Post-2014 London Hydrogen Activity: Options Assessment

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Author
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This study, funded by the London Hydrogen Partnership (LHP), assesses the future of hydrogen transport activities in London in light of past trials, new initiatives and industry trends.

It presents a series of recommendations on the steps required to protect and expand London’s existing bus fleet and refuelling infrastructure as well as a brief consideration of opportunities beyond buses.

Hydrogen fuel cell technology is one of very few genuine pathways to zero carbon transportation. To date London has been involved in a number of projects to trial the technology and assess its suitability for the capital.

More information on hydrogen as a fuel and its advantages can be found on: www.london.gov.uk/lhp/hydrogen.

Please note that all data contained within this report is based on initial budget costing from suppliers and is subject to change in the future. The analysis is prepared as information to guide policy decisions but the figures in this report should not be used for budgeting purposes without first confirming cost and performance data from suppliers.
Structure of the Study

Review of Hydrogen Fuel Cell Technology for Buses
- Global Development of Hydrogen Bus Projects
- Performance, Commercialisation and Capital Costs of Hydrogen Buses

The Existing Hydrogen Fuel Cell Bus Fleet in London
- Background and Performance of the Existing RV1 Bus Fleet
- Cash-flow Scenarios for Continuing RV1 Operation

Scope for New Hydrogen Buses and Infrastructure in London
- Strategies and Scenarios for Operating New Hydrogen Buses
- Environmental Justifications and Benefits of New Hydrogen Bus Projects
- Funding Opportunities for New Buses and Infrastructure

Hydrogen Opportunities Beyond Buses
- Global Development of Hydrogen Transport
- The UK and London as an Early Hydrogen Adopter
- Present and Future Opportunities for New Hydrogen Fuelled Transport in London
Review of Hydrogen Fuel Cell Technology for Buses

- Global Development of Hydrogen Fuel Cell Bus Projects
- Performance, Commercialisation and Capital Costs of Hydrogen Buses
Fuel Cell technology for buses has a growing presence in Europe

**CHIC project**
- Cologne – 2 buses
- Hamburg – 10 buses
- Bolzano – 5 buses
- Aargau – 5 buses
- London – 8 buses
- Milano – 3 buses
- Oslo – 5 buses

**High V.LO-City project (confirmed cities)**
- Liguria – 5 buses
- Antwerp – 5 buses
- Aberdeen - 10 buses (with the HyTransit project)

**Independent projects**
- Amsterdam – 2 buses
- Arnhem – 1 bus
- City of Barth – 1 midi-bus
- Dusseldorf – 2 midi-buses
- Hamburg hospital – 1 midi-bus
- Neratovice – 1 bus
By the end of 2012, almost 120 fuel cell buses will be in day to day service worldwide. More than 20 cities have tested the technology.

Hydrogen Fuel Cell bus projects beyond Europe are concentrated largely in the East and West Coast of the USA and Japan.

- **BC Transit trial (CHIC Phase 0 partner)**
- **Zero Emission Bay Area (ZEBA) bus trial**
- **Other main FC bus demonstrations**
An industry led study (NextHyLights) has mapped the pathway to commercialisation for hydrogen buses

The NextHyLights project includes a study into the future of Hydrogen Buses. The study included in-depth market research with all of the key players in the hydrogen bus sector. The project represents a consensus view of a cross section of the H2 industry on the potential of hydrogen buses. The study has made some important recommendations for the future of Hydrogen buses:

- Hydrogen buses are expected to achieve a reliability equivalent to diesel buses in the current generation of hybrid fuel cell vehicle trials (the CHIC and High V.Lo City projects).
- Once reliability targets are achieved the key barrier is commercial – hydrogen buses currently have a Total Cost of Ownership (TCO) at least four times that of an equivalent diesel or diesel hybrid bus.
- This cost barrier will be reduced by a combination of technology developments and through increased volumes in the passenger car segment, which reduce component costs through economies of scale.
- Prolonging the life of existing bus fleets to similar levels as diesel buses (approximately 7 years of operation in London and over 10 years overall) will prove another important aspect of the economic viability of hydrogen buses.

Selected results of the study are provided in subsequent slides.

The FCH JU is also conducting an expanded study of all of the bus drivetrains, which will report by the end of 2012 and add weight to this debate.

More information can be found here: www.nexthylights.eu
Increasing numbers of OEMs are competing globally in the manufacture of fuel cell buses.
## Fuel Cell buses could outcompete all other drivetrains’ overall environmental performance

<table>
<thead>
<tr>
<th></th>
<th>Operating benchmark</th>
<th>Hybrid Fuel Cell</th>
<th>Hybrid Diesel</th>
<th>Battery</th>
<th>Trolley</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fuel Economy</strong>*</td>
<td>Diesel bus: 0.35 - 0.5 litre/km (~ 3.5 – 5 kWh/km)</td>
<td>Up to 40% improvement over an equivalent diesel route at parity of calorific content</td>
<td>Up to 25% - 30% improvement over an equivalent diesel route</td>
<td>NA</td>
<td>Up to 50% improvement over an equivalent diesel route</td>
</tr>
<tr>
<td><strong>Range</strong></td>
<td>≥ 500 km (for urban service)</td>
<td>Up to 500 km</td>
<td>Equal to diesel buses</td>
<td>&lt; 100 km</td>
<td>-</td>
</tr>
<tr>
<td><strong>Pollution from Exhausts</strong></td>
<td>CO, NOx, SOx, PMs</td>
<td>Water vapour only</td>
<td>CO, NOx, SOx, PMs (up to 30% reduction over benchmark)</td>
<td>Absent</td>
<td>Absent</td>
</tr>
<tr>
<td><strong>CO2 emissions</strong></td>
<td>1.15 – 1.6 kg CO2/km (diesel fuel carbon content: 2.3 kg/litre)</td>
<td>Depends on the hydrogen carbon content. Up to 100% reduction over benchmark (e.g. renewable hydrogen)</td>
<td>Up to 30% reduction over benchmark</td>
<td>Depends on the electricity carbon content. Up to 100% reduction over benchmark (e.g. renewable electricity)</td>
<td>Depends on the electricity carbon content. Up to 100% reduction over benchmark (e.g. renewable electricity)</td>
</tr>
<tr>
<td><strong>Infrastructures</strong></td>
<td>Minimal (maintenance depots and diesel refueling points)</td>
<td>Need of hydrogen refuelling infrastructures (at bus depots) and delivery networks</td>
<td>Equal to diesel buses</td>
<td>Need of recharging infrastructure (at bus depot or along bus route)</td>
<td>Need of overhead contact wire networks throughout all bus route (approx. €400,000 - €1,000,000 per kilometre including substations)</td>
</tr>
<tr>
<td><strong>Operational flexibility</strong></td>
<td>--</td>
<td>Equal to diesel buses</td>
<td>Equal to diesel buses</td>
<td>Current range limitations (&lt;100 km) constrain operational flexibility</td>
<td>Bus will be fixed to particular routes limiting operational flexibility</td>
</tr>
</tbody>
</table>
Achieving diesel level availability is the aim of current trials – once this is demonstrated, the main remaining barrier will be the vehicle cost.

