FCH 2 JU STAKEHOLDER FORUM
Fuel Cells and Hydrogen: From Technology to Market

Hydrogen buses meet cities´ needs for zero emission transport

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Overview

1	➢ Status Fuel Cell Buses today
2	➢ CHIC, Clean Hydrogen in European Cities: Emerging Conclusions
3	➢ Hamburg: Strategy and lessons learnt
4	➢ Summary

Number of fuel cell buses in Europe close to 100 by 2016

Ongoing EU-funded fuel cell bus projects

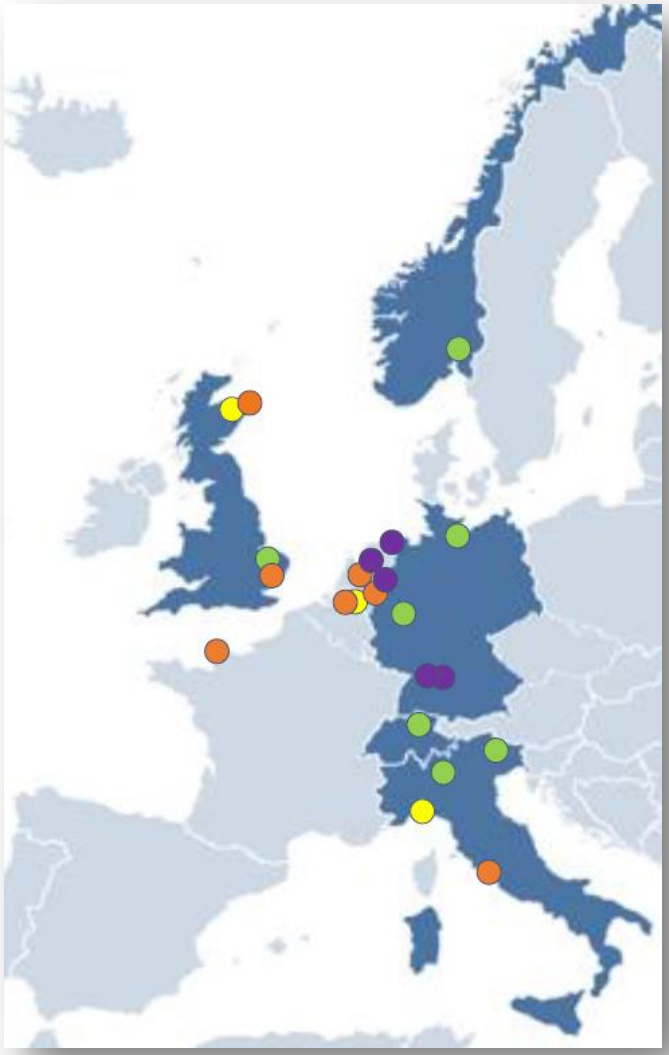
CHIC
- ✓ Bolzano, IT– 5 FC buses (2013)
- ✓ Aargau, CH – 5 FC buses (2011)
- ✓ London, UK – 8 FC buses (2011)
- ✓ Milan, IT – 3 FC buses (2013)
- ✓ Oslo, NO – 5 FC buses (2013)
- ✓ Cologne, DE – 4 FC buses (2011/14)
- ✓ Hamburg, DE – 6 FC buses (2011/2015)

High V.LO-City
- ✓ Liguria, IT – 5 FC buses (2015)
- ✓ Antwerp, BE – 5 FC buses (2015)
- ✓ Aberdeen, UK – 4 FC buses (2015)

HyTransit
- ✓ Aberdeen, UK – 6 FC buses (2015)

Legend

CHIC countries
✓ In operation
✓ Planned operation
(2015) Operation start/planned start



