Update on European hydrogen bus activity

September 2018

Element Energy Limited
Europe has gained significant exposure to fuel cell buses through CHIC - 56 fuel cell buses in eight cities - and successor projects

- London - 8 Wrightbus
- Aargau - 5 EvoBus
- Bozen/Bolzano - 5 EvoBus
- Milan - 3 EvoBus
- Oslo - 5 Van Hool
- 4 EvoBus - Hamburg
- 2 Solaris
- 2 APTS/Phileas - Cologne
- 2 Van Hool

Source: CHIC Emerging Conclusions
A first wave of European bus projects has recently finished – what Europe concluded from this 56 bus trial

Main conclusions from CHIC

- **The technology works** and can do the job in demanding public transport operations
- Hydrogen is **operationally highly attractive** and enjoyed by drivers and passengers
- There are still some **reliability** issues:
  - Initially due to components and systems design
  - Mainly now a function of a lack of scale in the supply chain
- There is an urgent **need for cost down** for the sector to really prosper → Large scale bus procurement projects (JIVE)
- Attention to **large scale H2** is also required → start to develop concepts for 100 bus depot fuelling (NewBusFuel)
- Following CHIC H2 is now considered in the same way as electric buses at least for politicians
While fuel cell bus costs have fallen significantly in recent years, further reductions will be needed for commercially viable offers.

Evolution of fuel cell bus costs in Europe

Capital costs of fuel cell buses ordered in different years
(non-articulated single deck buses)

2.0
1.5
1.0
0.5
0.0


Capital cost per FC bus EUR (m)

Scandinavian FC bus proposition (orders of 100+ vehicles): €450k**


JIVE projects

Year of bus order & relevant project

* 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://hydrogenvalley.dk/white-paper/.
### JIVE Overview – 290 buses around Europe – tenders beginning to show results

#### Objectives
- Deploy 290 FC buses across 22 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

**Map of Europe with regions highlighted:**
- **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)**

**Bar chart showing number of FC buses by region:**
- **Benelux:** 50
- **France:** 15
- **Germany / Italy:** 88
- **Northern / Eastern Europe:** 50
- **UK:** 88

**Total = 291 new FC buses for Europe**
TfL has led an exercise to establish a framework that allows joint procurement of fuel cell buses by public and private sector organisations.

Framework for joint procurement of FC buses – key features:

- Provide vehicles with a common (base) specification (with option to tailor buses according to specific needs) → **standardisation** and **economies of scale**.
- Allow consolidated **call off** orders to be placed.
- Enable other UK / European cities and UK bus operators to procure buses under similar terms.
- Live from mid 2018
In Germany, the cities of Cologne (30) and Wuppertaal (10) have placed a joint order for 40 buses, with plans for more.

Buses to be supplied by Van Hool
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>
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<tbody>
<tr>
<td><strong>(DE)</strong> EvoBus</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>
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<tr>
<td><strong>(IT)</strong> rampini</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>
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<tr>
<td><strong>(PL)</strong> SOLARIS</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>
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<td><strong>(PL)</strong> SOLBUS</td>
<td>First FC bus delivered to Syntus (Dutch bus operator) in mid-2016.</td>
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<td><strong>(PL)</strong> VanHool</td>
<td>Offers the “City Smile” 12m FC bus, based on a range extender concept. Demo bus present at the IAA 2016 (Hannover).</td>
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<td><strong>(BE)</strong> Vanhool</td>
<td>Market leader - &gt;40 FC buses operating in Europe and the US</td>
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<td><strong>(NL)</strong> VDL</td>
<td>Four FC buses delivered in 2011 as part of demonstration activities.</td>
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<tr>
<td><strong>(UK)</strong> Wrightbus</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>
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Note: this list is not exhaustive.
A number of exciting vehicles are at the operational prototype phase

Wrightbus double and single deck vehicles – prototype operational today, - available for order in 2019

Solaris 12m buses – operational prototype available in 2019, orders in 2020

Other new models coming from Alexander Dennis (UK – double deck) VDL (12m single deck), Solbus, Ursus and others
New refuelling solutions are also being developed to meet this step up in demand

For example, the Transport for London refuelling tender specification calls for:

- <5 minute fill time
- 12 buses filled per hour
- Target price for hydrogen <£5/kg

Tenders are ongoing

Slow fill solution in Pau (France)

Example of a low footprint solution for ~50 buses (from Nel) < 200 m²
In this context, we have been working on planning fuel cell bus deployment beyond the subsidised phase

- We have prepared a *White Paper* that makes the case for FC buses and sets out the next steps for key actors: policy makers, bus OEMs, component suppliers, infrastructure providers, and bus operators.

- This has involved holding discussions with a range of stakeholders (OEMs, infrastructure providers, potential investors, etc.) to develop a vision for the sector.
Hydrogen buses have the potential to become commercial

Hydrogen bus manufacturers can achieve a price of less than £350k for a 12m bus when provided manufacturing volumes of 100s of units per year. Maintenance costs can be comparable to diesel. £5/kg is the target price for fuel.
Similar site specific studies are now being carried out in specific locations (e.g. London, Cologne)

<table>
<thead>
<tr>
<th>Powertrain Type</th>
<th>Capex (£/bus)</th>
<th>No. of buses in fleet</th>
<th>Cost (£/mile)</th>
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<tbody>
<tr>
<td>Diesel hybrid</td>
<td>290k</td>
<td>55</td>
<td>6.20</td>
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<tr>
<td>Battery</td>
<td>400k</td>
<td>58</td>
<td>6.57</td>
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<tr>
<td>FC (mass market)</td>
<td>350k</td>
<td>55</td>
<td>6.56</td>
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<td>FC (niche)</td>
<td>500k</td>
<td>55</td>
<td>6.97</td>
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Zero emission premium relative to diesel hybrid

- **5.8%**
- **5.7%**
- **+12%**

**Cost of bus operations by powertrain type for a generic 50 PVR double deck bus route in London (per contracted mile) – 14 year contract period**

Exclusions: overhead costs, retraining costs, risk premiums, profit margins, etc.

PVR: peak vehicle requirement, FC: fuel cell

"Niche" scenario – economics only applicable to small fleets (e.g. as part of demonstration projects).
Sensitivity analysis shows the areas which still need work, e.g. approaches to residual values.

### Cost premium for operating zero emission buses on a generic double deck route with a PVR of 50 buses – sensitivity analysis results

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<td>5.8%</td>
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**Baseline assumptions:**
- Three additional battery electric buses in the fleet (relative to diesel or FC fleets).
- Hydrogen price of £5/kg.
- Costs over full life of buses (including powertrain overhaul costs).
- Equivalent bus lifetime and depreciation rate assumed across all powertrain types.
- Bus capex: £290k (diesel hybrid), £400k (battery electric), £350k (fuel cell electric).
What happens after JIVE? The Commercial Phase from 2020

• The JIVE project is starting to show results (albeit slowly due to challenges with procuring buses and stations)

• Ingredient to move beyond JIVE:
  – Scale of bus demand
  – Scale of demand at a depot
  – Access to low cost energy

• 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

• Projects and plans are emerging (for deployment in the early 2020s)