European bus projects – CHIC, High V.Lo City, HyTransit and 3Emotion

Emerging results

FCH JU programme review – Nov 2016

Ben Madden – Element Energy

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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

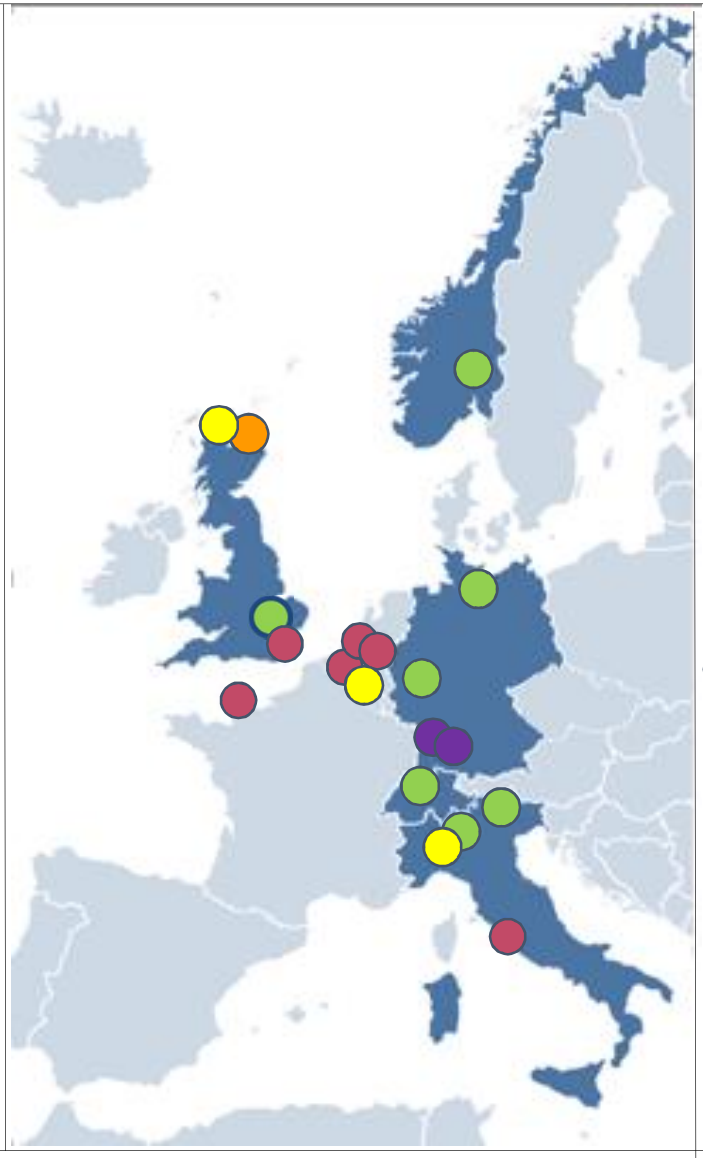
- ✓ Bolzano – 5 FC buses
- ✓ Aargau – 5 FC buses
- ✓ London – 8 FC buses
- ✓ Milan – 3 FC buses
- ✓ Oslo – 5 FC buses
- ✓ Cologne* – 4 FC buses
- ✓ Hamburg* – 6 FC buses

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:

