London hydrogen buses and the CHIC project

(Grant agreement No: 256848)

All-Energy - May 2016
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• Project status
• Emerging results – achievements and issues
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• Resolving the cost problems - Joint procurement project
Why go for fuel cell buses?

• The fuel cell bus is an electric bus that offers many advantages:

  **High daily range:**
  300 kms without refuelling – possibility of extension

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

  **Zero tailpipe emissions** (only water emitted) and CO₂ emissions savings – linked to hydrogen production source

  **Passengers and drivers comfort**
  ...due to reduced noise levels and smooth driving experience

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

  **A concrete answer to ambitious policy targets**
  set for transport decarbonisation
56 Fuel cell buses manufactured by 6 different bus OEMs in 9 different cities

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

- Co-funded by the FCH-JU
- Co-funded by other programmes

20 New Flyer in Whistler
The CHIC project is the first of a number of European bus demonstrations - 83 FC buses will soon be in operation

83 fuel cell buses in operation or about to start operation

Current EU-funded fuel cell bus projects

**CHIC**
- Bolzano – 5 FC buses
- Aargau – 5 FC buses
- London – 8 FC buses
- Milan – 3 FC buses
- Oslo – 5 FC buses
- Cologne* – 4 FC buses
- Hamburg* – 6 FC buses

**High V.LO-City** (operation start planned for 2015)
- Liguria – 5 FC buses
- Antwerp – 5 FC buses
- Aberdeen – 4 FC buses

**HyTransit** (operation start planned for 2015)
- Aberdeen – 6 FC buses

Current EU-funded fuel cell bus projects:

- **3Emotion** (operation start planned for 2016/2017)
  - Cherbourg – 5 FC buses
  - Rotterdam – 4 FC buses
  - South Holland – 2 FC buses
  - London – 2 FC buses
  - Flanders – 3 FC buses
  - Rome – 5 FC buses

Current national/regional-funded fuel cell bus projects:

- Karlsruhe * – 2 FC buses
- Stuttgart * – 4 FC buses

Legend:
- CHIC countries
- In operation
- Planned for operation
- Co-financed by regional/national funding sources

Last update: 04/02/2015
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)
Fuelling in London

- Delivered gaseous hydrogen
- ~ 350kg 500bar @ 15°C permanent storage
- Delivery ~ 900kg 500bar @15°C tube trailer
- Time for fuelling ~ 10 minutes
- Non communication fill
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• Resolving the cost problems - Joint procurement project

• Resolving the challenge of larger stations - NewBusFuel
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Project total (incl. ICE buses in Berlin)</th>
<th>Phase 1 cities</th>
<th>Project goal for the Phase 1 cities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total distance travelled [km]</td>
<td>8,352,195</td>
<td>2,955,949</td>
<td>2,750,000</td>
</tr>
<tr>
<td>Total hours on FC system [h]</td>
<td>425,854&lt;sup&gt;1&lt;/sup&gt;</td>
<td>192,949</td>
<td>160,000</td>
</tr>
<tr>
<td>Average FC runtime per bus [h]</td>
<td>7,886&lt;sup&gt;1&lt;/sup&gt;</td>
<td>7,421</td>
<td>6,000</td>
</tr>
<tr>
<td>Replacement of diesel fuel [litres]</td>
<td>4,004,139</td>
<td>1,206,199</td>
<td>500,000</td>
</tr>
<tr>
<td>Total H2 refueled [kg]</td>
<td>1,133,591</td>
<td>283,266</td>
<td></td>
</tr>
</tbody>
</table>

<sup>1</sup> This figure does not include the ICE buses in Berlin
• ISE, later Bluways, designed and integrated the buses.
  • No longer involved in project.
• Over 117,115 hours running in service.

**Total Hours in Service End March 2016**

<table>
<thead>
<tr>
<th>Vehicle No.</th>
<th>Hours in Service</th>
</tr>
</thead>
<tbody>
<tr>
<td>62991</td>
<td>18230</td>
</tr>
<tr>
<td>62992</td>
<td>7844</td>
</tr>
<tr>
<td>62993</td>
<td>18052</td>
</tr>
<tr>
<td>62994</td>
<td>18611</td>
</tr>
<tr>
<td>62995</td>
<td>19333</td>
</tr>
<tr>
<td>62996</td>
<td>14679</td>
</tr>
<tr>
<td>62997</td>
<td>8860</td>
</tr>
<tr>
<td>62998</td>
<td>11507</td>
</tr>
</tbody>
</table>
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• Resolving the challenge of larger stations - NewBusFuel
• Operating range can meet the demand of bus operators, with up to 400 km demonstrated, and 20h of service/day;

