Presentation of emerging conclusions

Detailed project’s presentation

(Grant agreement No: 256848)

December 2014
CONTENTS

• Executive summary

• Introduction

• Project status

• Emerging results – achievements

• Emerging results – issues identified

• Attitudes of stakeholders

• Next steps and final remarks

• Appendix – Berlin’s hydrogen ICE buses status
• **36 fuel cells electric buses** on the road in day-to-day passenger duty, while the 20 fuel cell buses in Whistler (Canada) ended their planned operation time on 31 March 2014.

• **The buses have driven over 6 million km.** Vehicles are able to satisfy the daily demands of urban bus routes without returning to the depot (e.g. up to 20 hour shifts without refueling and typically over 200km daily range).

• **50% fuel economy improvements** versus the previous fuel cell bus generation through a move to hybrid architecture as well as smaller, longer-life fuel cells.

• The **high throughput 350 bar stations** deployed in the project (the highest throughput stations in Europe) **have performed ahead of expectations**, with availabilities (c. 95% in average to date) and filling times (typically <10 minutes) consistently exceeding requirements – a major advance over previous trials. More than **one million kg of hydrogen has been tanked** since the project start.

• The move to **hybrid architecture** and to daily operation closer to conventional buses (e.g. long shifts) has led to a considerably **lower availability throughout the project to date than was the target (>85%)** – monthly availability has ranged between 40% and 80%. This created disappointments in those cities where stakeholders felt they were overpromised on the commercial readiness of the demonstration buses. The CHIC partners are working together to resolve these issues and demonstrate the readiness of the technology for widespread roll-out.
• Some of the CHIC projects have encountered delays, due to lengthy permitting procedures for hydrogen fuelling infrastructure (reflecting a lack of harmonised EU-wide regulations on hydrogen technologies), issues with procurement and late delivery of components which reflect the relative commercial immaturity of the sector.

• High awareness has been gained through a series of high profile events such as the provision of shuttle buses at the last two World Economic Forum in Davos. Frequent local dissemination activities are taking place in the cities raising awareness of citizens, school kids, students etc.

• Socio-economic work demonstrates a generally positive attitude towards hydrogen technologies amongst the general public, bus drivers etc. Drivers and passengers tend to like the vehicles and realise they are using a different type of bus with more comfort and less noise.

• Safety issues were not a major worry for the general public, as people trust in authorities and expect technologies to be safe before they are brought to market.
The CHIC project is a major European project to deploy a fleet of fuel cell electric buses and associated refueling infrastructure.

The project has been running since 2010 and will end in 2016. The project is being supported by the European Union through the Fuel Cells and Hydrogen Joint Undertaking (FCH-JU).

This document provides a summary of the project status, highlights key achievements and also suggests some of the emerging issues which need to be tackled by the fuel cell bus sector.

This presentation is periodically updated by the CHIC partners to provide a report on the project status and serves as basis for additional dissemination materials.
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Why engage with fuel cell electric buses?  
...perspectives for bus operators

### Operational flexibility

- Among the zero-emission powertrain options, fuel cell buses have the **longest range** and **shortest refuelling times** whilst still providing **full operational flexibility**
- A long term solution for a sustainable technology which **does not limit productivity and quality of service**

### Preparing for the future

- Society is moving towards a low carbon future. Engaging early in the process:
  1) Allows the development of **in-house expertise** and infrastructure
  2) Get direct benefits from the buses, while helping to drive down the technology costs, **reducing future deployment costs** for bus fleets across European cities
  3) **Improves the image** of the bus operator
  4) **Get support** from the FCH-JU and from a **dynamic network** of early adopters
Better quality of life

- **Air quality improvements**: fuel cell buses produce no toxic tailpipe emissions
- **GHG emissions reductions**: fuel cell buses offer reduced GHG emissions, with the potential for zero-emission transport when hydrogen is generated from renewables
- **Noise reductions**: fuel cell buses are quiet

Policy Choice

- Tool to comply with **EU, national and local regulations** on low-carbon mobility
- Offers a long term strategy duly focussed on **reducing dependency to fossil fuels** by increasing the use of local resources, producing new local jobs and improving economic competitiveness
- **Engaging early** with the technology helps prepare more optimised plans for the stepped introduction of clean solutions
Overview of the project

• Demonstration phase lasts from 2010 to 2016
• €25.88 million funding, €81.8 million in total costs
• 9 Cities/regions involved
• 23 partners from 8 countries (10 transport companies, 8 industry partners and 5 research/consultants)
• 26 fuel cell buses operated in five “Phase 1” cities receiving funding from the FCH JU
• Four “Phase 0” cities operating further fuel cells buses through separately funded programs
• 58 fuel cell buses demonstrated in total during the project
• 5 different bus manufacturers involved (3 in the Phase 1 cities)
• 5 hydrogen refueling stations (350bar) built in Phase 1 alone, in total 9 refueling stations
• Additional 41 fuel cell buses being deployed as part of follow-up projects