Hydrogen FC bus trials, such as the European CHIC in which London is participating, High V.LO-City or HyTransit, are producing data about the reliability of the technology and ultimately aim to demonstrate that FC buses can provide an equivalent level of service to diesel buses.

The CHIC project for example intends to provide results from the demonstration of more than 55 hydrogen buses across Europe. This trial draws on information from past trials in Germany and Canada and also involves additional cities that do not currently deploy vehicles but are interested in learning about the technology.

The main objectives of these trials are to prove the technical ability of the buses, provide information about their fuel economy, maintenance procedures and troubleshoot any unexpected problems. Another important aspect of the testing is to report on the environmental, economic and social impact of the use of FC buses in daily public transport operation.

Once the reliability has been demonstrated, the main remaining barrier to the commercialisation of hybrid fuel cell bus technology is its high cost.

The current capital cost of a hybrid fuel cell bus is approx. five times the cost of a conventional diesel bus, whilst its ownership cost is approx. four times higher.

Costs are currently driven by:

• The very high Capex and Opex of the fuel cell system – this is expected to decrease with time and volume of sales in the bus and passenger car segments.

• The various additional costs incurred by the bus OEMs in manufacturing the buses on a very small volume – these include additional labour costs, one-off tooling and a “risk premium”, where manufacturers require higher margins to enter new segments of the bus market.

• High costs for the basic hybrid drivetrain components (even diesel hybrid buses still do not offer a favourable ownership cost comparison with conventional diesel buses).
The capital cost of FC buses has substantially decreased over time and this decrease is expected to continue.
A bottom-up assessment gives an overview of the source of high costs.

Hybridised Fuel Cell Buses: Cost Break-down 2010 - 2020

N.B.: Cost figures for 12 metres, low floor hybrid fuel cell buses only. Buses are assumed to be powered by a 150kW fuel cell system. Cost figures are based on industry’s projections and several assumptions. For a detailed discussion, please refer to: NextHyLights, deliverable 3.1, [http://nexthylights.eu/](http://nexthylights.eu/).
The chart below shows that in the years 2018 to 2022 FC buses will be competitive with Trolley buses and that from 2025 onwards they will also be competitive with diesel buses.

N.B.: Cost figures for 12 metres, low floor hybrid fuel cell buses only. Buses are assumed to be powered by a 150kW fuel cell system. Cost figures are based on industry’s projections and several assumptions. For a detailed discussion, please refer to: NextHyLights, deliverable 3.1, [http://nexthylights.eu/](http://nexthylights.eu/)
The Existing Hydrogen Fuel Cell Bus Fleet in London

- Background and Performance of the Existing RV1 Bus Fleet
- Cashflow Scenarios for Continuing RV1 Operation (beyond CHIC funding obligations)
Background

The TFL hydrogen bus fleet has been operating since December 2010 (RV1 route).

A total of five buses have been commissioned (as of March 2012).

Three buses are now in the final stages of the build and will shortly be delivered to site.

The existing bus fleet in London has demonstrated the potential of the technology, but has suffered from poor performance by the contractor.

Performance

The actual technology has been performing very well. When a bus leaves the maintenance facility it is very unlikely to suffer a road call and tends to fulfil its planned duties for the full 19 hour day. This is a major step forward from the previous CUTE trial which has a maximum 12 hour day.

TfL management estimate that if it were not for issues directly related to the contractor issues the technology is capable of achieving close to 95% availability (the benchmark for success)

The buses are achieving excellent efficiencies of around 8kg/100km (CUTE was 25kg/100km)

However, the original lead contractor – system integrator ISE, went into Chapter 11 bankruptcy just before delivery of the first buses. The company was taken over by a small Belgian technology firm – Bluways.

Since then, the support for the buses has not matched the standards associated with standard diesel products. This has led to considerable delays in maintenance for all parts on the bus (e.g. fixing a broken window can take days). This leads to poor availability figures as shown in the breakdown on the following slides. This problem has also delayed production of the final 3 buses.

Recently, a new contract was established between TfL, Ballard and First Group aiming at improving the maintenance and availability of the buses.

TfL Conclusions

Hydrogen fuel cell technology works and is capable of meeting TfL’s technical needs

TFL would like to protect the initial investment in the RV1 fleet by continuing its operation for at least 4 more years.

For future projects, the contract should always be with a bus OEM, who should act as the sole contractor for the project, managing all component suppliers.
From Sept – Dec 2011 the 4 operating FC hybrid buses had an overall availability of 60% with 15.6% of downtime caused by H2/hybrid issues.

Service breakdown 01/09/2011 - 31/12/2011

- Total hours in service - cumulative: 60.0%
- Standard maintenance, RTAs, etc.: 9.5%
- Not scheduled for service: 8.0%
- H2 and hybrid drivetrain-related problems: 15.6%
- Other technical problems (non h2 or FC related): 0.9%
- Not in service due to lack of fuel: 5.3%
- Investigations/ modifications: 0.7%
Overall availability has improved since the start of Jan 2012 to greater than 69% - H2/Hybrid issues remain high at 15.7% - in most cases delays have been exacerbated by the management issues.

**Service breakdown 01/01/2012 - 31/01/2012**

- Total hours in service - cumulative: 69.8%
- Standard maintenance, RTAs, etc.: 5.3%
- Not scheduled for service: 3.0%
- H2 and hybrid drivetrain-related problems: 0.0%
- Other technical problems (non h2 or FC related): 6.2%
- Not in service due to lack of fuel: 15.7%
- Investigations/ modifications: 0.0%
There are three strategies for the operation of London’s existing bus fleet and infrastructure beyond the CHIC project

<table>
<thead>
<tr>
<th>Cash-flow Scenarios</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Base scenario – CHIC obligation</strong></td>
</tr>
<tr>
<td>• All 8 buses operate 12,000h</td>
</tr>
<tr>
<td>• Assumes the 4 years of operation are completed under current budget</td>
</tr>
</tbody>
</table>

1. **Operation outside the warranty period**
   - No stack related capex costs
   - Accepts a level of uncertainty.

2. **Operation outside the warranty period and re-core when stacks fail**
   - Operation of about 6000 hours outside warranty longest operation time scenario
   - Capex cost for stack recore

3. **Recore stacks at the end of existing warranty**
   - Capex cost for stack recore
   - Certainty form warranty
   - Buses 1,3,4,5 need stack recore a year before 2,6,7,8

Scenarios 1,2 are set to take advantage of the slow failure mechanism of the stacks. The stacks are estimated to work an additional 6000h before they reach the efficiency threshold (illustrated schematically below).

