the hybrid equipment supplementing rather than replacing the mechanical drive. One advantage of parallel hybrids is that they can use mechanical transmission alone. In the event of electrical failure, the vehicle can still operate using the diesel engine; this is not possible with a series hybrid. Through the process of regenerative braking, energy lost to braking is recovered and utilised to charge the battery. The Volvo 7900H and B5LH, fitted with the Volvo hybrid system, are examples of parallel hybrids.

Several manufacturers are starting to offer lower voltage hybrid assist systems, utilising smaller energy stores and downsized drivetrain componentry based on similar architecture to the 48V systems which are coming through in the passenger car sector.

Series Hybrid



Electric Parallel Hybrid



Current models include the Wrightbus Streetlite H.E.V and ADL E400 48V Hybrid.

Flywheel hybrids are currently being trialled by bus manufacturers. The use of a flywheel enables the parallel hybrid systems to be scaled down to provide just a torque-assist capability. Overall fuel savings are lower than conventional hybrids and there is little or no zero-emission driving capability.

3 Hybrid Buses

3.2 Environmental credentials

Euro VI hybrids produce very low PM and NOx emissions. There will be opportunities for short periods of zero emission operation on city routes when hybrid buses accelerate from stationary and are traveling at low speeds. Some hybrids can reach 1km in electric-only operation. Engine stop-start systems will contribute to reducing air pollution emissions.

Diesel heaters, when fitted, are potentially a source of uncontrolled air pollution emissions on hybrid buses. Some manufacturers are equipping hybrids with diesel heaters that can achieve very low emissions levels and can be powered by renewable diesel (biodiesel/HVO).

Hybrid buses certified under the LEB accreditation achieve between 24% and 37% WTW GHG emission savings compared to an equivalent Euro V bus. Well-to-Tank GHG emissions of hybrid buses relate to diesel production and distribution. The adoption of renewable diesel will lower upstream GHG emissions. Tail-pipe CO_2 emissions are highly influenced by the fuel efficiency of hybrid buses and reduce significantly during short distances in electric operation.

Hybrids are quieter in operation than conventional diesel buses, advantageous for both the driver and passengers.

3.3 What to consider when purchasing and operating hybrid buses

Total cost of ownership is a key factor to be assessed when considering purchasing a hybrid fleet. Parameters that need to be reviewed include: hybrid bus annual mileage, fuel consumption, ownership period, capital cost of the hybrid bus, Government financial incentives for supporting vehicle capital and operational costs, maintenance and price of diesel.
Hybrid buses currently have a higher capital cost than a conventional diesel bus. This can vary in magnitude depending on the hybrid architecture. Financial savings can be gained in operating hybrid buses through lower fuel costs due to improved fuel economy. Hybrids that are designed with reduced-sized hybrid drivetrains, smaller batteries or flywheel for energy storage can be lower in cost, although as previously mentioned may not return the same fuel savings. The bus route profile and driver behaviour can influence fuel savings.

The operating cost of hybrid buses will also include the purchase of urea (Adblue) for the SCR exhaust emissions after-treatment system. The cost of replacing more expensive electrical components will need to be factored in once the vehicle is out of warranty. In-house maintenance training is likely to be required for staff due to high voltage electrics used in hybrid buses.

A summary of the practical and financial factors that should be considered when purchasing and operating hybrid buses are outlined below.

Table 5: Key factors to consider when purchasing and operating hybrid buses

Operation	Maintenance
Route characteristics Passenger capacity No refuelling infrastructure required Awareness raising - integration of hybrid buses across the whole organisation Driver training to optimise fuel efficiency Fuel cost savings - route dependent	Diesel engine maintenance coupled with exhaust after treatment - Ad Blue for SCR and cleaning particle filters. Hybrid components likely to require replacement – lithium battery, traction motor and power electronics. Manufacturers typically offer a five-year warranty period for hybrid buses. Once out of warranty there will be a cost for an extension. Tailored packages to support the vehicle life are available.

There are 2366 hybrids in operation across the UK with the first buses coming into service in 2008. Bus operators running the largest hybrid bus fleet include Stagecoach, Go-Ahead, First Bus, Arriva and Transport for Greater Manchester . London, Manchester and Oxford are the cities operating the highest numbers of hybrid buses. Hybrid buses are available as single and double decker models.

The OLEV LEB grant has funded 120 hybrid buses. The winners were Merseyside Travel (51), Kingston University (7), Sheffield City Region Combined Authority (44), West Midlands Travel Ltd (10) and West Yorkshire (8).

3.4.1 LEB Accredited hybrid buses

Hybrid bus models that have been accredited under the Low Emission Bus Accreditation Scheme are shown in Table 6. Performance data has been obtained from the vehicle's LEB certificate[5].

[5] http://www.lowcvp.org.uk/initiatives/leb/LEBCertificates.htm

Table 6: LEB accredited hybrid bus models

	Hybrid Bus Models	Fuel Consumption	WTW GHG and Air Pollution Emissions
	**Volvo 7900 Electric** Single Decker Length: 12m Passenger capacity: 80 GVW: 18,000 kg	24.1 l/100km	WTW GHG emissions: 824.1 gCO_2e /km 10.05 gCO_2e/passenger km WTW GHG Savings: 34% Achieves Euro VI
	**Volvo B5HL** Double Decker Length: 10.5m Passenger capacity: 90 GVW: 19,000kg	25.7 l/100km	WTW GHG emissions: 870 gCO_2e /km 9.2 gCO_2e/passenger km WTW GHG Savings: 37% Achieves Euro VI
	**Streetlite H.E.V.** Single Decker Length: 7.1- 10.6m Passenger capacity: 69 GVW: 13,408 kg	22.2 l/100km	WTW GHG emissions: 731.4 gCO_2e /km 10.6 gCO_2e/passenger km WTW GHG Savings: 35% Achieves Euro VI
	**Wrightbus Street - Deck H.E.V** Double Decker Length: 7.1- 10.6m Passenger capacity: 95 GVW: 18,000 kg	27.4 l/100km	WTW GHG emissions: 904.2 g CO_2e/km 9.52 g CO_2e/passenger km WTW GHG Savings: 35% Achieves Euro VI
	**ADL E400 48V Hybrid** Double Decker Length: 10.3-11.5m Passenger capacity: 99 GVW: 18,000 kg	31.8 l/100km	WTW GHG emissions: 1072.1 gCO_2e /km 10.8 gCO_2e/passenger km WTW GHG Savings: 24% Achieves Euro VI
	**ADL E200 48V Hybrid** Single Decker Length: 11.5m Passenger capacity: 72 GVW: 13200 kg	23.0 l/100km	WTW GHG emissions: 767.9 gCO_2e/km 10.6 gCO_2eq/passenger km WTW GHG savings: 34% Achieves Euro VI

Notes: Fuel consumption will vary under real-world driving conditions, WTW GHG savings compared to equivalent Euro V diesel bus.

3 Hybrid Buses

3.4.2 LCEB accredited hybrid buses

Currently available hybrid bus models that are LCEB accredited are:

Manufacturer	Model
ADL	Single Deck: Enviro 200H, 350H Double Deck: Enviro 400H, Electrocity 2 HEV
Wrightbus	Double Decker: NRM
Optare	Single Decker: Versa HEV, Solo HEV

3.5 Hybrid bus fleet case study

Lothian Buses based in Edinburgh has aligned the operation of their bus fleet local air quality targets and carbon reduction through the use of hybrids. Hybrids represent 11% of total of 721 buses, a mix of Euro V and VI double and single deckers. Lothian routes are all a mix of urban and suburban, running west to east and north to south of the city, with all passing through the city centre of Edinburgh. All hybrids run on routes that pass through six air quality management areas; six routes are pure hybrid operated. In order to help cover the cost premium of hybrid buses, c£90,000 for a double decker, Lothian has won funding from the Scottish Green Bus Fund. The company has also been eligible BSOG LCEB incentive for its hybrid bus fleet.

Lothian has purchased both series and parallel hybrids, supplied by ADL and Volvo, over the last five years. The organisation has a good working relationship with both OEMs resulting in successful maintenance of their hybrid fleet. This ensures that maintenance issues are resolved very quickly. Lothian has required battery changes on several of their hybrid buses after the five-year warranty. They have extended the warranty for another three years. Lothian has observed no difference in breakdown of newer and older vehicles but Euro VI has been performing better in terms of fuel savings.

Lothian has needed to undertake battery replacement in their older hybrids whilst under warranty. They are expecting the latest batteries to last another five years and have extended the warranty period.

Lothian has expressed very good performance of their hybrid fleet based on 600,000 miles/year. Euro VI Volvo provide close to 1km electric range. Lothian have achieved between 30-36% fuel savings from the operation of their Euro V hybrid buses compared to equivalent Euro V diesel buses. This has been achieved on a mixture of routes. Euro VI hybrid buses have shown greater fuel savings, for example the Volvo DD B5HL has achieved 40% fuel savings. The company has saved £1.4million in fuel costs since 2011 thanks to hybrid use. Hybrids are only operated on profit making routes, this enables the company to recoup the increased capital cost of the hybrid buses.

Lothian has set clear targets for tautological new bus procurement over the next five years, with environmental performance being a central component of their procurement strategy. All single deckers will be hybrids by 2020 and 100% of their fleet will be Euro V and above by 2020. Lothian's long-term vision is to introduce plug-in hybrids into their fleet.

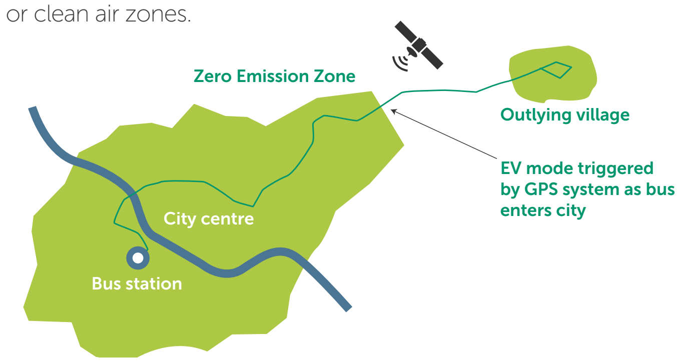
4 Plug-in Hybrid

4.1 Vehicle Technology

Hybrid buses that can additionally charge their batteries from external sources are known as plug-in hybrid buses. The speed and electric range depend on electric power capabilities and battery capacity. Provided that sufficient energy and power are available, a plug-in hybrid can provide emissions-free operation over parts or all of a bus route. This can give the zero emission benefits of an electric bus in the city centre combined with the range and flexibility of a diesel hybrid bus for sections of the route that are less emissions-sensitive. Plug-in hybrid buses can offer improved energy efficiency over conventional hybrids. They are designed with regenerative braking, enabling energy lost during decelerating to be recovered back to the batteries and stored to power the vehicle.