1 As part of the High V.LO-City, Hytransit and 3Emotion projects
The fuel cell buses are manufactured by 5 different bus OEMs:

- 5 EvoBus
- 5 EvoBus
- 3 EvoBus
- 8 Wrightbus
- 5 Van Hool
- 4 EvoBus + 2 Solaris
- 2 APTS/Phileas
- 2 Van Hool

+ 20 fuel cell buses in Whistler (Canada) and 4 H2 ICE buses in Berlin

Co-funded by the FCH-JU
Co-funded by other programmes
## Fuel cells buses - deployment timeline

### Cities starting operations

<table>
<thead>
<tr>
<th>City</th>
<th>Bus Introduced</th>
<th>Bus Introduced</th>
<th>Total number of buses on the road</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whistler</td>
<td>NewFlyer</td>
<td></td>
<td>20 FC buses</td>
</tr>
<tr>
<td>London</td>
<td>Wrightbus</td>
<td></td>
<td>25 FC buses</td>
</tr>
<tr>
<td>Cologne, Hamburg</td>
<td>APTS, EvoBus</td>
<td></td>
<td>31 FC buses</td>
</tr>
<tr>
<td>Aargau, Oslo</td>
<td>EvoBus, Van Hool</td>
<td></td>
<td>41 FC buses</td>
</tr>
<tr>
<td>Bolzano, London, Milano</td>
<td>EvoBus, Wrightbus</td>
<td></td>
<td>52 FC buses</td>
</tr>
<tr>
<td>Cologne, Hamburg</td>
<td>Van Hool, Solaris</td>
<td></td>
<td>36 FC buses¹</td>
</tr>
</tbody>
</table>

### Bus introduced

<table>
<thead>
<tr>
<th>City</th>
<th>Bus Introduced</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whistler</td>
<td>NewFlyer</td>
</tr>
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</tr>
<tr>
<td>Aargau, Oslo</td>
<td>EvoBus, Van Hool</td>
</tr>
<tr>
<td>Bolzano, London, Milano</td>
<td>EvoBus, Wrightbus</td>
</tr>
<tr>
<td>Cologne, Hamburg</td>
<td>Van Hool, Solaris</td>
</tr>
</tbody>
</table>

### Total number of buses on the road

<table>
<thead>
<tr>
<th>Year</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013-03/2014</th>
<th>04/2014 To date</th>
</tr>
</thead>
</table>

Note that two more fuel cells buses have been ordered in Hamburg, from a 6th manufacturer.

Note that four ICE-hydrogen buses (from a 7th manufacturer) are operated in Berlin.

¹ The 20 fuel cell buses in Whistler (Canada) have ended their planned operation time on 31 March 2014.
The CHIC buses are characterised by an improved bus architecture

<table>
<thead>
<tr>
<th>Component</th>
<th>CHIC range (Phase 0 and phase 1 cities)</th>
<th>Key improvements over previous fuel cell bus project</th>
</tr>
</thead>
</table>
| **Fuel cell system**        | 75 – 150 kW (rated peak output)         | • **Smaller** and cheaper systems  
                                 |                                                       | • Higher power density  
                                 |                                                       | • Extended life |
| **Battery system**          | 90 – 250 kW (Ni-MH or Li-ion)           | CHIC buses are characterised by a **hybridised powertrain**. A system integration of highly efficient batteries is needed |
| **Supercapacitor system**   | 180 - 240 kW (peak power)               | In a hybridised powertrain, the energy storage systems (battery, supercapacitors or both) can:  
                                 |                                                       | • Buffer peak loads  
                                 |                                                       | • Boost acceleration  
                                 |                                                       | • Allow energy recovery from braking |
| **Energy recuperation system** | Brake resistors or wheel-hub motors | Benefits:  
                                 |                                                       | • Greatly improved fuel efficiency (e.g. up to ~ 50% better than previous project HyFLEET:CUTE)  
                                 |                                                       | • Improved FC system life |
| **H₂ storage system**       | 4-8 tanks, 350bar 33 to 55 kg           | • **Lower number of tanks** at parity of mileage (better fuel efficiency) |
Phase 1 cities – the EvoBus buses

- Deployed in Aarau, Bolzano and Milan

<table>
<thead>
<tr>
<th>Component</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel cell system</td>
<td>120 kW (2 modules)</td>
</tr>
<tr>
<td>Battery system</td>
<td>250 kW (Li-ion)</td>
</tr>
<tr>
<td>Supercapacitor system</td>
<td>--</td>
</tr>
<tr>
<td>Energy recuperation system</td>
<td>Wheel-hub motor</td>
</tr>
<tr>
<td>H₂ storage system</td>
<td>7 tanks, 350bar ~ 35 kg</td>
</tr>
</tbody>
</table>
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

