European hydrogen bus activity

October 2018

Element Energy Limited
**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
  - 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

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**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
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
- **Hamburg**
- **Oslo** - 5 Van Hool
- **Cologne** - 2 Van Hool
- **2 APTS/Phileas**
- **2 Solaris**

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

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

[www.chic-project.eu](http://www.chic-project.eu)
Other demonstration projects put the combined fleet of buses on European roads at an estimated 80 buses by the end of this year.

**Demonstration projects**
- 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).
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.

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.
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

**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

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
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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<tr>
<td><strong>UK</strong></td>
<td>Funded for a proof-of-concept hybrid fuel cell double-decker bus with Arcola Energy and Warwick Manufacturing Group.</td>
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<tr>
<td><strong>EvoBus</strong></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></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>SOLARIS</strong></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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<tr>
<td><strong>(PL)</strong></td>
<td>First FC bus delivered to Syntus (Dutch bus operator) in mid-2016.</td>
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<tr>
<td><strong>SOLBUS</strong></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></td>
<td>Market leader - &gt;40 FC buses operating in Europe and the US</td>
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<td><strong>(NL)</strong></td>
<td>Four FC buses delivered in 2011 as part of demonstration activities.</td>
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<td><strong>(UK)</strong></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

Fuel economy <8kg/100km is being targeted for low AC/heating climatic zones
In Germany, the cities of Cologne (30) and Wuppertaal (10) have placed a joint order for 40 buses, also smaller orders for Rheinbahn and Pau.
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.
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**

![Graph showing the evolution of fuel cell bus costs in Europe.](image)

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

<table>
<thead>
<tr>
<th>Year of bus order &amp; relevant project</th>
<th>Capital cost per FC bus (EUR m)</th>
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<tbody>
<tr>
<td>2009</td>
<td>2.0</td>
</tr>
<tr>
<td>2012</td>
<td>1.5</td>
</tr>
<tr>
<td>2014</td>
<td>1.0</td>
</tr>
<tr>
<td>2017/18</td>
<td>0.5</td>
</tr>
<tr>
<td>2020</td>
<td>0.0</td>
</tr>
<tr>
<td>2023</td>
<td>0.0</td>
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**Scandinavian FC bus proposition**
- (orders of 100+ vehicles): €450k**

**FCH JU MAWP* (2014–2020) targets:**
- €650k (2020) / €500k (2023)

**JIVE projects**

**Range indicated by certain OEMs considering commercial roll-out**
- <€400k per bus, assuming >100 buses per year

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* **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/](http://hydrogenvalley.dk/white-paper/).
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.
EE view on the requisite targets for an FC bus breakthrough

- The analysis of the TCO case for hydrogen buses suggests that the hydrogen bus can a commercial breakthrough in cities regulating to ban diesel buses, provided:

1. **Low capital cost** $< \€400k/bus$, preferably $<\€350k/bus$
2. **Low maintenance costs** – target is parity with diesel bus maintenance, small premia may be viable
3. **Low fuel costs** – requires a combination of fuel economy and Hydrogen price:
   - Hydrogen price $< \€6/kg$, preferably $\€5/kg$, AND
   - Fuel economy $< 8kg/100km$, preferably $< 6.5kg/100km$ (for a 12m bus)
4. **Affordable finance** – implies acceptable residual values and trust in the marketplace

All of these targets need to be achieved together.....
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)

All of the bus projects in this presentation have received funding from the **Fuel Cells and Hydrogen Joint Undertaking**. This Joint Undertaking receives support from the **European Union’s Horizon 2020** research and innovation programme, the New European Research Grouping on Fuel Cells and Hydrogen ("**N.ERGHY**") and **Hydrogen Europe**.