Fuel cell buses

A commercially competitive zero emission bus solution?

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FCB OSLO18

Dr Eleanor Standen

eleanor.standen@element-energy.co.uk

Element Energy Limited
• **Introduction**
  
  • Context
  
  • FC buses: key developments to date
  
  • FC buses: A commercially competitive solution?
About Element Energy

**Element Energy** is a leading low carbon energy consultancy. We apply best-in-class financial, analytical and technical analysis to help our clients intelligently invest and create successful policies, strategies and products.

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**We operate in three main sectors**

**Low Carbon Transport**
- Electric vehicles
- \( \text{H}_2 \) vehicles
- Market uptake
- Infrastructure modelling
- Business planning
- Project delivery

**Built Environment**
- Financial viability
- Master planning
- Building design
- Policy advice
- Regional strategy

**Power Generation & storage**
- Renewables
- Micro-generation
- CCS
- Techno-economics
- Feasibility studies
- Geographic analysis

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**We offer three main services**

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- Technology assessments
- Market growth
- Market share
- Financial modelling
- Commercialisation advice

**Strategy and Policy**
- Scenario planning
- Techno-economic modelling
- Business planning
- Stakeholder engagement

**Engineering**
- CFD
- Software tools
- Prototyping
- Installations
• Introduction

• **Context**
  • FC buses: key developments to date
  • FC buses: A commercially competitive solution?
There is a potential market for thousands of new zero emission buses per year across Europe from the 2020s.

Overview of political commitments to accelerate uptake of zero emission buses in selected cities / countries across Europe (ZE = zero emission, TfL = Transport for London)

**Approximate urban bus fleet size indicated by numbers in brackets**: total across these cities / countries = 47,750

- **Norway (16,250)**
  - All new urban buses sold in 2025 to be zero emission or use biogas
  - Aim to have a fully ZE transport system by 2030

- **The Netherlands (10,000)**
  - All new buses procured from 2025 to be ZE

- **London, UK (9,500)**
  - From 2020
    - All single decks in central London ZE
    - TfL will only buy ZE single deck buses
  - From 2025
    - ZE bus purchase policy extended to all buses (single and double deck)

- **Copenhagen, Denmark (350)**
  - Phase out of diesel vehicles as part of plan to be carbon neutral by 2025

- **Hamburg, Germany (800)**
  - All buses purchased from 2020 to be ZE

- **Paris, France (6,850)**
  - Commitment to remove all diesel vehicles from city by 2025

- **Madrid, Spain (2,000)**
  - Commitment to remove all diesel vehicles from city by 2025

- **Athens, Greece (2,000)**
  - Commitment to remove all diesel vehicles from city by 2025
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• Context
• **FC buses: key developments to date**
• FC buses: A commercially competitive solution?
CHIC started in 2010 and delivered 56 fuel cell buses in eight cities from six different OEMs.

- **London** - 8 Wrightbus
- **Aargau** - 5 EvoBus
- **Bozen/Bolzano** - 5 EvoBus
- **Milan** - 3 EvoBus
- **Oslo** - 5 Van Hool
- **Hamburg** - 4 EvoBus
- **Cologne** - 2 Van Hool
- **2 Solaris**
- **2 APTS/Phileas**
- **+ 4 ICE H2 buses in Berlin**
- **+ 20 New Flyer – Whistler (Canada)**

Source: CHIC Emerging Conclusions
CHIC conclusions & next steps

CHIC project conclusions

Hydrogen fuel cell buses can offer:

✓ Operational flexibility (comparable to diesel)
✓ Zero local emissions
✓ Reduced CO₂ emissions, with a pathway to zero emission
✓ Satisfaction for end users (drivers & passengers)

Next steps

➢ Improve bus availability – by resolving teething technical issues & increasing scale
➢ Reduce bus prices – coordinated commercialisation process (see below)
➢ Harmonise regulations on hydrogen refuelling stations – work underway on international standards
The JIVE project aims to commercialise fuel cell buses through a large-scale demonstration across five Member States.