→ Deployed in Oslo and Cologne

<table>
<thead>
<tr>
<th>Component</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel cell system</td>
<td>150 kW (1 module) (rated peak output)</td>
</tr>
<tr>
<td>Battery system</td>
<td>100 kW (Li-ion)</td>
</tr>
<tr>
<td>Supercapacitor system</td>
<td>--</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, 350 bar ~ 35 kg</td>
</tr>
</tbody>
</table>
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)
Deployed in London

### Component Specifications

<table>
<thead>
<tr>
<th>Component</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel cell system</td>
<td>75 kW (1 module) (rated peak output)</td>
</tr>
<tr>
<td>Battery system</td>
<td>--</td>
</tr>
<tr>
<td>Supercapacitor system</td>
<td>240 kW (rated peak power)</td>
</tr>
<tr>
<td>Energy recuperation system</td>
<td>Brake resistors</td>
</tr>
<tr>
<td>H₂ storage system</td>
<td>4 tanks, 350bar ~ 33 kg</td>
</tr>
</tbody>
</table>
Phase 1 cities – the Wrightbus buses

Fuel cell buses in London (8 in total)
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• Appendix – Berlin’s hydrogen ICE buses status
## Overall project snapshot (to end August 2014)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Project total to date (including the 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>6,925,860</td>
<td>1,756,364</td>
<td>2,750,000</td>
</tr>
<tr>
<td>Total hours on FC system [h]</td>
<td>332,425</td>
<td>112,914</td>
<td>160,000</td>
</tr>
<tr>
<td>Average FC runtime per bus [h]</td>
<td>6,156&lt;sup&gt;1&lt;/sup&gt;</td>
<td>4,517</td>
<td>6,000</td>
</tr>
<tr>
<td>Total H2 refueled [kg]</td>
<td>985,475</td>
<td>163,149</td>
<td>-</td>
</tr>
<tr>
<td>Replacement of diesel fuel [litres]</td>
<td>3,717,967</td>
<td>707,161</td>
<td>500,000</td>
</tr>
</tbody>
</table>

<sup>1</sup> This figure does not include the ICE buses in Berlin
## City status (to end August 2014)
- the fuel cell buses have driven over 6 million km

<table>
<thead>
<tr>
<th>City</th>
<th>No. of buses</th>
<th>Manufacturer</th>
<th>km travelled</th>
<th>FC runtime per bus [h]</th>
<th>Total FC runtime [h]</th>
<th>Availability (average)¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cologne</td>
<td>4</td>
<td>APTS, Van Hool</td>
<td>93,481</td>
<td>1,128</td>
<td>4,513</td>
<td>44%²</td>
</tr>
<tr>
<td>Hamburg</td>
<td>4</td>
<td>EvoBus</td>
<td>206,003</td>
<td>3,272</td>
<td>13,087</td>
<td>53%</td>
</tr>
<tr>
<td>Whistler³</td>
<td>20</td>
<td>NewFlyer</td>
<td>4,005,000</td>
<td>10,096⁴</td>
<td>201,911⁴</td>
<td>67%</td>
</tr>
<tr>
<td>Aargau</td>
<td>5</td>
<td>EvoBus</td>
<td>711,802</td>
<td>6,443</td>
<td>32,213</td>
<td>80%⁵</td>
</tr>
<tr>
<td>Bolzano / Bozen</td>
<td>5</td>
<td>EvoBus</td>
<td>86,722</td>
<td>1,035</td>
<td>5,173</td>
<td>75%</td>
</tr>
<tr>
<td>London</td>
<td>8</td>
<td>Wrightbus</td>
<td>668,991</td>
<td>7,701</td>
<td>61,611</td>
<td>62%</td>
</tr>
<tr>
<td>Milan</td>
<td>3</td>
<td>EvoBus</td>
<td>31,646</td>
<td>944</td>
<td>2,833</td>
<td>48%</td>
</tr>
<tr>
<td>Oslo</td>
<td>5</td>
<td>VanHool</td>
<td>257,203</td>
<td>2,217</td>
<td>11,084</td>
<td>63%</td>
</tr>
</tbody>
</table>

¹ Availability calculation based on hours of operation (including when the bus is ready for operation, but there is no driver or hydrogen etc.);
² 2 APTS buses are prototype buses, their availability is therefore expected to be lower than the availability of the other buses
³ Operations ceased on 31st March 2014;
⁴ Data as of March 2014;
⁵ Availability calculation based on a km per month basis
### Phase 1 cities: 5 different bus operators, demonstrating daily performance of vehicles on conventional diesel routes

