Zero emission public transport – Fuel cell buses in Europe

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Element Energy Ltd

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• Introduction

• Context

• FC buses: key developments to date

• Future plans for FC bus deployment

• Conclusions
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.

We operate in three main sectors

- **Low Carbon Transport**
  - Electric vehicles
  - H₂ 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

We offer three main services

- **Business analysis**
  - 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
  • Future plans for FC bus deployment
  • Conclusions
Buses are likely to remain a central element of public transport systems in Europe and beyond

“Buses and coaches are an integral part of public transport and travel, and key elements in a sustainable transport system. They ensure inclusive sustainable mobility for all citizens and visitors - in the countryside and urban areas alike - through public transport services customised to mobility needs of the travelling public.”

Source: www.busandcoach.travel

Cities across Europe and beyond are facing common challenges:

- **Increasing urbanisation & congestion** – growing demand for transport services
- **Environmental challenges** – air quality, GHG emissions
- **Economic constraints** – providing affordable, reliable, high quality services with limited budgets

Electrification is currently the only viable option for delivering zero emission buses, with two principal options:

1) Battery electric buses
2) Fuel cell electric buses

Source (photos): Alexander Dennis, CHIC project.
Cities across Europe are beginning to plan to phase out diesel buses

Source: Mayor of London’s Transport Strategy – draft for public consultation, Figure 13, p.97 (June 2017).
Mayor of London’s Transport Strategy (draft) – key policies for buses

**From 2020**
- All new single deck buses to be zero emission
- All single deck buses in central London to be zero emission

**From 2025**
- All new single and double deck buses to be zero emission

**From 2037**
- 100% of TfL’s buses to be zero emission (electric or hydrogen)
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What is a fuel cell bus?

13m vehicle design (CHIC specification delivered to e.g. Cologne and Oslo)

<table>
<thead>
<tr>
<th>Component</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel cell system</td>
<td>120 kW (rated peak output)</td>
</tr>
<tr>
<td>Battery system</td>
<td>100 kW, 17.8kWh (Li-ion)</td>
</tr>
<tr>
<td>Supercapacitor system</td>
<td>None</td>
</tr>
<tr>
<td>Energy recuperation system</td>
<td>Brake resistors (2 units, 60kW each)</td>
</tr>
<tr>
<td>H₂ storage system</td>
<td>7 tanks, 350bar ~ 35 kg</td>
</tr>
</tbody>
</table>

Van Hool has used different configurations of this specification in different location. For example, for the buses in Aberdeen, 10 hydrogen tanks are used (50kg capacity). For London, a new, lighter, 2 axle version has been designed. For Pau, an 18m system is being built.
Why choose fuel cell buses?

**High daily range**
300+ km without refuelling

**Zero tailpipe emissions**
Only water emitted at the tailpipe

**Operational flexibility**
...no need for new street infrastructure, rapid refuelling (<10 min)

**Comfort for passengers and drivers**
...due to reduced noise levels and smooth driving experience

**CO₂ emissions savings**
– Hydrogen can be generated from a range of ultra-low carbon routes

**Collaboration**
A European network of frontrunners in place willing to share their expertise

Source: CHIC Emerging Conclusions
Where does hydrogen come from? One of the advantages of hydrogen is the range of sources with low carbon footprints.

A range of production options can lead to low carbon hydrogen:

- **Electrolytic production** at the point of renewable electricity production
- **Electrolytic production** close to the point of demand, balancing supply and demand
- **Production direct from biomass or waste**
- **Production from any hydrocarbon linked to carbon capture and storage**
- **Spare refinery or industrial capacity**—often have spare capacity for hydrogen – can be cleaned and used for energy applications

Other green options are being developed, but remain at the lab scale and include:

- Photochemical
- Biological processes (light and dark reactions)
- High temperature thermo-chemical cycles (nuclear or solar)
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 Solaris
- **2 APTS/Phileas**
- **2 Van Hool**

+ 4 ICE H2 buses in Berlin
+ 20 New Flyer – Whistler (Canada)

Source: CHIC Emerging Conclusions
Phase 1 cities – the EvoBus buses

- Fuel cell bus in Milan (3 buses in total)
- Fuel cell Postbus in Aarau (5 buses in total)
- Fuel cell buses in Bozen/Bolzano (5 buses in total)
Phase 0 and Phase 1 cities – the Van Hool buses

Fuel cell buses in Oslo (5 buses in total)

Fuel cell bus in Cologne (2 buses in total)
Phase 1 cities – the Wrightbus buses in London

Fuel cell buses in London (8 in total)
The Solaris buses

Hamburg, Germany  (2 buses in total)
The fuel cell systems have demonstrated reassuringly high system lifetimes

Two fuel cell technologies have now surpassed 25,000 hours in fuel cell bus operations

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**London buses (Ballard)**

A London bus recently surpassed the 25,000 hour mark on the busy urban RV1 route, a 6.9 year life with no major maintenance


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**AC Transit (Originally UTC)**