**Objectives**
- Deploy 139 FC buses across nine cities
- Achieve 30% cost reduction versus state of the art
- Operate 50% of the vehicles for at least 36 months
- Deploy the largest capacity HRS in Europe
- Achieve near 100% reliability of HRS
- Demonstrate technological readiness of FC buses and HRS
- Encourage further uptake

JIVE: Joint Initiative for hydrogen Vehicles across Europe

Fuel cell buses in cities participating in JIVE:
- **UK** – 56 FC buses
- **Denmark** – 10 FC buses
- **Latvia** – 10 FC buses
- **Germany** – 51 FC buses
- **Italy** – 12 FC buses

JIVE began in January 2017 and will be a six year project.
The *JIVE 2* project was confirmed earlier this year – this will support another 152 buses

**JIVE 2: Joint Initiative for hydrogen Vehicles across Europe Phase 2**

**Objectives**
- Deploy 152 FC buses across 14 cities
- Achieve a maximum price of €625k for a standard fuel cell bus
- Operate buses for at least three years / 150,000 km
- Validate large scale fleets in operation
- Enable new entrants to trial the technology
- Demonstrate routes to low cost renewable H₂
- Stimulate further large scale uptake

Manufacturers in Europe and beyond are responding to the growing demand for FC buses and preparing to offer new solutions. 

### Key players

<table>
<thead>
<tr>
<th>OEM (country)</th>
<th>Relevant experience / products</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALEXANDER DENNIS (UK)</td>
<td>Funded for a proof-of-concept hybrid fuel cell double-decker bus with Arcola Energy and Warwick Manufacturing Group.</td>
</tr>
<tr>
<td>EvoBus (DE)</td>
<td>Demonstrated 17 FC buses in the CHIC project, tens of FC buses produced to date. Releasing electric Citaro in 2018 and FC in ~2020.</td>
</tr>
<tr>
<td>rampini (IT)</td>
<td>Built the “H80” FC bus in 2007 (&gt;3,000 hrs / 50,000 km covered). New FC bus “H120” being homologated. Plans to produce tens of FC buses over the coming years.</td>
</tr>
<tr>
<td>Solaris (PL)</td>
<td>Two E18 FC buses in service in Hamburg. Ten FC range extender trolleybuses on order for Riga. Single deck products being offered on the Urbino platform.</td>
</tr>
<tr>
<td>Solbus (PL)</td>
<td>First FC bus delivered to Syntus (Dutch bus operator) in mid-2016.</td>
</tr>
<tr>
<td>Tempo Bus (PL)</td>
<td>Offers the “City Smile” 12m FC bus, based on a range extender concept. Demo bus present at the IAA 2016 (Hannover).</td>
</tr>
<tr>
<td>Van Hool (BE)</td>
<td>Market leader - &gt;40 FC buses operating in Europe and the US.</td>
</tr>
<tr>
<td>VDL Bus &amp; Coach (NL)</td>
<td>Four FC buses delivered in 2011 as part of demonstration activities.</td>
</tr>
<tr>
<td>Wrightbus (UK)</td>
<td>8 single deck FC buses in London as part of the CHIC project. Single and double deck FC buses available for order from 2017.</td>
</tr>
</tbody>
</table>

Note: this list is not exhaustive.
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While fuel cell bus costs have fallen significantly in recent years, further reductions are needed for commercially viable offers.

Evolution of fuel cell bus costs in Europe

![Graph showing the evolution of fuel cell bus costs in Europe with specific data points and targets.](image)

- **Capital costs of fuel cell buses ordered in different years (non-articulated single deck buses)**
- **Year of bus order & relevant project**
- **Price for fully commercial proposition:** <$350k per bus, assuming OEM gets orders >100 buses per year

**FCH JU MAWP** is the Fuel Cells and Hydrogen Joint Undertaking’s Multi-Annual Work Plan, the document that sets out the work plan and strategic targets for the second phase of the FCH JU’s programme of research and innovation.

**See [http://hydrogenvallley.dk/white-paper/](http://hydrogenvallley.dk/white-paper/).**
Cost and performance data validated by some OEMs suggests that FC buses could compete with other zero emission options without subsidy.

Ownership cost analysis for a single deck 12m bus

<table>
<thead>
<tr>
<th>Powertrain Type</th>
<th>Current Costs</th>
<th>Mass-market costs</th>
<th>JIVE Costs</th>
<th>Fuel cell electric</th>
<th>Actual BE bus costs vary between these two points</th>
<th>30% more buses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel hybrid ICE</td>
<td>€6/kg H₂ price assumed in FC bus cases, infrastructure cost included in H₂ price</td>
<td></td>
<td></td>
<td></td>
<td>Fuel costs</td>
<td>Current FC bus costs vary between these two points</td>
</tr>
<tr>
<td>Battery electric</td>
<td>€14,443</td>
<td>€13,594</td>
<td>€17,672</td>
<td>€34,560</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Single deck</td>
<td>€17,700</td>
<td>€13,200</td>
<td>€28,080</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Battery electric</td>
<td>€16,500</td>
<td>€23,010</td>
<td>€35,400</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Single deck</td>
<td>€55,357</td>
<td>€46,986</td>
<td>€53,429</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Battery electric</td>
<td>€25,574</td>
<td>€36,143</td>
<td>€31,207</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Single deck</td>
<td>€55,357</td>
<td>€46,986</td>
<td>€53,429</td>
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<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

PVR: peak vehicle requirement.