The failure of the stacks will be manifested by a slow decrease in efficiency. Buses will be taken out of operation before terminal failure.
As a base, the study calculates the cost of completing the CHIC obligation (due to late arrival of 3 buses, the project may take longer than expected). Under CHIC, TfL are expected to operate the fleet for at least 4 years and each bus for at least 12000h.

For this calculation, a cash flow was created, based on the existing TfL budget with additional information from interviews with key suppliers and HFC manufacturers. Costs are expressed as a difference in price from operating the same number of Diesel buses (in the table).

The study assumes that 8 buses will be operating by 2014 at 80% availability.

The cash-flows revolve around considerations of the following specific costs and implications:

- **Fuel cell** – Re-core + 15,000h warranty, PM kit, parts
- **Maintenance** – Fuel cell and Hybrid drive train
- **Fueling infrastructure** – Upgrade to H2 station (nozzle, cylinders), operation and maintenance of station, H2 cost
- **Other Costs** – Insurance, governance, etc.
There are issues of contract related uncertainty and additional risks related for the trialled technology

Contract related uncertainty

- TfL have recently changed their operation contract and are now working directly with Ballard and First Group for the maintenance of the buses but there is currently no agreement regarding the on-going costs of maintaining vehicles and the supply of hydrogen beyond the first 12,000 hours of operation for each bus.
- There hasn’t been an official discussion with gas providers regarding the provision of hydrogen beyond the current contract. The cost of fuel is therefore presented in a “Lower” and “upper” bound based on studies predicting hydrogen prices post 2014.
- TfL will need to have bilateral discussion with the relevant stake holders (AP, Ballard, First Group) to establish greater certainty around these costs. This will need to follow policy level decision regarding the operation of the buses beyond the initial period.

From past experience, it is important to note some additional risks related to the Hydrogen fleet:

- A steep rise in the international natural gas price will lead to significantly higher H2 cost.
- Failure in one of the buses will require a diesel bus substitute (£26K per bus per year).
- The analysis of the “unwarranted” options relies on an assumption that the FC stacks will last more than 6,000 hours outside the warranty. Any life less than this is not covered in these budgets and would lead to a shorter project extension.
Scenario 1 – Operating the buses until the original system fails (no additional project extension)

Beyond the CHIC obligation, the buses have an extra 3000h of warranty and an additional expected lifetime of 6000h after the warranty ends. In 2014-15 the last 3 buses are expected to still fulfil their 12,000h obligation. The estimated cost of operating the rest of the fleet in 2014-15 (beyond their CHIC operation) is approximately £244,501. In this scenario, the project is expected to run with 8 buses until early 2016 and 5 buses until early 2017.

<table>
<thead>
<tr>
<th>Operation beyond CHIC</th>
<th>Total cost beyond CHIC</th>
<th>Price for operating same number of diesel buses</th>
<th>Price of hydrogen project</th>
<th>Avg. price per year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower bound for H2 price</td>
<td>2 years</td>
<td>£2,102,075</td>
<td>£624,619</td>
<td>£1,477,456</td>
</tr>
<tr>
<td>Upper bound for H2 price</td>
<td>2 years</td>
<td>£2,250,450</td>
<td>£624,619</td>
<td>£1,625,831</td>
</tr>
</tbody>
</table>
Schematic Description of Scenarios 2 and 3

**Scenario 2**

- **Existing warranty recore**
  - 9000 Operation hours
- **Full refurbishment**
  - 15,000
  - 21,000
  - 36,000
- **Old warranty**
- **New HD6+**
- **Off warranty parts**
- **Capex for full recore - 15000h warranty**
- **Fuel cell system PM kit (£/hour fee to Ballard)**
- **Other systems parts and replacement (£/hour fee to Ballard)**

**Scenario 3**

- **Existing warranty recore**
  - 9000 Operation hours
- **Full refurbishment**
  - 15,000
  - 21,000
  - 30,000
- **Old warranty**
- **New HD6+**
- **Capex for additional 15,000 hour warranty**
- **Fuel cell system PM kit (£/hour fee to Ballard)**
- **Other systems parts and replacement (£/hour fee to Ballard)**

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The Existing Hydrogen Fuel Cell Bus Fleet in London
Scenario 2 – Re-coring the stacks after system failure

If TfL choose to capitalise on the warranty and life expectancy of the stacks and then upgrade the stacks to DH6+ with an additional 15000h warranty they could operate the buses for 5 years beyond the CHIC obligation. End of project: 8 buses operate until 2019 and 5 could continue until approximately March 2020. As the buses will be operating for more than 7 years an interior refurbishment should also be accounted for.

<table>
<thead>
<tr>
<th></th>
<th>Operation beyond CHIC</th>
<th>Total cost beyond CHIC</th>
<th>Price for operating same number of diesel buses</th>
<th>Price of hydrogen project</th>
<th>Avg. price per year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower bound for H2 price</td>
<td>5 years</td>
<td>£6,266,193</td>
<td>£2,200,365</td>
<td>£4,065,829</td>
<td>£813,165.72</td>
</tr>
<tr>
<td>Upper bound for H2 price</td>
<td>5 years</td>
<td>£6,763,232</td>
<td>£2,200,365</td>
<td>£4,562,867</td>
<td>£912,573.41</td>
</tr>
</tbody>
</table>
Scenario 3 – Re-coring the stacks at the end of the warranty

If TfL choose to upgrade the stack immediately as the warranty expires, an additional 4 years of operation will be available. In the last year only 4 hydrogen buses will be under warranty.

<table>
<thead>
<tr>
<th></th>
<th>Operation beyond CHIC</th>
<th>Total cost beyond CHIC</th>
<th>Price for operating same number of diesel buses</th>
<th>Price of hydrogen project</th>
<th>Avg. price per year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower bound for H2 price</td>
<td>4 years</td>
<td>£5,095,142</td>
<td>£1,664,098</td>
<td>£3,431,044</td>
<td>£857,761.11</td>
</tr>
<tr>
<td>Upper bound for H2 price</td>
<td>4 years</td>
<td>£5,477,539</td>
<td>£1,664,098</td>
<td>£3,813,441</td>
<td>£953,360.17</td>
</tr>
</tbody>
</table>
Summary – it appears possible to continue operation for relatively low additional costs.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Max. years of additional Operation</th>
<th>Funding range</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2 yrs</td>
<td>£1.4-1.6m</td>
<td>• Low price&lt;br&gt;• Helps to assess the real operational life time of the stacks</td>
<td>• Short run time&lt;br&gt;• Not protecting the investment in maintenance facility and H2 station</td>
</tr>
<tr>
<td>2</td>
<td>5 yrs</td>
<td>£4-4.5m</td>
<td>• Longest run time&lt;br&gt;• Helps assess the real operational life of the stacks&lt;br&gt;• Closer to a ‘real' commercial model.</td>
<td>• Expensive&lt;br&gt;• Uncertainty through period without warranty</td>
</tr>
<tr>
<td>3</td>
<td>4 yrs</td>
<td>£3.5-3.8m</td>
<td>• Increased certainty&lt;br&gt;• Limited risk to the budget from stack failure</td>
<td>• Does not take advantage of the full life expectancy of the stacks</td>
</tr>
</tbody>
</table>

Estimated times for the different scenarios:

<table>
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</thead>
<tbody>
<tr>
<td>4 years TfL commitment to CHIC</td>
<td></td>
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<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12,000h CHIC obligation</td>
<td></td>
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<td></td>
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<tr>
<td>Scenario 1</td>
<td></td>
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<tr>
<td>Scenario 2</td>
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<tr>
<td>Scenario 3</td>
<td></td>
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</tbody>
</table>

The Existing Hydrogen Fuel Cell Bus Fleet in London
Conclusions – extending the current trial

• Continued operation in order to protect the initial investment is possible with relatively low cost (compared with original investment for the first 4 years of ~£18m).