On sections of a bus route where the diesel engine is running, the battery can be replenished by the engine-driven generator while a combination of the engine and electric motor also propels the bus. The use of plug-in, inductive or conductive pantograph charging systems will reduce overall dependence on the diesel engine, but without making the bus fully dependent on charging stations. This flexibility makes the concept very versatile – 100% electric use may be possible all day on routes with charging stations at the ends of the route, but the same bus can be deployed on a standard diesel route with no charging infrastructure if needed. ADL and Volvo are the leading manufacturers offering plug-in hybrids but with very different zero emission ranges.

To get the best value from this technology, manufacturers control the electric (zero emission) mode using GPS known as 'geo-fencing' or 'Zone Management'. These are defined geographical zones where the bus automatically switches to EV mode on entering the zone. In some cases, these can also take into account time of day, so a route connecting a residential area to a city centre could deploy EV mode in the city during the day, but at night time EV mode would be activated in the residential area to reduce noise and emissions. Geo-fencing offers great opportunities on routes that experience poor air quality and are designated as low emission or clean air zones.



Plug-in hybrids can offer a useful stepping stone towards fully electric operations because they can utilise charging infrastructure where it is available but are not dependent on it. The buses can be deployed prior to introducing charging stations, yielding immediate benefits from their GPS-controlled zero-emissions capability. Plug-in hybrids suit city and suburban routes.

4.2 Environmental credentials

The latest plug-in hybrid buses achieve Euro VI and when operating as a conventional hybrid bus producing very low NOx and PM emissions. During operation in all-electric mode plug-in hybrids work like an electric bus and emit zero tail-pipe emissions. The longer the vehicle can operate in electric mode the lower the overall emission impacts. Diesel heaters, when fitted, are a source of uncontrolled air pollution emissions on plug-in hybrid buses. Some manufacturers are equipping hybrid buses with diesel heaters that are equivalent to Euro VI levels, offer 'geo-fencing' and can use renewable diesel (biodiesel/HVO).

Plug-in hybrid models certified under the LEB accreditation save between 33% and 49% WTW GHG emissions compared to an equivalent Euro V bus. The WTW GHG emissions of a plug-in hybrid bus takes into account the vehicle's ability to operate two different powertrains. WTT GHG emissions relate to diesel and electricity production and distribution. The adoption of renewable diesel (HVO/biodiesel) and renewable electricity will lower WTT GHG emissions. Tank-to-wheel CO2 emissions are highly influenced by the fuel efficiency of a plug-in hybrid bus when operating using its internal combustion engine in combination with the electric motor. Tail-pipe CO2 emission will drop to zero during all electric operation.

Plug-in hybrids are quieter in operation than conventional diesel buses, maximised when operating in all electric mode.

4.3 Charging infrastructure

The charging infrastructure and strategies for plug-in hybrid buses are the same as for electric buses (see Chapter 2), with many identical factors influencing installation and operation of charging equipment. Plug-in hybrid buses are highly suited to opportunity charging as this enables the plug-in hybrid bus to maximise zero emission operation. At the current time Volvo and ADL offer different charging solutions. ADL's Virtual Electric is aligned with inductive charging, whereas the Volvo 7900H exploits conductive pantograph charging.

4.4 What to consider when purchasing and operating plug-in hybrid buses

Total cost of ownership is a key factor to be assessed when considering purchasing plug-in hybrid buses. Parameters that need to be reviewed include: annual mileage in electric mode and hybrid operation, fuel and energy consumption, ownership period, capital cost of the plug-in hybrid bus, Government financial incentives for supporting vehicle capital and operational costs, maintenance, infrastructure cost including purchase, installation and operation, plus the price of diesel and electricity.

Plug-in hybrid buses currently have a high to significantly higher capital cost than a conventional Euro VI diesel bus. The capital cost will be influenced by the type of charging technology. Operational savings can be gained by maximising the number of miles plug-in hybrid buses run in electric mode. This is due to the lower cost of electricity compared to diesel. The cost of replacing more expensive electrical components, such the lithium ion battery, will need to be factored into the total cost of ownership once the vehicle is out of warranty. The operating cost of a plug-in hybrid bus will also include the purchase Adblue for the SCR exhaust emission after treatment system; this will reduce the longer the bus is operated in electric mode. In-house maintenance training may be required for staff due to the complicated electrics in plug-in hybrid buses. A summary of the practical and financial factors that should be considered when purchasing and operating plug-in hybrid bus fleet are outlined below.

Table 7: Key of factors to consider when purchasing and operation plug-in hybrid buses

Operation	Charging Infrastructure	Maintenance
Route length, topography & electric range Requirement of geo-fencing Passenger capacity Operation day length of the bus Flexibility of operational base/term of contract Depot space – to facilitate charging at night Driver training to optimise energy efficiency and range Lower fuel costs with more electric miles	Type of charger & locations Peak vehicle requirement Availability of 3 phase power Power capacity at charging site, possible upgrading of local power supply Managing peak demand Optimising route scheduling with bus charging Maintenance contract for infrastructure and telemetry	Diesel engine maintenance coupled with exhaust after treatment - Ad Blue for SCR and cleaning particle filters. Hybrid components likely to require replacement – lithium battery, traction motor and power electronics. Manufacturers typically offer five-year warranty period for hybrid buses. Once out of warranty there will be a cost for extension. Maintenance training for staff due to more complex electronics. Tailored packages to support the vehicle life are available

4.5 Plug-In hybrid bus market and products

There are five plug-in hybrid buses operating in the UK demonstrating the nascent stage of market development of this technology. These buses are operated by Tower Transit, on behalf of Transport for London, and First Bus in Bristol. The plug-in hybrid buses went into service in 2015. Plug-in hybrid buses are available as single and double decker models.

4.5.1 LEB accredited plug-in hybrid buses

Plug-in hybrid models that have been accredited under the Low Emission Bus Accreditation Scheme are shown on Table 8 on the next page. Performance data has been obtained from the vehicle's LEB certificate[6].

4.5.2 LCEB accredited plug-in hybrid buses

There are no plug-in hybrid buses accredited under the LCEB scheme.

[6] http://www.lowcvp.org.uk/initiatives/leb/LEBCertificates.htm

4 Plug-in Hybrid

4.6 Plug-in hybrid bus fleet case studies

Plug-in hybrid buses in Stockholm

Keolis is the second largest bus operator in Sweden and has been running 8 Volvo 7900 plug-in hybrid buses on Route 73 in Stockholm since November 2013. The buses are charged using conductive pantograph infrastructure. The buses have been funded through the EU ZeEUS programme which will test several electro-mobility solutions in European cities. The plug-in hybrid Stockholm bus project involved a number of stakeholders including Volvo Corporation (bus provided), Vattenfal AB (charge station installation), Siemens (conductive pantograph supplier), Stockholms Aens Landsting (Public Transport Authority).

Route 73 has ten stops evenly spread out along the approximate 7 km route. The route is fairly flat; half of the route is on streets where there is a large amount of traffic and congestion including a number of other bus lines. The electric range of the Volvo plug-in hybrid is sufficient for the vehicle to operate along the entire route in all electric mode. There are two conductive pantograph charging stations located along the route at the Karolinska Hospital and the Ropsten metro station. Conductive pantograph technology was selected due to the fact that this type of opportunity charging offered a cost effective solution and was considered an important technology to test in the ZeEUS project.

Performance results for the bus project to date are very positive. The total energy consumption for the Volvo plug-in hybrid buses is around 50% lower compared to a diesel bus. Passenger satisfaction identified the plug-in hybrid buses to be more environmentally friendly and quieter than the incumbent fossil fuel buses that run on Route 73. The plug-in hybrid bus was fuelled using hydrogenated vegetable oil (HVO), a renewable form of diesel. This significantly lowers the carbon footprint of the vehicle when operating in conventional hybrid mode.

Table 8: LEB accredited plug-in hybrid bus models

	Plug-in Hybrid Bus Models	Fuel/Energy Consumption and Electric Range	WTW GHG and Air Pollution Emissions
	**Volvo 7900 PHEV** Single Decker Length: 12m Passenger capacity:80 GVW: 18,000 kg	Fuel consumption: 10.2 l/100km Energy consumption: 53 kWh/100km Electric range: 7.8 km	WTW GHG emissions: 628.9 gCO2e/km 7.9 gCO2e/km WTW GHG savings: 49% Achieves Euro VI in diesel engine operation Zero emission in electric operation
	**ADL E400 Virtual** Electric Double Decker Length: 10.3m Passenger capacity: 81 GVW: 18,000 kg	Fuel consumption: 13.8 L/100km Energy consumption: 74.0kWh/100km Electric range: 39.9km	WTW GHG emissions: 414.6 gCO2e/km 10.2 gCO2e/passenger km WTW GHG savings: 33% Achieves Euro VI in diesel engine operation Zero emission in electric operation

Notes: Fuel and energy consumption/ electric range will vary under real-world driving conditions,
WTW GHG savings compared to equivalent Euro V diesel bus, charging via UK electricity grid

Plug-in hybrid buses in Bristol

First Bus in Bristol has been operating two ADL Virtual Electric plug-in hybrids since December 2015. The buses operate on Route 72, a busy street, which transects the Bristol air quality management area. In order to reduce air pollution impacts the plug-hybrid buses were equipped with geo-fencing technology that enables them to switch off their engine on entering route 72, and operate in zero emission electric mode along the whole stretch of this route.

The plug-in hybrid buses are charging overnight at First Bus's depot using a plug-in charger unit supplied by Siemens. The buses are opportunity-charged at the end of route 72, University of West of England, using a 100kw inductive charging unit supplied by IPT. The buses take forty-five minutes to fast charge on a depleted battery, this enables the buses to operate on Route 72 three to four times before requiring a top-up charge.

The top-up charge takes seven minutes, this give a twenty-mile electric range. The installation of the inductive charging unit was undertaken by SSE and involved upgrading of the local electricity network via a new sub-station. The installation work cost in the region of £60,000. First Bus has a maintenance contract with SSE for the inductive charging infrastructure.

Bristol City Council was awarded a grant by the Department of Transport to fund plug-in hybrid buses and an inductive charging infrastructure. Each plug-in hybrid bus costs £350,000 more than an equivalent Euro VI single decker diesel bus, with the inductive charging infrastructure costing an estimated £190,000.

