West Midlands Low Emission Bus Delivery Plan

A study commissioned by Centro
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July 2016

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Foreword

We have ambitious plans in the West Midlands to transform our economy and improve the health and quality of life of people living and working here. There is however a growing recognition that to do this, urban air quality must be improved. Having a high quality, attractive bus network is integral to that but only by transforming our bus fleets and reducing emissions will the true potential of the bus be unleashed.

The West Midlands Transport Emissions Framework, which was agreed by West Midlands ITA leaders in January 2016, signifies the increased importance of air quality in the transport agenda and the Low Emission Bus Delivery plan was a key part of this.

The formation of the new West Midlands Combined Authority and the new Bus Alliance that brings together bus operators, local councils and other partners provides a unique opportunity to bring stakeholders together to deliver that transformation. The Bus Alliance has already identified reducing emissions and improving air quality as a key objective and this Low Emission Bus Delivery Plan sets out a framework for effectively driving that ambition forward.

I am very encouraged that the investment already committed by bus operators will see emissions of pollutants reduce by over 60% over the next five years thanks largely to the transition to Euro VI engines. That will have a significant impact but we must be more ambitious and look further ahead and aim to have many zero emissions buses, either electric or hydrogen, operating on our roads by 2035. This report demonstrates that by pursuing an ambitious programme by 2035 the fleet could emit less than 10% of today’s emissions bringing about a real improvement in the quality of life for West Midland residents.

The engagement and contributions from all local authorities and bus operators in the region in preparing this plan have been great and the interest they have shown demonstrates that we do have a realistic prospect in leading the way in the transition to low emission buses. I’m looking forward to continuing the work with all of our partners through the Bus Alliance to implement this Plan.

Councillor John McNicholas
Picture: Launch of the Bus Alliance in November 2015, which included all of the region’s Bus Operators and Local Authorities.
Executive Summary
Executive summary

Background and objectives

There has been growing recognition that urban air quality problems must be addressed to improve the health of people living and working in UK cities. The West Midlands, being the second most populated region in England, is affected by these issues. In six out of the seven districts of the region nitrogen dioxide (NO₂) and/or particulate matter (PM₁₀) concentration thresholds are exceeded (relative to EU limits).

The bus sector is a key contributor to some poor air quality hotspots in urban areas and has consequently been a focus area for improvement to effectively tackle local air quality.

The objective of this study, commissioned by Centro, is to develop a Delivery Plan to 2035 for low emission bus adoption and the installation of the required refuelling infrastructure. The Delivery Plan aims to guide and support the transition of the West Midlands bus fleet towards a zero/low emission fleet and, by providing a quantification of impacts and prioritisation of efforts, will be a valuable source of evidence for funding applications.

Low Emission Bus technologies

The Department for Transport’s Office for Low Emission Vehicles updated the accepted definition of a Low Emission Bus (LEB) in 2015: a LEB must achieve a reduction of well-to-wheel CO₂ emissions of more than 15% against a Euro V diesel bus, and meet Euro VI limits for all other emissions. The new definition set the criteria for bus powertrain technologies to be considered

<table>
<thead>
<tr>
<th>Description</th>
<th>Natural gas</th>
<th>Electricity</th>
<th>Hydrogen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressed gas dispensed at 200 bar. Gas is either:</td>
<td></td>
<td></td>
<td>Compressed H₂ dispensed at 350 bar</td>
</tr>
<tr>
<td>Taken from gas grid and compressed</td>
<td>Electricity taken from the grid, through:</td>
<td>Hydrogen is either:</td>
<td></td>
</tr>
<tr>
<td>Delivered compressed from ‘mother station’</td>
<td></td>
<td></td>
<td>Made on site</td>
</tr>
<tr>
<td>Maturity (as of Feb 2016)</td>
<td>112 gas buses in the UK (&gt;100,000 globally)</td>
<td>111 electric buses in use in the UK (+50 soon, 10,000s globally), with several charging methods being deployed/trialled</td>
<td>18 buses trialled in London and Aberdeen (low 100s globally)</td>
</tr>
<tr>
<td>Largest fleets at Sunderland and Reading</td>
<td></td>
<td></td>
<td>Aberdeen: on-site electrolyser powered by clean electricity</td>
</tr>
<tr>
<td>Both using depot based gas grid connected stations</td>
<td>Till about to fully electrify a route following successful trial</td>
<td>London: delivery of compressed H₂ at 500 bar</td>
<td></td>
</tr>
<tr>
<td>Turn key solutions available</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Low carbon option</th>
<th>Natural gas</th>
<th>Electricity</th>
<th>Hydrogen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bus or station operator can buy a Green Gas Certificate to match gas use to biomethane injection</td>
<td></td>
<td>Power Purchase Agreement to be supplied with low carbon electricity</td>
<td>Electrolysis with low carbon electricity</td>
</tr>
<tr>
<td>Key requirements</td>
<td>Access to gas grid (higher pressure better) and high voltage for compressors OR proximity to ‘mother station’</td>
<td>Access to high voltage connection, at the depot and/or along the route</td>
<td>Access to high voltage connection for on site electrolyser</td>
</tr>
</tbody>
</table>

Table 1: Summary of alternative fuel buses and their refuelling infrastructure
in the Delivery Plan, which includes hybrid internal combustion engine (ICE), ICE running on (bio)methane, pure electric, and fuel cell electric technologies. Furthermore, with air quality improvement being the primary objective of this plan, retrofit technologies able to reduce NOx and PM emissions from existing diesel buses have also been considered. Table 1 provides an overview of LEB technologies that require a specific refuelling/recharging infrastructure.

The West Midlands bus fleet

There are currently around 2,300 buses operating in the West Midlands, a number expected to remain roughly constant to 2035. Around 200 buses per year will be procured to replace vehicles scrapped at the end of their lifetime. There is evidence of existing commitment to trialling low emission buses with 52 hybrid currently on the road, representing 2.2% of the fleet, a number on a par with national statistics.

Today Euro III buses make up almost half the fleet, indicating that 50% of the buses on the road today are an order of magnitude more polluting than the current emission limit defined by the EU. However, EU regulations stipulate that all new buses purchased today must meet Euro VI emission standards. Owing to the stringency of the Euro VI standard, NOx emissions from the total bus fleet is expected to fall by 64% by 2020. This positive finding indicates that even with no LEB uptake, contributions from the West Midlands bus fleet to local air pollution will fall significantly in the next five years (Figure 1).

The Low Emission Bus Delivery Plan

Future uptake of LEBs

Three scenarios, informed by consultation with bus operators, project future LEB uptake in the region. A baseline scenario has been included to describe the impact of no major change from the status quo; diesel ICE uptake continuing to dominate bus procurement with a small, growing penetration of hybrid buses. Two other scenarios were developed (Figure 2):

- a moderate ambition scenario involving primarily hybrid or gas ICE powertrains, with low sales of fuel cell and battery electric vehicles.
• A high ambition scenario involving hybrid or gas ICE technologies in short term, relatively quickly supplemented by zero emission buses.

Initial fleet NOx emission reductions, consistent across all scenarios, are brought about mainly through the transition to EURO VI buses. However, by 2035, further savings of 33% and 54% could be realised relative to the baseline (Figure 3).

In the early years, CO2 emission savings relative to the baseline from the more ambitious scenarios are small. But by 2035, savings of up to 30% could be achieved under the moderate ambition scenario with >50% LEBs in the fleet, of which 30% are zero emission. Furthermore, under the high ambition scenario savings of up to 48% could be reached with 75% LEBs in the fleet (including 50% zero emission buses).

![Figure 2: Moderate and high ambition scenarios for new bus uptake (remaining market share is captured by diesel buses)](image)

![Figure 3: West Midlands bus fleet NOx and CO2 emissions under the three scenarios](image)
**Infrastructure needed to support LEVs uptake**

Hybrid technologies do not require additional refuelling infrastructure but gas ICE, electric and hydrogen buses each require their own dedicated refuelling/recharging equipment.

Initial electric bus deployment on selected shorter routes will involve overnight, depot-based charging infrastructure. Post-2030, converting over 20% of routes to electric will require addressing routes that go beyond current electric bus driving ranges and would therefore require charging ‘en route’. Analysis suggests that, if adopted, frequent, short ‘top-up’ charging events would cause the most significant impact to the grid. By 2035, electrical recharging infrastructure is unlikely to have an associated electricity supply challenge (700 buses by 2035 would annually need <1% of West Midlands electricity consumption) but could encounter a power capacity challenge by adding significant additional peak power demand (its magnitude will depend on the diversity of charger use and charging strategies).

Hydrogen buses, owing to the high capacity of their on-board storage tanks, will only require depot based refuelling infrastructure solutions. The Delivery Plan describes up to 480 hydrogen buses by 2035, and shared across multiple depots (e.g. 80 buses per depot), will require new engineering solutions for large-scale (multi tonne per day) refuelling. National Express and Birmingham City Council are currently involved in a pan-European R&D project aiming to resolve a significant knowledge gap around large-scale hydrogen refuelling, therefore outputs from this study will benefit the West Midlands as hydrogen bus uptake increases.

**Areas to prioritise for greatest air quality impact**

In order to maximise the benefit of EURO VI buses and LEBs, these should be deployed on routes where buses make a large contribution to air quality issues. A prioritisation of such routes was developed during the project, as shown in Figure 4.
Executive Summary

Recommendations and next steps

A number of barriers to adoption of LEBs can only be addressed on a national or European level (e.g. low market availability, high capital costs), but opportunities have been identified for Local Authorities and Centro to support bus operators in the transition to a low emission bus fleet.

Developing a series of local push factors (e.g. expand Statutory Quality Bus Partnerships boundaries, disseminate information describing areas with worst air quality) and pull factors (e.g. create public award for most progressive operator, pool and redistribute BSOG subsidies) will strengthen efforts from central government to promote LEB uptake.

Unfamiliarity with funding application documents can often exclude smaller operators from participating in funding rounds. Hosting workshops for local bus operators to inform them of funding streams available and to share experience and offering local financing solutions (e.g. low interest rates to support purchase of high capex LEBs) through the Bus Alliance, if feasible, could benefit the wider bus sector.

Many bus operators have stated that understanding the real-world performance of LEBs would greatly support their investment decisions. Therefore creating a local forum to share experience with LEB (vehicle and infrastructure) trials and outputs from activities outside the West Midlands could be beneficial.

Bus operators are generally unfamiliar with installing and owning new LEB infrastructure. Supporting operators with third parties (e.g. grid operators, planning authorities, land owners, competitor operators) to help expedite and simplify experience could encourage greater interest in LEB investment.

Whilst the primary objective of the Delivery Plan is to improve local Air Quality, ensuring a low carbon fuel supply will be important for meeting the UK’s decarbonisation targets. Therefore establishing a dialogue between local renewable generator project developers and bus operators (e.g. to incentivise co-locating renewable generators with new bus depot facilities), and integrating strategies for the evolving regional energy system and the transport system will ensure good communication of opportunities.

The main recommendations are summarised in Figure 5, along with the key milestones of the LEB Delivery Plan.
### Executive Summary

**West Midlands Low Emission Bus Delivery Plan**

#### Suggested timeline and key milestones to support LEB delivery plan

<table>
<thead>
<tr>
<th>Year</th>
<th>Funding</th>
<th>Incentives</th>
<th>Data sharing</th>
<th>Refuelling/recharging infrastructure</th>
<th>Low carbon sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
<td>All technologies: FCH JU topic 1.6 deadline&lt;sup&gt;1&lt;/sup&gt;</td>
<td>Develop concept for West Midlands Low Emission Bus Fund&lt;sup&gt;2&lt;/sup&gt;</td>
<td>Availability of outputs from EU projects</td>
<td>Provide support with third parties (network operators, planning authorities, land owners)</td>
<td>Hybrid or gas ICE (new bus sales): 16%</td>
</tr>
<tr>
<td></td>
<td>Fuel cell</td>
<td>Low Emission Leaders title awarded every two years</td>
<td>Local sharing</td>
<td>At least 2 depots with charging facilities and 1 hydrogen station</td>
<td>Electric: 12%</td>
</tr>
<tr>
<td></td>
<td>Electric</td>
<td></td>
<td></td>
<td></td>
<td>Fuel cell: 4%</td>
</tr>
<tr>
<td>2020</td>
<td>DfT Low Emission Bus Scheme; £30m grant funding through multiple calls</td>
<td>2eEUS&lt;sup&gt;3&lt;/sup&gt;</td>
<td>Outputs from trials of medium-sized hydrogen bus fleets (1–20 buses)&lt;sup&gt;4&lt;/sup&gt;</td>
<td>Integrate urban energy system and transport planning considerations as LEB fleet sizes grow</td>
<td>21–24%</td>
</tr>
<tr>
<td></td>
<td>Off Low Emission Bus Scheme, £30m grant funding through multiple calls</td>
<td>EBSF&lt;sup&gt;2&lt;/sup&gt;</td>
<td></td>
<td></td>
<td>17–19%</td>
</tr>
<tr>
<td>2025</td>
<td>Additional EU funding calls to support fuel cell and/or electric buses could be issued</td>
<td>Clean Air Zone in Birmingham, new Statutory Quality Bus Partnerships</td>
<td></td>
<td>4–6 depots with charging facilities and 1 large hydrogen station (4t/day)</td>
<td>8–9%</td>
</tr>
</tbody>
</table>

#### Market share

- Hybrid or gas ICE (new bus sales):
  - 2015: 16%
  - 2020: 21–24%
  - 2025: 8–9%

- Electric (new bus sales):
  - 2015: 12%
  - 2020: 17–19%

- Fuel cell (new bus sales):
  - 2015: 4%

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<sup>1</sup> FCH JU topic 1.9 (£32m) call for proposals aims to support deployment of at least 100 hydrogen buses at three locations over a 4–6 year period.