• the fuel cell bus offers a flexibility of service equivalent to a diesel bus and fits well into the Bus Rapid Transit concept

<table>
<thead>
<tr>
<th>City</th>
<th>Range¹</th>
<th>Daily duty²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aarau</td>
<td>180 - 250 km</td>
<td>18-20 hours</td>
</tr>
<tr>
<td>Bolzano</td>
<td>220-250 km</td>
<td>12 hours</td>
</tr>
<tr>
<td>Cologne</td>
<td>350 km</td>
<td>12-16 hours</td>
</tr>
<tr>
<td>Hamburg</td>
<td>400 km</td>
<td>8 – 16 hours</td>
</tr>
<tr>
<td>London</td>
<td>250 - 300 km</td>
<td>16-18 hours</td>
</tr>
<tr>
<td>Milano</td>
<td>170 km</td>
<td>Up to 16 hours</td>
</tr>
<tr>
<td>Oslo</td>
<td>200 - 290 km (seasonal)</td>
<td>Up to 17 hours</td>
</tr>
<tr>
<td>Whistler³</td>
<td>366 – 467 km (seasonal)</td>
<td>4 – 22 hours</td>
</tr>
</tbody>
</table>

¹ Average figures, also based on tank size and average consumption
² Daily duty figure subject to route type (sites may operate the same bus on more than one route)
³ Planned operations ceased on 31st March 2014
Dramatic fuel economy improvements

• One of the most significant results of the trial program is the improvement in the fuel economy: 8kg H₂/100km app. for the 12m buses (= ~ 27l diesel) = 30% more energy efficient than a diesel bus¹ 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

¹ Assumption: fuel consumption of a diesel bus: 40 l of diesel/100km
• All European partners are able to fill a bus from empty in less than 10 minutes in average.

<table>
<thead>
<tr>
<th>City</th>
<th>Refuelling time</th>
<th>Station specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>London</td>
<td>&lt;10 minutes</td>
<td>10 minutes</td>
</tr>
<tr>
<td>Aargau</td>
<td>&lt;10 minutes</td>
<td>10 minutes</td>
</tr>
<tr>
<td>Bolzano/Bozen</td>
<td>&lt;10 minutes</td>
<td>15 minutes</td>
</tr>
<tr>
<td>Oslo</td>
<td>&lt;10 minutes</td>
<td>10 minutes</td>
</tr>
<tr>
<td>Cologne</td>
<td>&lt;10 minutes</td>
<td>10 minutes</td>
</tr>
<tr>
<td>Hamburg</td>
<td>&lt;10 minutes</td>
<td>10 minutes</td>
</tr>
<tr>
<td>Whistler</td>
<td>20 minutes</td>
<td>10 minutes</td>
</tr>
</tbody>
</table>

• Remaining concern around refuelling stations operation: inability of stations to meter hydrogen supply accurately enough (i.e. as for other conventional fuels) as no accurate hydrogen meter is currently available; an accurate metering system is under development for 700bar stations(cars), a further solution for 350bar stations is being investigated
High station availability

- The **availability** of stations in the CHIC project has been consistently **high**, with an average availability **over 95%** at most sites; and the stations are well integrated in busy bus depots.

- This compares favourably with the HyFLEET:CUTE project, where problems with on-site production, compression and dispensers dogged the trial.

<table>
<thead>
<tr>
<th>City</th>
<th>Availability to date*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aargau</td>
<td>&gt; 96%</td>
</tr>
<tr>
<td>Bolzano</td>
<td>&gt;98%</td>
</tr>
<tr>
<td>Londres</td>
<td>&gt; 98%</td>
</tr>
<tr>
<td>Milan</td>
<td>&gt; 94%</td>
</tr>
<tr>
<td>Oslo</td>
<td>&gt; 94%</td>
</tr>
<tr>
<td>Cologne</td>
<td>&gt; 97%</td>
</tr>
<tr>
<td>Hambourg</td>
<td>&gt; 92% (since Aug. 2013: &gt; 98%)</td>
</tr>
<tr>
<td>Whistler</td>
<td>&gt; 98%</td>
</tr>
</tbody>
</table>

- However, this figure is not high enough to allow H$_2$ to satisfy a large share of a city fleet – A new European project, NewBusFuel, starting in summer 2015 will look at engineering solutions for depots integrating a larger fuel cell bus fleet (50-200 buses).