The AC Transit bus surpassed 25,000km in July 2017. the buses started operating in 2010


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Heavy duty fuel cell manufacturers targeting bus applications are aiming at warranties of 20,000 hours or more
### Phase 1: 5 high throughput, 350bar stations
About 300 tonnes of H$_2$ dispensed  (to end March 2016)

<table>
<thead>
<tr>
<th>City</th>
<th>Picture</th>
<th>HRS/H$_2$ Producer</th>
<th>Operation start</th>
<th>Type of HRS / source of H$_2$</th>
<th>Nber of fillings</th>
<th>Kg H$_2$ refuelled</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aargau</td>
<td><img src="image1.png" alt="Picture" /></td>
<td>Carbagas (Air Liquide)</td>
<td>2012</td>
<td>Onsite electrolyser - 100% H$_2$ from RES (hydropower, solar &amp; wind energy, biomass) (+ trailer delivery as backup)</td>
<td>6,503</td>
<td>92,686</td>
</tr>
<tr>
<td>Bozen</td>
<td><img src="image2.png" alt="Picture" /></td>
<td>Linde</td>
<td>2014</td>
<td>Onsite electrolyser - 100% H$_2$ from RES (mix of hydropower, solar and wind energy) (+ trailer delivery as backup)</td>
<td>1,938</td>
<td>34,917</td>
</tr>
<tr>
<td>London</td>
<td><img src="image3.png" alt="Picture" /></td>
<td>Air Products</td>
<td>2010</td>
<td>Trailer delivery of gaseous H$_2$ (SMR)</td>
<td>6,971</td>
<td>118,109</td>
</tr>
<tr>
<td>Milan</td>
<td><img src="image4.png" alt="Picture" /></td>
<td>Linde</td>
<td>2013</td>
<td>Onsite electrolyser from the electricity grid (mix of grid, CHP, solar energy) (+ trailer delivery as backup)</td>
<td>1,288</td>
<td>15,406</td>
</tr>
<tr>
<td>Oslo</td>
<td><img src="image5.png" alt="Picture" /></td>
<td>Air Liquide</td>
<td>2012</td>
<td>Onsite electrolyser: 100% H$_2$ from RES (hydro power) (+ trailer delivery as backup)</td>
<td>3,477</td>
<td>71,105</td>
</tr>
</tbody>
</table>

SMR= Steam Methane Reforming  - RES: Renewable Energy Sources; CHP: Combined Heat-and-Power
### Phase 0: 3 high throughput, 350bar stations
Some 650 tonnes of H₂ dispensed (to end March 2016)

<table>
<thead>
<tr>
<th>City</th>
<th>Photo</th>
<th>HRS/H₂ producer</th>
<th>Operation start</th>
<th>Type of HRS / source of H₂</th>
<th>Nber of fillings</th>
<th>Kg H₂ refuelled</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cologne</td>
<td><img src="image" alt="Cologne Photo" /></td>
<td>Air products</td>
<td>2011</td>
<td>Trailer delivery of gaseous H₂ by-product sourced nearby (chlor alkali electrolysis)</td>
<td>1,642</td>
<td>22,235</td>
</tr>
<tr>
<td>Hamburg</td>
<td><img src="image" alt="Hamburg Photo" /></td>
<td>Linde</td>
<td>2012</td>
<td>Onsite electrolyser - H₂ from RES (+ trailer delivery as backup)</td>
<td>2,220</td>
<td>36,750</td>
</tr>
<tr>
<td>Whistler</td>
<td><img src="image" alt="Whistler Photo" /></td>
<td>Air Liquide Canada</td>
<td>2009</td>
<td>Liquid H₂ generated from hydro-electric power in Quebec, delivered to the buses in gaseous form</td>
<td>23,671</td>
<td>591,590</td>
</tr>
</tbody>
</table>
Dramatic fuel economy improvements

• One of the most significant results of the trial program is the **improvement in the fuel economy**: 8 kg H₂/100km app. for the 12m buses (= ~ 27 l diesel) = 30% more energy efficient than a diesel bus\(^1\) and a >50% improvement compared with previous fuel cell bus generation (HyFLEET:CUTE)

• Why? use of **fully hybridised powertrains, smaller and more optimised fuel cell systems**

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\(^1\) Assumption: fuel consumption of a diesel bus: 40 l of diesel/100km
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
Other demonstration projects put the combined fleet of buses on European roads at an estimated 80 buses by the end of this year.

**Activity**
- CUTE & HyFLEET: CUTE (2001-09)
- CHIC
- High V.Lo.City
- HyTransit
- 3Emotion
- JIVE
- *JIVE successor* (TBC)

**Strategic milestones**
- FCH JU Stakeholders’ Forum* (14/11/14)
- TEN-T Days 2015, Riga** (23/06/15)
- Commercialisation study published
- Strategies for joint procurement study published
- International Zero Emission Bus Conference

**Future planning**
- Strategies for joint procurement
- FCH 2 JU 2016 Call deadline
- FCH 2 JU 2017 Call deadline
- Transition to commercialisation

* Plans for commercialisation of FC buses confirmed in joint letter from five European bus OEMs at the FCH JU’s Stakeholders’ Forum, Brussels (14/11/14).