Ongoing EU-funded fuel cell bus project

3Emotion
- ✓ Cherbourg, FR – 5 FC buses (2016/17)
- ✓ Rotterdam, NL – 4 FC buses(2016/17)
- ✓ South Holland, NL – 2 FC buses
- ✓ London, UK – 2 FC buses (2016/17)
- ✓ Flanders, BE – 3 FC buses (2016/17)
- ✓ Rome, IT – 5 FC buses (2016/17)

National/regional-funded projects

- ✓ Karlsruhe, DE – 2 FC buses (2013)
- ✓ Stuttgart, DE – 4 FC buses (2014)
- ✓ Arnhem, NL – 3 FC buses (2016/17)
- ✓ Groningen, NL – 2 FC buses (2016/17)
- ✓ Brabant, NL – 2 FC buses (2016/17)

Update: October 2015

CHIC – an overview

What?	• **Deployment of 56 fuel cell electric buses** and their refuelling infrastructure[1]
When?	• Between **2010 to 2016** (post-2016 under discussion)
Who?	• **23 partners from 8 countries** • 9 operators/6 bus OEMs involved
How much?	• **€25.88 million** European co-financing (FCH JU), total budget of €81.8 million
FCH JU?	• **Public private partnership** between the European Commission, the industry and research promoting the uptake of **hydrogen and fuel cell technologies**

[1] + 4 ICE H2 bus

Technical targets have been achieved – assembling a large amount of data

Parameter	Project total (incl. ICE buses in Berlin)	Phase 1 cities	Project goal for the Phase 1 cities
Total distance travelled [km]	8,352,195	**2,955,949**	2,750,000
Total hours on FC system [h]	425,854[1]	**192,949**	160,000
Average FC runtime per bus [h]	7,886[1]	**7,421**	6,000
Replacement of diesel fuel [litres]	4,004,139	**1,206,199**	500,000
Total H2 refueled [kg]	1,133,591	**283,266**	

[1] This figure does not include the ICE buses in Berlin

Buses satisfy the demands of daily bus operation, equivalent flexibility to diesel

- Operating range meets the demand of bus operators, with up to 400 km and 20h of service/day
- Fuel cell bus offers a flexibility of service equivalent to a diesel bus and fits well into Bus Rapid Transit concept

City	Range[1]	Daily duty[2]
Aarau	180 - 250 km	18-20 hours
Bolzano	220-250 km	12 hours
Cologne	350 km	12 - 16 hours
Hamburg	400 km	8 - 20 hours
London	250 - 300 km	16 - 18 hours
Milano	170 km	Up to 16 hours
Oslo	200 - 290 km (seasonal)	Up to 17 hours
Whistler[3]	366 – 467 km (seasonal)	4 – 22 hours

- Compares well with the previous generation of fuel cell buses, whose range was at 200 km