5 Hydrogen Fuel Cell Buses

5.1 Vehicle technology

A hydrogen bus uses a hydrogen fuel cell to power an electric motor that provides propulsion. The fuel cell converts the chemical energy from hydrogen into electrical energy and releases only water vapour. Hydrogen fuel cell buses have an electric range of 250-400km. Hydrogen is stored in cylinders on the roof of the bus. Different technical solutions exist for the main architecture of the fuel cell bus powertrain. It can comprise fuel cell stacks as a direct energy source for propulsion in combination with super-capacitors and different sizes of lithium ion batteries as energy storage. To achieve sufficient electrical power to propel a vehicle, multiple cells have to be compiled into a fuel cell stack. The leading fuel cell type for automotive applications is the polymer electrolyte membrane fuel cell. Recent hydrogen fuel cell buses are equipped with hybrid technology to improve the fuel efficiency and electric range of the vehicle.

Hydrogen is stored in cylinders in compressed state (typically 350bar) on the roof of a hydrogen bus. The number of storage tanks influences the range of a hydrogen bus, commonly the maximum number of storage tanks is ten. Hydrogen fuel cell buses are well suited to city routes. Hydrogen fuel cell buses in the UK are available from Wrightbus, fitted with the Ballard fuel cell stack, and Belgian coach and bus manufacturer Van Hool, equipped with the Ballard fuel cell stack.

5.2 Hydrogen overview

Hydrogen is an energy carrier that can be produced from several pathways, each varying in efficiency, carbon intensity and cost. The main hydrogen productions routes in the UK are steam reformation of natural gas at oil refineries and a by-product from the chemical industry. Hydrogen is transported in compressed storage containers by road to a fleet operators' refueling station. It is possible to reform natural gas supplied from the national grid on site, thereby lowering transportation requirements. This method has yet to be exploited.

Hydrogen can be generated via the electrolysis of water, which produces hydrogen from splitting water molecules. This method facilitates the production of 'green' hydrogen via the use of renewable electricity to power an on-site electrolyser. Other renewable pathways include the reformation of biomethane produced from anaerobic digestion plants and gasification of organic waste. These pathways have yet to enter the market.

In order to be eligible for fiscal incentives offered in the UK, hydrogen buses will need to operate on hydrogen produced from low carbon pathways.

5.3 Environmental credentials

Hydrogen fuel cell buses produce zero tail-pipe air pollution emissions offering benefits to air quality in cities.

The WTW GHG emissions of a hydrogen fuel cell bus are highly influenced by the method of hydrogen production and transportation. Steam methane reformation and industrial pathways for producing hydrogen can result in GHG emissions higher than diesel. Conversely generating hydrogen by electrolysis using renewable energy, or biogenic waste, has much lower GHG emissions than diesel. In the case of electrolysis, the amount of electricity required to split water molecules can be high, subsequently the efficiency of hydrogen production will influence WTT GHG emissions. Reducing the requirement to transport hydrogen by road tanker by producing hydrogen on site will serve to lower the carbon footprint of hydrogen production. Tail-pipe CO_2 emissions are eliminated due to the electric prolusion of hydrogen fuel cell buses.

Hydrogen fuel cell buses are much quieter than conventional diesel buses, offering benefits to passengers and reduced noise in cities.

5.4 Hydrogen refuelling infrastructure

Refuelling station installation and operation

There are several options for hydrogen refuelling infrastructure. Hydrogen can be transported as compressed hydrogen in tube trailers (900kg at 500bar) and can then either be decanted from the trailer into storage on the customer site or for larger demands the trailer can be left on site and the customer can draw directly from the storage. For vehicle refuelling it can be supplied as a compressed gas at either 350bar or 700bar pressures. The footprint of a hydrogen fuelling station is very similar to a CNG refuelling station.

The use of water electrolyser technology enables the production of hydrogen on site at a refuelling station. When powered by renewable electricity this is recognised as 'green' hydrogen production. The system commonly includes power electronics, hydrogen production and gas management systems, water purification and monitoring systems, gas drying equipment and a remote monitoring system. Once produced the hydrogen gas is compressed, stored and dispensed on demand at high pressure (nominally 350 bar). The equipment requires connection to water and electricity supplies. In terms of power requirements electrolysers serving 10 buses would require 1.5 MVA to produce 180 m3/hr. Cost savings can be made by producing hydrogen on site during the cheapest time of day for electricity production and store this ready for the bus refuelling. Companies supplying water electrolysers are ITM Power and Hydrogenics.

Hydrogen refuelling stations are based on a modular design comprising of three elements:

1. Main skid housing and any on-site hydrogen production equipment, hydrogen compressor, control equipment and small amount of high pressure storage

2. Bulk hydrogen storage – tubes and vertical tanks. In the UK tubes are the preferred storage medium. Vertical tanks around 20m high can reduce the station site footprint, these are being deployed in Germany.

3. Hydrogen dispenser, depending on the distance from the skid it may include pre-cooling equipment.

A number of factors will influence the cost of a hydrogen refuelling station installation. Parameters include whether hydrogen is delivered to a depot or generated on site, volume of hydrogen storage, power capacity at depot for equipment such as electrolysers, possible upgrading of local electricity grid connection maybe required, distance to utilities, complexity of civil works.

As there is a low number of hydrogen refuelling stations in the UK at present, especially for bus fleets, characterising installation time is therefore challenging. A number of demonstration projects suggest a typical time period is eighteen months.

Companies leading the supply of hydrogen gas and hydrogen refuelling infrastructure are Air Products and BOC (Linde Group). Hydrogen fuelling stations can either a) be leased by a bus operator, with the refuelling station provider retaining ownership and dealing with maintenance and repair of the station or b) purchased outright by a bus operators and then pays the refuelling station supplier for annual maintenance plan and any replacement parts.

Health and Safety Requirements

There is a requirement for Hazardous Substances Authorities (typically local planning authority) to consult the Health and Safety Executive (HSE) on applications for hazardous substances if over two tonnes of hydrogen is stored on one site. The Control of Major Accident Hazard Regulations 1999 (COMAH) becomes relevant if over five tonnes is stored. In this case the HSE and Environmental Agency in England and Wales or the HSE and Scottish Environment Protection Agency in Scotland must be notified. Planning regulations have to be established for hydrogen storage and rely on industry best practice. Safety distance from storage containers is an important factor with a best practice minimum safety distance of 3m being adopted. Planning bodies tend to adopt highly conservative attitude to separation distances which can lengthen the planning process for station operators. Increased site security is likely to be necessary for bus depot with a hydrogen refuelling station.

Typically, the hydrogen refuelling station supplier would carry out a full site survey including risk assessment to determine where the station and its associated equipment can be sited. Other studies such as the Hazard and Operability Study (HAZOP), those related to the Dangerous Substances and Explosive Atmospheres Regulations (DSEAR) would also be conducted to determine the safe siting and operation of the station. A bus operator would have to consider how the hydrogen refuelling station is incorporated into its site safety plan.

Consideration needs be given to what modifications might be required to the existing maintenance depot to allow for the inclusion of hydrogen buses. Bus operators can seek advice from the fuel cell bus manufacturers and the fuel cell stack suppliers. The HSE may need to approve modifications to the depot and maintenance protocols.

5.5 What to consider when purchasing and operating hydrogen fuel cell buses

Total cost of ownership is a key factor when considering the adoption of hydrogen fuel cell buses. Parameters that should be reviewed include: annual bus mileage, hydrogen consumption, ownership period, capital cost of the hydrogen fuel cell bus, Government financial incentives for supporting vehicle capital and operational costs, maintenance, refuelling infrastructure cost including capital, installation and operation, plus the price of hydrogen. If an electrolyser is used for onsite hydrogen production additional factors are: capital cost of the electrolysers and maintenance, annual electricity consumption and price of electricity. Consideration of water usage and drainage should also be taken into account.

5 Hydrogen Fuel Cell Buses

Flow diagram of hydrogen refuelling infrastructure installation

Bus Operator provides details of his fleet requirements, timing of fleet deployment (initial phase and long-term plans) and daily filling routines to hydrogen refuelling station provider

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Hydrogen fuelling station provider undertakes site survey at a depot

↓

Hydrogen refuelling station provider will design the station in line with bus fleet requirements

↓

Hydrogen refuelling station provider will undertake civil and electrical engineering design

↓

Health and safety procedures establised

↓

Bus operator and/or project partners prepare and submit planning application. Local authority health and safety representatives may be consulted as part of the planning process

↓

Hydrogen refuelling station provider - component procurement and station build

↓

Appoint contractors for civil engineering and other works required, connection to local electricity grid required, if an electrolyser is on site connection to local water supply will also be necessary

↓

Hydrogen fuelling station installation and commissioning, staff training

Hydrogen fuel buses have a significantly higher capital cost than a conventional Euro VI diesel bus. Operational costs are influenced by the price of hydrogen. Currently the price of hydrogen produced by water electrolysis is more expensive than hydrogen produced by stream methane reformation; hydrogen produced from pathways is higher in price than diesel. In-house maintenance of a hydrogen bus is similar to a conventional hybrid bus, with maintenance related to fuel cell and hydrogen storage tanks residing the fuel cell supplier. Maintenance considerations outside of vehicle warranty will include replacement fuel cell stack components and battery pack.

The storage capacity of the hydrogen refuelling station and inclusion of electrolysers will affect both capital and operational costs. The complexity of the station installation, in particular ground works, will influence the capital cost of the refuelling station.

The small number of hydrogen bus projects running in the UK have involved multi-stakeholder partnerships, both private and public, and relied on large scale European grant funding due to the high cost of hydrogen buses and hydrogen refuelling infrastructure.

A summary of the practical and financial factors that should be considered when purchasing and operating hydrogen fuel cell buses fleet are outlined in the table below.

Table 9: Summary of factors to consider when purchasing and operating hydrogen buses

Operation	Refueling Infrastructure	Maintenance
Route charactertistic & electric range Passenger capacity Operation day length of the bus route Driver training Health and safety training for driver and depot staff Install hydrogen refuelling station first then order buses Hydrogen purchased and delivered or produced on site Use of renewable hydrogen to lower carbon footprint and gain eligibility for fiscal incentives	Number of hydrogen buses and frequency of refuelling to determine capacity of components Refuelling station purchased outright or leased from supplier Sufficient space for hydrogen refuelling station at depot Adequate utilities - power supply, water supply and drainage for electrolyers Health and safety requirements Safe access and secure area to refuel the station for tube trailer deliveries	Maintenance of fuel cells entails monthly checks and fuel cell refurbishment after 15,000 hours in operations, undertaken by fuel cell supplier. Maintenance of the hydrogen bus including hybrid drive line -manufacturers typically offer five-year warranty period. Once out of warranty there will be a cost for extension. Maintenance of the hydrogen refuelling station lies with the station and technology suppliers.