<table>
<thead>
<tr>
<th>Phase 1 City</th>
<th>Operator</th>
<th>Type of route (length, stops)</th>
<th>Average speed</th>
<th>Workshop strategy</th>
<th>Maintenance facility (picture)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aargau</td>
<td>PostBus</td>
<td>Rural - hilly - low temperature winter</td>
<td>22 km/h</td>
<td>EvoBus workshop in Kloten, one maintenance bay</td>
<td><img src="image1.png" alt="Image" /></td>
</tr>
<tr>
<td>Bolzano / Bozen</td>
<td>STA / operated by SASA</td>
<td>Urban - flat - low temperature winters, high temperature summers (14.3 km; 44 stops)</td>
<td>17.2 km/h</td>
<td>Conversion facility, one bay (max two buses in line).</td>
<td><img src="image2.png" alt="Image" /></td>
</tr>
<tr>
<td>London</td>
<td>Transport for London</td>
<td>Urban - flat – moderate climate (6.23 km, 27 stops)</td>
<td>12 km/h</td>
<td>New-build facility – purpose built with 2 maintenance bays</td>
<td><img src="image3.png" alt="Image" /></td>
</tr>
<tr>
<td>Milan</td>
<td>ATM</td>
<td>Urban - flat - high temperature summers (9.5 km, 30 stops)</td>
<td>12-13 km/h</td>
<td>Conversion of a small area of an existing diesel maintenance depot</td>
<td><img src="image4.png" alt="Image" /></td>
</tr>
<tr>
<td>Oslo</td>
<td>Ruter</td>
<td>Suburban to urban - flat/hilly - low temperature winters (20 km, 48 stops)</td>
<td>20 km/h</td>
<td>Conversion of a single existing bay</td>
<td><img src="image5.png" alt="Image" /></td>
</tr>
</tbody>
</table>
Phase 1: 5 new high throughput, 350bar stations over 163 tonne of H₂ dispensed (to end August 2014)

<table>
<thead>
<tr>
<th>Phase 1 City</th>
<th>Type of HRS / source of H₂</th>
<th>Manufacturer</th>
<th>Start of operation</th>
<th>Image</th>
<th>Number of fillings</th>
<th>Kg H₂ refuelled</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aargau</td>
<td>Onsite electrolyser (+ trailer delivery as backup)</td>
<td>Carbagas (Air Liquide)</td>
<td>2012</td>
<td><img src="image1" alt="Image" /></td>
<td>3,931</td>
<td>57,890</td>
</tr>
<tr>
<td>Bolzano/Bozen</td>
<td>Onsite electrolyser (+ trailer delivery as backup)</td>
<td>Linde</td>
<td>2014</td>
<td><img src="image2" alt="Image" /></td>
<td>434</td>
<td>7,423</td>
</tr>
<tr>
<td>London</td>
<td>Liquid H₂ tanker with high pressure delivery into onsite storage</td>
<td>Air Products</td>
<td>2010</td>
<td><img src="image3" alt="Image" /></td>
<td>3,899</td>
<td>61,808</td>
</tr>
<tr>
<td>Milan</td>
<td>Onsite electrolyser (+ trailer delivery as backup)</td>
<td>Linde</td>
<td>2013</td>
<td><img src="image4" alt="Image" /></td>
<td>305</td>
<td>3,107</td>
</tr>
<tr>
<td>Oslo</td>
<td>Onsite electrolyser (+ trailer delivery as backup)</td>
<td>Air Liquide</td>
<td>2012</td>
<td><img src="image5" alt="Image" /></td>
<td>1,642</td>
<td>32,921</td>
</tr>
</tbody>
</table>
Phase 0: 4 high throughput, 350bar stations over 623 tonne of H₂ dispensed (to end August 2014)

<table>
<thead>
<tr>
<th>City</th>
<th>Type of HRS / source of H₂</th>
<th>Manufacturer</th>
<th>Start of operation</th>
<th>Image</th>
<th>Number of fillings</th>
<th>Kg H₂ refuelled</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cologne</td>
<td>Trailer delivery of gaseous H₂ by-product sourced nearby</td>
<td>Air products</td>
<td>2011</td>
<td><img src="image1.jpg" alt="Image" /></td>
<td>782</td>
<td>13,703</td>
</tr>
<tr>
<td>Hamburg</td>
<td>Onsite electrolyser (+ trailer delivery as backup)</td>
<td>Linde</td>
<td>2012</td>
<td><img src="image2.jpg" alt="Image" /></td>
<td>1,094</td>
<td>17,728</td>
</tr>
<tr>
<td>Whistler</td>
<td>Delivered liquid</td>
<td>Air Liquide Canada</td>
<td>2009</td>
<td><img src="image3.jpg" alt="Image" /></td>
<td>23,671</td>
<td>591,590</td>
</tr>
</tbody>
</table>
London’s buses and the refuelling station were launched by the Deputy Mayor in a major press event in December 2010.