<sup>2</sup> FCH JU R&D project to develop engineering solutions for large-scale hydrogen refuelling (06/2015–12/2016)

<sup>3</sup> EU demonstration project testing 35 electric buses in eight European cities (11/2013–04/2017)

<sup>4</sup> EU R&D project to develop new generation of urban bus systems (05/2015–04/2018)

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**Figure 5: Suggested timeline and key milestones to support the LEB Delivery Plan**
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<td>Buses and depots in use</td>
<td>40</td>
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<td>3.1.1</td>
<td>Current bus fleet</td>
<td>41</td>
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<td>3.1.2</td>
<td>Current depot situation</td>
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Abbreviations

AM  Annual mean
AQ  Air quality
AQMA  Air Quality Management Area
BEV  Battery electric vehicle
BIS  Department for Business, Innovation & Skills
BSOG  Bus Service Operators’ Grant
CBM  Compressed biomethane
CHIC  Cleaner Hydrogen In European Cities
CNG  Compressed natural gas
CO  Carbon monoxide
CO₂  Carbon dioxide
COMAH  Control of Major Accident Hazard
CVBF  Clean Vehicle Bus Fund
DECC  Department of Energy and Climate Change
DEFRA  Department of Environment, Food and Rural Affairs
DfT  Department for Transport
DNO  Distribution Network Operator
DOC  Diesel Oxidation Catalyst
DPF  Diesel Particulate Filter
EBSF_2  European Bus System of the Future 2
EGR  Exhaust Gas Recirculation
EU  European Union
EV  Electric vehicle
FCEV  Fuel cell electric vehicles
FCH JU  Fuel Cells and Hydrogen Joint Undertaking
GHG  Greenhouse gas
GVW  Gross vehicle weight
H₂  Hydrogen
HC  Hydrocarbons
HEV  Hybrid electric vehicle
HP  Horse power
HRS  Hydrogen refuelling station
ICE  Internal combustion engine
LA  Local Authority
LBM  Liquefied biomethane
LEB  Low Emission Bus
LNC  Lean NOx Catalyst
LNG  Liquefied natural gas
LowCVP  Low carbon vehicle partnership
LTS  Local transmission system
MPAN  Metering point administration number
NTS  National transmission system
OEM  Original Equipment Manufacturer
OLEV  Office of Low Emission Vehicles
PHEV  Plug-in hybrid electric vehicle
PM  Particulate Matter
PTEG  Passenger Transport Executive Group
RTFC  Renewable Transport Fuel Certificate
RTFO  Renewable Transport Fuel Obligation
SCR  Selective Catalytic Reduction
SQBP  Statutory Quality Bus Partnerships
SMR  Steam methane reformer
TCO  Total cost of ownership
TEN-T  Trans-European Transport Network
TfL  Transport for London
TTW  Tank to wheel
WE  Water electrolyser
WM  West Midlands
WMCA  West Midlands Combined Authority
WT  Well to tank
WTW  Well to wheel
ZeEUS  Zero Emission Urban Bus System
ZEV  Zero emission vehicle
| Abbreviations | West Midlands Low Emission Bus Delivery Plan |
Introduction

West Midlands Low Emission Bus Delivery Plan
1 Introduction

This chapter provides an overview of the context and aims of the Delivery Plan.
1 Introduction

1.1 Background

Air Quality

In recent years, there has been growing recognition that urban air quality problems must be addressed to improve the health of people living and working in UK cities. The West Midlands, being the second most populated region in England, is affected by these issues. Coventry, Dudley, Sandwell and Walsall have areas of nitrogen dioxide (NO₂) exceedance, whereas in Birmingham and Wolverhampton both NO₂ and particulate matter (PM) thresholds are exceeded (relative to EU limits). As a result, six of the seven West Midlands districts have declared Air Quality Management Areas (AQMAs). In late 2015, the predicted continued lack of compliance with air quality thresholds has pushed Defra to request a Clean Air Zone for Birmingham City centre.

Improving Air Quality has thus become a priority and buses, while representing a limited share of vehicles on the road, are significant contributors to air pollution in the most congested urban areas and therefore AQMAs. In addition to addressing Air Quality issues, several districts have implemented carbon dioxide (CO₂) emission reduction targets. Most notably, Birmingham aims to reach a 60% reduction by 2027, against 1990 levels¹.

West Midlands Combined Authority

The newly formed West Midlands Combined Authority (WMCA) is instrumental to the delivery of an effective and progressive public transport system in the West Midlands. The vision, set out in West Midlands’ Strategic Transport Plan ‘Movement for Growth’ is to ‘make great progress for a Midlands economic ‘Engine for Growth’, clean air, improved heath and quality of life for the people of the West Midlands. We will do this by creating a transport system befitting a sustainable, attractive and economically vibrant conurbation in the world’s sixth largest economy’.

In line with this vision, and recognising the need for a structured approach to improve air quality and carbon emissions in the region, dialogue was initiated between Local Authorities and public transport operators to develop a low emission bus strategy. The strategy provides a Delivery Plan for low emission bus deployment to 2035 and the required refuelling infrastructure, tailored to operational requirements.

In 2015 the West Midlands Bus Alliance was established. This will be instrumental in delivering initiatives outlined in this plan. The Alliance is an innovative collaboration of partners, including bus operators, the West Midlands Combined Authority, other Local Authorities, Local Enterprise Partnerships, the Police and Transport Focus. Improving air quality and reducing emissions from buses is a key objective for the Alliance.

1.2 Objectives

The objective of this study is to develop a Delivery Plan to 2035 for low emission bus adoption and

¹ [http://www.birmingham.gov.uk/sustainability](http://www.birmingham.gov.uk/sustainability)
the installation of the required refuelling infrastructure. It will guide and support the transition of the West Midlands bus fleet towards a zero/low emission fleet. The Delivery Plan, by providing a quantification of impacts and prioritisation of efforts, will also be a valuable source of evidence for funding applications.

The implementation of the Delivery Plan will be an essential aspect of the West Midlands Transport Emissions Framework. As part of the ‘Movement for Growth’, the West Midlands Transport Emissions Framework will understand the wider transport impact on air quality and also land use planning, environmental control, public health and energy policy agendas and aligned to the move to a Combined Authority and Devolution Deal. The framework builds on and will be aligned to work undertaken by the various authorities in the West Midlands as well as the Government, businesses, freight and transport operators and the wider public sector, communities and commuters.

1.3 Scope

Geographical scope and timeframe of the study

The West Midlands region is divided in seven districts (Birmingham, Coventry, Dudley, Sandwell, Solihull, Walsall and Wolverhampton) located in the centre of the UK. The time period under consideration is the next two decades, i.e. from now to 2035.
**Vehicles included in the study**

The Delivery Plan covers all buses operating in the West Midlands, but excludes coaches.

For the purpose of this report, buses are split across three segments: single deck (both rigid and articulated), double deck, and mini & midi buses. Their typical specifications are laid out in Figure 7.

’Sprint’ – the region’s rapid transit network is not specifically included, however it is anticipated that this new mode will be low emission and supplement the wider bus network.

**Low emission technologies under consideration**

In 2015, the Department for Transport (DfT) and the Office for Low Emission Vehicles (OLEV) revisited an outdated definition (established in 2009) of a low emission bus to appropriately address the two most relevant objectives of reducing CO₂ emissions and improving local air quality. The new definition states that a Low Emission Bus (LEB) must achieve a reduction of well-to-wheel CO₂ emissions of more than 15% against a Euro V diesel bus, and meet Euro VI limits for all other emissions. Two additional aspects of this update include a new bus test cycle; the LowCVP UK Bus Test Cycle, and the opportunity for zero emission technologies to benefit from maximum grant funding.

The new LEB definition issued by the UK government established the criteria for bus powertrain technologies to be considered in the Delivery Plan; these include hybrid internal combustion engine (ICE), ICE running on (bio)methane (referred to as ‘gas buses’ in this report), pure electric, and fuel cell electric technologies. Furthermore, with air quality improvement being the primary objective of this plan, retrofit technologies able to reduce NOx and PM emissions from existing diesel buses have also been considered.

### 1.4 Approach

First, data on the current bus fleet was collected from bus operators, through a dedicated data framework and with the assistance of Centro. From the extensive data collected, a model of the existing West Midlands bus fleet was created. It is underpinned by key metrics (e.g. mileage, fuel consumption, vehicle lifetime) as reported by operators.

A workshop was then run with bus operators, to validate and refine the data collection findings, as well as discuss the barriers and potential for uptake of LEBs.

Building on this input, scenarios for future bus market shares were produced, with different levels of ambition for LEB uptake. The fleet model was then used to compare the relevant metrics (e.g. total emissions, total fuel consumption) for each scenario against a baseline scenario where no

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change to the current bus technology procurement occurs.

In parallel to this work, with inputs from each district regarding AQ hotspots, a map of streets to prioritise for the deployment of LEBs was created, and is a part of the Delivery Plan.

The approach is summarised in **Figure 8** and modelling assumptions are described in this report.
1.5 Structure of the report

The Low Emission Bus Delivery Plan is divided into a further four sections:

Section 2 presents the low emission bus technologies, from current market availability and deployment, to cost, available funding and technical performance. In the case of alternative fuels, the refuelling technologies are also succinctly described, in terms of options and typical characteristics.

Section 3 focuses on the West Midlands bus fleet. It presents detailed results from the data collection exercise (e.g. stock breakdown by EURO band, fuel efficiency, mileage and depot characteristics) as well as key findings from the workshop.

Section 4 lays out the Delivery Plan. Starting with LEB uptake scenarios and emission savings, it then describes the enablers needed to support them, e.g. in terms of refuelling infrastructure and other factors. Areas to prioritise for the rollout of LEBs, to maximise their AQ benefits, are also presented, for each district.

Section 5 summarises the overall findings from the work and draws recommendations for the West Midlands Combined Authority and the Local Authorities to implement the Delivery Plan.
2 Low emission buses

This chapter describes the low emission bus technologies, from current market availability and deployment, to cost, available funding and technical performance. In the case of alternative fuels, the refuelling technologies are also succinctly described, in terms of options and typical characteristics.
2 Low emission buses

From a diverse choice of hybrid powertrain solutions to pure electric and hydrogen buses, the choice of low emission buses is expanding quickly and now covers all bus types. This section provides an overview of available bus technologies, alongside their refuelling options.

2.1 Bus technology overview

The UK government and the European Union have implemented a series of incentive measures and policies to support alternative fuel development. According to the Carbon Plan\(^3\), buses will play an important role in raising awareness of new technologies, and a number of policy measures are already in place or planned, such as the development of ultra-low emission zones in several city centres by 2020. The increased uptake of alternative fuel vehicles is seen as essential to achieving national carbon reduction targets. Table 2 below summarises the main sources of funding and grants recently made available for buses in the UK.

- £90 million available through the Green Bus Fund has supported the deployment of over 1,000 hybrid and gas buses since 2009.
- Two rounds of the Clean Bus Technology Fund provided an additional £5 million and £7 million for bus upgrades to improve air quality in cities (2013-14 and 2015-16).
- £30 million from OLEV for the Low Emission Bus Scheme to support low emission buses (LEB) and their infrastructure from 2015 to 2020. To be certified as a LEB, a bus must be at least EURO VI-compliant and bring 15% GHG Well to Wheel savings compared to EURO V diesel bus.
- EU support for hydrogen and electric buses and infrastructure is currently available through multi-partner projects.

Different alternative powertrains are currently being trialled or are already available on the market. The following diagram summarises the different technologies in the scope of the delivery plan, and their levels of complexity and maturity. This is followed by Table 3 and Table 4, which provides a comparison of refuelling options, cost and emissions performance of the main bus technologies.