• There are considerable uncertainties in hydrogen price which will need to be better understood through continued commercial discussions with suppliers.

• Future deployments should focus on negotiation with one OEM as the main contractor for the project in order to avoid the current situation of multiple suppliers, responsible for different aspects of the project, which has led to reliability issues.
Scope for New Hydrogen Buses and Infrastructure in London

- Strategies and Scenarios for Operating New Hydrogen Buses
- Environmental Justifications and Benefits of New Hydrogen Bus Projects
- Funding Opportunities for New Buses and Infrastructure
Additional bus projects in London will need to demonstrate progress towards improved costs before a business case can be developed.

The latest RV1 TfL trial is aiming to demonstrate an operational performance similar to diesel buses.

For future trials TfL will need to see progress towards a commercially plausible hydrogen bus system. This will mean cost reductions for the buses. TfL provided an indicative guide to their expectations below.
## Specification and suitability of Hydrogen buses from global OEMs – current availability for London is limited to 12m buses

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Suitability</th>
<th>Cost</th>
<th>Exp. Cost 2015/6</th>
<th>RHD</th>
<th>Length</th>
<th>Availability</th>
</tr>
</thead>
<tbody>
<tr>
<td>OEM lead subcontractors</td>
<td>Issues over supply</td>
<td>£950k</td>
<td>?</td>
<td>Yes</td>
<td>12</td>
<td>Same model as in the current RV1 fleet but with different partners – uncertainty of how realistic this is</td>
</tr>
<tr>
<td>Van Hool</td>
<td></td>
<td>£1.1M</td>
<td>£650k (with volume - first indications)</td>
<td>Yes</td>
<td>Possible 12. currently only 13m for the UK</td>
<td></td>
</tr>
<tr>
<td>EvoBus</td>
<td></td>
<td>£1.5M</td>
<td>?</td>
<td>No</td>
<td>12</td>
<td>No right hand drive version at the moment. The price includes a comprehensive support package</td>
</tr>
<tr>
<td>Rampini ZEV (too small for London)</td>
<td>(unofficial estimate)</td>
<td>£0.5M &lt; x &lt; £1M</td>
<td>?</td>
<td>N/A</td>
<td>7.57</td>
<td>Trailed in Italy and Germany.</td>
</tr>
<tr>
<td>APTS (artic not acceptable)</td>
<td></td>
<td>£1.3M</td>
<td>?</td>
<td>Yes</td>
<td>18</td>
<td>Bendy buses - depending on the policy regarding</td>
</tr>
<tr>
<td>TATA Motors (no UK supply chain for buses)</td>
<td></td>
<td>?</td>
<td>?</td>
<td>N/A</td>
<td>12</td>
<td>Indian company. Recently started working with Ballard. The technology might not be mature enough</td>
</tr>
<tr>
<td>Proterra US only</td>
<td>(unofficial estimate)</td>
<td>£1M &lt; x &lt; £1.5M</td>
<td>?</td>
<td>N/A</td>
<td>10.7</td>
<td>Currently operate only in the USA. Support could be limited</td>
</tr>
</tbody>
</table>
Scope for new buses and infrastructure for London – 3 scenarios are proposed based on existing routes

There are 5 additional ‘12m routes’ in London (the current RV1 platform) that are using approx. 100 buses. This suggests that in the early years the general tendency to build 12m hydrogen buses does not cause a constraint.

In the longer term, the 2,674 single deck buses operating in London are all a viable market, but may require modifications to their routes and/or development of new 10-11m buses to allow full fuel cell routes.

Based on an analysis of London’s routes, it is possible to develop three scenarios for additional bus deployment in London:

- **Scenario 1** – 5 new buses for Temple Mills - Existing depot
- **Scenario 2** – One new route at a new depot, based on a PVR of 9 buses - Outer London depot
- **Scenario 3** – Based on a PVR of 51 buses - Central London depot

In both cases a HIGH and LOW cost scenario can be explored.
- In the HIGH scenario, buses cost approx. the same as today’s Van Hool vehicles and fuelling station costs are assumed to be at the upper extreme
- In the LOW scenario buses in 2015 fall to £650k and the maintenance costs are halved. Lowest cost fuelling station costs are assumed.
Assumptions used to calculate options for new buses were collected through from discussions with suppliers

<table>
<thead>
<tr>
<th>Assumptions</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bus Cost (High) - 1-10 purchased</td>
<td>£1m</td>
</tr>
<tr>
<td>Bus Cost (Low) - 1-10 purchased</td>
<td>£650k</td>
</tr>
<tr>
<td>Bus Cost (High) - ~50 purchased</td>
<td>£650k</td>
</tr>
<tr>
<td>Bus Cost (Low) - ~50 purchased</td>
<td>£500k</td>
</tr>
<tr>
<td>Drivetrain maintenance (High)</td>
<td>£47,900 Per year</td>
</tr>
<tr>
<td>Drivetrain maintenance (Low)</td>
<td>£24,000 Per year</td>
</tr>
<tr>
<td>Depot upgrade</td>
<td>£410k Euro</td>
</tr>
<tr>
<td>H2 Price Hgh</td>
<td>£7 per kg</td>
</tr>
<tr>
<td>H2 price Low</td>
<td>£3.30 per kg</td>
</tr>
<tr>
<td>H2 bus efficiency</td>
<td>0.08 kg/km</td>
</tr>
<tr>
<td>New H2 station capex - High</td>
<td>€2.4m</td>
</tr>
<tr>
<td>New H2 station capex - Low</td>
<td>€1.2m</td>
</tr>
<tr>
<td>Offsets</td>
<td></td>
</tr>
<tr>
<td>Diesel bus</td>
<td>£8,000 per year</td>
</tr>
<tr>
<td>Maintenance avoided</td>
<td>£13,000 per year</td>
</tr>
<tr>
<td>Fuel cost exc VAT</td>
<td>£1.10 per litre</td>
</tr>
<tr>
<td>Diesel bus efficiency</td>
<td>0.37 l/km</td>
</tr>
</tbody>
</table>
Budget for Scenario 1

The table below describes the upper and lower bound ranges for a scenario involving 5 new buses at Temple Mills.