5.6 Hydrogen fuel cell bus market and products

There are eighteen hydrogen fuel cell buses operating in the UK located in London and Aberdeen. Transport for London via their contractor Tower Transit operates eight Wrightbus hydrogen fuel cell buses. TfL will be introducing two Van Hool hydrogen fuel cell buses into their fleet in 2017 as part of the European funded fuel cell bus programme 3Emotion (Environmentally Friendly, Efficient, Electric Motion). Stagecoach and First Bus operate ten hydrogen fuel cell buses in Aberdeen on behalf of Aberdeen City Council. OLEV LEB grant funding has been awarded to Birmingham City Council and Transport for London for deploying forty-two hydrogen fuel buses with hydrogen refuelling infrastructure over the next three years.

5.6.1 LEB accredited hydrogen fuel cell buses

No hydrogen fuel bus cell buses have been certified as a Low Emissions Bus. The Van Hool A300 Fuel Cell Bus has been accredited as an LCEB.

5.7 Hydrogen fuel cell bus case study

The Aberdeen hydrogen bus project involves multiple industry and public sector stakeholders to deliver Europe's largest demonstration of hydrogen fuel cell buses in Aberdeen. The £19 million project deploys ten Van Hool A300 fuel cell buses on operational routes throughout the city.

The project is part-funded by Europe under the FP7 innovation funding scheme as well as contributions from the UK Government, Scottish Government, Innovate UK, SSE, SGN, Scottish Enterprise, First Bus, Stagecoach and Aberdeen City Council. The project runs for three years having commenced in 2015.

A hydrogen production and refuelling station has been built producing low carbon hydrogen on-site via water electrolysis. The electrolyser is currently powered by grid electricity on a green tariff; the next phase of the project will look to produce the electricity from renewable sources making the entire process ultra-low emission. The refuelling station provided by BOC Linde Group is situated in the centre of the city at Aberdeen City Council's Kittybrewster depot. The hydrogen refuelling station compromises of two Linde IC 90 Ionic compression stations, three Hydrogenic electrolysers capable of 60nm3/hour H2 and 420kg of buffer storage at 500bar. Although the station currently serves 10 buses, it is sized sufficiently to deal with 20 buses with some modular extension.

Stagecoach and First Bus share the hydrogen refuelling station. The buses take ten minutes to refuel over a four hour window each day. The fuel cell buses have a range up to 260 miles on city routes, and are demonstrating good reliability. The hydrogen fuel cell buses are maintained by Van Hool, with particular focus on the fuel cell stack. More general maintenance of the buses is carried out by Stagecoach and First Bus.

6 Gas Buses Using Biomethane

6.1 Vehicle technology

The power train for gas buses is a spark ignition engine. This is a mature engine technology with over 17 million gas vehicles operating globally. Gas is stored on board the bus in compressed cylinders.The range of a gas bus is determined by the volume of on board gas storage, typically they cover a range of 250 miles. Manufacturers offering gas buses in the UK are Scania and MAN. Gas buses suit a variety of routes including city and rural and those with hilly terrains.

The fuel source for gas buses can be natural gas or biomethane. A gas bus can only be certified as a Low Emission Bus (and Low Carbon Emission), and claim the LCEB incentive, when using biomethane as a fuel.

6.2 Biomethane overview

Biogas is produced when organic matter is decomposed by micro-organisms in the absence of air. This occurs through the process of anaerobic digestion (AD). Biogas is a mixture of methane, carbon dioxide and other chemicals. It requires cleaning to around 95-98% methane to allow it be compressed and injected into the National Gas Grid. Biomethane can be extracted from the local gas grid and used as renewable vehicle fuel by bus operators. The main supplier of biomethane for the UK bus market is Gas Bus Alliance.

The Government has incentivised the injection of biomethane into the National Gas Grid through the Renewable Heat Incentive. In the UK there are over a hundred AD facilities injecting biomethane into the gas grid. Organic waste feed stocks used in these plants include agricultural waste such as farm slurry and crop residues. Biomethane can additionally be produced from municipal food waste disposed at landfill sites, as well as sewage treatment plants. AD operators can sell biomethane as physical gas and the low carbon property of biomethane through certification schemes. The latter enables the AD industry to certify the 'green' credentials of biomethane and allow end users, such as bus operators, to claim the 'bio' benefit of the methane gas. There are currently two schemes operating in the UK:

1. Biomethane Certification Scheme run by Green Gas Trading
2. Green Gas Certificates run by a subsidiary of the Renewable Energy Association

Gas bus operators are required to supply their green gas certificate to the Department of Transport and Transport Scotland in order to claim the LCEB incentive.

6.3 Environmental credentials

Scania and MAN gas buses release very low NOx and PM emissions and currently meet Euro VI. Both MAN and Scania gas buses are equipped with exhaust gas recirculation and catalysts to control air pollution exhaust emissions.

The Well-To-Wheel GHG emissions savings for LEB accredited gas buses powered by biomethane range from 80% - 84% compared to a Euro V diesel bus. The production of biomethane benefits greenhouse emission reduction as this entails capturing methane and carbon dioxide that would have been released into the atmosphere during the decomposition of organic waste. Well-to-Tank GHG emissions of biomethane vary in relation to the type of organic waste stock used in the AD process. Farm slurry is associated with higher GHG emissions saving than crop residues. Well-to-Tank GHG emissions are additionally influenced by the transmission and distribution of gas along the national grid. Tail-pipe CO2 emissions are typically on parity with diesel bus due to the lower efficiency of spark ignition engines; however new spark ignition engines are showing efficiencies close to diesel engines. Methane emissions are controlled via a three-way catalyst. (Tail-pipe CO2 emissions are not included in WTW GHG emission calculations for road biofuels.)

Wider environmental benefits include reduced noise emissions from gas buses, avoided impacts associated with fossil fuel extraction, production and transportation due to indigenous waste material being use a fuel source. A by-product of the AD process is solid digestate that can be used as organic fertilizer, reducing ammonia emissions and nitrate pollution to aquatic ecosystems.

6.4 CNG refuelling infrastructure

Gas buses are refuelled using a compressed natural (CNG) gas refuelling station, typically located at a bus depot. A gas refuelling station consists of the following elements: gas supply to the compression module, electrical supply to the compression module, the gas compression module, high pressure storage array at 250-300bar, dispenser, dryer. Typically, as the volume of gas used increases in a biomethane bus fleet all the above elements will need to be increased in varying degrees. A fleet of ten biomethane buses will use approximately 1,000Kg/day and a fleet of 100 biomethane buses uses 10,000kg/day.

Biomethane is delivered to the local gas supply mains by the national gas distribution grid. The CNG refuelling station is connected to the mains gas and electricity supply. Biomethane is compressed to the required pressure and stored at 250-300bar ready for fuelling gas buses. Refuelling is commonly carried out using 'fast fill'. This is similar to filling up at a service station and takes about the same time to complete, around five minutes.

6.4.1 Installing and operating gas refuelling infrastructure

CNG Refuelling Station installation
The UK has a network of different pressure gas mains - National Transmission System (NTS), High Pressure (LTS), Intermediate Pressure (IP), Medium Pressure (MP) and Low Pressure (LP). The (LP) main connects to the majority of consumers at a pressure of 30 to 75mbar. An understanding of the local gas grid is an essential element in setting up CNG refuelling stations. It is important that the local gas supply mains has sufficient pressure and capacity to accommodate the number of gas buses that require refuelling. Strict requirements have to be met in connecting to the national gas grid and can only be carried out by the local gas network provider or an approved contractor.

There will be upfront costs to bring utility supplies to a depot when installing a CNG refuelling station; these will be variable and determined by the site survey. These costs include gas and electrics to the site and ground work (civils).

6 Gas Buses Using Biomethane

The distance of the refuelling station to the gas supply will influence the cost of the installation, the same will apply to electricity connection. If the refuelling infrastructure is sized correctly at the start of the project, the number of vehicles refuelling can be increased without further utility costs being incurred, thereby achieving significant cost benefits from scaling up the operation.

The lead time for installing a CNG refuelling station can be up to nine months. Extended periods of time can be required for ordering station components, connecting to the gas grid, obtaining planning consent and undertaking ground works. Defining lead times and setting delivery dates early on with contractors will make the installation process more efficient and reduce potential time delays. Another important factor to take into consideration is commencing the installation of the CNG refuelling station well in advance of ordering new gas buses. This will ensure the delivery of new vehicles aligned with the commissioning of the CNG refuelling station.

Refuelling Infrastructure Supply Models
There are two refuelling infrastructure models for operating CNG refuelling station.

1. Bus Operator Procure and Operate
A bus operator purchases the CNG refuelling station outright and operates the station themselves with contracted service and maintenance. In this model the bus operator takes the risk associated with running the station, and a low level of expertise. The operator will separately purchase biomethane gas. Companies leading the supply, installation and operation of CNG refuelling stations are Roadgas and Gas Bus Alliance.

2. Wet Leasing
This model entails a company supplying biomethane and CNG refuelling infrastructure, overseeing the station installation, operation and maintenance. The station will be provided and installed at no cost to the end user but with a marginally higher price per unit of biomethane to reflect the cost and risk undertaken by the supplier. Contracts are put in place to provide clarity and certainty regarding the gas pricing mechanism over future years. Full repair and maintenance are offered over different contract periods, service contracts are typically ten years. Wet leasing has the added advantage of reducing the capital outlay require by bus operators to introduce gas vehicles and the assurance that the infrastructure required is operated by experts in the gas supply industry.

Flow Diagram of CNG Station Installation

Bus Operator needs to provide details of his fleet requirements, timing of fleet deployment (initial phase and long term plans) and daily filling routines to CNG station provider

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CNG Station Provider carries out site survey which includes assessing availability of local gas and electric supplies

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CNG Station Provider liaises with the District Network Operator (DNO) to establish the availabilty of gas and electric supplies and whether reinforcement will be required

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CNG Station Provider carries out a survey to recommend any changes that may be required when undertaking maintenance on gas buses in the operator's depot

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CNG Station Provider will design and supply to the bus operator the refuelling station specification to meet requirements

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Bus Operator or CNG Station Provider will need to assess what local planning permission is required and make the appropriate applications

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Bus Operator needs to nominate a gas supplier and notify the CNG Station Provider

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CNG Station Provider will liaise with gas supplier for meter installation

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CNG Station Provider will liaise with the DNO's to bring both gas and electric supplies to the station location.