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\(^3\) The Carbon Plan outlines the UK Government's plans to deliver the emissions savings it has committed to achieving by 2050. Full details can be found at: [https://www.gov.uk/government/publications/the-carbon-plan-reducing-greenhouse-gas-emissions—2](https://www.gov.uk/government/publications/the-carbon-plan-reducing-greenhouse-gas-emissions—2)
Figure 9: Portfolio of existing low emission bus technologies

Table 3: Summary of alternative fuel buses and their refuelling infrastructure
### Summary of low emission technologies

<table>
<thead>
<tr>
<th>Technology</th>
<th>Hybrid powertrains</th>
<th>Gas ICE</th>
<th>Retrofit to reduce pollutants</th>
<th>Battery electric</th>
<th>Fuel cell electric (hydrogen)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low emission buses</td>
<td>Diesel engine combined with an electric motor or mechanical storage</td>
<td>Spark-ignition engine running on methane</td>
<td>Improves emissions of existing pre-Euro VI fleet</td>
<td>100% battery powered</td>
<td>Hydrogen fuel cell and electric motor</td>
</tr>
<tr>
<td><strong>Emission benefits over EURO VI diesel</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NOx</td>
<td>Similar to diesel EURO VI</td>
<td>Similar to diesel</td>
<td>Brings Euro II-V diesel close to Euro VI standard</td>
<td>100% reduction</td>
<td>100% reduction</td>
</tr>
<tr>
<td>PM</td>
<td>Up to 20-40% reduction</td>
<td>Up to 80% WTW reduction (biomethane)</td>
<td>No impact or slight increase</td>
<td>Up to 100% WTW reduction (renewable electricity)</td>
<td>Up to 100% WTW reduction (e.g. electrolysis using renewable electricity)</td>
</tr>
<tr>
<td>CO₂</td>
<td>Up to 20-40% reduction</td>
<td>No impact or slight increase</td>
<td>Up to 100% WTW reduction (renewable electricity)</td>
<td>Up to 100% WTW reduction (renewable electricity)</td>
<td>Up to 100% WTW reduction (e.g. electrolysis using renewable electricity)</td>
</tr>
<tr>
<td><strong>Capital premium diesel</strong></td>
<td>+50-80% for electric hybrids, 30-40% for flywheel hybrids</td>
<td>+20-30%</td>
<td>10-20% of capex</td>
<td>+80-140% (low volume production)</td>
<td>At least 400% (low volume production)</td>
</tr>
<tr>
<td><strong>Cost over diesel</strong></td>
<td>Same as for diesel buses</td>
<td>250 to 500 km</td>
<td>No impact on range</td>
<td>200-300 km</td>
<td>250-400 km</td>
</tr>
<tr>
<td>Range (km)</td>
<td>Same as for diesel buses</td>
<td>Close to diesel</td>
<td>Same as for diesel buses</td>
<td>Hours or several short high rate charges during the day</td>
<td>&lt; 10 minutes</td>
</tr>
<tr>
<td><strong>Refuelling time</strong></td>
<td>Same as for diesel buses</td>
<td>Close to diesel</td>
<td>Same as for diesel buses</td>
<td>Hours or several short high rate charges during the day</td>
<td>&lt; 10 minutes</td>
</tr>
<tr>
<td>Energy use compared to diesel (single deck figure)</td>
<td>15-20% lower consumption (12-15 MJ/km)</td>
<td>20-30% higher consumption (19-20 MJ/km)</td>
<td>No impact or slight increase</td>
<td>50-60% lower consumption (6-7 MJ/km)</td>
<td>20-25% lower consumption (10-12 MJ/km)</td>
</tr>
</tbody>
</table>

---

4. CHIE project, TfL bus data, Element Energy for Sefton Council ‘Alternative fuels strategy for the Liverpool City Region’ 2016, DEFRA
5. WTW: Well to wheel. WTW CO₂ emissions account for the emissions during fuel production and transport as well as during the operation of the vehicle. Used Cooking Oil numbers based on truck applications
2.2 EURO VI diesel buses

Historically, new European emission standards defined by the EU have reduced NOx emission limits for buses by 20-40% against the preceding EURO standard. However, EURO VI, the most recent standard introduced in 2013, stipulates an 80% emission limit reduction compared with the preceding standard. Furthermore, PM emission limits were reduced by 50% under EURO VI.

After initial concerns from industry that the new NOx emission standard could not be met cost-effectively, successful innovation has enabled real-world emissions from EURO VI buses to show good performance for controlled pollutants. A number of operators in the West Midlands have experience with EURO VI buses, reporting attractive fuel economy but large differences between driving cycles.

The EURO VI standard is sufficiently stringent that significant emission reductions could be achieved through regular fleet renewal alone.

2.3 Retrofit technologies

Retrofit technologies are a cost effective alternative to lower bus emissions when the purchase of new buses is not an option. In addition to the 123 locally funded bus conversions, Centro has received a £486,000 grant from the Clean Bus Technology Fund. This grant, which aims to upgrade buses with technology to reduce emissions in poor air quality areas, is enough to convert 27 buses in the West Midlands area in 2016, to supplement 21 converted in 2015.

A number of retrofit technologies are available to reduce particulate matter (PM), NOx, volatile hydrocarbons (HC) and carbon monoxide (CO) emissions. A non-exhaustive list is provided below with the basic principles of operation:

- Diesel Oxidation Catalyst (DOC): Stainless steel canister containing a honeycomb structure coated with catalytic metals which react with CO, HCs, and PM. DOCs can be coupled with NOx reduction technologies for additional emission reductions

---

References for ‘real world’ EURO VI heavy duty engines testing include TfL, In-service emissions performance of Euro 6/VI vehicles, 2015; ICCT, Comparison of real-world off-cycle NOx emissions control in Euro IV, V, and VI, 2015
Dielectric Particulate Filter (DPF): Filters removing particulate matter in diesel exhaust, certain DPFs can reduce HC and CO too. Regenerative active filters burn or oxidize accumulated matter automatically but still require maintenance. LiqTech\(^7\) states that EURO I to EURO IV diesel engines can meet EURO VI standards on PM when using their new DPF technology

Selective Catalytic Reduction (SCR): System in which a liquid-reducing agent (e.g. urea) chemically transforms nitrogen oxides into nitrogen, water and tiny amounts of CO\(_2\) (then expelled via the tailpipe). SCR can be combined with DPFs and DOCs to achieve greater PM reductions

Exhaust Gas Recirculation (EGR): a portion of engine exhaust is redirected back to the engine to cool and reduce peak combustion temperatures and pressures, thereby reducing NOx. This is commonly factory-fitted by engine manufacturers, and retrofits are difficult

Lean NOx Catalyst (LNC): NOx is adsorbed onto an adsorbent ‘trap’, before being converted to N\(_2\) and water using hydrocarbons as a reactant (during a period of rich engine operation). This brings up to a 40% NOx reduction. This increases fuel consumption (e.g. +5% to 7%) and requires advanced monitoring systems. LNCs are paired with either a DPF or a DOC

Diesel particulate filters are the most popular solutions, and today are fitted on all of TfL’s EURO II & III buses (a total of 6,500 buses). Similarly, 1,400 TfL buses to-date have been retrofitted with a Selective Catalytic Reduction technology.

The main asset of the retrofitting technologies is that they can be easily integrated to an existing fleet to reach at least EURO V standard from EURO IV or previous models. **Table 5** summarises the main retrofit technologies in terms of impact and approximate cost.

<table>
<thead>
<tr>
<th>Emissions reductions and costs of key retrofit technologies</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Main technologies</strong></td>
</tr>
<tr>
<td>Diesel Particulate Filter (DPF)</td>
</tr>
<tr>
<td>Selective Catalytic Reduction (SCR)</td>
</tr>
<tr>
<td>Reduces PM to close to Euro VI levels</td>
</tr>
<tr>
<td>Reduces NOx to close to Euro VI levels</td>
</tr>
</tbody>
</table>

Other retrofit technologies that convert a conventional bus into a hybrid or electric bus, are discussed in Sections 2.5 and 2.6 respectively.

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\(^7\) Famous Danish DPF manufacturer

\(^8\) Element Energy, Alternative Fuels Strategy for the Liverpool City Region, 2016
2.4 Gas buses

Vehicle availability

While there are only 112 gas buses in use in the UK today, globally Compressed Natural Gas (CNG) buses are a relatively mature technology, with greater deployment in other countries.

Currently only buses with dedicated CNG drivetrains are available to the UK market. Figure 11 presents the availability of CNG buses in the UK today, and also a future Scania double decker expected to be introduced later in 2016. Further expansion of the single deck dedicated CNG bus market is expected as models currently sold in mainland Europe are made available to UK customers.

### Market availability of gas buses in the UK

<table>
<thead>
<tr>
<th>Models</th>
<th>Power and torque</th>
<th>Size &amp; passengers</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single deck</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Man - EcoCity</td>
<td>270 to 300 HP</td>
<td>12 to 14.7m</td>
<td>250 to</td>
</tr>
<tr>
<td>Scania - ADL E300</td>
<td>200 to 222 kW</td>
<td>70 to 120</td>
<td>500km</td>
</tr>
<tr>
<td>EvaBus - Citaro NGT</td>
<td>1050 to 1350 Nm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tata - Starbus CNG/hybrid</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Double deck</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scania – model based on ADL ENVIRO 400 body</td>
<td>280 HP</td>
<td>10.2 to 11.4m</td>
<td>c. 350km</td>
</tr>
<tr>
<td>(available in 2016)</td>
<td>206 kW</td>
<td>75 seats</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1350 Nm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Articulated</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EvaBus - Citaro NGT</td>
<td>300 to 380 HP</td>
<td>18 m</td>
<td>250 to</td>
</tr>
<tr>
<td></td>
<td>222 to 280 kW</td>
<td>115 to 165</td>
<td>500km</td>
</tr>
<tr>
<td></td>
<td>1200 to 1300 Nm</td>
<td>passengers</td>
<td></td>
</tr>
</tbody>
</table>

Figure 11: Market availability of gas buses in the UK

Costs and funding

Premiums for gas buses are c. £30,000 - £40,000 (over diesel bus costs of c. £125,000 for single and £190,000 for double decks\(^9\)). This makes gas one of the cheapest “low emission” options, with premiums significantly lower than those for series hybrid, electric or hydrogen buses. Gas buses are eligible for grants under the £30 million OLEV low emission bus fund, for which first round applications closed in October 2015. Public announcements indicate that over 90 gas buses have been put forward by operators; if funded, this could almost double the GB gas bus fleet\(^10\).

Indicative fuel cost savings are around 23p/mile for a 12m bus, equivalent to £11,500/year for an annual mileage of around 80,500km. In addition, cost and emission savings for operators are currently maximised by the Bus Service Operators’ Grant Low Carbon Emission Bus incentive, which pays bus operators 6p/km for kilometres run on biomethane\(^11\).

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\(^9\) Source: Element Energy discussion with OEMs. Other OEMs / models available across Europe


\(^11\) At least 4 bids include gas buses, including one for 82 double deck gas buses, http://busandcoach.com/news/articles/2016/waiting-for-decission-on-gas-buses/

\(^12\) http://assets.dft.gov.uk/publications/certification-of-dedicated-gas-buses/guidance.pdf
The key measures currently in place in the UK to support the development of natural gas vehicles economy are outlined in Table 6:

### Measures to support development of the gas bus market

- Fuel duty differential: announced in December 2013, to be reviewed in 2018 and expected to be maintained to 2024. (25p/kg for gas; 58p/l for diesel, translating into a difference of 12p/km)
- Additional fuel rebate for bio-methane buses; buses receive a rebate through the Bus Service Operators’ Grant (BSOG) for the proportion of km travelled using bio-methane (minimum 50%)
- £30m OLEV fund over 3 years (i.e. between April 2016 and March 2019) for local authorities and bus operators

### Gas bus refuelling

In the UK, gas buses currently on the road are fuelled by compressed natural gas (CNG) at c. 200 bar (250 bar for the new Scania double-decker). Bus operators using gas have a dedicated depot filling point e.g. Reading Transport, Arriva buses across the North-East and North-West of England.

Infrastructure providers have developed attractive commercial offerings where operators are not exposed to high capital costs and ownership responsibilities for the refuelling equipment. Instead, bus operators are effectively leasing the infrastructure via payments stipulating a minimum CNG consumption.

Key facts are summarised in Figure 12.

### Gas refuelling for buses – overview and UK example

#### Bus gas refuelling – key facts

- Refuelling time similar to diesel fuelling process
- Indicative price: £0.65-£1/kg, i.e. c. 28p/km (45p/mile) for a single deck
- The gas is either
  - Taken from the gas grid and compressed to 200 bar
  - Delivered compressed from a ‘mother station’
- Green Gas Certificates can be purchased to match gas use to biomethane injection into the gas grid

#### Broad costs and specifications

- Costs will vary mainly depending on the extent of civil works. As an example, the station in Reading cost c. £1 million
- Indicative footprint of gas bus station:
  - 30 m x 20m (600sqm) for 10 buses, 2 dispensers
  - Trailer solution less space demanding
- Main CNG solution providers include Gas Bus Alliance, RoadGas and CNG Fuels

#### UK example: Reading gas bus station

Source: Element Energy, industry inputs and Low Carbon truck trial. Pictures from http://www.getreading.co.uk
2.5 Hybrid buses
Vehicle availability

Over 2,300 diesel hybrid buses are currently operating in the UK, making diesel hybrid the most common low emission bus technology in the country. Two main powertrain technologies are available:

- Parallel hybrids include an ICE engine to provide the main power, assisted by a small electric motor or other energy source assisting the ICE and allowing for regeneration of braking energy. These hybrids may have a short range in full electric mode of ~1km or in low/zero emission mode.