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1preliminary figure - * Dec 2014
As is the case for all innovative technologies, one cannot expect a fuel cell bus to be 100% operational on day one, a teething period is necessary, during which lower availability is expected. This can be explained as the supply chain is still immature, and is expected to be solved with an increase in scale in the sector.

It has to be noted that the most of the issues are not directly linked to the fuel cell.

An availability upgrade programme has been implemented in 2014 with positive results: the availability in some cities exceed 90%, with an average >80% in the Phase 1 cities.
Reasons for out of service (London)

1. Planned maintenance: 13%
2. Bodywork damage / RTC: 17%
3. Non start / Cut out: 21%
4. System service light: 12%
5. Differential: 3%
6. Other: 5%
7. H2 tank valve: 1%
8. Cooling: 1%
9. Fuel cell defect: 11%
10. Road call H2 / hybrid: 7%
11. Road call Non H2 / hybrid: 6%
12. Lack of fuel: 1%
13. CAN error: 2%

12/05/2016
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The CHIC project is demonstrating that fuel cell buses have the potential to provide the same operational flexibility as conventional diesel buses.

They can do this with zero emissions, substantial GHG emission improvement and satisfying the travelling public and the drivers.

Main Challenges:

- **Bus availability needs to improve** over 85% - expected to be resolved by a) resolving the teething issues in the current trial and b) scale in the supply chain.

- **Bus prices need further reduction to enable genuine market traction** (less than €500,000) - resolved through the FCH JU commercialisation study.

- Depot-scale refueling solutions are still required (e.g. for 100 buses/day) – new FCH JU backed depot engineering study.
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The consultancy team consists of seven organisations coordinating activities in five clusters

The consultancy team is being led by Element Energy (also the UK cluster coordinator), and includes partners to coordinate activities across Europe:

- **France** – Hydrogène de France
- **Germany** – ee energy engineers & hySOLUTIONS
- **Netherlands** – Rebel Group & Twynstra Gudde
- **Northern Europe** – Latvian Academy of Sciences
- **UK** – Element Energy
Thank you for your attention

www.chic-project.eu

Email: h2businfo@chic-project.eu

@CHIC project
NewBusFuel project

- Aberdeen
  - Linde
  - Aberdeen City Council

- Birmingham
  - ITM Power
  - Birmingham City Council

- London
  - Air Products
  - London Bus Services Limited

- De Lijn
  - Linde
  - De Lijn

- Wuppertal
  - Hydrogenics
  - Wuppertaler Stadtwerke

- Madrid
  - Abengoa Hidrógeno
    - Empresa Municipal de Transportes de Madrid

- Bolzano
  - Ingenieurbüro Bergmeister
    - Institut für Innovative Technologien Bozen Konsortial
    - Siemens, Linde

- Oslo/Akershus
  - HYOP
  - Akershus City Council
    - Kunnskapsbyen Lillestrom Forening

- Riga
  - Industry role to be tendered
    - Riga Satiksme

- Hamburg 1
  - Vattenfall Innovation
    - Hamburger Hochbahn
    - Siemens

- Hamburg 2
  - Air Products
    - Hamburger Hochbahn

- Potsdam
  - Mc Phy Energy
    - ViP Potsdam
    - H2 Logic

- Stuttgart
  - Siemens
    - Stuttgarter Strassenbahnen

**Inter-study partners:** Element Energy, thinkstep, EvoBus
REFUELLING INFRASTRUCTURE – providing convenience in three main clusters

London Cluster: ITM Power Air Products

Copenhagen Cluster: CHN (Copenhagen Hydrogen Network)

Southern Cluster: LINDE OMV
H2ME – 29 stations and 325 fuel cell vehicles

Hydrogen Mobility Europe

Endorsers:
- Mobilité Hydrogène France
- H₂ Mobility
- UK H₂ Mobility
- Scandinavian Hydrogen Highway Partnership
- Hydrogen mobility grouping in Benelux
- Hydrogen mobility grouping in Austria

Project partners:
- AIR LIQUIDE
- DAIMLER
- AREVA H₂Gen
- BOC
- HYUNDAI
- cenex
- H₂ Logic
- HONDA
- E I FER
- ITM POWER
- H₂ MOBILITY
- LINDE
- NISSAN
- HYOP
- McPhy
- OMV
- NYORKA

H2ME main demonstration areas
H2ME observer partners
TENT-T corridor (selection)
H2ME stations