↓

CNG Station Provider carries out the civil works and installs and commissions the station

↓

CNG Station Provider prepares a Written Scheme of Examination and provides support and maintenance

Gas Bus Alliance offers a package of combining the supply of biomethane gas with the installation and maintenance of a CNG refuelling station. Service contracts are usually five years with rolling renewals. Installation of CNG refuelling station will cover all health and safety requirements related to storing compressed gas.

CNG Refuelling Station Operations
Regular maintenance is required to ensure that the refuelling station is operational and safe at all times. Maintenance consists of two aspects – equipment servicing (mainly on the compressors, service intervals are dictated by hours run) and inspections of the pressure systems. A gas refuelling station falls within the scope of the Pressure Systems Safety Regulations (PSSR's). The CNG station provider prepares a Written Scheme of Examination (WSE) which details the inspections required to comply with the PSSRs. Periodic inspections are then carried out in accordance with WSE. These are normally undertaken in conjunction with equipment servicing schedules.

Workshop modifications are limited to the removal of any naked flame space heaters above the gas bus maintenance area, and ensuring that there is adequate roof ventilation. A gas detector is also required to be fitted at the highest ventilation point.
All CNG fuel installations are subject to strict construction and inspection regulations, including a Risk Assessment and Hazard Operability Analysis for each individual installation. Gas refuelling stations are enclosed with security fencing and will have restricted access. Health and safety requirements include overhead venting linked to gas detectors are installed in covered areas where gas buses operate such as maintenance workshops and fuelling dispensers.

6.5 What to consider when purchasing and operating gas buses using biomethane

Total cost of ownership is a key factor to be assessed when considering purchasing gas buses. Parameters that need to be reviewed include: annual mileage of the gas bus, fuel consumption, ownership period, Government financial incentives for supporting vehicle capital and operational costs, maintenance, purchase and operation of CNG refuelling station outright or 'wet leasing', plus the price of biomethane.

Gas buses are moderately more expensive than diesel bus, however operation costs can be lower due to lower fuel and buses maintenance costs. Biomethane is lower in purchase cost than diesel, benefitting from lower fuel duty than diesel. In terms of CNG refuelling station cost this will depend on the supply model adopted. A number of factors influence the purchase and installation cost of a CNG refuelling station, these will vary considerably from one location to another. These include gas throughput, gas quality, proximity to gas and electricity mains, number of dispensers, storage modules, peak bus filling times, upgrading work to gas supply and extent of civil works.

A summary of the practical and financial factors that should be considered when purchasing and operating gas buses fleet are outlined in Table 10 on the opposite page.

6.6 Gas bus market and products

There are 112 gas buses fuelled by biomethane operating across six regions of the UK. The first gas buses came into service in 2013. The largest fleets are run by Reading Buses, Stagecoach and Arriva. Gas buses are available in single and double decker models.
The OLEV LEB grant has funded a further seventy-eight gas buses running on biomethane with refuelling infrastructure. The winners are Reading Buses (16), Nottingham City Transport (53) and Mersey Travel (9).

6.6.1 LEB accredited gas buses

Gas bus models fuelled by biomethane that have been accredited under the Low Emission Bus Accreditation Scheme aare shown in Table 11 on the next page. Performance data has been obtained from the vehicle's LEB certificate[7].

[7] http://www.lowcvp.org.uk/initiatives/leb/LEBCertificates.htm

6 Gas Buses Using Biomethane

Table 10: Key factors to consider when purchasing and operating gas bus fleet

Operation	Refuelling Infrastructure	Maintenance
Flexibility with route Passenger capacity Station delivery has longer lead time than bus delivery, order first Lower fuel costs Health and safety training for staff Reduction in diesel deliveries and bunkering on site	Purchase and operation of CNG refuelling station or 'wet-leasing' Gas throughput of station, related to number of gas buses Distance to the gas mains and pressure of local gas supply Power availability and distance to mains Footprint of CNG station and availability of space at depot Fleet planning – size the gas and electric supply to cater for fleet expansion at the beginning of installation CNG station reduces cost	Lower vehicle maintenance, main part requiring changing - spark plugs No requirement for Ad Blue or maintaining diesel particle filter Maintenance contract for refuelling station required if not adopting 'wet leasing'

Table 11: LEB accredited gas bus models

	Gas Bus Models	Fuel Consumption	WTW GHG and Air Pollution Emissions
	**Scania ADL E300** Single Decker Length: 12m Passenger capacity: 70 GVW: 18,000 kg	43.4 kg/100km	WTW GHG emissions: 210.1 gCO2 e/km 3 gCO2 e/passenger km WTW GHG saving: 82% Achieves Euro VI
	**MAN Ecocity** Single Decker Length: 12m Passenger capacity: 81 GVW: 18,000kg	50.4 kg/100km	WTW GHG emissions: 244.5g CO2 e/km 3 gCO2 e/passenger km WTW GHG savings: 80% Achieves Euro VI
	**Scania ADL 400S** Double Decker Length: 11.4m Passenger capacity: 86 GVW: 18,000 kg	42.9 kg/100km	WTW GHG emissions: 207.9 gCO2 e/km WTW GHG savings: 84% 2.4 gCO2 e/passenger km Achieves Euro VI

Notes: Fuel consumption will vary under real-world driving conditions; WTW GHG emission savings compared to Euro V diesel equivalent, biomethane is 'Green Gas Certificated' MAN Ecocity LEB test data is estimated.

6.6.2 LCEB accredited gas buses fuelled on biomethane

Currently available gas bus models that are LCEB accredited are:

Manufacturer	Model
Scania	Single Deck: Scania ADL E300S
MAN	Single Deck: Ecocity

6.7 Gas bus fleet case study

Reading Buses have operated 34 gas buses run on biomethane since 2013 across six routes in Reading. The company was awarded funding from Green Bus Fund to help cover the cost premium of the gas buses, approximately £30,000 per bus. The company trialled both MAN and Scania single deck gas buses before purchasing their first buses, both performed very well. Reading Buses choose Scania as the rest of their bus fleet comprises of ADL and Scania vehicles.

Reading Buses report excellent performance of their gas buses. The buses have performed very well on all routes, experiencing significantly less breakdowns than their diesel buses. Reading Buses have reported a productive partnership with gas bus supplier Scania over the last three years.

Reading Buses purchased and installed the CNG refuelling station located at their depot, this cost £800,000. This was arranged through CNG refuelling company Waltsila.

Reading was fortunate that their refuelling station was very close to the low pressure mains, and gas throughput was sufficient for the number of biomethane buses in their fleet. Gas Bus Alliance supply Reading's biomethane gas and maintain their refuelling station. Reading benefits from the BSOG LCEB incentive using their Green Gas Certificates. Reading Buses advocates bus operators choose wet leasing for CNG refuelling station as this reduces risk for the bus operators and makes installation and managing the station much easier and simpler for the operator. Reading Buses offers third party access to their refuelling stations to John Lewis and Iveco who operate gas trucks.

The company has had very positive feedback from passengers and seen a growth of 7-15% over the last two years on their biomethane bus routes. The company has achieved a 30% savings in fuel costs which will help offset the cost of their CNG refuelling station over time.

Reading Buses has purchased five ADL Scania E400S double decker buses that will go into service during the latter part of 2016. These buses were approximately 15% more expensive than an equivalent Euro VI diesel bus and purchased without grant funding. Reading Buses has won funding from the OLEV LEB grant to purchase another sixteen double decker Scanias and upgrade their CNG refuelling station to increase gas storage capacity.

7 Renewable Diesel

7.1 Biodiesel overview

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.

The Renewable Transport Fuel Obligation (RTFO) is one of the Government's main policies for reducing greenhouse gas emissions from road transport through incentivising the use of bio content in UK vehicle fuel. Only biofuels that achieve a minimum GHG emission saving of 35% compared to diesel and meet sustainability criteria can be used. UCO is currently the most abundant feedstock for manufacturing UK biofuels, with a continuing trend away from crop-based biofuels due to historic concerns over sustainability and conflict with food crops. Standard diesel currently sold in the UK is blended with 7% biodiesel.

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. With regards to the UK bus market Argent Energy is one of the main biodiesel suppliers. The company produces biodiesel from waste oils and fats sourced from animal rendering plants.

7.2 Vehicle technology

Whilst biodiesel can be used as a renewable fuel in diesel buses at different blend ratios, bus operators are advised to consult their vehicle manufacturer(s) to gain approval for using biodiesel as the warranty of the engine maybe affected. With regards to high biodiesel blends, notably B100, the vehicle will require modification.

It is important that biodiesel is manufactured to a high quality in order to avoid potentially damaging effects to the diesel engine. One particular issue is fuel filter blocking caused from biodiesel's cold flow properties. Biodiesel should be tested against the European biodiesel standard EN/BS 14214. Some biodiesel suppliers will ensure the finished blend also achieves a high quality standard. The new European standard for B20 and B30 is EN/BS 16709. Buses running on biodiesel are suited to a variety of bus routes, identical to diesel buses.

Since the introduction of European standards for biodiesel (EN 14214 and EN 16709), vehicle and engine models from a growing number of manufacturers such as Scania, Cummins and Volvo are now warranted for a variety of biodiesel blends including B20. Biodiesel has a lower energy density than standard diesel suggesting that a fuel consumption penalty may arise at higher blends. Limited evidence is available to validate this supposition.

7.3 Environmental credentials

There is a scarcity of vehicle emissions test data to demonstrate the tail-pipe air pollution impacts of using biodiesel in comparison to standard diesel in buses; however recent evidence has been made available by Transport for London. Transport for London undertook a pilot trail of biodiesel B20 in a selection of their buses in 2015. Vehicle emissions testing was commissioned at Millbrook Proving Ground for a Euro V ADL E400 bus running on B20 and pump diesel. The results revealed a small reduction in particulate matter emissions and no change in NOx emissions[8].

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% CO2 eq saving[9] in comparison to standard diesel, B100 would offer 85% CO2 eq saving. Further GHG emission reductions are possible through locally sourced waste materials due to avoided CO2 emissions associated with road distribution. Tail-pipe CO2 emissions of biodiesel are on parity with diesel; these are not included in WTW GHG emission calculations for biofuels.

The sustainability of biodiesel is vastly improved if produced from organic waste material, with greater benefits gained from the local sourcing of waste feedstocks and production of biodiesel.