What happens next? The Commercial Phase

- A number of cities and hydrogen companies are now looking at how to move to the next, commercial phase beyond the JIVE deployments.
- There are clearly some important ingredients:
  - **Scale of bus demand** – 100’s of units per year appear to provide acceptable cost reductions
  - **Scale of demand at a depot** – is required to reduce the price of hydrogen
  - **Access to low cost energy** – critical to achieving affordable hydrogen, best option is location dependent

- Achieving this will require continued commitment to **zero emission policies**, without prejudice against hydrogen...
- ... and willingness from operators to **commit to large scale fleets**, ideally in concerted procurements

- With this, hydrogen looks capable of being the most affordable and most flexible zero emission option for urban buses, particularly for heavy duty routes (long range, large vehicles etc)

Top tips for future FC bus projects – scale is key to achieving a commercial proposition

<table>
<thead>
<tr>
<th>Previous and existing projects have learned lessons:</th>
</tr>
</thead>
<tbody>
<tr>
<td>✓ Scale is important:</td>
</tr>
<tr>
<td>✓ Reduces capital costs and H₂ costs</td>
</tr>
<tr>
<td>✓ Allows more robust service and maintenance arrangements</td>
</tr>
<tr>
<td>✓ Maintenance arrangements need to be robust:</td>
</tr>
<tr>
<td>✓ Aim to have your own mechanics trained quickly</td>
</tr>
<tr>
<td>✓ Good spare parts inventory nearby, with regular and FC components</td>
</tr>
<tr>
<td>✓ Ensure robust contracts with OEMs with penalties for poor availability</td>
</tr>
<tr>
<td>✓ Procurement should be simple:</td>
</tr>
<tr>
<td>✓ Structure should mirror typical arrangements between OEM and bus operator (without transport authority being involved)</td>
</tr>
<tr>
<td>✓ Contract direct with OEM, not a system integrator</td>
</tr>
<tr>
<td>✓ Some depot modifications will be required:</td>
</tr>
<tr>
<td>✓ Sensors &amp; vent pipes in buildings, check ATEX requirements.</td>
</tr>
<tr>
<td>✓ Ensure the drivers are positive about the change:</td>
</tr>
<tr>
<td>✓ Give training to ensure understanding of the technology and its benefits.</td>
</tr>
</tbody>
</table>
Join us at the:

2018 European Zero Emission Bus Conference

Cologne • November 27 & 28th

For more information – to be included in the mailing list or for sponsoring opportunities:

Madeline Ojakovoh
Element Energy
madeline.ojakovoh@element-energy.co.uk
+44(0) 203 813 3901

Sabrine Skiker
Hydrogen Europe
s.skiker@hydrogeneurope.eu
+32(0) 4 72 42 45 57

EUZEBconference
#ZEB2018
Appendix slides
# Single deck bus fleet: key assumptions – calculations based on a 10 bus route