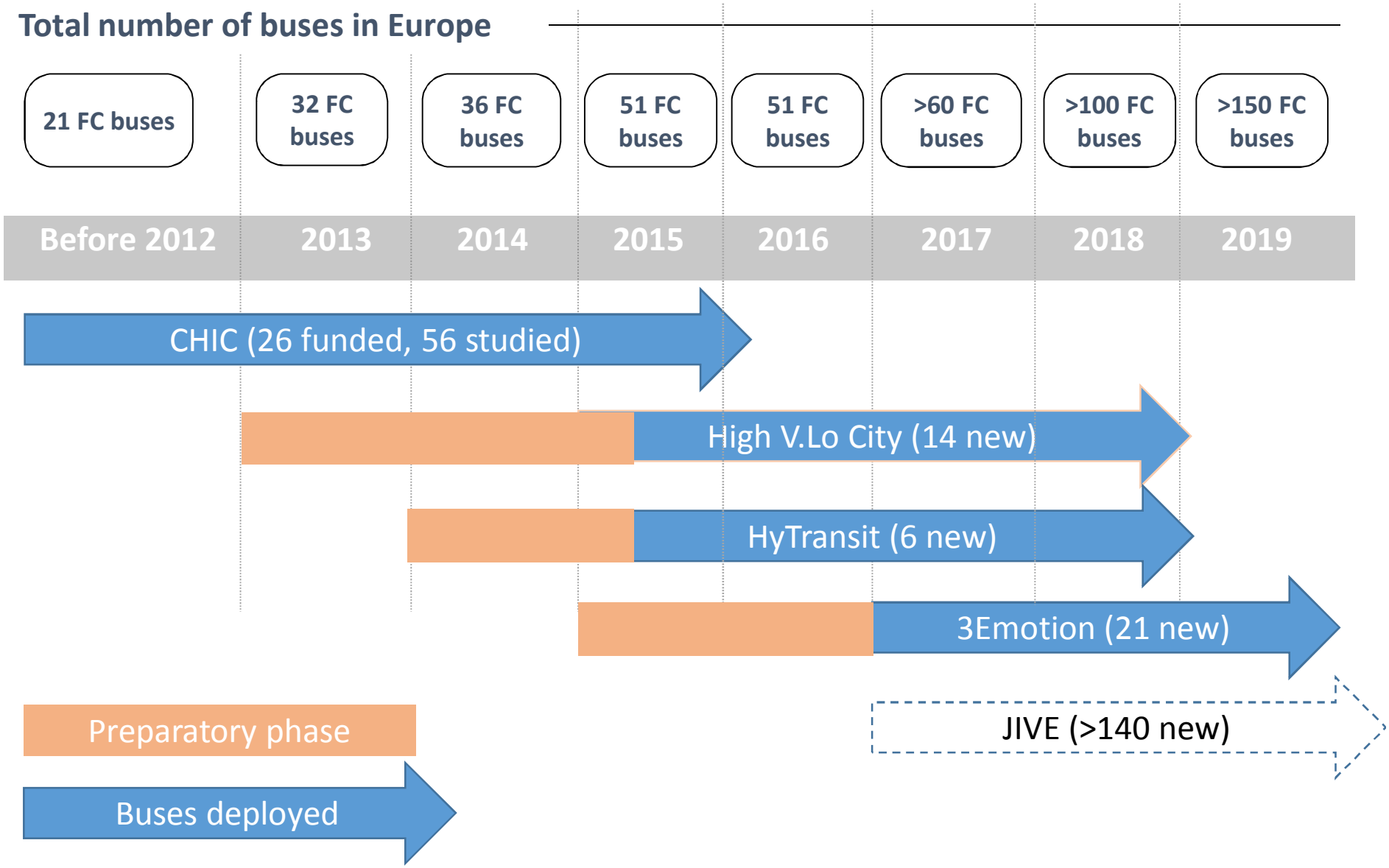
- ✓ Karlsruhe * – 2 FC buses
- ✓ Stuttgart * – 4 FC buses

Legend:

- CHIC countries
- ✓ In operation
- ✓ Planned for operation
- * Co-financed by regional/national funding sources

Last update: 04/02/2015

The various projects are in different stages of completion



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)

The Solaris buses in Hamburg

Hamburg, Germany (2 buses in total)

Van Hool buses through High.V Lo City, HyTransit and 3EMotion

Aberdeen (10 buses in total) – HyTransit and High V. Lo City

Antwerp (5 buses in total) – High V. Lo City

… with more buses to come…

Phase 1: 5 high throughput, 350bar stations
About 380 tonnes of H_2 dispensed (to end Sept 2016)