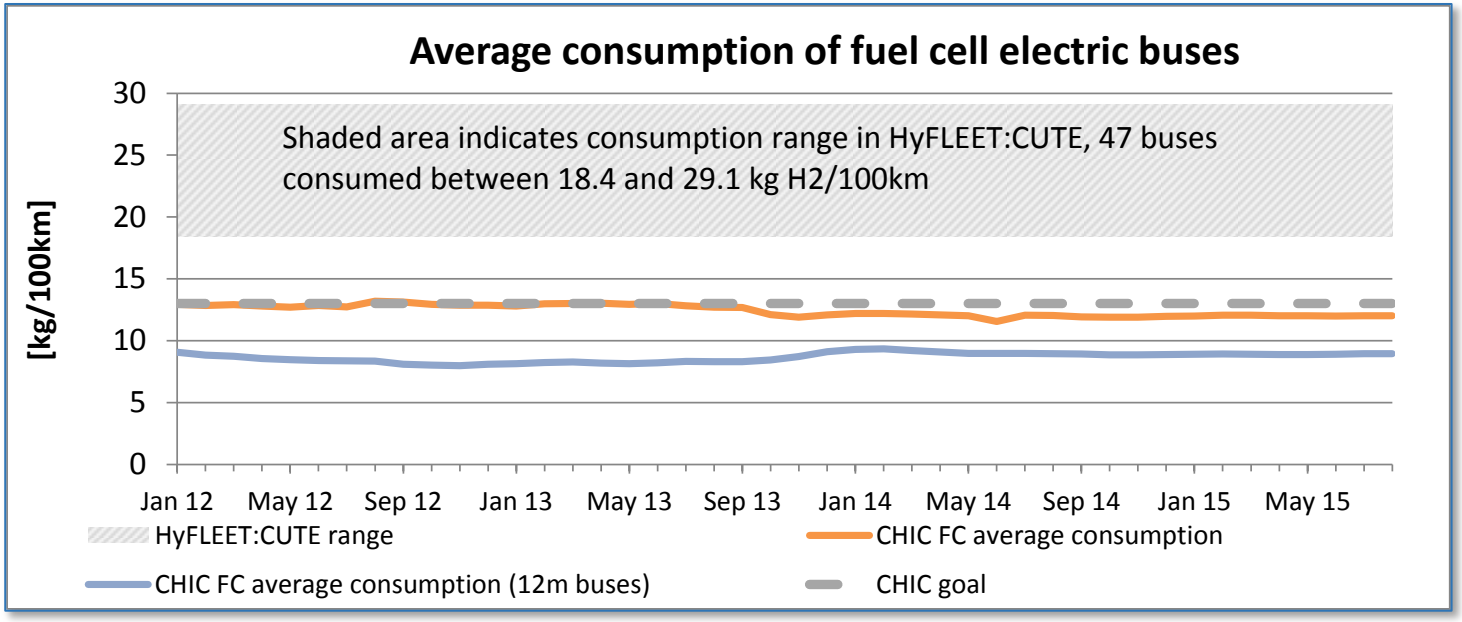
[1] Average figures, also based on tank size and average consumption

[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 diesel bus
- More than 50% improvement compared with previous fuel cell bus generation (HyFLEET:CUTE)
- Improvements due to use of fully hybridised powertrains, smaller and more optimised fuel cells



[1] Assumption: fuel consumption of a diesel bus: 40 l of diesel/100km

Stations show a very high level of reliability

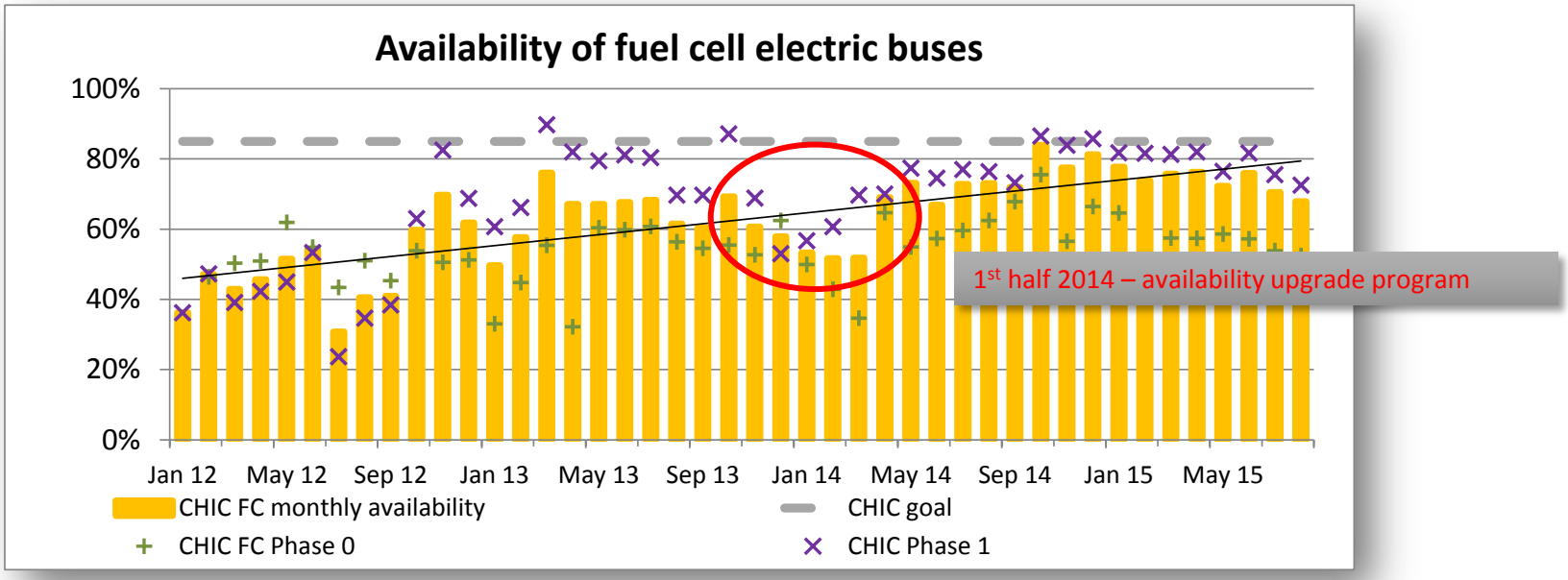
- Availability of stations has been consistently high, with an average availability over 95% at most sites; many stations are well integrated in busy bus depots
- This compares favourably with the HyFLEET:CUTE project, where problems with on-site production, compression and dispensers dogged the trial