- Series hybrids use electric motors to provide all motive power, with an internal combustion engine used to power the generator and recharge the battery. The full electric range remains limited but can nevertheless reach ~10km.

The majority (65%) of diesel hybrids in the UK today are OEM developed, series technology. Hybrid technology integrated during the manufacturing phase (as opposed to retrofit) is advantageous for minimising additional weight, directly improving range and fuel consumption.

Hybrid technologies exist for all bus types procured by operators in the West Midlands (see Figure 13).

<table>
<thead>
<tr>
<th>Models</th>
<th>Typical size &amp; passengers</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Single deck</strong></td>
<td></td>
</tr>
<tr>
<td>Wrightbus - StreetLite</td>
<td>8 to 15m</td>
</tr>
<tr>
<td>ADL – ENVIRO 200H and ENVIRO 350H</td>
<td></td>
</tr>
<tr>
<td>Volvo – 7900H</td>
<td></td>
</tr>
<tr>
<td>Optare – Versa HEV (midibus), Solo HEV (midibus)</td>
<td></td>
</tr>
<tr>
<td><strong>Double deck</strong></td>
<td></td>
</tr>
<tr>
<td>Wrightbus - New Road Master, Gemini 2</td>
<td>10 to 12m</td>
</tr>
<tr>
<td>ADL – ENVIRO 400H</td>
<td>Typically 60 to 90 passengers</td>
</tr>
<tr>
<td>Volvo – BSLH (Wrightbus Gemini 2 body)</td>
<td></td>
</tr>
<tr>
<td><strong>Articulated</strong></td>
<td></td>
</tr>
<tr>
<td>Volvo – 7900H articulated</td>
<td>Typically 18 m</td>
</tr>
<tr>
<td>EvoBus – Citaro G</td>
<td>Typically 150 – 160 passengers</td>
</tr>
</tbody>
</table>

Source: Element Energy, LowCVP, manufacturers’ website. Note: other hybrid bus developers in Europe include Van Hool, MAN, Solaris and others.
Other alternative hybrid technologies are currently being trialled or introduced to market. The aim of these new systems is to increase fuel savings and the pure electric range of the buses. Some emerging solutions are:

- **Plug-in electric hybrids** have an ICE drivetrain with a larger supplementary battery and electric motor than regular electric hybrids. The battery can be recharged by an external power source (usually a charge point at the depot) and internally via the ICE and regenerative braking system. Examples of plug-in electric hybrids are shown in Figure 13.

- **Flywheel hybrids** use a high speed flywheel to recover and store kinetic energy from deceleration phases, which is mechanically re-used to ease acceleration of the bus and thus save fuel and reduce emissions. UK based engineering company Torotrak demonstrated their ‘Flybrid’ technology fitted to a Wrightbus Euro VI StreetLite bus in October 2015.

- **GPS assisted diesel hybrids** use an on-board GPS system to signal the ICE to turn off when entering ‘geo-fenced’ air quality hotspots, thereby enabling the buses to drive in electric mode in the most air quality sensitive areas. An ADL technology based on their Enviro 400H is currently being tested by TfL and First Group have been trialling two double decker hybrids in Bristol since January 2016.

- **Hydraulic hybrids** use gas accumulators to store energy during braking and hydraulic pump motors to provide secondary motive power to supplement primary ICE power. Whilst the technology can offer up to 25% fuel savings, the accumulators are not as energy dense as batteries so the ICE cannot be turned off and therefore ‘zero emission’ mode is not possible. Artemis Intelligent Power is currently developing an OEM hydraulic hybrid solution.

**NOTE**: companies like Vantage Power and MagTec retrofit existing buses (single or double deck) with hybrid powertrains.

### Costs and funding

Cost premiums for electric hybrid buses are typically between 50% and 80% compared to an equivalent diesel bus. Electric hybrid technologies are eligible for grants under the £30 million OLEV low emission bus fund and also qualify for the Low Carbon Emission Bus incentive (~6p/km) on top of the BSOG. The technology can achieve from 20% to 40% fuel savings compared to a diesel equivalent\(^\text{15}\), and consequently significant CO\(_2\) emission reductions. The payback period of these vehicles can be more than 8 years when no subsidies are available to offset the high cost premium.

Current market availability of single deck plug-in electric hybrid buses indicates a 140% capital cost premium for the vehicle compared with regular diesel buses\(^\text{16}\). This premium is smaller than for other low emission bus technologies and fuel savings are higher than for non-plug-in hybrids (and strongly depend on the electric range).

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\(^{15}\) Lower bound from LowCVP and TfL studies. Upper bound potential stated by manufacturers for single deck buses

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30
Non-electric hybrid buses (flywheel or hydraulic) have significantly lower capital cost premiums (8-12%) and owing to minor fuel savings (10-15%) can generally offer bus operators a payback period of 2-3 years without subsidy. Furthermore, flywheel hybrid buses can generally still function normally if a technical failure to the flywheel occurs – this is advantageous since electric hybrids will not drive if a component from the electric hybrid system fails.

### 2.6 Electric buses

#### Vehicle availability

There are two distinct types of electric bus technology:

- Battery Electric Vehicles (BEVs) have a single drivetrain consisting of an electric motor powered by an on-board battery system therefore producing zero tailpipe emissions and significantly reduced operational noise. Typical driving ranges are 80-190 miles (c.100-300km) with a fully charged battery.

- Plug-in Hybrid Electric Vehicles (PHEVs) have a drivetrain that combines the elements of an ICE with a motor and battery, as described in the previous section.

Currently small BEV fleets are being trialled in eight different regions around the UK. A total of 111 BEVs are operational representing c. 3% of all low emission buses active on UK roads today.

Current battery chemistry restricts the energy density of lithium-ion batteries for BEVs resulting in limited vehicle ranges compared to other LEB technologies. In addition, battery recharging time can take several hours compared to <10 minutes for diesel buses.

Until recently, market availability has been limited to single decker BEVs (see Figure 13) but OEM double decker models are now becoming available. For example, in 2014 UK company Magtec begun trialling a double decker BEV in York. Transport for London started using five BYD full electric double-decker buses in March 2016. Daimler has also announced a battery-electric Citaro model for 2018.

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36 DfT LEB Scheme grant guidance and calculator documents.
37 TTR and TRL for the LowCVP: Barriers and opportunities to expand the low carbon bus market in the UK, 2016
38 http://www.greencarcongress.com/2016/03/20160319-ff.html
Low emission buses

Electric buses development in the UK

**BYD**
- Supplying Nottingham City Council with 13 electric buses plus charging equipment.
- 12m buses with ~150 miles range on a c. 5 hour charge (at the depot).

**ADL & BYD**
- Supplying 51 single decker, 90 passenger battery electric buses to Go-Ahead London. This will be the largest fully electric fleet in Europe.
- Buses will be built on BYD's chassis and use BYD electric drivetrain and battery technology. They will be bodied by ADL.

**Wrightbus**
- Supplied Arriva with 8 electric single decker buses (9.6m, Streetlite midibus) for Milton Keynes. Induction charging so that buses can run 17 hours per day by charging at each end of the route (est. min 80 miles range between charges).

**Optare**
- Have deployed over 80 fully electric buses across the UK and in other countries.
- 12 single decker battery electric buses (60 passengers) operating in York’s Park & Ride scheme.
- 90 mile range with one hour fast recharging. Top ups at the P&R facilities allow 120 mile range per day.

![Figure 14: Electric buses development in the UK](image)

Costs and funding

Owing to the wide range of single decker BEV technologies available, a broad capital cost premium range of 80%-140% is observed compared to regular diesel single decker buses. Nevertheless, indicative fuel savings of 45p/km for a 12m single decker bus are reported compared to a diesel equivalent, which represents £13,500/year with an annual mileage of ~43,000km. Moreover, the maintenance cost of an electric vehicle can be reduced by up to 50% compared to diesel vehicles\(^\text{20}\). Such high savings could offset the significant cost premium in as little as 4 to 5 years.\(^\text{21}\)

In addition, a £30 million OLEV fund is available for low emission buses during 2015-2020, after which prices can be expected to be considerably lower. Similarly to natural gas and hybrid buses, plug-in buses are eligible for the LCEB incentive of ~6p/km. EC funding is also available for trials and has already been used for a current trial in London of 12m full electric buses.

Electric bus charging

Dedicated in-depot conductive charging points are the most common infrastructure solution for BEVs, requiring high voltage (400 V) 3-phase connections. Alternative charging solutions are being trialled to improve the operating cycle and reduce the range anxiety. There are two approaches to charge electric buses:

- Overnight charging involves recharging bus batteries whilst the buses are parked at the depot after a period of operation. Manual conductive charging is described above.

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\(^{20}\) Element Energy, manufacturers' website. Note: other battery electric bus developers are active in Europe. MAGTEC provide completed EV drive systems to retrofit buses up to 12t GVW including traction, battery and charging systems

\(^{21}\) For example, energy consumption figures of 0.4l/km for diesel bus and 1.1kWh/km for electric bus, at £1/l and £0.1/kWh gives a 40% fuel cost reduction in favour of the electric bus. Energy use figures based on TfL London Electric Vehicle Partnership, Electric Buses, 2014 and FCH JU, Urban Buses: alternative powertrains for Europe, 2012.

\(^{22}\) TTR for LowCVP: Barriers and opportunities to expand the low carbon bus market in the UK (Task 2: Review and role of incentive mechanisms), 2014.
and automatic inductive charging eliminates the need for staff to attach charging cables.

- Opportunity charging involves recharging bus batteries during operation to extend the driving range. At strategic points along a bus route, ultra-rapid charging solutions (either conductive or inductive) will be installed to ‘top-up’ battery state of charge. A number of trials have demonstrated different charging strategies balancing the trade-off between charge point power and recharging time:

  - The TOSA articulated electric bus in Geneva is recharged by multiple 400 kW conductive charge points for 15 second intervals along its urban bus route and for 3–4 minutes at the end of the route to fully recharge the batteries.
  
  - Arriva is trialing eight Wrightbus electric buses in Milton Keynes which are recharged by 120 kW inductive charge points for ten minute periods along the bus route.
  
  - Foothill Transit’s 12 Proterra electric buses were operated in California for around 13 hours per day supported by 13 daily charges from 500 kW conductive charge points, typically lasting 5 minutes each.

Some examples are shown in **Figure 15**.

![Figure 15: Overview of charging options for electric buses](image)

<table>
<thead>
<tr>
<th>Charging at the Depot (‘overnight’)</th>
<th>Charging along the road (‘opportunity’)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Manual process</strong></td>
<td><strong>Automated process (e.g. guide via Wi-Fi and/or other sensors)</strong></td>
</tr>
<tr>
<td>Large bus battery required to deliver full range; long charging times (2 to 7 hours, depending on daily top-ups)</td>
<td>Electric range is shorter than overnight-charged buses with brief (2-15 minutes) charging in dedicated areas</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Conductive (plug-in)</th>
<th>Inductive</th>
<th>Conductive</th>
<th>Inductive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cable solutions typically use &lt;60kW systems although up to 200kW possible</td>
<td>Wireless can be preferred for operational reasons</td>
<td>Overhead solutions can use 100–450 kW fully automated systems</td>
<td>Up to 300 kW (Milton Keynes project uses 120kW). TfL to also test systems for hybrid buses (Enviro 400H)</td>
</tr>
<tr>
<td>Most common solution adopted in current trials. Circa £30k per charger</td>
<td>60–300 kW depending on use and battery type</td>
<td>System to be tested by Lothian in UK (for Volvo 7900EH units)</td>
<td>Static only in the UK (dynamic used in S. Korea)</td>
</tr>
</tbody>
</table>

---

20 Element Energy, manufacturers website. Note: other battery electric bus developers are active in Europe. MAGTEC provide completed EV drive systems to retrofit buses up to 18t GVW including traction, battery and charging systems
21 For example, energy consumption figures of 0.4l/km for diesel bus and 1.1kWh/km for electric bus, at £1/l and £0.1/kWh gives a 40% fuel cost reduction in favour of the electric bus. Energy use figures based on TfL London Electric Vehicle Partnership, Electric Buses, 2014 and FCH JU, Urban Buses: alternative powertrains for Europe, 2012.
22 TTR for LowCVP, Barriers and opportunities to expand the low carbon bus market in the UK (Task 2: Review and role of incentive mechanisms), 2014.
2.7 Hydrogen buses

Vehicle availability

Fuel cell (FC) buses use a fuel cell system to convert chemical energy (stored in hydrogen molecules) into electrical energy to power an electric motor. Hydrogen is stored in on-board high pressure tanks with sufficient capacity to give analogous vehicle ranges as regular diesel buses, and current dispensing technology can refill a FC bus in <10 minutes.

Bus availability is limited when compared with other low emission bus technologies. Major OEM Van Hool offers a 12-13m, single deck, non-articulated FC bus and Daimler is currently developing their second generation vehicle expected to be made available in the next few years.