City	Picture	HRS/H_2 Producer	Operation start	Type of HRS / source of H_2	Nber of fillings	Kg H_2 refuelled
Aargau		Carbagas (Air Liquide)	2012	Onsite electrolyser - 100% H2 from RES (hydropower, solar & wind energy, biomass) (+ trailer delivery as backup)	7,364	103,769
Bozen		Linde	2014	Onsite electrolyser - 100% H2 from RES (mix of hydropower, solar and wind energy) (+ trailer delivery as backup)	2,627	48,027
London		Air Products	2010	Trailer delivery of gaseous H_2 (SMR)	7,997	133,949
Milan		Linde	2013	Onsite electrolyser from the electricity grid (mix of grid, CHP, solar energy) (+ trailer delivery as backup)	1,610	20,709
Oslo		Air Liquide	2012	Onsite electrolyser: 100% H2 from RES (hydro power) (+ trailer delivery as backup)	3,619	73,715

SMR= Steam Methane Reforming - RES: Renewable Energy Sources; CHP: Combined Heat-and-Power

Phase 0: 3 high throughput, 350bar stations
Some 650 tonnes of H_2 dispensed (to end March 2016)

City	Photo	HRS/H_2 producer	Operation start	Type of HRS / source of H_2	Nber of fillings	Kg H_2 refuelled
Cologne		Air products	2011	Trailer delivery of gaseous H2 by-product sourced nearby (chlor alkali electrolysis)	1,642	22,235
Hamburg		Linde	2012	Onsite electrolyser - H2 from RES (+ trailer delivery as backup)	2,220	36,750
Whistler		Air Liquide Canada	2009	Liquid H2 generated from hydro-electric power in Quebec, delivered to the buses in gaseous form	23,671	591,590

RES: Renewable Energy Sources

Stations in Aberdeen (HyTransit) and Antwerp (High V. Lo City)

Aberdeen (on-site electrolysis)

Solvay (bi-product hydrogen)

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- Project status
- Emerging results – achievements and issues
- Conclusions
- Resolving the cost problems - Joint procurement project
- Resolving the challenge of larger stations - NewBusFuel

Overall project snapshot: all technical targets have been achieved (data from end Sept 2016)