	City	Availability to date (Aug. 2015)
Phase 1	Aargau	> 96%
	Bolzano	> 98%
	London	> 98%
	Milan	> 96%
	Oslo	> 94%
Phase 0	Cologne	> 97%
	Hamburg	> 97%
	Whistler	> 98%

- This figure is not high enough to satisfy a large share of a city fleet. The project NewBusFuel started in summer 2015 to evaluate engineering solutions for depots integrating larger bus fleets (50-200 buses – 1,000-5.000 kg hydrogen/day) in 13 locations across Europe

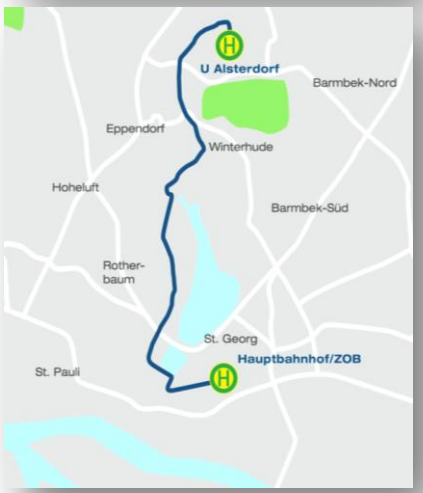
Availability: after teething issues, most cities reach project targets

- As with all innovative technologies, one cannot expect fc buses to be 100% operational on day one, all cities partners have faced a teething period: period where availability of the buses has been low
- Reasons are e.g. unfamiliarity of the vehicles to maintenance staff and no standards in layout of vehicles, immature supply chain and after sales etc.
- It has to be noted that most of the issues are not directly linked to the fuel cell
- 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



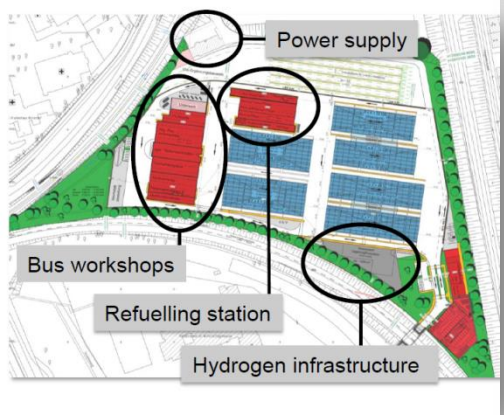
As of 2020, only zero emission buses are purchased