7.4 Biodiesel storage and refuelling infrastructure

Storage requirements will vary between different blends; B100 will have different requirements from B20 and B30. Biodiesel B20 and B30 can be stored in existing bunded diesel tanks with associated dispensing pumps. If an extra storage tank is required bus operators should consider asking the biodiesel supplier if the provision of a tank can be provided in the fuel contract. The storage of B100 requires a bespoke bunded tank. There is a risk of biodiesel solidifying in cold temperatures, this will be higher for B100. This can be fixed by adding biodiesel specific additives to the supplied fuel, frequently turning biodiesel or heated fuel lines.

Normal good practice is to have an annual tank cleaning regime. This prevents the build-up of sludge in the bottom of the tank and helps to ensure clean fuel is delivered to vehicles. Biodiesel is more hydroscopic than diesel and easily absorbs moisture from the atmosphere. This water can encourage microbial growth in the fuel storage tank. If left unchecked high microbial growth can lead to fuel filter blockages. Water ingress into biodiesel storage tank should be avoided at all times so tank hatches should always be secured well. Anti-microbial products can be added to the biodiesel to stop microbial growth in both storage and fuel tanks.

[8] The Mayor's Biodiesel Programme, Operational Guidance Note v2, GLA 2015
[9] RTFO Statistics, Year 8, Report 4, 2016

7.5 What to consider when purchasing and operating biodiesel buses

The total cost of ownership associated with using biodiesel should take into account a number of factors: annual mileage of bus, fuel consumption, biodiesel blend, any requirement for vehicle modification, Government incentives for using biodiesel, vehicle maintenance, biodiesel storage tank and dispenser purchase and maintenance, biodiesel price.

The total cost of ownership will vary depending on the biodiesel blend, generally the adoption of biodiesel will be relatively low cost. For use of B100 new and existing diesel buses will entail with a small premium for biodiesel modification. The storage of B100 will result in slightly higher cost than standard diesel. The use of biodiesel will require minor additional vehicle maintenance. Frequency of fuel filter changes will be higher for B100 than lower blend biodiesel. The price of biodiesel is presently comparable with standard diesel.

A summary of the practical and financial factors that should be considered when purchasing and operating biodiesel bus fleets are outlined in Table 12 below.

7.6 Biodiesel market

There are a total of 9,186 buses running on biodiesel blends ranging from B20 to B100. The two bus operators leading the adoption of biodiesel are Stagecoach and Transport for London. The largest fleets operate in Scotland.

Transport for London currently operates a third of their buses, 3000 vehicles, on B20 biodiesel. By 2020 the target is to have the entire fleet of 9,000 buses utilising B20. The motivation behind the adoption of biodiesel lies with the Mayor's Biodiesel Programme. The aim here is to produce biodiesel from organic waste feedstock arising from London and use it within the city itself.

An LEB certification has yet to be awarded to a Euro VI diesel bus running on biodiesel.

7.7 Biodiesel bus fleet case study

Stagecoach operates 4,581 buses on biodiesel motivated by the company's sustainability agenda to reduce CO2 emissions. Fifteen buses are run on 100% biodiesel in Kilmarnock and Canterbury. 4566 buses are fuelled using biodiesel blend B30 operating in Scotland, Lancashire, Manchester, Merseyside, Yorkshire, Midlands and Oxfordshire. Argent Energy has been Stagecoach's biodiesel supplier for the last four years. The company produces biodiesel from waste oil derived from animal rendering plants. The adoption of biodiesel has reduced Stagecoach's overall bus fleet CO2 emissions in the region of 25%. Stagecoach plans to take the number of buses run on biodiesel to 6,186 by the end of the 2016.

In Dundee, one of Stagecoache's largest biodiesel fleets, B30 has been used in both conventional diesel buses, including latest Euro VI, and hybrids supplied by Scania, Volvo, ADL and Optare. Stagecoach gained permission from these manufacturers to use biodiesel in order to ensure the vehicle would remain covered under their warranties. The company has benefited from the Scottish BSOG biodiesel rebate. The buses running on B30 have been reliable and performed as well as standard diesel buses; they have experienced no reduction in fuel consumption. Limited additional maintenance is required to the buses running on B30; the main task is to change the fuel filter every three months at a cost of less than £10. This is easily recouped through the Scottish BSOG rebate. In terms of storage, the B30 is delivered to site and stored in a bunded fuel tank. Service maintenance for the tank entails regularly inspection which is generally increased in the winter. The storage tank is cleaned once a year.

Table 11: Key factors to consider when purchasing and operating buses on biodiese2

Fleet Operation	Refueling Infrastructure	Maintenance
Flexibility with route Confirm with bus manufacturer biodiesel use will not affect vehicle warranty Use of B100 will require vehicle modification Ensure biodiesel supplier can independently guarantee quality of biodiesel Aim to source biodiesel from low carbon, sustainable feed stocks Switching to biodiesel does not require any specialist training	Biodiesel has the same refuelling system as a conventional diesel bus B20/B30 can use existing diesel storage tanks New bunded tanks requirement for B100, may require heated fuel lines Ensure sufficient space at depot for new bunded storage tanks Consider if fuel provider can include new fuel tanks in cost of fuel	Biodiesel storage tank requires annual cleaning regime Additional vehicle maintenance - increased fuel filter changes

7 Renewable Diesel

7.8 Hydrotreated Vegetable Oil Overview

Hydrotreated vegetable oil (HVO) a renewable diesel fuel produced by hydrotreating vegetable oils or animal fats in oil refinery type equipment. It can be produced from vegetable or waste oil products. There are distinct advantages to HVO use compared to biodiesel and as such manufacturers are strongly focusing on HVO research trials. The advantages are:

- Very consistent fuel quality regardless of the feedstock
- Less chance of fuel degradation as oxygen is removed from the fuel
- Superior energy density
- Can be used as 'drop-in' fuel
- Produces straight chain molecules which are more easy to burn than complex aromatic diesel fuel

Unlike biodiesel there are currently fleets operating using HVO in the UK. Neste Oil is the market leader in the provision of HVO, with three processing plants in Europe and Asia. Neste Oil has historically produced HVO using crop-based oil, however more recently around 64% is derived from waste feed-stocks. HVO is being deployed in both conventional diesel and hybrid buses by a small number of bus fleet operators in Europe, mainly in Sweden.

7.9 Vehicle technology

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.

7.10 Environmental credentials

There is a limited vehicle emissions test data to demonstrate the air pollution impacts of using HVO in buses compared to standard diesel, especially in the UK. A large-scale demonstration trial of HVO use in city buses named OPIBIO, was carried out in Helsinki in 2011 [10] . Vehicle emissions testing revealed reductions in regulated air pollution emissions including NOx and PM exhaust emissions from city buses using 100% HVO; see section 8.12. With regards to WTW GHG emissions, as with biodiesel, the key to maximising GHG emissions savings is the use of waste oil feedstock. HVO produced from UCO achieves a 91% GHG emissions saving compared to standard diesel[11].

7.11 What to consider when purchasing and operating buses on HVO

The total cost of ownership associated with using HVO should take into account a number of factors: annual mileage of bus, fuel consumption, Government incentives for using HVO, vehicle maintenance and HVO price.

There is limited information on current pricing of HVO in vehicle fleets. No vehicle modifications are required for HVO use and hence no cost premium for new or existing buses. There will be no additional vehicle or fuel storage tank maintenance costs.

7.12 HVO case study

Helsinki Region Transport, Neste Oil, Proventia Emission Control, VTT Technical Research Centre of Finland and Aalto University carried out a 3.5 year study named "OPTIBIO" to demonstrate the use of HVO in city buses (Euro II, III, IV, V and EEV emission certification). The project cooperated with the bus manufacturer Scania. The fleet study took place in Helsinki involving 300 buses. The fuels were a 30% HVO blend and 100% HVO. The field test was supplemented by a comprehensive laboratory vehicle emissions testing programme carried out at VTT Technical Research Centre of Finland. The buses were tested on a chassis dynamometer, using a city bus test cycle, to assess exhaust emissions and fuel consumption.

The city buses covered 50 million kilometres between September 2007 and December 2010, of which 1.5 million kilometres was on 100% HVO. Average distance per vehicle was 170,000 km. The project confirmed that HVO is successful as a drop-in fuel, meaning that HVO can replace diesel fuel 100% without any modifications to the refuelling system or to the vehicles, without causing any operational problems. HVO was found not to have any negative operational impacts on buses fitted with exhaust after treatment systems such as SCR.

Vehicle emission testing demonstrated no change in fuel consumption of the buses using 100% HVO. NOx emissions reduced by 10% and PM emissions by 30% when compared to an equivalent diesel bus.

[10] Optimized usage of NExBTL renewable diesel fuel, OPTIBIO, VTT Research Notes 2604, 2011
[11] Well-to-Tank Appendix 4 – Version 4a: Description, results and input data per pathway, JRC/CONCAWE 2014

8 Euro VI Diesel Fitted with Electrified Ancillaries

8.1 Vehicle technology

Conventional ancillaries such as the air compressors, electrical systems and the alternator on a bus are driven by the engine and consume power according to demand. Improvements in fuel economy can be achieved by packaging up a range of techniques that can reduce energy consumption from the engine to power these systems. Different vehicle manufacturers have developed various solutions that are fitted to a standard Euro VI diesel buses to achieve improvements in fuel efficiency. Diesel bus fitted with electrified ancillaries can run on exactly the same routes as conventional diesel buses.

For the ADL 'Smart Accessories' range the electrical system and the compressed air system are controlled to enable charging when the vehicle is coasting/decelerating, thus charging these systems whilst the engine is not fuelling. In order to gain further reductions in fuel consumption ADL has designed the E400 with light weighting, e-cooling and start-stop technology.

'Micro hybrid' is the terminology Wrightbus uses to describe the intelligent control of engine ancillaries to harvest energy thereby giving rise to fuel savings. Wrightbus offers a range of micro-hybrid models, such as the StreetLite (single decker) and StreetDeck (double decker), which have been designed with a variety of measures to improve fuel efficiency. The features include improved opportunity charging for the electrical system, optimising electric radiator fan, opportunity charging for the pneumatic system and electric power steering, plus light weighting of the vehicle bodywork.

8.2 Environmental credentials

Euro VI diesel buses designed with electrified ancillaries achieve very low NOx and PM emissions.

WTW GHG emission savings of Euro VI diesel buses equipped with electrified ancillary buses are in the order of 25% higher than a conventional Euro V diesel bus. Well-to-Tank GHG emissions relate to diesel production and distribution. The adoption of renewable biodiesel will lower Well-to-Tank GHG emissions. Tail-pipe CO_2 emissions are highly influenced by the fuel efficiency of the buses.