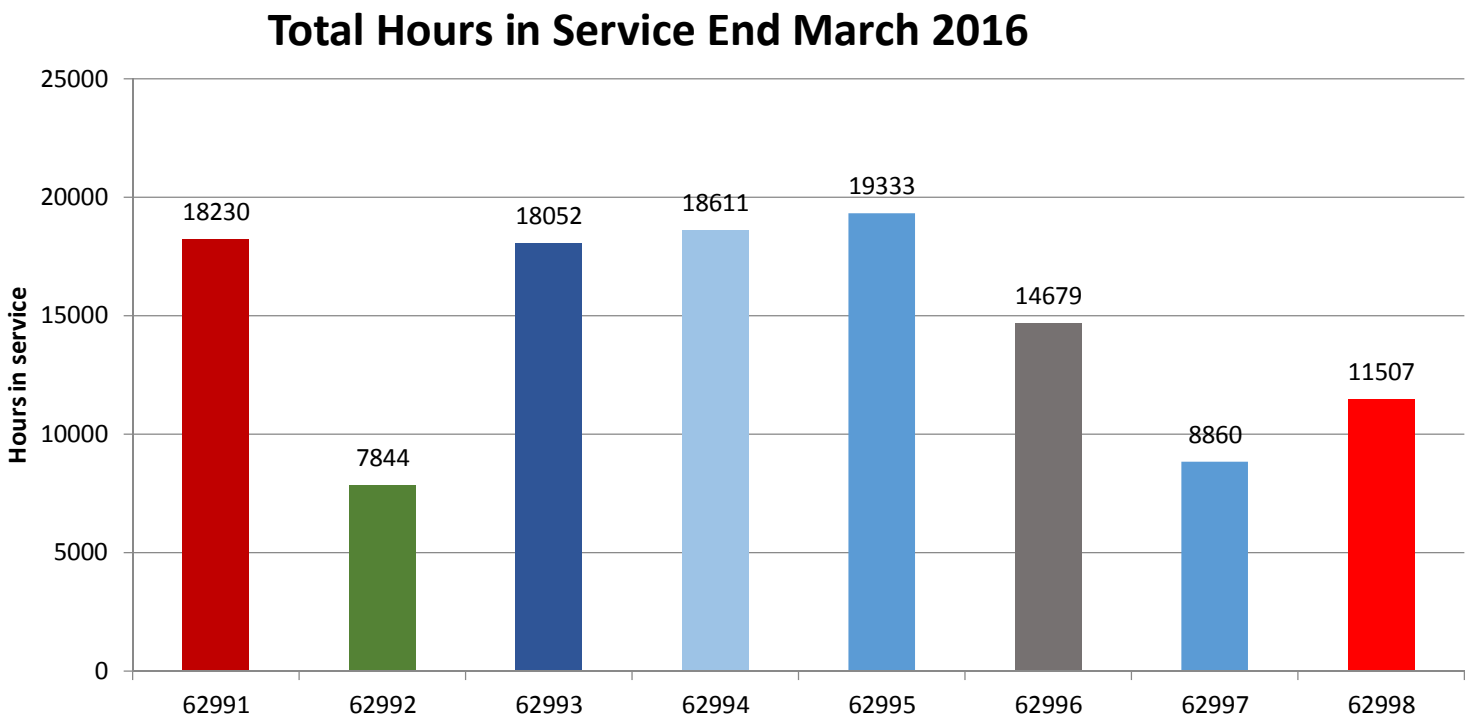
Parameter	Project total (incl. ICE buses in Berlin)	Phase 1 cities	Project goal for the Phase 1 cities
Total distance travelled [km]	9,626,116	**3,991,056**	2,750,000
Total hours on FC system [h]	519,498	**269,394**	160,000
Average FC runtime per bus [h]	6,820	**6,690**	6,000
Replacement of diesel fuel [litres]	4,469,043	**1,633,990**	500,000
Total H2 refueled [kg]	1,256,492	**380,168**	*No target*

→ **Over 8 million kilometers driven up to now**
→ **Over 4 million litre of diesel saved so far**

[1] and [2] Figures do not include the ICE buses in Berlin

[3]

London buses – FC durability



Bus mileage (HyTransit and High V.Lo City)

Site	Total km driven	Date
HyTransit		
Aberdeen	460 991	26/09/2016
High V.LO-City		
Aberdeen	246 092	01/10/2016
Antwerp	124 056	19/08/2016
Total High V.LO-City	**370 148**	
Total both projects	**831 139**	
Total Aberdeen 10 buses	**707 083**	

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Satisfying the demands of daily bus operation

- **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

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 – 16 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