Two small FC bus fleets are being trialled in the UK, 10 FC buses in Aberdeen and 8 in London. Elsewhere in Europe, successful trials and advantages over alternative low emission technologies (zero tailpipe emissions, equivalent diesel driving ranges and refill times) have interested Local Authorities and bus operators. As a result, an initiative has been established between the UK, Germany, Netherlands, Latvia and Italy to coordinate a large scale FC bus procurement exercise to reduce the FC bus capital cost premium. The collaboration follows on from a letter of understanding signed by five major European bus manufacturers (Daimler, Solaris, MAN, Van Hool, VDL bus & coach) in 2014, which expressed OEMs willingness and readiness to deploy 500 FC buses by 2020.

Vehicle range depends on the number of hydrogen storage tanks and generally vehicles are equipped with sufficient storage capacity to support 250-400 km driving ranges (hydrogen storage tank capacity is tailored to route requirements). Drivetrain maintenance of FC buses is more time consuming than for diesel buses due to a lack of experienced technicians, and spare parts availability can be limited. However, both issues have shown significant improvement across UK and EU trials.

Figure 16 shows suppliers currently offering FC buses on the market.

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22 Emerging conclusions from CHIC project (public-private partnership, demo of 56 FC buses between 2010-2016, in eight European countries)
Costs and funding

Currently FC bus capital costs are high (>£600,000\textsuperscript{24}), reflecting low production volumes. However, the next stage of bus trials is likely to involve large scale procurement (as described above), with involvement from multiple cities across Europe, which aims to bring costs down below £500,000 per vehicle\textsuperscript{25}. Bus operators will still require support from public sources, but the lessons learnt from such wide scale deployment could significantly accelerate the commercialisation of FC buses.

FC buses are eligible for the LCEB incentive of 6p/km on top of the BSOG and can benefit from the £30 million OLEV fund for low emission buses. European demonstration projects are funded by the Fuel Cell and Hydrogen Joint Undertaking (FCH JU), an institution focussed on accelerating the development of emerging hydrogen technologies through public-private partnerships.

FC bus fuel consumption is c. 20-25% lower than diesel bus consumption (in energy terms), which can lead to fuel cost savings from operating FC buses.

Hydrogen bus refuelling

Dedicated depot based refuelling solutions are offered by a number of international bulk gas handling organisations (e.g. Air Products, Air Liquide and Linde). Hydrogen refuelling station
configurations can vary significantly but all arrangements dispense hydrogen at 350 bar pressure. There are two main approaches for hydrogen supply:

- **On-site production** of hydrogen involves installing a hydrogen generation unit (employing either water electrolysis (WE) or steam methane reforming (SMR)) with on-site compression and storage equipment at the depot. This option is suited to customers with poor availability of local hydrogen production facilities, and can potentially allow customers to benefit from new revenue streams through providing balancing services to the electricity grid (if WE system is deployed).

- **Delivered hydrogen** involves scheduled delivery of either compressed hydrogen via high pressure tube trailers, or liquid hydrogen via cryogenic trailers to be regassified at the depot. Advantages include reduced infrastructure footprint, fewer components (reduced on-site risk) and better flexibility to respond to increases in hydrogen demand.

### Hydrogen refueling for buses – overview, examples from the UK & EU

<table>
<thead>
<tr>
<th>Hydrogen bus refuelling overview and UK cases</th>
<th>BUs HRS – examples from Europe</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Hydrogen fuel is provided as pressurised gas at 350bar</td>
<td>Bus HRS in Switzerland with on-site electrolytic H₂ production. Total H₂ storage capacity: 450 kg; total footprint: 295 m²</td>
</tr>
<tr>
<td>• On-site fuel production by electrolysis is an option (usually a 3 phase connection is required 11kV or 33kV)</td>
<td>The London bus HRS is a very compact station with a footprint of &lt;35m² and 350kg fixed hydrogen storing capacity (at 500bar). Extra capacity of 900 kg when the station is connected to a 500 bar hydrogen trailer</td>
</tr>
<tr>
<td>• HRS footprint depends on number of buses and H₂ production methods. HRS footprint can be lower than 400 m² for a 10 bus fleet</td>
<td>Bus HRS in Milano with on-site electrolytic H₂ production. Total H₂ storage capacity: 250 kg, total footprint: 330 m²</td>
</tr>
<tr>
<td>• HRS cost for a 10+ bus fleet: around ~ £1m (more if on-site production is included)</td>
<td></td>
</tr>
</tbody>
</table>

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27 [Sources: Element Energy, CHIC project](http://www.fch.europa.eu/sites/default/files/study%20electrolyser_0-Logos_0.pdf)
Low emission buses
3 The West Midlands bus fleet

This chapter focuses on the West Midlands bus fleet. It presents detailed results from the data collection exercise (e.g. stock breakdown by EURO band, fuel efficiency, mileage and depot characteristics) as well as key findings from the bus operator workshop.
3 The West Midlands bus fleet

Over 2,000 buses operate in the West Midlands, using over 230,000 litres of diesel to travel over 515,000 km per day. Local bus operators provide an essential service to the West Midlands population transporting around 275 million passengers per year and significantly reducing traffic congestion on busy roads. Whilst the West Midlands bus fleet is a large contributor to poor local air quality in the region, far greater emissions are offset from encouraging people to take public transport instead of driving.

Fleet data was collected to understand the associated emissions and opportunities for low emission bus refuelling/recharging infrastructure. Findings were presented to local bus operators during a dedicated workshop to discuss availability of low emission buses and infrastructure. Input from local operators helped reinforce assumptions for uptake scenarios and inform the wider LEB Delivery Plan. This section presents findings from the data collection and workshop activities.

3.1 Buses and depots in use

Nine local bus operators (representing over 95% market share of the West Midlands bus fleet) were asked to complete a detailed Excel-based questionnaire to provide information about their bus fleets and depots.

Bus data collected included:
- Total buses in the fleet
- Composition by size (double deck, single deck, midi bus), powertrain and EURO standard
- Typical ownership period
- Annual mileage
- Average fuel consumption

Bus depot data collected included:
- Depot address
- Outdoor and indoor footprint
- Tenure/ownership status
- Utility connections (electricity power capacity, gas grid pressure availability)
- Total bunkered diesel

Additional data was collected independently from bus operators through resources available to Element Energy including DNV GL for detailed local gas pipeline data, National Grid maps for high pressure pipeline, Western Power Distribution website for high voltage power line locations and online map analysis for the footprint of depots.
3.1.1 Current bus fleet

Mileage and fuel consumption

Fuel consumption across the West Midlands fleet is similar across different operators with an average of 38.9l/100km for a single decker, 50.9l/100km for a double decker and 30.8l/100km for a midi bus. However, annual mileage figures vary significantly across different operators, ranging from 3,500 to 80,000 miles per year, therefore weighted averages were used for further analysis: 72,605km for a single decker, 90,707km for a double decker and 71,370km for a midi bus. Results from the data collection exercise are summarised in Figure 18.

Generally, bus ownership periods were consistent across local operators. On average new buses are owned and operated for 13 years for a single decker, 15 years for a double decker and 10 years for a midi bus. To maintain a constant fleet size about 200 buses per year are procured by the nine operators consulted.

Fleet composition

From the consultation exercise, information was obtained for 2,223 buses of the total 2,331 buses operating in the West Midlands, i.e. 95% of the total fleet.

Today Euro II-V buses make up 95% of buses in the West Midlands fleet (Figure 15). Euro III buses still dominate and represent almost half the fleet, indicating that 50% of the buses on the road today are an order of magnitude more polluting than the current emission limit defined by the EU (See Table 7 & Figure 44). All new buses introduced today will need to be at least Euro VI, therefore the share of Euro II-V buses will gradually decline to 2035 as existing, more polluting buses are scrapped.

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28 The DfT VEH0604 table reports c. 15,000 buses and coaches registered in the West Midlands, a number significantly different due to the difficulty in differentiating mini buses and vans.
Evidence for existing commitment to trialling low emission buses was found, with 52 hybrids currently on the road, representing 2.2% of the West Midlands fleet and previous experience with three battery electric buses at Coventry Park and Ride.

Using these data we forecasted the evolution of the future West Midlands bus fleet assuming the total number of buses remains constant (consistent with feedback from operators). Different scenarios for future evolution are described later in Section 4.1.3.

### 3.1.2 Current depot situation

Using depot location information, a map illustrating the geographic distribution of existing operator depots in the region has been developed (see Figure 20). Overall 23 depots have been identified (25 total active depots but three are due to close soon) and their capability to house new low emission bus infrastructure has been assessed.

On average, bus depots host 175 buses (45 single decker, 105 double decker and 25 midi) and with available capacity to store 100,000 litres of diesel on site – equivalent to 3 weeks reserve (in reality only one week of reserve is stored). At the time of writing no existing depots have gas, hydrogen or electric refuelling/recharging infrastructure.
Access to high voltage electricity

Plug-in hybrid and battery electric buses require charging infrastructure at the depot (unless inductive charging along a bus route is adopted). The higher the rated power of the charge point, the faster the battery on the bus will be recharged – currently battery technologies vary significantly and are compatible with rated power between 60-300kW.
Assessing electrical infrastructure at existing depots (i.e. spare capacity of the depot connection and the local network) was not straightforward. Bus operators could not readily provide information on spare capacity at their depot (difference between the capacity they pay for and capacity they actually use) nor spare capacity of the local network. As a result, information provided by the local distribution network operator (Western Power Distribution) on high voltage transformer locations in the area was used as a proxy for depot proximity to high voltage power lines.

We found that no depots are close to a 33kV power line, but around half (11 depots) have an 11kV transformer on site. A further four and seven depots respectively are within 100m and 500m of an 11kV transformer, whilst the final depot, with the poorest electrical infrastructure nearby, is about 1 km from the nearest 11kV transformer.

Access to 11kV transformers is a good indication that depots have access to a 3-phase / 400V grid connection. However, no details on local grid capacity constraints were readily available without making a formal grid connection application to Western Power Distribution for each depot. Therefore for the purposes of this study, we have assumed that depots’ access to 11kV transformers to be the governing electrical infrastructure factor when selecting the most suitable depot(s) for battery electric or plug-in electric bus uptake (but this does not guarantee the installation of charging post will not trigger the need for an upgrade of the connection).

Access to gas grid

Gas buses available to the UK market are refuelled exclusively with compressed natural gas (CNG), which is most cost effectively supplied via the gas grid (or CNG trucks for small volumes). Different gas pressure access points are available and a trade-off must be made between economics (higher pressure grid connections are more costly but require less on-site compression) and Well-to-Tank emissions (background leakage rate is a higher percentage of overall throughput for stations connected to the lower pressure network and more power is needed for compression).

Generally, higher pressure gas grid access is most compatible with bus fleet refuelling: the electricity needed to compress gas before dispensing could represent up to 20% of the production cost per kg of CNG for a Low Pressure (LP) connection compared to only 2-3% for a high pressure connection (Local Transmission System). Furthermore, less compression equipment is needed if higher pressure access is obtained, thereby reducing the overall footprint of the refuelling infrastructure.

Of the 28 depots assessed, 11 have an LTS connection within 1km, including one depot with an LTS connection within 200m (Figure 21). Installing new pipework between refuelling infrastructure and gas grid access points is costly, particularly in urban areas, and therefore minimising distances is a priority.

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29 Gas can also be supplied via trucks as LNG and regasified on-site before dispensing but this supply pathway is not compatible with this study due to the large distances (c. 190 miles) between current LNG import terminals and the West Midlands.

30 Based on the "Feasibility study for the development of an initial CNG/LNG gas network infrastructure" EE report for Birmingham City Council
Footprint and tenure

Bus depots in urban areas are inherently space constrained and since most LEB technologies require dedicated infrastructure, understanding the availability of land at existing depots was essential. Furthermore, LEB fuels requiring on-site compression and storage also require safety distances to be factored into engineering designs. For example, 400-600m² can be taken as a guiding value for a gas or hydrogen refuelling station.

Remaining tenure on existing land leases will also influence a bus operator’s willingness to invest in new infrastructure. Generally, business cases for new refuelling infrastructure installations are made for 10 year periods as a minimum.

Local bus operators indicated that 17 depots have at least 1000m² of outdoor land, which might be used to park buses overnight. Generally, bus depots are highly space constrained but outdoor land can be used as a guiding indication of potentially available land for new infrastructure.

Of the 13 depots for which tenure feedback was provided, seven depots are either owned outright or have over 10 years remaining on their lease. Figure 22 summarises these findings.
3.2 Bus operators’ feedback

3.2.1 Workshop organisation

Bus fleet operators of the West Midlands region were invited to a workshop in September 2015. The objectives of the meeting were to:

- Introduce Centro’s aims for the Low Emission Bus Delivery plan highlighting the national and local context
- Describe the low emission bus technologies available in the UK
- Explain OLEV’s low emission bus funding scheme
- Discuss the scope for future low emission buses uptake
- Clarify refuelling needs and potential locations for new refuelling infrastructure

The session was attended by five bus operators from the West Midlands, namely National Express, Stagecoach, Arriva, Diamond and Johnsons representing more than 2,000 buses in the region out of the total 2,331 (i.e. >85%). Their commitments and outputs will consequently have a direct influence on the future bus fleet.