The Oslo vehicles and station had a major launch event attended by national and regional politicians on May 2012 at the buses depot.

The Aargau buses were used to transport visitors at the World Economic Forum in Davos 2013 and 2014, Locarno Film Festival (August 2012 and 2013)...

A large number of dissemination activities are taking place in the cities/regions in which the buses are displayed. Numerous dissemination materials have been developed, among which videos which are available on the project website ([www.chic-project.eu](http://www.chic-project.eu)).
• Operating range can meet the demands of bus operators

• This compares well with the previous generation of fuel cell buses, whose range was less < 200 km, where buses were forced to operate in half day shifts before fuelling.

<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 hours</td>
</tr>
<tr>
<td>Bolzano</td>
<td>220-250 km</td>
<td>12 hours</td>
</tr>
<tr>
<td>Cologne</td>
<td>250 km</td>
<td>Up to 10 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>18 hours</td>
</tr>
<tr>
<td>Milano</td>
<td>122 km</td>
<td>Up to 16 hours</td>
</tr>
<tr>
<td>Oslo</td>
<td>200 - 290 km (seasonal)</td>
<td>Up to 15 hours</td>
</tr>
<tr>
<td>Whistler</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
One of the most significant results of the trial program is the improvement in the bus fuel economy: >50% fuel economy compared with previous fuel cell bus generation (HyFLEET:CUTE).

Why? use of fully hybridized powertrains, smaller and more-optimized FC systems.

Average consumption of the FCH buses

- Shaded area indicates consumption range in HyFLEET:CUTE, 47 buses consumed between 18.4 and 29.1 kg H2/100km.
Some partners able to fill a bus from empty in ~ 7 minutes.

<table>
<thead>
<tr>
<th>City</th>
<th>Average fill time observed</th>
<th>Station specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>London</td>
<td>9 minutes</td>
<td>10 minutes</td>
</tr>
<tr>
<td>Aargau</td>
<td>7 minutes</td>
<td>10 minutes</td>
</tr>
<tr>
<td>Oslo</td>
<td>7 minutes</td>
<td>10 minutes</td>
</tr>
<tr>
<td>Cologne</td>
<td>7 minutes</td>
<td>10 minutes</td>
</tr>
<tr>
<td>Hamburg</td>
<td>7 minutes</td>
<td>10 minutes</td>
</tr>
<tr>
<td>Whistler</td>
<td>20 minutes</td>
<td>10 minutes</td>
</tr>
</tbody>
</table>

Comparison previous generation of fuel cell buses: > 1 hour were reported in some cities

→ **Major barrier overcome** to fuel cell bus adoption

Remaining concern around filling stations operation: **inability** of stations **to meter hydrogen supply accurately enough** (i.e. as for other conventional fuels) (no accurate hydrogen meter currently available; will need to be developed before a widespread roll-out of the technology is attempted)
The **availability** of stations in the CHIC project has been consistently **high**

Average station availability is **over 95%** at most sites, currently two exceed the target of 98% for the stations in the trial.

This compares favourably with the HyFLEET:CUTE project, where problems with on-site production, compression and dispensers dogged the trial. This led to an average availability of 89.8% for the whole trial.

### CHIC Emerging Conclusions

#### High station availability

<table>
<thead>
<tr>
<th>Phase</th>
<th>City</th>
<th>Availability to date (August 2014)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>London</td>
<td>&gt; 98%&lt;sup&gt;1&lt;/sup&gt;</td>
</tr>
<tr>
<td>1</td>
<td>Aargau</td>
<td>&gt; 97%</td>
</tr>
<tr>
<td>1</td>
<td>Milan</td>
<td>&gt; 98%</td>
</tr>
<tr>
<td>1</td>
<td>Oslo</td>
<td>&gt; 94%</td>
</tr>
<tr>
<td>0</td>
<td>Cologne</td>
<td>&gt; 97%</td>
</tr>
<tr>
<td>0</td>
<td>Hamburg</td>
<td>&gt; 91% (since May ’13: &gt; 97%)</td>
</tr>
<tr>
<td>0</td>
<td>Whistler</td>
<td>&gt; 98%</td>
</tr>
</tbody>
</table>

<sup>1</sup>Data from February 2014
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• Emerging results – achievements

• Emerging results – issues identified

• Attitudes of stakeholders

• Next steps and final remarks

• Appendix – Berlin’s hydrogen ICE buses status
Concerns over bus availability

• The availability of fuel cell buses on the project has not yet consistently met the CHIC target (85% availability) and has until now been lower than HyFLEET:CUTE (average >92%, note that buses were operated via single shifts and that two full time staff were made available at each site) and the diesel industry standard (95% availability)