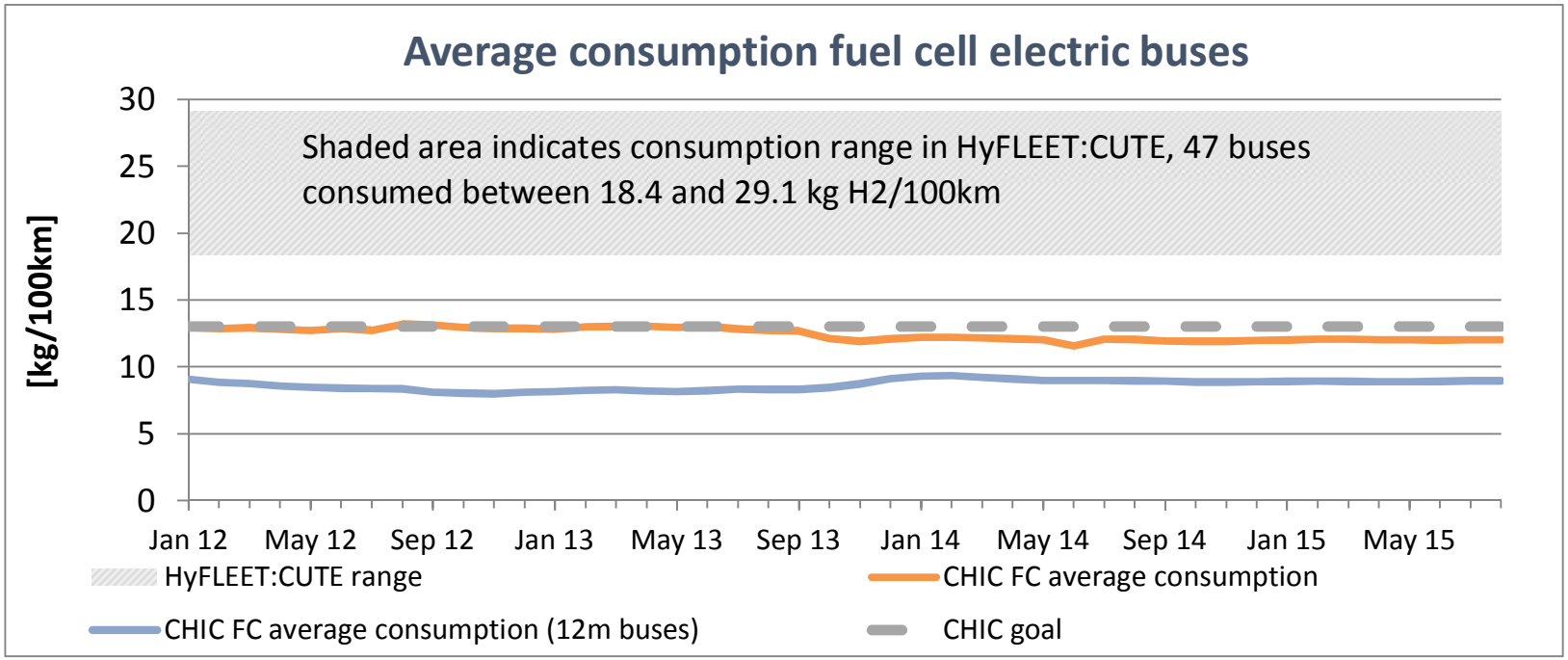
[1] Average figures, also based on tank size and average consumption

[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 H_2/100km app. for the 12m buses (= ~ 27l diesel) = 30% more energy efficient than a diesel bus** [1] **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

Rapid refuelling times

- All European partners are able to fill a bus from empty **in less than 10 minutes** in average.

City	Refuelling time	Station specification
London	<10 minutes	10 minutes
Aargau	<10 minutes	10 minutes
Bolzano/Bozen	<10 minutes	15 minutes
Oslo	<10 minutes	10 minutes
Cologne	<10 minutes	10 minutes
Hamburg	<10 minutes	10 minutes
Whistler	20 minutes	10 minutes

- Remaining concern around refuelling stations operation: **inability** of stations **to meter hydrogen supply accurately enough** (i.e. as for other conventional fuels)

High station availability

- The **availability** of stations in the CHIC project has been consistently **high**, with an average availability **over 95%** at most sites; the stations are well integrated in busy bus depots
- However, this figure is not high enough to allow hydrogen to satisfy a large share of a fleet