The Lower bound assumes that the filling station O&M costs are already funded through an extension to the existing project. Bus costs are £650k/bus.

In the upper bound, bus costs are assumed the same as today and it is assumed that the new budget must fund the AP O&M costs.

<table>
<thead>
<tr>
<th>Costs in £'000's</th>
<th>SCENARIO 1 - Lower bound - assumes existing facility keeps operating AND lower bound bus costs</th>
<th>SCENARIO 1 - Upper bound - assumes high cost buses and a requirement to pay for AP O&amp;M costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buses Capex</td>
<td>£3,223,140</td>
<td>£4,958,678</td>
</tr>
<tr>
<td>Buses Opex (4 years)</td>
<td>£958,813</td>
<td>£958,813</td>
</tr>
<tr>
<td>Refuelling station Capex</td>
<td>£0</td>
<td>£0</td>
</tr>
<tr>
<td>Refuelling station H2 + Opex (4 years)</td>
<td>£356,073</td>
<td>£880,550</td>
</tr>
<tr>
<td>Offset costs for bus company</td>
<td>-£973,520</td>
<td>-£973,520</td>
</tr>
<tr>
<td>TOTAL COSTS</td>
<td>£3,564,506</td>
<td>£5,824,520</td>
</tr>
</tbody>
</table>

Note that the bus operator costs here assume a 4 year only project (i.e. only diesel 'lease' values are offset against the H2 project costs).
Budget for Scenario 2

The table below describes the upper and lower bound ranges for a scenario involving 9 new buses at a new site.

The Lower bound assumes bus costs of £650k/bus, with maintenance costs halved. Filling station capex is £1m, with TfL’s current H2 and O&M costs).

In the upper bound, bus costs are assumed the same as today. Filling station capex is £2m and H2 costs are increased to £7/kg.

### Costs in £'000's

<table>
<thead>
<tr>
<th></th>
<th>SCENARIO 2 - Lower bound - assumes low cost buses and H2</th>
<th>SCENARIO 2- Upper bound - assumes high cost buses and H2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buses Capex</td>
<td>£5,801,653</td>
<td>£8,925,620</td>
</tr>
<tr>
<td>Buses Opex (4 years)</td>
<td>£1,358,799</td>
<td>£2,221,731</td>
</tr>
<tr>
<td>Refuelling station Capex</td>
<td>£991,736</td>
<td>£1,983,471</td>
</tr>
<tr>
<td>Refuelling station H2 + Opex (4 years)</td>
<td>£1,165,408</td>
<td>£1,884,027</td>
</tr>
<tr>
<td>Offset costs for bus company</td>
<td>-£1,752,336</td>
<td>-£1,752,336</td>
</tr>
<tr>
<td><strong>TOTAL COSTS</strong></td>
<td><strong>£7,565,259</strong></td>
<td><strong>£13,262,513</strong></td>
</tr>
</tbody>
</table>

Note that the bus operator costs here assume a 4 year only project (i.e. only diesel ‘lease’ values are offset against the H2 project costs).
Budget for Scenario 3

In this scenario, we consider a large bus fleet. 51 buses would be required.

The Upper bound assumes the current “volume” price for the Van Hool bus (£650k) and the lower bound assumes procurement allows a cost of £500k.

H2 prices are as in Scenario 2 and represent the largest uncertainty on the project.

All analysis considers a 4 year project.

<table>
<thead>
<tr>
<th></th>
<th>SCENARIO 3 - Lower bound - assumes £500k buses, £3.3/kg H2, €1.2m station</th>
<th>SCENARIO 3 - UPPER BOUND assumes £650k buses, £7/kg H2, €2.4m station</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buses Capex</td>
<td>£25,289,256</td>
<td>£32,876,033</td>
</tr>
<tr>
<td>Buses Opex (4 years)</td>
<td>£5,468,457</td>
<td>£10,358,402</td>
</tr>
<tr>
<td>Refuelling station Capex</td>
<td>£991,736</td>
<td>£1,983,471</td>
</tr>
<tr>
<td>Refuelling station H2 + Opex (4 years)</td>
<td>£3,631,942</td>
<td>£7,704,119</td>
</tr>
<tr>
<td>Other costs</td>
<td>£0</td>
<td>£0</td>
</tr>
<tr>
<td>Offset costs for bus company</td>
<td>-£9,929,904</td>
<td>-£9,929,904</td>
</tr>
<tr>
<td>TOTAL COSTS</td>
<td>£25,451,487</td>
<td>£42,992,122</td>
</tr>
</tbody>
</table>
Potential sources of funding for the buses

- **Internal budgets within TfL** – will require a low cost bus (sub £500k) to develop a plausible business model.

- **Sponsorship** – has not been tried to date; in a booming market, could lead to considerable sources of funding. Barclays Cycle Hire: Barclays have invested £50m over two phases, with the scheme costing approximately £120m (or £240m in other sources).

- **DfT direct funding** – has funded £millions for air quality initiatives in the past. This would require approaching DfT directly with budget figures.

- **H2 funding** – Future TSB rounds could provide support. Unlikely to lead to more than £2.5m.

- **Future JTI calls** – the final call under FP7 is in 2013. Will have capacity for a large bus project.

- **Beyond FP7** – the future Horizon 2020 (FP8) is expected to continue the FCH JU, though the format for the calls etc is not yet established.

- **TEN-T** – Could support new refueling infrastructure for buses. Will not fund vehicles.
Summary of scenarios

Based on the funding discussion above, it is highly unlikely that the funding from national or international bodies will exceed 50%.

This gives an estimate for the level of support which will be required from local sources for four years of operation.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Additional funding range</th>
<th>Potential funding (national and international)</th>
<th>London budget range</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 – New 5 bus fleet at Temple Mills</td>
<td>£3.5-£5.8m</td>
<td>£1.7-£2.9m</td>
<td>£1.7-£2.9m</td>
</tr>
<tr>
<td>2. – New route (and new depot) – 9 buses</td>
<td>£7.7-13.2m</td>
<td>£3.8-6.6m</td>
<td>£3.8-6.6m</td>
</tr>
<tr>
<td>3- New 51 bus fleet and central London depot</td>
<td>£25-44m</td>
<td>£12.7-£21.5m</td>
<td>£12.7-£21.5m</td>
</tr>
</tbody>
</table>

Of the funding mechanisms, the FCH JU call in 2013 has perhaps the largest available budget and should be a target of any future work to target expansion of the London bus fleet.
High level conclusions on a future bus deployment

Even for the lower bound estimates, it appears to be a considerably lower cost option to continue the existing 8 bus project compared with starting a new project.

There is a considerable range between the upper and lower bound cost estimates.