<table>
<thead>
<tr>
<th>Powertrain:</th>
<th>Diesel ICE</th>
<th>Battery electric</th>
<th>Battery electric</th>
<th>Battery electric</th>
<th>Fuel cell electric</th>
<th>Fuel cell electric</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bus type:</td>
<td>Single deck</td>
<td>Single deck</td>
<td>Single deck</td>
<td>Single deck</td>
<td>Single deck</td>
<td>Single deck</td>
</tr>
<tr>
<td>Scenario:</td>
<td>Regular</td>
<td>Current costs, Long-range</td>
<td>Mass market costs, Long-range</td>
<td>30% extra vehicles</td>
<td>Regular</td>
<td>2020 production volume</td>
</tr>
<tr>
<td>Bus availability</td>
<td>%</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Additional vehicle requirement</td>
<td>%</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.30</td>
<td>-</td>
</tr>
<tr>
<td>Bus capex</td>
<td>€/bus</td>
<td>165,200</td>
<td>525,000</td>
<td>385,000</td>
<td>385,000</td>
<td>649,000</td>
</tr>
<tr>
<td>Bus lifetime</td>
<td>years</td>
<td>14</td>
<td>14</td>
<td>14</td>
<td>14</td>
<td>14</td>
</tr>
<tr>
<td>Powertrain overhaul capex</td>
<td>€/bus</td>
<td>4,873</td>
<td>250,000</td>
<td>121,000</td>
<td>121,000</td>
<td>99,000</td>
</tr>
<tr>
<td>Powertrain lifetime</td>
<td>years</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Bus drivetrain maintenance</td>
<td>€/year/bus</td>
<td>11,800</td>
<td>17,700</td>
<td>17,700</td>
<td>17,700</td>
<td>35,400</td>
</tr>
<tr>
<td>Diesel consumption</td>
<td>l/100km</td>
<td>37</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Electricity consumption</td>
<td>kWh/100km</td>
<td>-</td>
<td>170</td>
<td>160</td>
<td>160</td>
<td>-</td>
</tr>
<tr>
<td>Hydrogen consumption</td>
<td>kg/100km</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>8.0</td>
</tr>
<tr>
<td>Diesel price</td>
<td>€/litre</td>
<td>1.20</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Electricity price</td>
<td>€/kWh</td>
<td>0.11</td>
<td>0.11</td>
<td>0.11</td>
<td>0.11</td>
<td>6.0</td>
</tr>
<tr>
<td>Hydrogen price</td>
<td>€/kg</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>8.0</td>
</tr>
<tr>
<td>Bus regular maintenance</td>
<td>€/year/bus</td>
<td>11,800</td>
<td>11,800</td>
<td>11,800</td>
<td>11,800</td>
<td>11,800</td>
</tr>
<tr>
<td>Driver salary</td>
<td>€/year</td>
<td>44,000</td>
<td>44,000</td>
<td>44,000</td>
<td>44,000</td>
<td>44,000</td>
</tr>
<tr>
<td>Additional driver salary</td>
<td>€/year</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Depot overheads</td>
<td>€/year/bus</td>
<td>7,700</td>
<td>7,700</td>
<td>7,700</td>
<td>7,700</td>
<td>7,700</td>
</tr>
<tr>
<td>Infrastructure capex (overall)</td>
<td>€</td>
<td>236,000</td>
<td>236,000</td>
<td>306,800</td>
<td>306,800</td>
<td>306,800</td>
</tr>
<tr>
<td>Infrastructure capex (per bus)</td>
<td>€/bus</td>
<td>5,035</td>
<td>5,035</td>
<td>5,035</td>
<td>5,035</td>
<td>5,035</td>
</tr>
<tr>
<td>Infrastructure maintenance (per bus)</td>
<td>€/year/bus</td>
<td>5,900</td>
<td>5,900</td>
<td>5,900</td>
<td>5,900</td>
<td>5,900</td>
</tr>
<tr>
<td>Infrastructure lifetime</td>
<td>years</td>
<td>14</td>
<td>14</td>
<td>14</td>
<td>14</td>
<td>14</td>
</tr>
</tbody>
</table>

Note: financing costs are not included in this analysis. Other costs (insurance, training, etc. are also excluded). Driver costs based on an assumption of two drivers per bus. Assumed annual mileage per bus is 70,000 km/yr in all cases.

Hydrogen refuelling station costs included in hydrogen price.
CHIC conclusions & next steps

CHIC project conclusions

Hydrogen fuel cell buses can offer:

✓ **Operational flexibility** (comparable to diesel)
✓ **Zero local emissions**
✓ **Reduced CO₂ emissions**, with a pathway to zero emission
✓ **Satisfaction for end users** (drivers & passengers)

Next steps

➢ **Improve bus availability** – by resolving teething technical issues & increasing scale
➢ **Reduce bus prices** – coordinated commercialisation process (see below)
➢ **Harmonise regulations** on hydrogen refuelling stations – work underway on international standards
After facing teething issues, and implementing an upgrade programme, most cities reached the project target.

- As is the case for all innovative technologies, all cities partners had to face a teething period: period where availability of the buses has been unacceptable at the start of operations.
- These periods have been caused by unfamiliarity of the vehicles to maintenance staff and issues with the build quality of vehicles coming out of the factory and the fact that the supply chain was still immature (expected to be solved with an increase in scale in the sector).
- It has to be noted that most of the issues are not directly linked to the fuel cell.
- An availability upgrade programme was implemented in 2014 with positive results: the availability in some cities exceed 90%, with an average >80% in the Phase 1 cities.