3.2.2 Workshop outputs

Bus operators agreed that the LEB Delivery Plan will help Centro and Local Authorities take a coordinated approach to access funding and that the strategy will support their own internal bidding process.

The objectives of the LEB Delivery Plan were well received, and most attendees felt the LEB procurement discussions benefitted from an open forum and a clear dialogue with LAs.

Operators were interested in discussing LEB technologies available in the UK, but a number of technical, financial and logistical barriers need addressing before large LEB procurements can be considered. Cost, availability and reliability are the core concerns of operators. The main barriers to LEB adoption or issues encountered with LEB in the past, as reported by bus operators, are summarised in Table 7.

Among the workshop attendees, only one operator (National Express, the largest operator in the region) stated that vehicle emissions affect their procurement strategy and as a result have ruled out any future procurement of gas ICE buses as they do not offer significant emission savings over regular diesel buses. For this reason, the LEB uptake scenarios do not include an explicit role for gas in the West Midlands fleet. Instead gas ICE bus uptake has been grouped with uptake for hybrid buses represented as ‘Hybrid or gas ICE’ in the uptake scenarios (see next section).
### Barriers for large LEB procurement

<table>
<thead>
<tr>
<th>Type</th>
<th>Barriers to LEB uptake</th>
</tr>
</thead>
</table>
| **Technical** | • Poor communication between third parties responsible for different components causing longer maintenance periods and delayed spare part sourcing  
• Back-up diesel buses required due to poor LEB availability  
• Poor data available on LEB drivetrain replacement requirements and residual value  
• Diesel HEV technologies save less fuel than expected  
• Option to operate with hybrid technology deactivated is preferred  
• Drivers need specific training to optimally use LEBs |
| **Logistical**| • Uncertainty around teething period for different LEBs  
• Funding applications require significant administrative resource  
• Depot space for new refuelling/recharging equipment is not readily available  
• Refuelling schedules are inflexible and incompatible with multiple fuels from a single depot  
• Opportunity charging installations can compromise operational flexibility (i.e. cannot change route) |
| **Financial**  | • Cost premium is difficult to commercially justify  
• New business models required to operate LEBs and infrastructure |
| **Regulatory** | • Legislation on co-locating multiple fuel types (e.g. hydrogen with diesel) is unclear |
4 Low emission buses delivery plan

This chapter lays out the Delivery Plan. Starting with LEB uptake scenarios and emission savings, it then describes the enablers needed to support them, e.g. in terms of refuelling infrastructure and other barriers. Areas to prioritise for the rollout of LEBs, to maximise their AQ benefits, are also presented, for each district.
4 Low emission buses delivery plan

The LEB Delivery Plan lays out the pathway to a cleaner bus fleet for the West Midlands. The plan consists of three main elements described in this section: quantification of future fleet emissions and possible reduction through LEB uptake, the description of enablers (in particular infrastructure) needed to support the LEBs, and identification of roads to prioritise for the rollout of LEBs.

4.1 Future LEB uptake and corresponding emission savings

Assuming the West Midlands bus fleet size remains constant to 2035, local operators will procure over 4,300 new buses over the next 20 years. Expansion of the LEB market and commitment to reducing emissions is uncertain, therefore future procurement activities could have different levels of LEB uptake. To represent this, we have developed three new bus sales scenarios for the West Midlands fleet. The sections below describe the market share of technologies and corresponding emission reductions from the three new sales scenarios.

4.1.1 New bus sales scenarios

The new bus uptake scenarios described below take into account expected market availability, technology readiness, policy targets (both regional and national), and are strongly influenced by findings from consultation with local bus operators.

The three new bus sales scenarios are:

- **Baseline scenario**: Diesel ICE uptake continues to dominate bus procurement with a small, growing penetration of hybrid buses (15% by 2035). This scenario does not require any new refuelling infrastructure.

- **Moderate ambition scenario**: Primarily hybrid powertrains, with low sales of fuel cell and battery electric vehicles (Figure 24). LEB sales increase from 41% in 2020 to a majority share in 2030 and 60% by 2035. Market share of diesel bus sales falls by 58% by 2035 compared to 2015 levels. Current depot opportunities are used and new depot/depot upgrade investments are limited.

- **High ambition scenario**: Hybrid technologies in short term, relatively quickly supplemented by zero emission buses (battery and fuel cell electric vehicles). No diesel ICE and 80% zero emission sales by 2035 (Figure 24).

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29 Fleet size could change with introduction of Sprint routes, expansion of Midland Metro routes and the potential introduction of other light rail technologies (e.g. Very Light Rail technology being developed by Transport Design International to connect Black Country locations to the national rail network), but has been kept constant for the Delivery Plan modelling activities due to uncertainty.
In Figure 24, ‘Hybrid or gas ICE’ includes optimised Internal Combustion Engine technologies (e.g. hybrid electric, flywheel, hybrid hydraulic) and gas buses (fuelled by (bio)methane). These technologies offer moderate fuel savings (and subsequent CO₂ emission savings) for a relatively low capital cost premium but only limited NOx emission savings (c. 20% for hybrid electric technologies,32 and no measured advantage for gas for Euro VI buses). As a result, the share of gas buses in the region is unlikely to be high.

The early market share of electric buses represents National Express’s strategy to deploy at least 50 BEVs by 2020 but is contingent on obtaining OLEV support.

The fuel cell electric vehicle (FCEV) early market share corresponds to a 22 FCEV trial currently under development between National Express and Birmingham City Council under the next stage of a fuel cell bus joint procurement strategy led by the FCH JU.

### 4.1.2 The future bus fleet under the baseline scenario

#### Fleet composition

The baseline scenario assumes the current fleet renewal rate is constant and no alternative fuel buses are procured. Figure 25 shows the evolution of the EURO standard composition of the fleet. By 2020, the fleet share of EURO VI buses will increase from 8% to 67% as old EURO III buses are retired. By 2025, 92% of the fleet will be EURO VI.

It should be noted that in March 2016 the West Midlands Bus Alliance partners agreed that by 2020 all buses should be a minimum of EURO V but this is not quite achieved in the baseline scenario. This implies some retrofit of existing pre-EURO V buses will be required to meet this target. Based on current retrofit costs, it would cost c. £1 million to retrofit the remaining 5% pre-EURO V buses.

It is also worth noting that EURO V buses fitted with SCR and not EGR can have worse NOx emissions than EURO IV buses.33 The baseline scenario shows that, based on the usual retirement rates, there will still be c. 650 EURO V buses in circulation. Lowering their emission through retrofit could cost up to £6.5 million.

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32 NAEI, Emission factors for alternative vehicle technologies, 2013 reports a 20% NOx reduction for hybrid buses over Euro V buses but flag an overall lack of evidence, especially for the case of Euro VI

33 DEFRA’s interpretation of EU model COPERT 4(V10): Euro V (with SCR) produces 10.68 gNOx/km at 11km/h compared with 7.37 gNOx/km from Euro IV and 4.39 gNOx/km from Euro V (with EGR)
NOx emissions

Emission intensity data (NOx per km) for vehicles certified to each Euro emission standard is published by the UK Government’s Department of Environment, Food and Rural Affairs (DEFRA). An average speed of 11 km/h for all buses and Defra’s emission factors for buses were used to calculate the impact on emissions of a greater share of EURO VI buses: a reduction of NOx emission levels of over 60% between 2015 and 2020 (Figure 26). Furthermore, by 2035, an 85% reduction in NOX emissions is achieved.

CO2 emissions

Bus manufacturers are not obligated to ensure their vehicles meet a CO2 emission limit (Euro emission standards I – VI only consider Air Quality), but are incentivised to make vehicles more efficient (and less CO2 emitting) in order to reduce bus operator fuel costs.

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34 Absolute numbers are indicative – based on DEFRA emission factors, assuming 11km/h for all buses. EURO VI emissions are 60-85% lower than EURO V and V emissions at 11km/h, but 85-95% lower at speeds >= 30km/h. However low speeds are more representative of the bus speeds in the areas with AQ issues (city centre, congested streets).
Recent reports\textsuperscript{35} suggest technology improvements could reduce CO\textsubscript{2} emissions by 6\% and 8\% for diesel ICE and diesel hybrids by 2030 compared to 2015. Since diesel hybrid penetration is low the corresponding CO\textsubscript{2} emission reduction expected for the West Midlands fleet is c. 6\% by 2035 (Figure 27).

\textbf{4.1.3 The future bus fleet under the moderate & high scenarios}

\textbf{Fleet composition}

Due to the stock turnover, initial uptake of LEBs is slow: by 2025 diesel ICE buses still make up c. 75\% of the West Midlands fleet under both scenarios. However, by 2035, both new bus sale scenarios yield a majority share of LEBs in the overall fleet composition (Figure 28). Zero emission buses make up 30\% and 50\% respectively of the fleet for moderate and high ambition scenarios.

\textsuperscript{35} Based on Alternative powertrains for Europe report - 6\% for diesel by 2030 compared to 2015
**NOx emissions**

Initial fleet NOx emission reductions, consistent across all scenarios, are brought about mainly through the transition to EURO VI buses: LEBs only represent a minor share of the stock. By the 2030s, the LEB uptake scenarios deliver significant emission savings over EURO VI diesel buses through increasing uptake of zero emission technologies (Figure 29). 33% and 54% savings could be realised by 2035 for moderate and high ambition scenarios relative to the baseline.

![Figure 29: West Midlands bus fleet total NOx emissions (t NOx) under three scenarios](image)

**CO₂ emissions**

As outlined above, adopting the baseline scenario would only achieve minor CO₂ emission savings (<5%). In the early years, CO₂ emission savings relative to the baseline from the more ambitious scenarios are small (<10%). However, by 2035, savings of up to 30% could be achieved under the moderate ambition scenario with >50% LEBs in the fleet, of which 30% are zero emission. Furthermore, under the high ambition scenario savings of up to 48% could be reached with 75% LEBs in the fleet (including 50% zero emission buses).

An optimised high ambition scenario (high ambition – green production) describes an option where all fuels are renewably produced, giving c.62% savings relative to the baseline.

---

36 Absolute numbers are indicative only – based on DEFRA emission factors, assuming 11km/h for all buses
**West Midlands bus fleet Well to Wheel CO₂ emissions (kt CO₂)**

<table>
<thead>
<tr>
<th>Year</th>
<th>Baseline</th>
<th>Moderate ambition</th>
<th>High ambition</th>
<th>High ambition - green production</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
<td>267</td>
<td>262</td>
<td>253</td>
<td>258</td>
</tr>
<tr>
<td>2020</td>
<td>258</td>
<td>233</td>
<td>226</td>
<td>226</td>
</tr>
<tr>
<td>2030</td>
<td>211</td>
<td>193</td>
<td>176</td>
<td>113</td>
</tr>
<tr>
<td>2035</td>
<td>202</td>
<td>131</td>
<td>176</td>
<td>-30%</td>
</tr>
</tbody>
</table>

**NOTE ON MODELLING ASSUMPTIONS**

The evolution of fleet and emissions has been modelled based on fleet turnover inferred by the bus ownership period (as reported by bus operators) and constant overall number of buses (2,331) – this is in line with DfT traffic projections that stay constant for buses to 2040. Annual mileages are kept constant at today’s values for each bus segment.

**Energy use**

The 2015 bus fuel use rates are based on numbers reported by operators. The improvement of the diesel engine fuel use is based on the Alternative powertrains for Europe report (6% and 8% for diesel and diesel hybrid by 2030 compared to 2015). Hybrid buses are assumed to bring 28% fuel saving over diesel buses, based on performance reported by Transport for London. 2015 BEV electricity consumption data is based on TFL reported e-bus performances and future improvement is based on (R-AEA, 2012) (7% improvement by 2030). FCEV hydrogen consumption data is from Alternative powertrains for Europe report (15% improvement by 2030).

**NOx and PM emissions**

NOx emissions have been modelled with NOx g/km as per DEFRA emission factors at 11km/h (worst case); assuming 20% reduction from hybrid technologies. FCEVs and BEVs have no tailpipe emissions. PM emissions calculations are not reported as the trends are identical to NOx emissions.

**CO₂ emissions**

DEFRA CO₂ emission factors have been used for diesel (2.67 kgCO₂/l and 0.58 kgCO₂/l for TTW and WTT respectively). Grid carbon levels decrease to 77gCO₂/kWh by 2035 (National Grid ‘Slow progress’ scenario), hydrogen production emissions decrease to 3.5 kgCO₂/kgH₂ by 2035. The ‘Green production case’ assumes carbon free electricity and hydrogen.
4.2 Enablers and infrastructure needs

Specific barriers to adoption of low emission buses are well understood. The high total cost of ownership premium compared to a regular diesel bus, including high vehicle and infrastructure capital costs and uncertain residual values, is the most significant barrier for bus operators. In addition, vehicle reliability, performance, maintenance costs and spare part supply chain are all barriers to adoption that govern bus operators’ procurement decisions.