This will need to be resolved to allow any budgets to be established for any future deployment - suggests a requirement to actively engage suppliers in reducing uncertainty.

Furthermore, the capital cost of buses is the key determinant of the cost. At present, it is challenging to persuade manufacturers to consider higher volumes at lower prices.

Again, this suggests a need to bring suppliers into a dialogue with TfL. Here, the focus will need to be on using potential procurement to drive down costs. **It is recommended that TfL launch a formal dialogue with suppliers on potential procurement of 5-50 buses for 2015/6 to force more clarity on costs from suppliers.** It may be possible to conduct this exercise in parallel with other European centres (e.g. Hamburg).

Whilst this would not necessarily lead to a procurement, (which would depend on prices received), it would help to ensure the bus OEM’s begin to develop plausible costs for the technology. Depending on price, TfL/GLA could take a view about whether a new project would represent value for money.

The size of the TfL shortfalls do appear manageable relative to the scale of the investment required for the current bus demonstration project. However, new London budgets will be required to support the project and this will be challenging in today’s economic climate.

Of the funding options available the FCH JU call in 2013 appears to be the best capitalised and most appropriate, especially for the larger bus deployment scenarios.
Hydrogen Opportunities Beyond Buses

- Global Development of Hydrogen Transport
- The UK and London as an Early Hydrogen Adopter
- Present and Future Opportunities for New Hydrogen Fuelled Transport in London
Many manufacturers are targeting 2015 for commercial sales of their vehicles.

**Toyota**
- Has announced that it will sell hydrogen vehicles in 2015 for below $50,000.

**Hyundai / Kia**
- Announced a plan to sell 500 fuel cell vehicles in 2012, with a subsequent increase in production.

**Daimler**
- Announced a major investment in Burnaby, Canada to build a factory for series production of their fuel cells.

**GM Project Driveaway**
- Testing 100 fourth generation FCEVs worldwide, including 10 in Germany with Opel.
There are numerous factors that make the UK very well positioned to advance as an early Hydrogen adopter

Geographic factors
- Constrained infrastructure needs – island
- London could be a focus for early rollout, limiting the need for wide geographical coverage (at least in the early years)

Growing momentum
- High level political interest
- Clustered activity: London Hydrogen Partnership, Midland, isle of Wight, Aberdeen
- Niche opportunities: Buses, taxies, etc

Large vehicle market
- The UK is a major European car market
- The main hydrogen stakeholders have a large combined UK market
- High volumes of fuel retail through specialist retailers (e.g., supermarkets) distinguishes the market from elsewhere in Europe

Support for LC technology
- Plug-in Car Grant and Plug-in Van Grant
- Active in Carbon Capture development
- CO2-based vehicle taxation (VED)
- H2Mobility
- CO2 targets

The UK as an early Hydrogen adopter
UK H2Mobility is evidence of genuine momentum around introduction of H2 vehicles from 2015

- Mark Prisk (Business Secretary) launched the UK H2Mobility initiative on the 18th January 2012.
- This is a public private initiative based on the success of a similar activity in Germany, which is now planning investments in a nationwide infrastructure from 2015.
- The UK study is tasked with assessing strategies for the roll-out of hydrogen vehicles (passenger vehicles and vans) and infrastructure from 2015.
- It is an unprecedented partnership between three Government departments, 13 industrial players and the Fuel Cells and Hydrogen Joint Understanding.
- For London – there is little point in developing detailed vehicle roll-out plans until this initiative reports – first public report is expected in late autumn 2012.
- London should also consider mechanism to engage more closely with the initiative.

The German H2Mobility project launched in 2009

The UKH2Mobility project launched in 2012
A number of demonstration projects in London have led to the emergence of a refuelling network for the city.

The Greater London region has been active in hydrogen demonstration since 2003 when the cities’ transport agency Transport for London participated in the CUTE programme bringing three hydrogen buses to the city. Hydrogen projects in the city are initiated through the London Hydrogen Partnership, which is a public/private grouping, including the Greater London Authority and a range of private sector partners.
The growing number of hydrogen initiatives in London is expected to result in a more substantial HFC vehicles presence over the next years.

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**Existing Fully Funded Projects**

- **The TfL bus project** has resulted in refuelling station at Lea Interchange and 5 buses in operation on the RV1 route as of 2011.
- **The CHIC project** will deploy an additional 3 buses to the RV1 fleet, as well as a new refuelling station in 2012.
- **A fully-capable 700bar hydrogen refuelling station** is installed at Milbrook on the M1 providing a key link to the Midlands. This is part-TSB funded.
- **The HyTEC project** will deploy a new publically accessible refuelling station to Heathrow in time for the Olympics, alongside 5 hydrogen fuel cell taxis.
- **HyTEC** will deploy 10 further taxis and 5 scooters (to Met Police) before the end of 2012.

**Projects expecting funding approval**

- **HyLift-EUROPE** will deploy 200 hydrogen fuel cell forklifts and baggage tugs to Europe, including at least 10-15 tugs to Heathrow Airport.
- **Ene.Field** will deploy 1,000 fuel cell micro-CHP units to homes across Europe including roughly 200 in London.
- **The London Hydrogen Network Extension (LHNE)** TSB bid will upgrade and link the four funded (Milbrook, Lea Interchange, Heathrow, un-sited CHIC station), to form a fully-integrated pan-London refuelling network, which is entirely compatible with OEM vehicles (fast-fill 700bar).
- **LHNE** will also deploy additional 11 hydrogen vehicles.

**Projects submitted for funding in 2012**

- **HESTON** will be re-submitted to the FCH JU and will deliver a new waste-to-green H2 facility in the East of London, enabling the entire existing fleet and significant additional deployments to be fuelled with its green H2.
- **H2DrivesEU** will be bringing additional OEM vehicles and a new central London refuelling station.

**UKH2M and more**

- **The UKH2 Mobility programme** was launched in January (with backing from the LHP) with a view to enable commercial rollout of H2 vehicles from 2015. London is being seen as the focal point for early deployments and as a stepping stone to full UK-wide rollout.
- London is looking to leverage London’s links to UKH2Mobility partners, and encourage the city’s participation in European projects (as submitted to the 2012 FCH JU call) for proposals for the deployment of further OEM vehicles to London’s refuelling network.
By 2015, London is expected to become a center for Hydrogen Fuel Cell activity and advance towards commercialisation.