• The range of monthly availabilities on the CHIC project has been between c. 40% and 80%

• Reasons for poor availability include:
  – Immature supply chains – taking a long time to understand problems and provide spare replacement parts; These issues are improving as partners become more familiar with novel bus operations and spare parts stock requirements
  – Problems with management of maintenance contracts – particularly in London, where bankruptcy of the maintenance partner led to issues, (resolved by bringing bus maintenance “in house”);
  – Component failures – air compressors, DC converters etc. have caused considerable issues on some of the trials – solutions are being implemented, see next slide.
  – Limited pool of maintenance staff – availability tends to dip when key personnel are on vacation
    • This is an inevitable effect of small scale operations and would be resolved by larger scale deployment
    • However it has also been observed at a factory level, where suppliers need to ensure new systems are in place to ensure parts availability all year
Partners have not yet met the CHIC availability target but an improvement is noted over the last months

- The low availability is down to the use of novel hybrid drivetrains in a low volume sector. As the components problems and the issues of immaturity of supply chains are ironed out, availability is expected to rise towards the target (85%) by the project end.

Average availability of the CHIC fuel cells buses

Reduced availability mainly due to an increase in the defects of conventional vehicles parts, hybrid-related components and manufacturer investigations.
• The bus availability has improved in the last months (average: 70%)

• Real reliability improvements are being made, this is caused by three factors:
  1. **Improved understanding of the buses** by maintenance personnel and hence improved systems
  2. **Drivers creating operating procedures to overcome some** of the design/technology **issues** which have not yet been fixed
  3. **Faulty component parts** research and **replacement** with more reliable parts

→ Examples of components failures, corrective measures being implemented within an agreed deadline are presented in the next slide
### Improving bus availability – ex. of corrective measures

- Examples of components failures and corrective measures addressed

<table>
<thead>
<tr>
<th>Problem (non-exhaustive list)</th>
<th>Corrective solution</th>
<th>Implementation timeline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil level sensoring on the air pressure compressor generates a yellow fault message</td>
<td>- Replacement of air pressure compressor (latest generation)</td>
<td>start 2. quarter 2014. Completion expected Dec. 2014</td>
</tr>
<tr>
<td></td>
<td>- Installation of new software for the flexible programmable control unit</td>
<td></td>
</tr>
<tr>
<td>High voltage fuses mechanically triggered</td>
<td>Replace of all fuses within the scope of the scheduled maintenance</td>
<td>Anchored within maintenance schedule (6 Monthly Service)</td>
</tr>
<tr>
<td>Shut down of a Fuel cell-system generates a yellow fault message</td>
<td>Implementation of a light messaging system for the driver when a fuel cell system shuts down</td>
<td>Implemented in June 2014. Completed August 2014</td>
</tr>
<tr>
<td>Temperature difference during the warm up phase of the high temperature cooling circuit generates a yellow fault message</td>
<td>Reduction of the temperature difference in the high temperature-circuit. New Software programme for the cooling parameters between the two circuits</td>
<td>Implemented in June 2014. Completed July 2014</td>
</tr>
<tr>
<td>Failure DC/DC-converter</td>
<td>development of a new converter generation, defective converters will be exchanged immediately</td>
<td>Implemented March 2014. Completed May 2014</td>
</tr>
</tbody>
</table>

**NOTE:** selected bus operators have noted that bus drivers tend to lose trust in the bus as a consequence of the recurring technical problems and rely on unnecessary road-calls, thus reducing the overall bus availability
Lessons learnt - partners’ perception and expectations of the bus availability

• Project’s partners did not have the same expectations as regards the technology readiness level (TRL) at the project’s start; note that the higher buses availability observed in the previous fuel cell bus project High FLEET:CUTE has certainly contributed to raising partners’ expectations for CHIC.

• The lower than expected availability of the buses during the first part of the demonstration has produced issues in some cities as:
  1. Bus drivers and other key operation personnel have had to deal with a larger number of unexpected problems/false alarms during their routes – this made them less keen to drive the vehicles and created a negative attitude to the vehicles.
  2. Operators experienced longer than expected response times for the provision of in-situ technical support from some of the suppliers.

• This has led to a concern that in some cities, operators were overpromised with the level of reliability which could be achieved. Furthermore, some operators ended up spending more financial and staff resources than those originally planned to keep the buses and refuelling stations running.

• In the majority of the CHIC cities all of the key stakeholders are enthusiastically engaged in the project and its vision, in spite of the availability problems.

• Technical Readiness Level is moving from TRL 7 to 8 during the project.

• Where stakeholders have been made aware of the demonstration nature of the buses from the start, the problems of poor availability have not affected the ongoing support for the project.
The CHIC consortium is taking a comprehensive approach in trying to improve the availability performance of the CHIC buses.