Operators are likely to incrementally introduce LEBs into their existing fleets and therefore will either need to accommodate multiple refuelling infrastructure options at their existing depots or build new facilities. Both options entail considerable logistical challenges related to land leases, space constraints and access to utilities.

The next sections describe enablers to address these challenging barriers for each LEB technology considered in the Delivery Plan.

4.2.1 Electric buses fleet and recharging needs

The total electric buses implied by the Delivery Plan will require at least four depots to be fitted with charging facilities by 2025. Both the moderate and high ambition scenarios are shown in Figure 31.

**Electric buses in use and corresponding electricity demand**

<table>
<thead>
<tr>
<th>Buses in use</th>
<th>Moderate ambition</th>
<th>High ambition</th>
</tr>
</thead>
<tbody>
<tr>
<td>2020</td>
<td>58</td>
<td>58</td>
</tr>
<tr>
<td>2025</td>
<td>188</td>
<td>195</td>
</tr>
<tr>
<td>2030</td>
<td>313</td>
<td>359</td>
</tr>
<tr>
<td>2035</td>
<td>657</td>
<td>668</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MWh use/day</th>
<th>2020</th>
<th>2025</th>
<th>2030</th>
<th>2035</th>
</tr>
</thead>
<tbody>
<tr>
<td>2020</td>
<td>18</td>
<td>18</td>
<td>49</td>
<td>51</td>
</tr>
<tr>
<td>2025</td>
<td>49</td>
<td>51</td>
<td>81</td>
<td>93</td>
</tr>
<tr>
<td>2030</td>
<td>81</td>
<td>93</td>
<td>126</td>
<td>184</td>
</tr>
<tr>
<td>2035</td>
<td>126</td>
<td>184</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Figure 31: Electric buses in use and corresponding electricity demand*
The c. 700 electric buses in 2035 would need c. 70 GWh, which represents under 1% of the current 24,500 GWh consumed annually in the West Midlands. As such electric buses will not represent an electricity demand challenge. The practical and possible cost challenge will be around the provision of power capacity (GW), as discussed next.

Initial electric bus deployment will be focused on routes with compatible mileages for overnight charging with <100 kW infrastructure (i.e. routes requiring daily mileage under 250 km).

Post-2030, converting over 20% of routes to electric will require addressing routes that go beyond the bus driving range and thus require charging ‘en route’. In addition, space constrained depots might require out of depot charging solutions.

Some extreme cases shown in Figure 32 illustrate that, by 2035, the grid reinforcement need and thus cost will strongly depend on the recharging strategy.

Figure 32: Power capacity needed for the 2035 fleet of electric buses (MW)

Figure 33: Illustrative deployment of 400kW ultra-fast chargers for the 2035 high ambition electric fleet

Assuming average West Midlands bus annual mileage, 20 buses per route, 668 electric buses using 275 kWh/day each, 400kW chargers, charger used once per route only and no sharing across bus routes (worst case scenario)
The size of an acceptable ‘en route’ charging time window, developed by bus operators, will govern the level of deployment and associated cost of ‘en route’ charging solutions. This is illustrated in Figure 33. It shows that fully charging electric buses through 400 kW chargers ‘en route’ would require 83 stops of 30s, or 21 stops of 2 minutes. If this solution was deployed for the entire 2035 electric bus fleet, this would represent an installed capacity of 1.1GW or 0.3GW respectively, i.e. 22% or 6% of the current power demand from West Midlands as a whole but since it is unlikely that all chargers would be active at the same time, the actual in-use power demand will be less and will depend on operator logistics and uptake of demand side response services.

4.2.2 Hydrogen buses fleet and refuelling needs

Hydrogen bus deployment in the near term will be limited to demonstration projects, and infrastructure will be installed as required for these projects. The large bus operators in the West Midlands all use dedicated in-depot refuelling facilities, and in the long term this is likely to be the case for hydrogen buses. To increase station loading and improve economics in the short term, operators could develop facilities with additional publically accessible pumps alongside depots to allow other hydrogen vehicles to be refuelled or consider shared-access refuelling station in the context of a small deployment/trial.

The number of hydrogen buses implied by the Delivery Plan will require new engineering solutions for depot refuelling. National Express and Birmingham City Council are currently involved in NewBusFuel, a pan-European R&D project aiming to resolve a significant knowledge gap around large-scale hydrogen refuelling, i.e. 100s of buses per day compared to 10s of buses per day as is for current demonstration sites. Initial concept designs for Birmingham have identified a potential depot for a small fleet (22 buses) but refuelling infrastructure for a large 200 FC bus fleet would require a new depot to be built.

### Hydrogen buses in use and corresponding hydrogen demand

<table>
<thead>
<tr>
<th>Buses in use</th>
<th>Hydrogen fuel cell buses in use and corresponding hydrogen demand</th>
<th>Moderate ambition</th>
<th>High ambition</th>
</tr>
</thead>
<tbody>
<tr>
<td>2020</td>
<td>Trial on 1 route with a dedicated refuelling station</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>2025</td>
<td>c. 5% of routes converted</td>
<td>75</td>
<td>83</td>
</tr>
<tr>
<td>2030</td>
<td>All operating from one depot with a very large station (eg. 4t/day) or across several depots with smaller stations</td>
<td>135</td>
<td>181</td>
</tr>
<tr>
<td>2035</td>
<td>c. 5-10% of routes converted</td>
<td>240</td>
<td>485</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tonnes H₂/day</th>
<th>2020</th>
<th>2025</th>
<th>2030</th>
<th>2035</th>
</tr>
</thead>
<tbody>
<tr>
<td>2020</td>
<td>0.5</td>
<td>1.4</td>
<td>2.6</td>
<td>4.9</td>
</tr>
<tr>
<td>2025</td>
<td>0.5</td>
<td>1.6</td>
<td>3.4</td>
<td>9.9</td>
</tr>
</tbody>
</table>

Source: Element Energy modelling. Based on electrolysis efficiency improving over time, corresponding to 52 kWh/kgH₂ in 2020 and 50 kWh/kgH₂ in 2035 (from c. 56 kWh/kgH₂ today).
4.2.3 Other enablers for uptake of low emission buses

In addition to LEB refuelling infrastructure enablers described in Sections 4.2.1 and 4.2.2, there are a number of relevant vehicle technology requirements needed to support the future fleet of non-diesel buses.

An overview of barriers to LEB uptake was provided in Table 6. In this section we aim to set out the key elements expected to enable the moderate and high ambition scenarios to be realised.

Cost

Bus payback times are dependent on capital and operating costs, and vary significantly from one technology to another. Analysis suggests that a 7-8 year payback period is needed for a bus technology to reach 10-20% market share of annual sales, and 5 years or less is needed for significant uptake (50-80%). Anything with payback exceeding 10 years will only be considered by a small minority of the market.38

In the absence of any fiscal incentives, BEV ownership (including infrastructure) is expected to have a payback period of five years compared to a regular diesel bus,39 whereas the cost premium of owning and running diesel hybrids would not be recovered within the bus lifetime. However, if the regular BSOG (available for any diesel bus) and the supplementary uplift (available for LEBs achieving 30% CO₂ emission savings to similar sized diesel bus) are available, the payback period for BEVs and gas-ICE buses would be seven years. This payback time is compatible with a 20-30% market share of BEV/FCEV sales in the early years, but from 2035 the scenarios require 30-50% market share of pure electric vehicle uptake. Therefore vehicle capital costs will need to fall and payback periods reduce to at least 5 years before BEV/FCEVs get high levels of procurement interest.

Incorporating alternative, less mature technologies into commercial operation will naturally have risk implications. LEB manufacturers can offer extended warranties (compared to standard diesel bus warranties) to share some of the risk premium.

A number of ‘early adopter’ bus operators trialling hybrids, BEVs and FCEVs have successfully trained technicians to maintain LEB drivetrains in-house. However, less experienced bus operators are faced with additional subcontracting costs when procuring new LEB technologies (e.g. with compressed gas or high voltage systems). LEB manufacturers could offer to train bus operator technicians at reduced cost or during larger workshops as interest increases. This approach would enable operators to foster internal expertise and knowledge, which could incentivise continued interest in a particular LEB technology and reduce overall maintenance costs.

Performance

Commercial bus operation and maintenance has many logistical complexities therefore minimising interference with day-to-day depot operation is essential. LEB technologies must offer the same performance as a regular diesel bus if high levels of uptake are to be achieved.

Significant progress has been made to address start up times of LEB technologies thereby

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38 TTR for LowCVP: Barriers and opportunities to expand the low carbon bus market in the UK (Task 2: Review and role of incentive mechanisms), 2014.
39 Excluding BSOG (adopted by many UK bus operators today) gives diesel vehicles a particularly unfavourable payback
enabling hybrid, gas-ICE, electric and hydrogen buses to be operated on commercial bus routes.

Today diesel hybrids exhibit similar expected ranges and refuelling times of a standard diesel bus but improvements can still be made to FCEV refuelling times, whilst BEV uptake is impeded by low range and also high recharging times. Relevant bodies are working to optimise hydrogen dispenser flow rates to meet the desired 3-5 minute/fill target – once reached this will enable a FCEV to replicate diesel bus performance. A variety of innovative on-route recharging configurations are being tested to extend operational BEV ranges and charge point power ratings are being increased to bring BEV charge times closer to the diesel target.

LEB technologies must exhibit equivalent availability (ability for a bus to operate as planned) to standard diesel buses before bus operators will consider extending LEB activities beyond small demonstrations. Whilst recent trials report promising availability for hybrid, BEV and FCEV drivetrains, overall vehicle availability is the most relevant factor. A poor spare part supply chain and a scarcity of qualified LEB technicians has delayed maintenance activities, requiring diesel vehicles to be substituted into the LEB fleet. High levels of LEB uptake will only be achieved once LEBs show >95% availability.

A number of bus manufacturers have internally discontinued LEB development activities causing significant problems for bus operators if spare parts or vehicle information is needed for repairs. To provide greater confidence in the LEB market, manufacturers could make clear, long-term commitments to the development and maintenance of particular LEB technologies.

Choice

Today there is a low market availability of low emission bus models in the UK compared with the standard diesel bus market. As more LEBs are introduced increased competitiveness and marketing are likely to enable increased uptake. Furthermore, bus leasing organisations widening their vehicle offering to include LEBs will allow smaller, less financially secure bus operators to engage with LEBs.

4.3 Areas to prioritise for greatest air quality impact

Maps showing priority deployment roads/routes for LEBs have been developed for each district with input from relevant Air Quality officers. This section describes the approach and sets out the resulting maps.

4.3.1 Approach and overall map of priority routes for LEBs

In accordance with the European Union’s Air Quality Directive, the West Midlands Local Authorities have each identified the most severe AQ hotspots in their districts accounting for areas of exceedance as well as levels of exposure. To inform the Delivery Plan, the LAs overlaid their AQ hotspot maps with local bus route data. This information was used to identify the areas where LEBs would most benefit local air quality.

AQ hotspot modelling methodology differed across the six LAs in the region and outputs are not easily comparable, therefore each district has been analysed independently. As such the priority levels shown next apply at district level only.
Figure 35 shows a summary of priority bus routes or roads for LEB deployment in the West Midlands.

The priority bus routes or streets for deployment are shown in Figure 35. Annotated maps for each district are shown next. This map was also developed under GoogleMaps, to become an easy to update shared tool for WMCA, the districts and bus operators. National Express used the first version of the map for their LEB strategy (for the OLEV bus scheme application) and gave positive feedback.
4.3.2 District level results

Birmingham

Birmingham City Council’s AQ monitoring activities revealed that annual mean NO\textsubscript{2} levels and the 24 hour mean PM\textsubscript{10} level are exceeded. To improve local AQ and GHG emissions, the City Council introduced a 60% CO\textsubscript{2} reduction target by 2027 (compared to 1990 levels) and implemented a Statutory Quality Partnership Scheme (SQPS) stipulating all local service single decker buses to be Euro 4 (core operation) or Euro 3 (complementary operation), and all double decker buses to be Euro 3 (core operation) or Euro 2 (complementary operation). The SQPS zone is currently limited to an area within the City Centre ring road. This will be extended to the full ring road area in the coming years, and threshold amended to higher EURO standards.

The introduction of the Clean Air Zone (as per DEFRA new AQ action plan) will mean other vehicles than buses will also need to meet a given EURO standard.

As the largest district with the most congested roads in the region, the greatest share of prioritised routes are in Birmingham. Six primary bus routes into the city centre, where there are high levels of NO\textsubscript{2}, have been identified as priority (see Figure 36).

![Figure 36: Priority areas for Low Emission Buses deployment – Birmingham](image)

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Absolute numbers are indicative only – based on DEFRA emission factors, assuming 11km/h for all buses
Coventry

Annual mean NO\textsubscript{2} levels have been found to exceed permitted levels in Coventry by the Council’s AQ monitoring division. Furthermore, high PM2.5 concentrations in the district are estimated to have contributed to the death of 168 people aged 25 or over in 2010. As such, the district has identified four priority areas from internal modelling activities (see Figure 37).
Dudley

Annual mean NO₂ levels have been found to exceed permitted levels in Dudley. The council has attributed 19% of total NO₂ emissions to buses, and has identified 13 AQ hotspots – operating LEBs in locations 1 to 3 would achieve the greatest impact on total NO₂ emissions (see Figure 38).
Sandwell

In Sandwell, the NO₂ annual mean levels exceed the set threshold and ten areas have been identified as NO₂ hot spots. Among these, four are relevant to buses and would benefit most from Low Emission Buses (see Figure 39).