8.3 What to consider when purchasing and operating electrified ancillary buses

Total cost of ownership is a key factor to be assessed when considering purchasing Euro VI buses fitted with electrified ancillary buses. Parameters that need to be reviewed include: annual mileage, fuel consumption, ownership period, capital cost of the bus, Government financial incentives for supporting operational costs, maintenance and price of diesel.

Electrified ancillary buses are marginally more expensive than conventional Euro VI diesel buses. Operational savings can be gained from reduced fuel costs due to improvements in fuel economy. There is some minor additional maintenance compared to a conventional diesel bus, purely down to extra complexity of the electric ancillary systems.

Table 12: LEB accredited Euro VI diesel buses fitted with electrified ancillaries

	Euro VI diesel buses with electrified ancillary models	Fuel Consumption	WTW GHG and Air Pollution Emissions
	**ADL E400 LCEB Spec** Double Decker Length: 10.3-11.5m Passenger capacity: 99 GVW: 18,000 kg	34.60 l/100km	WTW GHG emissions: 1151.4 gCO2e/km 11.63 gCO2e/passenger km WTW GHG savings: 18% Achieves Euro VI

This will be covered in the vehicle warranty typically offered over a two or five-year period. The operating cost of an electrified ancillary bus will also include the purchase of Adblue for SCR exhaust emission after-treatment system.

8.4 Euro VI diesel bus fitted with electrified ancillaries market and products

There are just over 1000 diesel buses fitted with electrified ancillaries operating across the UK, with the first buses coming into service in 2013. The largest fleets are run by First Bus, Arriva and Go-Ahead Group, and the regions with the highest numbers of vehicles are Glasgow, Hampshire and Yorkshire.

8.4.1 LEB accredited Euro VI diesel buses fitted with electrified ancillaries

Electrified ancillary models that have been accredited under the Low Emission Bus Accreditation Scheme are shown in Table 12. Performance data has been obtained from the vehicle's LEB certificate[12].

8.4.2 LCEB accredited electrified ancillary buses

Currently available electrified ancillary bus models that are LCEB accredited are:

Manufacturer	Model
ADL	Single Deck: Enviro 200 LCEB Spec Double Deck: Enviro 400 LCEB Spec
Wrightbus	Single Deck: StreetLite (MHv2) Double Deck: StreetDeck (MHv2)

8.5 Electrified ancillary bus fleet case study

First Bus operate 741 Euro V and Euro VI fitted with electrified ancillary buses across the UK. These comprise of Wrightbus StreetLites and StreetDecks (621) and ADL E200 and E400 Smart Accessories (120). When assessing the whole-life costs of different technologies First Bus was attracted to electrified ancillary buses as they provided reasonable fuel cost benefits at a marginal increase in vehicle capital cost. The vehicles are commercially viable without the need for grant funding. Both the Wrightbus and ADL electrified ancillary buses have proved very reliable and are tolerant to a wide range of route characteristics including hilly routes in Sheffield and Bristol. The vehicles are performing well in terms of fuel economy with the actual percentage improved highly dependent on the bus route and comparator vehicle. Compared to the older vehicles in their fleet or the buses being replaced the electrified ancillary buses are in excess of 30% more fuel-efficient. The electrified ancillary buses are simple to maintain, with all maintenance carried out in-house. Given the success of First Bus's current fleet of electrified ancillary buses the company has placed orders for another 131 buses this year.

[12] http://www.lowcvp.org.uk/initiatives/leb/LEBCertificates.htm

9 Retrofit SCR Technology

9.1 Bus retrofit technologies for NOx emission reduction

There are a variety of technologies that can be retrofitted in existing diesel buses to reduce tail-pipe NOx emissions and improve urban air quality. Technologies that have been trialled and deployed in the UK are: exhaust after-treatment using selective catalytic reduction (SCR), diesel engine conversion to spark ignition engine and diesel engine conversion to hybrid or electric powertrain. The conversion of diesel buses to fully electric propulsion and electric with range extended capabilities, powered by either hydrogen fuel or CNG, is being trialled by Reading Buses and TfL. The availability of performance data should increase over the next 6-12 months. Stagecoach in Lincoln converted ten Euro III diesel buses to Euro V gas buses powered by biomethane. York City Council has converted a diesel tourist bus to be fully electric, with further buses to be converted. SCR is the most adopted retrofit technology in the UK, with evidence to support emission performance. This section of the guide focuses on retrofit SCR technology.

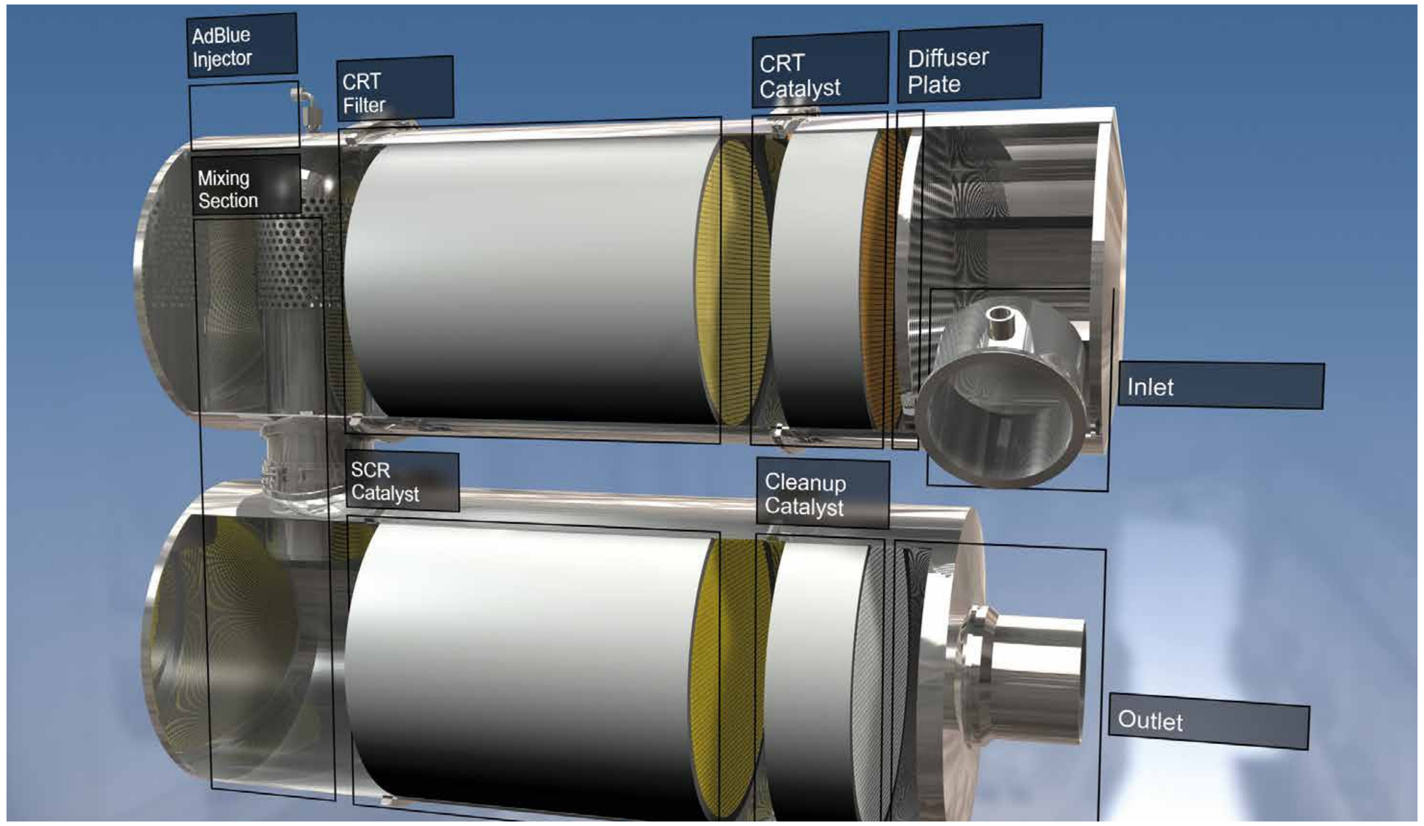
The introduction of Clean Air Zones, and London's Ultra Low Emission Zones, will set stringent NOx emission requirements for new and retrofitted buses. An important characteristic of any retrofit technology when fitted to a bus is the ability to achieve very low NOx and NO2 emissions whilst not resulting in any adverse impact on other air pollutants or greenhouse gas emissions. Robust vehicle emissions testing is necessary to demonstrate the performance of retrofit equipment in achieving technology suppliers' claimed environmental performance[13].

9.2 Selective Catalytic Reduction - technology overview

Selective Catalytic Reduction (SCR) is an exhaust after-treatment technology targeting NOx emissions in diesel vehicles. The technology has been used for several years by the automotive industry to meet Euro IV, V and VI NOx engine emission standards for heavy duty vehicles, and more recently Euro VI heavy-duty vehicles.

The system injects a urea (purchased as Ad Blue) into the exhaust stream of a diesel engine which passes through a special catalyst. The urea sets off a chemical reaction that converts nitrogen oxides into nitrogen and water vapour that are then expelled through the vehicle tailpipe. The SCR system is commonly fitted after a Diesel Particulate Filter (DPF) that reduces particulate matter emissions. The effective operation of SCR systems is highly influenced by exhaust gas temperature. The temperature window for urea injection in the SCR system is typically 250-450 degrees centigrade. Temperature, the amount of urea, injection design and catalyst activity are the main factors that determine actual NOx reduction.

Exhaust after-treatment technology companies supplying retrofit SCR for buses in the UK are Eminox, HJS, Baumot UK, Provenia and Green Urban. The application of retrofit SCR has over the last four years focused on Euro II and III diesel buses. Euro IV and V buses are now being successfully refitted with SCR; this is likely to increase over the next few years.



In order to guarantee the durability and performance of retrofit SCR technology, control and diagnostic equipment can be fitted to buses. The most common approach is to use NOx sensors. These are simple, indicative devices for monitoring tail-pipe NOx emission levels when the vehicle is operating under real-world driving conditions. Twin sensors are typically fitted, one before and one following the after-treatment technology. The difference between the two measurements gives an indication of real-world NOx conversion performance. All UK SCR suppliers offer the fitment of NOx sensors with the SCR system.

Eminox has introduced a sophisticated on-board diagnostic system that enables the bus driver to observe the performance of the retrofit SCR system in real-time. The system features an in service NOx alarm, Adblue level gauge, summary screen showing back pressure and NOx reduction performance and has a service indicator.