The industry partners are diagnosing the technical problems, implementing concrete solutions and – where possible within the scope of the project – improving the supply of spare components to avoid delays.

Bus operators and suppliers are collaborating on a daily basis to help improve the issues relating to management and day to day maintenance.

Overall, the operation of the CHIC buses is consistent with the level of maturity of the fuel cell hybrid powertrain solutions implemented in the project. Each of these buses are the first deployments of their model and are undergoing the expected teething issues for a new bus technology. Similar patterns have been observed for e.g. diesel hybrid introduction.

This reinforces the value of the activities being carried out in CHIC as producing valuable expertise and lessons to:

- Help improve the design of specific bus components and supply of spare parts
- Support the sector in moving from a demonstration to a more commercially-ready status in the near future
The start date of all of the projects has been later than originally envisaged.

There are numerous reasons for this:

- Delays in procurement processes (Oslo, Bolzano\(^1\))
- Delays in permitting for stations and maintenance facilities (London, Milan)
- Delays in construction of the refueling facilities (Milan\(^2\))
- Delays in manufacture/shipment of buses (Oslo, London)
- Poor availability of the buses in the commissioning phase (Oslo)

Again, the majority of these issues are related to the immaturity of the sector and of novel bus drivetrain components.

These delays also suggest a need to improve awareness of the technology and associated issues amongst decision makers and regulators in member states.

Advice have been developed in a “Recommendations for delivering fuel cell buses”

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\(^1\) Due to revision of the regional project funding (caused by the implementation of two national austerity packages during the procurement process) and changes in the national tender rules; \(^2\) Due to a transport incident during the delivery of key infrastructure components
EXECUTIVE SUMMARY

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EMERGING RESULTS – ISSUES IDENTIFIED

ATTITUDES OF STAKEHOLDERS

NEXT STEPS AND FINAL REMARKS

APPENDIX – BERLIN’S HYDROGEN ICE BUSES STATUS
The qualitative research:

• Approx. 185 face-to-face, 45-90 minutes interviews in five of the CHIC regions (Aargau, Bolzano, region of Cologne, Hamburg, and Oslo) were conducted between August 2011 and March 2013. Interview partners were bus drivers, citizens/passengers, regional stakeholders and CHIC-partners.

Main findings are:

• Socio-economic work demonstrates a generally positive attitude towards hydrogen technologies amongst the general public, bus drivers etc.

• The electric drive trains significantly improve the work environment for bus drivers

• Very few interviewees questioned the project idea and technology concept, the majority of interviewees supported it

• A majority of interviewees addressed or questioned hydrogen origin, and related their acceptance to the use of renewable energies for hydrogen production.

• Safety issues were not a topic in the general public, as people trust in authorities and expect technologies be safe before brought to market.

• The work also demonstrates the potential value of integrating the perspectives of sceptical decision makers and opinion formers into the fuel cells and hydrogen dialogue
Selected public statements:

**Politicians**
- London – Deputy Mayor (Kit Malthouse): “*With these buses, people can now see, touch and feel this technology for themselves and help play an exciting part of London’s energy future*”
- Hamburg – First Mayor (Olaf Scholz): “*From 2020 HOCHBAHN will procure only emission free buses*”

**Bus drivers**
- “*It is a great bus, very comfortable to drive, the public loves it!*”
- “*If you are looking for a good vehicle, take a hydrogen one!*”
- “*It enthusiasms (despite of teething problems)!*”
- “*[..] this is a very good project. You have to think about the future. Somebody has to act. It costs a lot of money but this shouldn’t be the issue [..]*”

**Users**
- “*The bus is very quiet!*”
- “*When you take the bus you can’t hear the engine.*”
- “*Fuel cell buses are good for the environment*”
• Executive summary
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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 for a wide range of public transport routes. This is achieved with improved efficiency of fuel use and without harmful emissions.

The CHIC project has also highlighted a series of key challenges which will need to be addressed by the next generation of fuel cell buses and infrastructure:

**Buses:**

- **Bus availability needs to improve** over 85% - much of this is expected to be resolved by tackling the teething issues associated with the early deployment of new technology. This will include the ongoing availability improvements which are expected under CHIC although it will also likely also require further component and supply chain development for bus generations beyond the CHIC trials.

- **Warranties of fuel cells for buses have increased** to 15,000 hours (best in class). However, given the length of daily service of buses, longer warranties (e.g. 35-40,000 hours) will likely be needed to be consistent with conventional bus overhauls.
Buses (cont’d):

• Prices of buses have fallen considerably during the CHIC project. Lowest new vehicle prices are now below €1m. Further reductions are also being offered (linked to volume purchase) by some of the CHIC suppliers. However, these prices need further reduction to enable genuine market traction (less than €500,000). Different costs projections are being analysed in the framework of the fuel cell bus commercialisation study (see next slides)

• Expand the FC bus platform choice (e.g. 18 m or large capacity buses)

Refueling infrastructure:

• CHIC has demonstrated fuelling station designs which are appropriate for c. 5 to 20 buses per day. Partners have raised concerned that the observed performance may not automatically apply to depot-scale refueling solutions (e.g. for 100 buses/day or more). These solutions need to be properly investigated as part of any larger-scale rollouts.