For example, Bearwood Road is a key priority area for the Delivery Plan since buses, despite representing 6% of the traffic, account for 57% of NO₂ and 32% of PM emissions.

Figure 39: Priority areas for Low Emission Buses deployment – Sandwell

<table>
<thead>
<tr>
<th>Street or road name</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A4092 Bearwood Road</td>
</tr>
<tr>
<td>2</td>
<td>Blackheath Town Centre</td>
</tr>
<tr>
<td>3</td>
<td>Horseley Heath</td>
</tr>
<tr>
<td>4</td>
<td>All Saints Way / Newton Road</td>
</tr>
</tbody>
</table>

Low emission bus priority deployment in order of priority
Walsall

In Walsall, NO\textsubscript{2} emission exceedances have been identified for both the hourly and annual mean. As part of this study, the Walsall Council has identified nine hotspots where Low Emission Buses would have the greatest impact on NO\textsubscript{2} emissions (Figure 40).

![Map of Walsall showing priority areas for Low Emission Buses](image)

**Low emission bus priority deployment in order of priority**

<table>
<thead>
<tr>
<th>Street or road name</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 A34 Green Lane</td>
</tr>
<tr>
<td>2 A34 Bloxwich High Street</td>
</tr>
<tr>
<td>3 B4210 Bloxwich Lane</td>
</tr>
<tr>
<td>4 A4148 Pleck Road</td>
</tr>
<tr>
<td>5 A4148 Bescot Road</td>
</tr>
<tr>
<td>6 A461 Lichfield Street</td>
</tr>
<tr>
<td>7 A461 Lichfield Road</td>
</tr>
<tr>
<td>8 A4138 Darlston Road</td>
</tr>
<tr>
<td>9 Wednesbury Road</td>
</tr>
<tr>
<td>10 A454 Wolverhampton Road</td>
</tr>
</tbody>
</table>

*Figure 40: Priority areas for Low Emission Buses deployment – Walsall*
Wolverhampton

In the district of Wolverhampton, both NO₂ (annual mean) and PM10 (24-hour mean) exceed the legal thresholds. Introducing Low Emission Buses will help address these issues, in particular in the nine areas illustrated in Figure 41. Among these, Broad Street is the highest priority, followed by sites labelled 2 to 6.

Figure 41: Priority areas for Low Emission Buses deployment – Wolverhampton
Solihull

Air Quality is not monitored in Solihull and therefore no AQ Management Areas have been identified. Nonetheless, three areas with local AQ issues and high bus traffic have been identified, to prioritise LEB deployment (see Figure 42). In addition, Solihull Council is implementing a Statutory Quality Partnership Scheme (SQPS) across the town centre, which will contribute to the accelerated delivery of lower emission buses in the area.

### Low emission bus priority deployment in order of priority

<table>
<thead>
<tr>
<th>Street or road name</th>
</tr>
</thead>
<tbody>
<tr>
<td>1  B425 Lode Lane</td>
</tr>
<tr>
<td>2  Station Road / Poplar Road</td>
</tr>
<tr>
<td>3  A34 / B4102 radial corridor</td>
</tr>
</tbody>
</table>

**Figure 42**: Priority areas for Low Emission Buses deployment – Solihull
5 Recommendations and next steps

This chapter summarises the overall findings from the work and draws recommendations for the WMCA and the Local Authorities to implement the Delivery Plan.
5 Recommendations and next steps

Background and approach

The Low Emission Bus Delivery Plan describes a moderate and high ambition scenario for future uptake of LEBs to 2035. The scenarios are expected to bring 30-55% NOx emission savings and also reduce CO₂ emissions by 30-50% from the total West Midlands bus fleet.

A number of barriers to adoption of LEBs can only be addressed on a national or European level (e.g. low market availability, high capital costs), but opportunities have been identified for Local Authorities and the WMCA to support bus operators transition to a low emission bus fleet, summarised below in the following recommendations:

Incentives

A number of incentives, both push (e.g. DEFRA’s Clean Air Zones, Centro’s Statutory Quality Bus Partnerships) and pull (e.g. DfT’s supplementary Bus Service Operator Grant), have successfully encouraged local bus operators to reduce their fleet emissions and adopt LEB technologies, but only on a small scale.

Recommendations for the West Midlands Bus Alliance:

• Continue plans to expand Statutory Quality Bus Partnership boundaries, thereby excluding more high polluting buses from a greater number of bus routes.
• Introduce an award scheme to recognise the most proactive bus operator(s) and allow winners to publicise success across their fleet.
• Illustrate areas with most severe Air Quality issues via LA and/or WMCA website(s), highlight on-going efforts to improve AQ in relevant areas in particular ‘clean bus routes’.
• Consider developing a ‘West Midlands clean bus fund’, potentially by pooling BSOG payments (as for Better Bus Areas) and distributing to most progressive operators. As 80% of subsidised routes are run by smaller operators, this would give them the option to join in the transition towards LEBs.

Funding

National and European governments have shown long-term commitments to provide financial support for LEB deployment. However, unfamiliarity with funding application documents and narrow application submission deadlines can often exclude smaller operators from participating in funding rounds.

Recommendations for the West Midlands Bus Alliance:

• Host workshops for local bus operators to inform them of funding streams available and relevant deadlines, and to share key learnings and feedback from accepted or rejected applications.
• Investigate the options and feasibility of providing financing solutions, e.g. low interest rates to support purchase of high capex LEBs.
• Proactively lobby for funding support schemes to reduce emissions from buses.

At national level, long term commitments from Government to differentiated incentives (e.g. BSOG) should be provided, so that as capital costs come down, investment decisions can be made on payback periods and ongoing cost savings rather than requiring up-front funding.

Another consideration for Government would be to devolve some of the national funding to the region that in turn would use it to implement the Delivery Plan.

Data sharing
Multiple LEB trials are underway in the West Midlands but dissemination of results from the trials is poor. Many bus operators have stated that understanding the real-world performance of LEBs would greatly support their investment decisions.

Recommendations for WMCA:
• Act as an independent party to collate, verify and anonymise (where possible) LEB and infrastructure performance data to be shared with all bus operators in the region.
• Create local forum to share experience and learnings with LEB technologies; the forum should include operators operating in the region but should also link with existing platforms (such as the LowCVP Bus Working Group) to benefit from and bring wider national learnings back to local operators.
• Work with Local Authorities to agree a prioritisation for LEB deployment across the region; this could be supported by a common air quality modelling framework.

Infrastructure
New LEB infrastructure requires space, utility connections and effective interpretation of regulations, codes and standards – tasks that bus operators generally have little experience with. Furthermore, slow responses to applications for planning consent or gas/electricity grid connections can impact operators’ willingness to consider LEB procurement.

Recommendations for WMCA and Local Authorities:
• Establish constructive dialogues between internal environmental/transport and planning departments of Local Authorities, and consider introducing an agreement to expedite planning applications relating to developments that would bring environmental benefits to the region.
• Coordinate communication to gas and electricity grid operators to streamline
Recommendations and next steps

Technically complex grid connection activities.

- Promote cooperative ownership models allowing multiple operators to share infrastructure maximising utilisation in early years of deployment.
- Identify and make suitable council owned land available for new shared infrastructure or new depot facilities.
- Ensure that any recharging infrastructure outside depots (e.g. ‘en route’) should be harmonised/consistent with emerging standards, to minimise operator lock-in or monopoly.
- Request local bus operators with wider UK experience (e.g. National Express, Arriva, Stagecoach) to share knowledge and experience of infrastructure from deployments beyond the West Midlands.

Low carbon sources

The primary objective of the Delivery Plan is to improve local Air Quality. However, as LEB technologies mature, ensuring a low carbon fuel supply will be important for meeting the UK’s decarbonisation targets.

Various proxies enable buses to be supplied with renewable fuel (e.g. Green Gas Certificates for (bio)methane or green tariff Power Purchase Agreements for electricity) but their availability can be limited. In future, co-locating new bus depots and low carbon generators with a private wire connection (e.g. siting a depot for hydrogen refuelling with on-site electrolytic hydrogen production adjacent to a wind farm, or a depot for electrical recharging near an anaerobic digestion plant) could ensure renewable energy supply and bring economic savings from reduced grid connection and grid reinforcement costs and avoided distribution and transmission network charges.

 Provision of low carbon fuel supply for the region should be coordinated across all relevant transport modes and is discussed in greater detail in the Birmingham City Council ‘A city blueprint for low carbon fuel refuelling infrastructure’.

Recommendations for West Midlands Bus Alliance:

- Establish a dialogue between local renewable generator project developers and bus operators, e.g. to incentivise co-locating renewable generators with new bus depot facilities.
- Ensure integration between the evolving regional energy system and the transport system is considered in the region’s strategies.

The main recommendations are summarised in Figure 43, along with the key milestones of the LEB Delivery Plan.
Other alternatives are not included because they do not require dedicated infrastructure (hybrid vehicles, low blend biofuels) or their uptake among fleet is not expected to require an infrastructure beyond a depot-based tank (high blend biodiesel, used cooking oil).

Suggested timeline and key milestones to support LEB delivery plan

<table>
<thead>
<tr>
<th>Year</th>
<th>All technologies</th>
<th>Fuel cell</th>
<th>Electric</th>
<th>Push</th>
<th>Pull</th>
<th>Innovations</th>
<th>Refuelling/recharging infrastructure</th>
<th>Low carbon sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
<td>FCH JU topic 1.6 deadline(^1)</td>
<td>Develop concept for West Midlands Low Emission Bus Fund (^1)</td>
<td>NewBusFuel(^2)</td>
<td>Provided support with third parties (network operators, planning authorities, land owners)</td>
<td>At least 2 depots with charging facilities and 1 hydrogen station</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2020</td>
<td>DfT Low Emission Bus Scheme; £30m grant funding through multiple calls</td>
<td>Electric</td>
<td>zeEUS(^3)</td>
<td>Outputs from trials of medium-sized hydrogen bus fleets (&gt;20 buses)(^1)</td>
<td>4-6 depots with charging facilities and 1 large hydrogen station (4t/day)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2025</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Integrate urban energy system and transport planning considerations as LEB fleet sizes grow</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Market share (new bus sales)

- Hybrid or gas ICE: 16% (2015), 21-24% (2020), 21-24% (2025)
- Electric: 12% (2015), 17-19% (2020), 17-19% (2025)
- Fuel cell: 4% (2015), 8-9% (2020), 8-9% (2025)
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6 Appendix
6 Appendix

6.1 EURO standards and NO₂ and Particulate Matter thresholds

6.1.1 The EURO standards

Since the early 90’s, the EURO standards have been implemented by the European Union setting mandatory emission limits for the new vehicle sales. Following the timescale presented in the Table 8, every new vehicle had to comply with the on-going restrictions.

These increasingly restrictive norms (See Figure 44) demonstrate a very efficient results in terms of technologies enhancement from the OEMs thanks to particulate filter and selective catalyst reduction. The implementation of such a legislation aimed to improve the welfare and the health of the European citizens.

![Table 8: EURO standard introduction dates (heavy duty vehicles)](image1)

![Figure 44: EU emission standards for heavy duty vehicles under steady state testing (NOx and PM)](image2)
6.1.2 Legal limits

Action to manage and improve air quality is largely driven by European (EU) legislation. The 2008 ambient air quality directive (2008/50/EC) sets legally binding limits for concentrations in outdoor air of major air pollutants that impact public health such as particulate matter (PM10 and PM2.5) and nitrogen dioxide (NO₂). This Directive was made law in England through the Air Quality Standards Regulations 2010. Table 9 provides the concentration thresholds of the main pollutants.

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Concentration</th>
<th>Averaging period</th>
<th>Permitted exceedances each year</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO₂</td>
<td>200 µg/m³</td>
<td>24 hours</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>40 µg/m³</td>
<td>1 year</td>
<td>n/a</td>
</tr>
<tr>
<td>PM10</td>
<td>50 µg/m³</td>
<td>24 hours</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td>40 µg/m³</td>
<td>1 year</td>
<td>n/a</td>
</tr>
<tr>
<td>PM2.5</td>
<td>24 µg/m³</td>
<td>1 year</td>
<td>n/a</td>
</tr>
</tbody>
</table>

Table 9: Main pollutants limits that UK Local Authorities are in charge of respecting
About the authors

**Element Energy Limited** is a low carbon consultancy providing a full suite of services from strategic advice to engineering consultancy in the low carbon energy sector. Element Energy’s strengths include techno-economic forecasting and delivering strategic advice to clients on all opportunities connected to the low carbon economy. Element Energy has experience in the design of strategies for the coordinated deployment of low carbon infrastructure.

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Reviewer
Alex Stewart, Element Energy, Director

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Notes on maps
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