- Objective: maintain the attractiveness and efficiency of bus services
- Ensure the sustainability of bus range, even at future higher prices and declining availability of fossil fuels
- In addition to stricter European regulations on air quality (NO_x) , CO_2 emissions and noise are a growing issue
- Timely preparation of technical facilities and workshops as well as creating expertise among staff
- Evaluation of innovative buses with different drivetrains on one line: *Innovation Line 109*



Operational experiences, lessons learnt

- Same flexibility and productivity as diesel buses are main benefit of fuel cell buses compared to battery or plug-in buses
- Shift in monitoring from *buses only* to systematic and constant supervision of the overall *bus system* (incl. energy supply etc.)
- Battery buses most likely need a signifanctly high coverage of infrastructure while for fc buses one refueling station per depot is sufficient
- Complexity of systems must be mastered by the staff/drivers
- Upscaling of hydrogen refueling infrastructure still a challenge (permissions, modularity etc.)

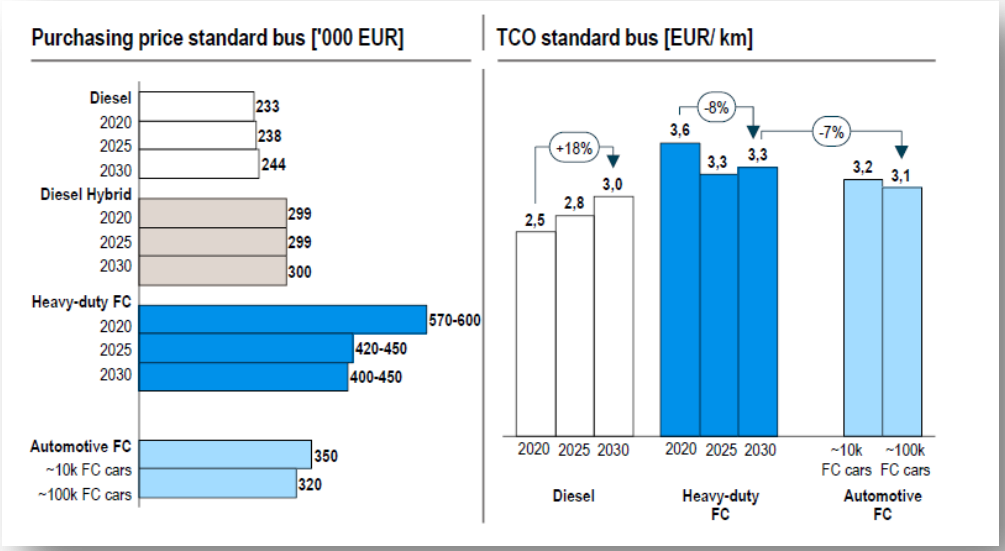


Commercialisation of fc buses in Europe – cost reduction

Cost projections for fuel cell buses are expected to decrease significantly by 2030

However:

- 2 scenarios: FC systems developed specifically for heavy-duty vehicles (“heavy-duty pathway”) or fc systems developed for FC cars and adapted to buses (“automotive pathway”).
- Heavy duty pathway: the overall costs for FC buses are expected to decrease to a cost premium of 11-18% compared to diesel buses in 2030
- Automotive pathway: costs are expected to decrease even further, the fc-bus purchasing price could reach the range of current diesel hybrid buses



Comparison price development and TCO of standard FC buses for different powertrain options and technology pathways (in 1,000€)

- A supportive regulatory framework for fuel taxation supports fc bus commercialisation
- Study is available on the CHIC website

Source: FCH JU study: ”fuel cell electric buses: Potential for Sustainable Public Transport in Europe”, Sept. 2015

Commercialisation of fc buses in Europe – coalition has been mobilised

- A coalition of industry and bus operators has been established (incl. most of the CHIC cities), in order to identify the number of fc buses necessary to bridge the gap towards commercialisation by using scale effects and reducing current costs
- Coalition currently prepares large-scale demonstration projects with a total of approximately 300/400 fc buses in Europe by 2020.