**Revised action plan**
- London hydrogen buses project - 8 buses plus large refueling facility

**LHP 2012-2015 Action plan**
- Fully funded:
  - CHIC fuelling station
  - Milbrook fuelling station
  - HyTEC station at Heathrow
  - 5 fuel cell taxis
  - Fuel cell scooters
  - Passenger cars

**Awaiting funding:**
- HyLift-EUROPE: 10-15 Baggage Tugs
- Ene.Field: 200 fuel cell micro-CHP boilers

**Total expected deployments by end 2013:**
- 40-65 vehicles.
- 4-5 fuelling stations

**New Funding requests submitted:**
- London Hydrogen Network Expansion TSB
- HESTON green H2 production
- H2Drives

**Commercialisation:**
- Pre-commercial and commercial rollouts by OEMs and infrastructure providers, based on recommendations from UKH2Mobility

**2006**
- LHP Action plan

**2010**
- Revised action plan

**2012**
- LHP 2012-2015 Action plan

**2013**
- Awaiting funding:
  - HyLift-EUROPE: 10-15 Baggage Tugs
  - Ene.Field: 200 fuel cell micro-CHP boilers

**2015**
- Total expected deployments by end 2013:
  - 40-65 vehicles.
  - 4-5 fuelling stations

**Hydrogen Opportunities Beyond Buses**
Hydrogen FC taxis could make a significant contribution to the strategies for tackling London high emissions.

Diesel powered taxis make up 4% of London’s ground-based transport CO2 emissions, 25% PM10, 25% PM2.5 and 10% Nox emissions*. In conjunction with green hydrogen, HFC taxis could drive real change in London’s environmental target achievements.

The mayor declared (in his Air Quality Strategy) a target of **Zero emission taxis by 2020** and hydrogen has the potential to play a major role in reaching this goal.

The HyTEC project in London is due to trial the operation of 5 London taxis over the next 3 years.

As with other vehicle types, the main obstacle for the commercialisation of HFC taxis is high costs but equipment manufacturers predict a positive trend over coming years (see table below**).

<table>
<thead>
<tr>
<th></th>
<th>2012</th>
<th>2016</th>
<th>2019</th>
</tr>
</thead>
<tbody>
<tr>
<td>Δ cost from a diesel equivalent</td>
<td>~5 X the Capex cost</td>
<td>Capex cost premium approx. 20-25%</td>
<td>Capex cost premium approx. 5%</td>
</tr>
<tr>
<td>Maintenance cost premium</td>
<td>TBD</td>
<td>+10%</td>
<td>Neutral to lower</td>
</tr>
<tr>
<td>Rationale behind projection</td>
<td>TSB programme</td>
<td>HyTEC programme and other auto OEM programmes</td>
<td>HyTEC programme and other auto and non auto OEM programmes for FC technology commercialisation</td>
</tr>
</tbody>
</table>

*Source: The Mayor's Climate Change Action Plan
** discussions with suppliers
The costs associated with hydrogen taxis rollouts are relatively modest on current projections

Taking into consideration the cost trajectory for the taxis presented in the previous table, the taxis are expected to have relatively minor cost difference from a diesel equivalent.

**TCO comparison for taxis in 2016 and 2019:**

<table>
<thead>
<tr>
<th></th>
<th>Diesel</th>
<th>H2</th>
<th>2016</th>
<th>2019</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assumptions:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Capex</td>
<td>£35,000</td>
<td>£43,750</td>
<td>£36,750</td>
<td></td>
</tr>
<tr>
<td>Maintenance (assumes 10% from capex for diesel)</td>
<td>£3,500</td>
<td>£3,850</td>
<td>£3,500</td>
<td></td>
</tr>
<tr>
<td>Fuel efficiency</td>
<td>0.08 l/km</td>
<td>0.009 kg/km</td>
<td>0.009 kg/km</td>
<td></td>
</tr>
<tr>
<td>Fuel cost</td>
<td>£1.2/l</td>
<td>£10/kg</td>
<td>£10/kg</td>
<td></td>
</tr>
<tr>
<td>Total fuel (based on 55,000k per year)/year</td>
<td>£5,280</td>
<td>£5,115</td>
<td>£4,950</td>
<td></td>
</tr>
<tr>
<td><strong>Total cost of ownership for 5 yeas</strong></td>
<td><strong>£78,900</strong></td>
<td><strong>£88,575</strong></td>
<td><strong>£79,000</strong></td>
<td></td>
</tr>
<tr>
<td>Difference</td>
<td></td>
<td></td>
<td><strong>£9,675</strong></td>
<td><strong>£100</strong></td>
</tr>
</tbody>
</table>

Based on these numbers, a fleet of 50 taxis by 2016 will need less than £½ million funding assistance to allow for 5 years of operation to equate with diesel taxi Total Cost of Ownership (TCO). By 2020, a fleet of this size may not require any governmental assistance as the TCO is targeted to reach parity with a diesel ICE taxi.

This suggests that additional work to develop a) a better understanding of the real costs and infrastructure implications, and b) an understanding of the regulatory mechanisms available to underpin a transition to FC taxis would be worthwhile, in partnership with Intelligent Energy.
Establishing hydrogen as a truly zero emission fuel must be through the promotion of Green Hydrogen

Ultimately the aim of a hydrogen roll-out is to move to zero carbon hydrogen sources. Two options are plausible for London:

1. **Biogas** – the HESTON project is a submission to the FCH JU which will lead to a bio-gas fuelled Combined Heat hydrogen and Power production unit. This has the advantage of being able to produce relatively low cost green hydrogen for the city. Over 800kg/day will be available, enough to fuel the London fleet beyond 2016 with green hydrogen. If the application is successful this will be available in 2014. Within this project, hydrogen price is expected to fall below €10/kg.

2. **Electrolysis** - Currently there are no plans for electrolyser projects in London. The price of hydrogen from electrolysis directly depends on the price of green electricity and can range from 6 to 16 €/kg. These figures are derived from a refuelling station case-study working on 50% on-site hydrogen from electrolysis (in Hamburg). They refer to 2 state-of-the-art alkaline electrolyser capable of producing up to 375kg/hydrogen per day; Green electricity prices between €0.05 and €0.2 / kWh and 10 years as discount period and 3.5% interest on capital. These costs for hydrogen production are higher than those from fossil fuel (The FCH JU sets a retail price target of < €5). This suggests that acquiring green hydrogen for London’s H2 vehicles will require a small cost premium. A hybrid approach that encourages development of green sources and continued fossil derived H2 will be a cost-effective strategy in the short term with a view to moving to 100% green hydrogen in the long term.

An Air Products plant in California, producing hydrogen, electricity and heat from Biogas.
An additional factor that could influence the price of green hydrogen is the success of Carbon Capture and Storage methods.

If CCS is successful, Green H2 costs will be considerably lower.

Source: A portfolio of power-trains for Europe: a fact-based analysis, 2010
HFC transportation has great potential for significant environmental benefits both in the short and long term

- London has not been meeting EU air quality standards consistently and is facing EU fines of 300+ million Euro unless significant improvement is made.

- The Mayor’s Air Quality Strategy published in 2010 sets out to drastically cut London's emissions from transportation and the Mayor’s Climate Mitigation Energy expresses a target of 60% less emissions in London by 2025 (on a 1990 level).

- Given the current mode of production of ‘brown hydrogen’ (hydrogen from non-renewable sources) used by the buses they contribute approx. 25% less CO2 than a diesel equivalent (assuming 8kg H2 per 100k).