** Declarations from innovative first buyers of five national clusters and from innovative producers signalling commitment to commercialising FC buses. TEN-T Days 2015, Riga (23/06/15).
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Element Energy has been coordinating demand aggregation for fuel cell buses across five “clusters” since 2015

Strategies for joint procurement of fuel cell buses (July 2016)

www.fch.europa.eu/sites/default/files/Strategies%20for%20joint%20procurement%20of%20FC%20buses_0.pdf
Working with city representatives, the cluster coordinators identified demand for >600 fuel cell buses across Europe.

Potential demand for fuel cell buses by cluster and bus type

Note that these are provisional estimates based on the work of the cluster coordinators to date. No firm commitment has been made by the cities. While the cluster coordinators have sought to provide realistic and relatively conservative deployment numbers, in practice these figures may fall as more detailed local feasibility work is undertaken.

Source: Strategies for joint procurement of fuel cell buses, Element Energy et al. for the FCH JU, Figure 9, p.30 (July 2016).
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><strong>Alexander Dennis</strong> (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><strong>EvoBus</strong> (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><strong>Rampini</strong> (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><strong>Solaris</strong> (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><strong>SoliBus</strong> (PL)</td>
<td>First FC bus delivered to Syntus (Dutch bus operator) in mid-2016.</td>
</tr>
<tr>
<td><strong>Urbino Bus</strong> (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><strong>VanHool</strong> (BE)</td>
<td>Market leader - &gt;40 FC buses operating in Europe and the US</td>
</tr>
<tr>
<td><strong>VDL</strong> (NL)</td>
<td>Four FC buses delivered in 2011 as part of demonstration activities.</td>
</tr>
<tr>
<td><strong>Wrightbus</strong> (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.
The FCH JU funded JIVE project will help commercialise fuel cell buses through a large-scale demonstration in 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

**Current FC buses**
- UK – 56 FC buses
- Germany – 51 FC buses
- Denmark – 10 FC buses
- Latvia – 10 FC buses
- Italy – 12 FC buses

**Future FC buses (Project JIVE)**
- UK – 56 FC buses
- Germany – 51 FC buses
- Denmark – 10 FC buses
- Latvia – 10 FC buses
- Italy – 12 FC buses

**Future FC buses (other projects)**
- Articulated bus (Project JIVE)

JIVE began in January 2017 and will be a six year project.
The JIVE 2 project was submitted in April 2017 – 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

### JIVE 2 in European Clusters

- **Benelux Cluster** (50 FC buses)
- **France Cluster** (15 FC buses)
- **Germany / Italy Cluster** (88 FC buses)
- **Northern / Eastern Europe Cluster** (50 FC buses)
- **UK Cluster** (88 FC buses)

**Total = 291** new FC buses for Europe

**Graph:**
- No. of FC buses
  - **Benelux:** 50
  - **France:** 15
  - **Germany / Italy:** 88
  - **N. / E. Europe:** 50
  - **UK:** 88

**Legend:**
- Light blue: JIVE
- Dark blue: JIVE 2

The fuel cell bus commercialisation coalition developed a ramp-up scenario that suggests c.400 FC buses deployed in Europe by 2020.

**Ramp-up scenario for FC buses in Europe**

**Number of fuel cell buses in Europe deployed / planned by project**

Existing / planned projects will deliver 350–400 FC buses by the early 2020s – further scale-up will be required to deliver the vision of the European ramp up scenario.

The NewBusFuel project examined options for large-scale hydrogen refuelling at bus depots.

Source: NewBusFuel project – see http://newbusfuel.eu/publications/
Accessing low cost (renewable) energy supplies will be key to generating cost-effective hydrogen.

**Overall \( H_2 \) costs in €/kg \( H_2 \) for the generic HRS example with 3,000 kg \( H_2 \)/d using on-site electrolysis**

- **H\(_2\) target cost range**: 4 - 6 €/kg \( H_2 \)

The main NewBusFuel project results are available as two reports: a techno-economic summary and a guidance document.

The two main project reports are intended to assist procurement activities for bus operators with no prior experience of hydrogen refuelling technologies.
What happens after JIVE? The Commercial Phase from 2020

• A number of countries 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 demand** – 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)

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Hydrogen fuel cell buses in Europe – conclusions

- The technology has been **demonstrated in a range of real-world environments** – millions of kilometres & thousands of refuelling events to date

- Key challenges to further adoption:
  - Improved availability of vehicles – to be achieved via the ongoing demonstration projects
  - Cost reductions – vehicles and hydrogen fuel

- Procurement plans are in place for approximately 300 buses before 2020

- A commercialisation process is underway that could lead to competitive fuel cell buses in the 2020s

- **The prize is large:**
  - commercial zero emissions buses for our cities
  - kick starting a new clean fuel for many vehicles types
  - Technologies which enable a fully zero emission energy system