Strong committments

- 5 major bus OEMs expressed their commitment to commercialise hundreds of fuel cell buses in a Letter of Understanding (LoU) signed on 12/11/2014
- Local authorities replied to this letter through a LoU on 23/06/2015, showcasing their readiness and willingness to integrate hundreds of buses in their bus fleets
- Study results were published in September 2015

35 locations participating in the coalition

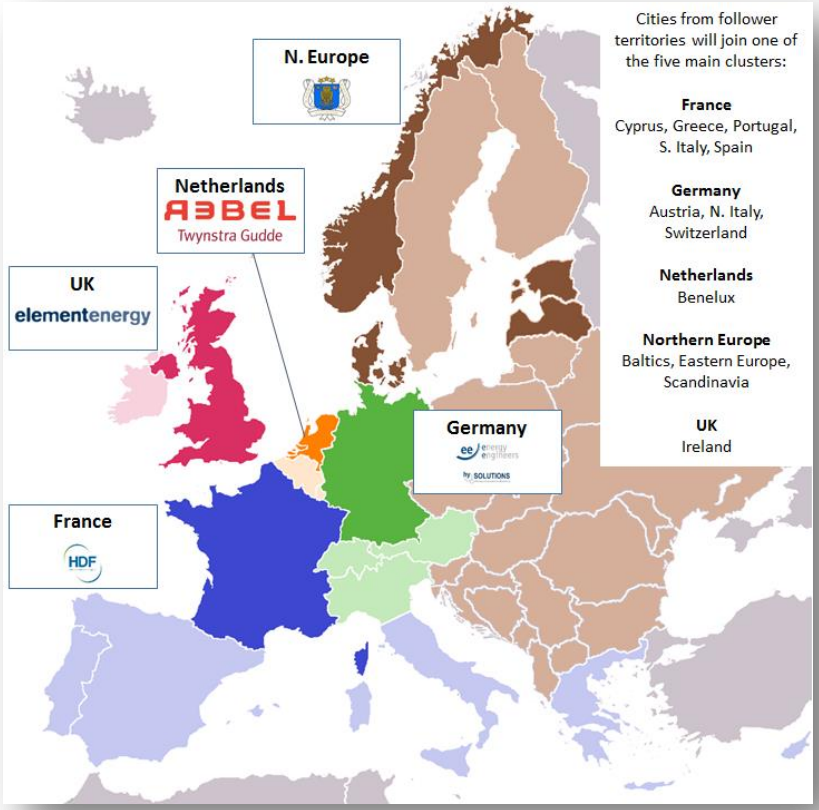
Signing LoU bus OEMs, 12/11/2014

Source: FCH JU study: "fuel cell electric buses: Potential for Sustainable Public Transport in Europe", Sept. 2015

Joint procurement strategy

- As a follow-up to the study a project to unlock the market potential of fuel cell buses by bringing down the costs, looking in detail at match funding, technical specifications and joint procurement has been launched.
- For this purpose, 5 clusters have been identified across Europe

- The European coordination of the project lead by Element Energy (also UK coordinator), and includes partners for cluster 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



Source: Element Energy

Summary and next steps

- CHIC and other ongoing bus projects are demonstrating that fuel cell buses have the potential to provide the same operational flexibility as conventional diesel buses
- They can do this with zero local emissions, a contribution to transport decarbonisation and satisfying the travelling public and the drivers
- A systematic connection between the sectors renewable energy and transport enhances effectiveness of both systems and ensures added economic value in the regions

Ways forward

- 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 and initial market oriented funding*
- Regulations on hydrogen refueling stations construction and safety need to be further harmonised at EU and international level
- Rigorous CO_2-regulations are needed to foster the use of emission free drive trains in public transport and improve air quality in cities

Thank you for your attention

www.chic-project.eu
www.hysolutions-hamburg.de