- The more substantial short term benefits of the FC buses are expressed in Nox and PM savings of 100% for the city as there are zero exhaust emissions from these vehicles. HFC mode of transit can be particularly useful for travelling in London’s Low Emission Zones (LEZ) & Congestion Charging Zone.

- In order to meet the proposed LEZ phase 5 requirements TfL will need to take action that will involve the retrofitting of approximately 2,800 buses*. The choice of hydrogen buses could drive this change quicker and more efficiently than diesel hybrid buses that still emit a certain amount of pollutants.

Changing the source of hydrogen will lead to substantial saving in emissions for the bus fleet

<table>
<thead>
<tr>
<th>Tonnes of CO2 avoided versus a 12m Diesel Citaro baseline</th>
<th>Zero carbon H2 – emissions avoided</th>
<th>Central London emissions saving per year</th>
</tr>
</thead>
<tbody>
<tr>
<td>2026 Estimated EU average H2 CO2 content (assuming 7kgCO2 /kg H2)***</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8 Bus extension</td>
<td>175</td>
<td>400</td>
</tr>
<tr>
<td>50 bus scenario</td>
<td>1,000</td>
<td>2,500</td>
</tr>
<tr>
<td>10% penetration in to the TfL bus fleet by 2026 (800 buses)</td>
<td>15,300</td>
<td>40,000</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Central London emissions saving per year**

- **8 Bus extension**: 0.0012 Tonnes PM10, 2 Tonnes Nox
- **50 bus scenario**: 0.0075 Tonnes PM10, 12 Tonnes Nox
- **10% penetration in to the TfL bus fleet by 2026 (800 buses)**: 0.12 Tonnes PM10, 192 Tonnes Nox

**Assumptions**

<table>
<thead>
<tr>
<th>Mileage</th>
<th>50,000 km/year</th>
<th>RV1 average</th>
</tr>
</thead>
<tbody>
<tr>
<td>fuel economy diesel single deck</td>
<td>0.37 l/km</td>
<td>TfL test data – fleet average</td>
</tr>
<tr>
<td>fuel economy FC bus</td>
<td>8 g/km</td>
<td>Based on RV1 route data</td>
</tr>
</tbody>
</table>

**Diesel CO2**

- 1,000 g/km

**Diesel Nox**

- 0.5 g/km

**diesel PM**

- 0.00032 g/km

**Source**

- Based on average CO2 trajectories in A portfolio of power-trains for Europe: a fact-based analysis, 2010

**Notes**

- **Relative to a single deck Citaro bus**
- **Source**: Based on average CO2 trajectories in A portfolio of power-trains for Europe: a fact-based analysis, 2010
### Emissions savings from different taxis roll-out scenarios

<table>
<thead>
<tr>
<th>Tonnes of CO2 avoided versus a new LTI taxi for London</th>
</tr>
</thead>
<tbody>
<tr>
<td>**Current H2 @ Temple Mills (14.7kgCO₂/kg H₂)</td>
</tr>
<tr>
<td>--------------------------------------------------------</td>
</tr>
<tr>
<td><strong>50 taxis</strong></td>
</tr>
<tr>
<td><strong>100 taxis</strong></td>
</tr>
<tr>
<td><strong>700 taxis (assumes 100 new taxis sold per year from 2019 to 2026)</strong></td>
</tr>
</tbody>
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- **Mileage**: 55,000 km/year
- **LTI estimate**
- **fuel economy diesel TX4**: 0.08 l/km [source](http://www.car-emissions.com/cars/view/39724)
- **fuel economy on H2**: 0.01 kg/km, LTI estimate
- **Diesel CO₂**: 233 g/km [source](http://www.car-emissions.com/cars/view/39724)
- **Diesel Nox**: 0.3 g/km [source](http://www.car-emissions.com/cars/view/39725)
- **diesel PM**: 0.028 g/km [source](http://www.car-emissions.com/cars/view/39726)

*** Source: Based on average CO₂ trajectories in A portfolio of power-trains for Europe: a fact-based analysis, 2010
Summary and conclusions

Various trials already taking place in London and elsewhere in the world show positive results regarding fuel economy, availability and range of hydrogen fuel cell vehicles.

Extending the operation of the current bus fleet

London has already made significant progress in the hydrogen vehicle field and has the largest HFC bus fleet in Europe. Results of the first year of the trial suggest that the technology has the technical potential to replace diesels on reliability grounds, but that there are still number of contractor performance issues related to a) the immaturity of the H2 bus supply chain and b) the specifics of the contracting arrangements on the project.

This study has presented several ways in which the initial investment can develop to extended operation by 2 – 5 years with a relatively low cost compared with the original investment. As the infrastructure already exists, operating the existing fleet for longer is the most cost effective option for expanding HFC bus operation in London.

Before committing to an expansion of the existing project, a number of uncertainties regarding the management, maintenance and fuel costs need to be better resolved in commercial discussions between TfL and suppliers. Once these are resolved, it will be possible to refine the optimum scenario and present the case for additional investment to TfL management, the Mayor and his advisor.

Additional bus fleets

Lessons learnt from the current trial indicate that a preferable way for deploying hydrogen buses should be through a main OEM (as opposed to an aggregation of manufacturers with divided responsibility as per current contract).

Analysis of a range of new fleet options (from 5-50 buses) suggest that;

a) Buses will be available to London and there are routes which can accommodate them in the 2015 timescale.

b) The buses will not be cost competitive with diesels and hence will still require additional funding for any project to occur.
Summary and conclusions

c) There is considerable uncertainty over the costs of buses and H2 supply for deployment beyond 2015 – these will need to be resolved through dialogue with suppliers about real orders. The level of uncertainty is largest around the effect of larger orders (e.g. 50 buses) on prices for buses in London.

It is recommended that to reduce uncertainty and to begin planning for a larger fleet, TfL or the LHP should initiate a formal dialogue with some of the large OEMs that are involved with hydrogen buses. This would use the real potential of a TfL procurement in 2015 to solicit detailed responses from manufacturers (Van Hool, EvoBus, UK manufacturers). It is suggested that a broad range of vehicles is considered 5-50.

A similar discussion is required with H2 providers.

Beyond Buses

Beyond buses, the field of HFC passenger cars is evolving. Results from the UKH2mobility project will help in steering the activity in this sector in the near future.

The relatively low projected capital cost difference between diesel taxis and hydrogen taxis mark this sector as promising for future large scale deployment. This could be backed by regulation which is controlled by the Mayor. Upcoming trials will provide more information regarding performance and suitability of hydrogen taxis for London.

It is recommended that LHP work with Intelligent Energy to better understand a) the potential and b) the regulatory mechanisms required around an H2 taxi roll-out.

Once the UKH2Mobility study is complete, the LHP should begin planning for passenger car roll-out, using the data from that project. The HyTec project includes a workpackage on future planning through which some of this planning work could take place.