• Discussions with policy makers and opinion formers make it clear that routes to affordable hydrogen from green sources need to be demonstrated and also well articulated.
• Demonstration of the operation of **over 60 fuel cell buses**, mainly through 3 EU-funded demonstration projects

• An additional project deploying 21 fuel cell buses will start soon

### Current national/regional-funded fuel cell bus projects:
- **Karlsruhe** – 2 FC buses
- **Stuttgart** – 4 FC buses
- **Amsterdam** – 2 FC buses (in operation until 12/2014)

### 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
  - (Berlin* – 4 H₂ ICE buses – in operation until 12/2014)
  - 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
Next steps for the commercialisation of fuel cell buses in Europe (1/2)

- The FCH JU is developing a new commercialisation approach for fuel cell buses which aims at:
  - **Bridging the gap** until the technology is fully mature
  - Bring together a sufficient number of cities and regions to create a sufficient critical mass to allow the deployment of low cost and reliable vehicles (through economies of scale)
  - Provide costs analyses for bus operators and cities and development of regional clusters to support the deployment of 500-1,000 fuel cell buses, supported by the FCH-JU

First results: cost projections for fuel cell buses

- The study expect a substantial reduction of the technology cost premium by 2030
- Deploying more buses earlier will support scale effects and cost reductions
- This will reduce the need for securing additional funding
First results: a large coalition mobilised

- A coalition of industry and public stakeholders has been established
- Bus OEMs committed to the commercialisation of fuel cell buses in a *Letter of Understanding* signed on 12/11/2014

Next steps

- **Price analysis** and funding available: assessment of whether the 500-1000 bus target can be reached
- **Increase the level of commitment** from both bus operators and local/regional governments
- Set-up **regional clusters** to formJoint procurement
- Dissemination of know-how from past/ongoing projects → The final results of the study will be made available in summer 2015

- The CHIC partners are supporting this new initiative by collaborating on dissemination and passing on the lessons learnt and the extensive knowledge accumulated during the project
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The Phase 0 City Berlin is running a fleet of 4 Hydrogen Internal Combustion Engine (ICE) buses

**Key facts:**
- Operation started in June 2006, during the FIFA World Cup 2006 in Germany and will end in December 2014
- The buses are the same as for the previous EU-funded HyFLEET:CUTE project (running between 2006 and 2009)
- The city is running H₂ Internal Combustion Engine buses based on the standard low floor MAN City Bus Lion’s City model

<table>
<thead>
<tr>
<th>No. of buses</th>
<th>Manufacturer, Model</th>
<th>Start of operation</th>
<th>Km travelled</th>
<th>Average Consumption</th>
<th>Availability (average)</th>
<th>H₂ refueled [kg] (Number of fillings)</th>
<th>Type of Route</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>MAN Lion’s City</td>
<td>June 2006</td>
<td>837,036</td>
<td>23.1 kg H₂ Per 100 km</td>
<td>92%</td>
<td>193,733 (11,803)</td>
<td>Urban - flat - moderate climate</td>
</tr>
</tbody>
</table>

**Technical Specifications**

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Length total</th>
<th>12 m</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Net. Weight</td>
<td>12 t</td>
</tr>
<tr>
<td>Capacity</td>
<td>80 people</td>
<td></td>
</tr>
<tr>
<td>Range</td>
<td>&gt;200 km</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Engine</th>
<th>Model</th>
<th>MAN Aspirated-Engine (H 2876 UH01)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engine Output</td>
<td>150 kW at 2200 RPM</td>
<td></td>
</tr>
<tr>
<td>Torque</td>
<td>760 Nm at 1000-1400 RPM</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Storage unit</th>
<th>System Capacity</th>
<th>10x4,93kg = 49,3kg</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Compression</td>
<td>max. 350 bar</td>
</tr>
</tbody>
</table>

**Monthly average availability of the Berlin buses**

- CHIC Monthly availability
- Average availability
- CHIC goal
If you have any specific question related to the project and its lessons learned, feel free contact:

• **CHIC Fuel Cell Hydrogen Bus Help-line:**
  Element Energy Ltd.
  Tel. +44 (0) 330 119 0989 // +44 20 3195 8119

• **CHIC Hydrogen Refuelling Infrastructure Help-line:**
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  Tel. +49 69 305-17881
Thank you for your attention

www.chic-project.eu

Email: h2businfo@chic-project.eu

@CHIC project