9.3 Environmental credentials

Retrofit SCR systems can lower tail-pipe NOx emissions by more than 90% when retrofitted to Euro III, IV and V diesel buses, coupled with similar reductions in NO2 concentrations. There will be a slight increase in nitrous oxide emissions due to NO2 in the presence of ammonia over the SCR catalyst; also apparent in Euro VI diesel buses.

9.4 What to consider when purchasing and operating retrofit SCR equipment

The total cost of ownership associated with adopting retrofit SCR equipment should take into account a number of factors: the purchase cost of the technology, the control and diagnostics equipment and fitting, the cost of Adblue and maintenance.

The cost of SCR fitment will depend on the type and Euro standard of the bus. Bus operators will incorporate checking and replenishing Adblue as part of their daily maintenance regime. On-board diagnostic equipment will aid in notifying bus driver when Adblue top-up is required and any maintenance issues with the SCR system. The amount of Adblue required for the SCR system is related to annual mileage of the bus. Retrofit suppliers typically offer an annual service package which includes replacement of the SCR injector and various system filter changes.

9.5 Retrofit SCR bus market

There are approximately 3000 diesel buses that have been retrofitted with SCR technology operating across the UK. The DfT ran four grant programmes[14] between 2013 and 2015 to assist local authorities to purchase retrofit technologies capable of reducing vehicle NOx emissions. SCR was the most funded technology. Over 1000 buses in cities experiencing poor air quality have been retrofitted with SCR technology thanks to the DfT's retrofit programmes. Public bodies leading retrofit SCR bus projects include Bradford City Council, Gateshead and Sunderland, Leicester City Council, Brighton, Transport for London (TfL), West Yorkshire Combined Authority, Mersey Travel and Colchester Borough Council. TfL has led its own SCR bus retrofit programme.

[13] LowCVP has designed a Clean Vehicle Retrofit Accreditation Scheme on the request of DfT, awaiting confirmation of launch date. Air pollution and GHG emission standards for retrofitted buses have been proposed with accompanying vehicle emission testing protocols.

[14] Clean Bus Technology Fund 2013,2015, Clean Vehicle Technology Fund 2014.

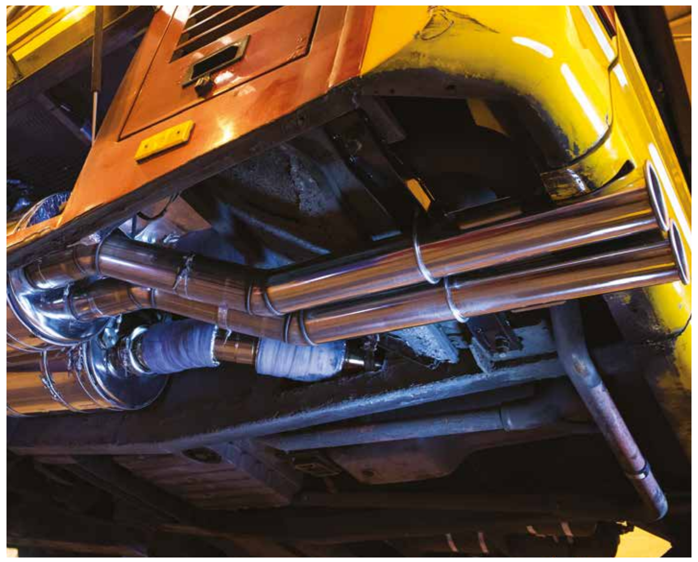
9 Retrofit SCR Technology

9.6 Retrofit SCR case study

TfL has been managing the largest SCR retrofit programme for Euro III buses since 2011 to help reduce NO2 concentrations London. Currently 2,100 of TfL's buses have been retrofitted within SCR technology supplied by Eminox, HJS and Provenia. Vehicle emission testing undertaken by TfL of retrofitted Euro III buses revealed NOx reductions of more than 88%. The equipment has been fitted to a range of buses including Volvo, ADL Envrio 400H, DAF, ADL Dart and Trident, Scania and various other models manufactured by Wrightbus. TfL has secured over £10million in Government funding to support their retrofit programme and have worked in partnership with their contracted bus operators to install and maintain the equipment. To date the retrofitted buses have been proved to be reliable. TfL has an annual service contract with all its retrofit equipment suppliers. Real-world evidence of the air quality benefits associated with TfL's retrofit buses has been seen on Putney High Street during 2013. Roadside NO2 concentrations dropped by 16% following the fitment of SCR to a high proportion of Euro III buses operating on this street.

TfL plans to retrofit a further 4000 Euro IV and V diesel buses operating across the London over the next few years to deliver greater reductions in NO2 concentrations. The retrofitted buses will be equipped with on-board diagnostic equipment to ensure the continued performance of the SCR equipment.

TfL has established emission-based performance standards for retrofit technology suppliers, primarily to ensure compliance with the Ultra Low Emission Zone and achieving equivalent Euro VI emission standards. The performance standards cover oxides of nitrogen, nitrogen dioxide, particulate matter, particulate number, ammonia and GHG emissions. Retrofit technology suppliers are required to meet these standards, with evidence of retrofit bus performance demonstrated through vehicle emissions testing over the Millbrook London Bus Test cycle (MLTB).



Diagrams 3 and 4 show the results of vehicle emissions testing undertaken at Millbrook Proving Ground for TfL Euro V buses retrofitted with SCR equipment supplied by HJS and Eminox. Diagram 5 shows NOx emissions to reduce by more than 95% from both Euro V buses following SCR retrofit. Tail-pipe NOx emissions achieve TfL's NOx emission limit for retrofit equipment of 0.5 g/km. Diagram 6 reveals similar large scale reductions in NO2 emissions following SCR fitment to both Euro V buses. Both SCR equipment manufacturers achieve TfL's NO2 emission limit for retrofit technology of 0.1 g/km.

Diagram 3: Vehicle Emissions Testing Results - NOx Emissions for TfL Euro V Buses Before and After SCR Retrofit

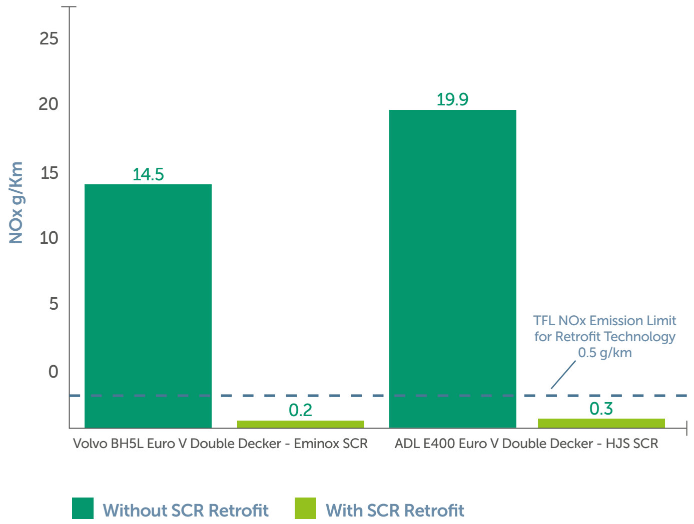
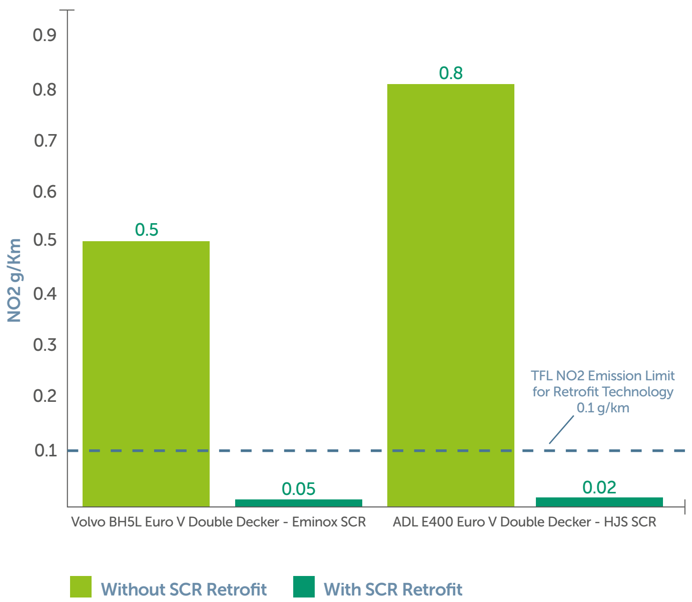


Diagram 4: Vehicle Emissions Testing Results - NO2 Emissions for TfL Euro V Buses Before and After SCR Retrofit



10 Further Information

Low Carbon Vehicle Partnership

LEB Accreditation Scheme, LEB Certifications, Market Monitoring
LowCVP Low Emission Bus Website (http://www.lowcvp.org.uk/initiatives/leb/Home.htm)

Bus Manufacturers

Volvo Bus (http://www.volvobuses.com/en-gb/home.html)
Wrightbus (http://www.wrightsgroup.com/Divisions/Wrightbus)
ADL (http://www.alexander-dennis.com)
Optare (http://www.optare.com/)
BYD Europe (http://www.bydeurope.com/)

EV Infrastructure

Evolt (https://www.swarco.com/apt/Products-Services/eMobility)
Siemens (https://www.siemens.com/global/en/home.html)
ABB (https://www.abb.com/)

CNG Refuelling Infrastructure

Gas Bus Alliance (http://www.gasalliance.eu/)
Roadgas (http://www.roadgas.co.uk/)
CNG Fuels (http://www.cngfuels.com/)

Biomethane Supply

Gas Bus Alliance (http://www.gasalliance.eu/)

Green Gas Certification Schemes

Green Gas Certificate Scheme (http://www.greengas.org.uk/)
Renewable Energy Association (http://www.r-e-a.net/)

Hydrogen Supply and Refuelling Infrastructure

Air Products (http://www.airproducts.com/)
ITM Power (http://www.itm-power.com/)
BOC (http://www.boconline.co.uk/en/index.html)

Retrofit SCR technology Suppliers

Eminox (http://www.eminox.com/)
HJS (http://www.hjs.com/homepage.html)
Baumot UK (http://twintecbaumot.de/en)

Biodiesel Supply

Argent Energy (http://www.argentenergy.com/)
Harvest Energy (http://www.harvestenergy.co.uk/)
Greenergy (http://www.greenergy.com/)

Retrofit Electric and Hybrid Powertrain Suppliers

Magtec (http://www.magtec.co.uk/index.php/en/)
Vantage Power (http://vantage-power.com/)

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