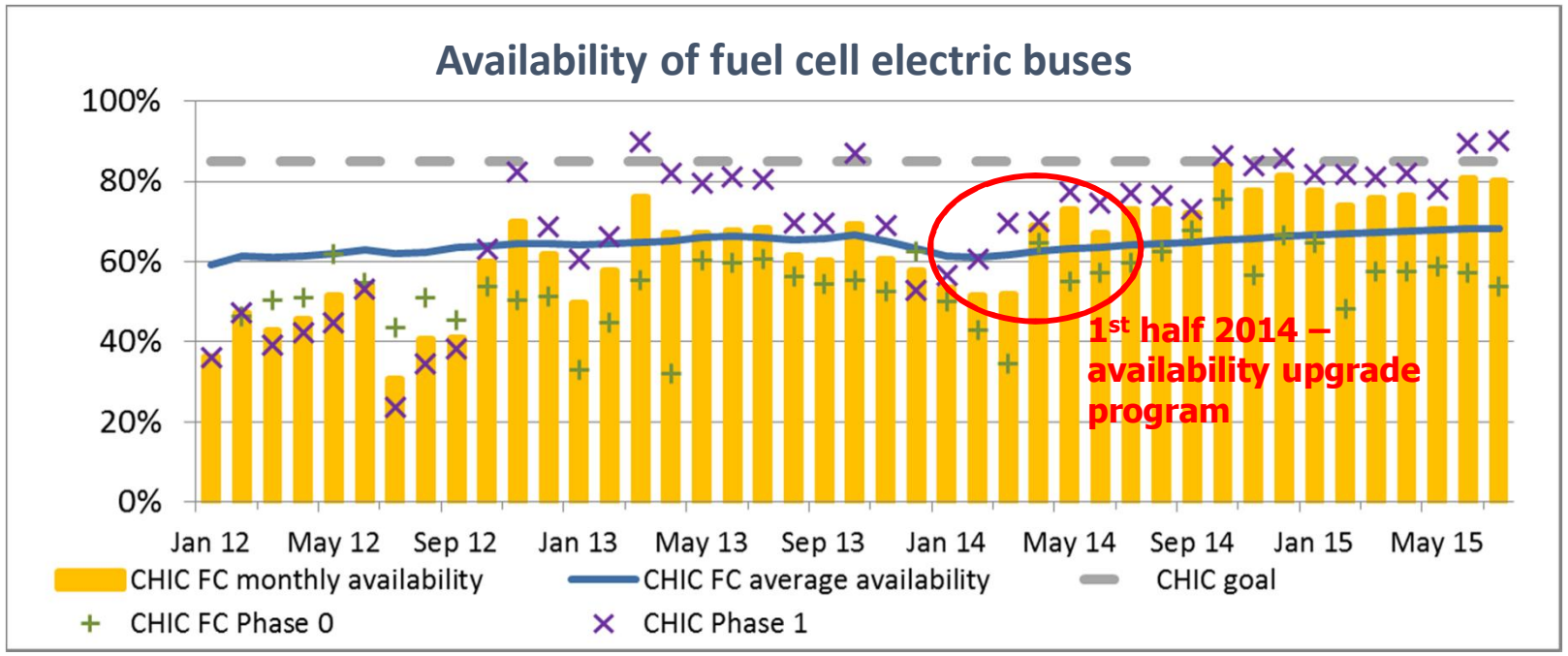
	City	Availability to date (Aug. 2015)
Phase 1	Aargau	> 96%
	Bolzano	> 98%
	London	> 98%
	Milan	> 96%
	Oslo	> 94%
Phase 0	Cologne	> 97%
	Hamburg	> 93% (since Aug. 2013: > 98%)
	Whistler	> 98%

In Aberdeen this figure is over 99.8% after two years

- The 18-month EU project NewBusFuel started in summer 2015 to look at engineering solutions for depots integrating a larger fuel cell bus fleet (50-200 buses – 1,000-5000kg hydrogen/day in 12 locations across Europe)

Availability: After having faced teething issues, most of the Phase 1 cities are reaching the project target

- 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**



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Progress against targets – summary (end 2016)

Application	Parameter	Unit	2012	FCH-JU target		
				2017	2020	2023
Fuel cell electric buses	Specific FC system cost	€/kW	< 3500	< 1800 750	1000 500	800 400
	FC Bus System Lifetime	hours	10000	15000 2 x 8000	20000 2 x 10000	25000 2 x 12500
	FC Bus cost	k€	1300	700	650	500
	Fuel consumption (vehicle, average of SORT1 and SORT2 cylce)	kgH2/100km	9	8.51	8	7.59
	Availability	%	85	90	95	99
	Assumed number of units (per year) as cost calculation basis			< 50	200	> 500

Start of CHIC

Status today (end 2016)

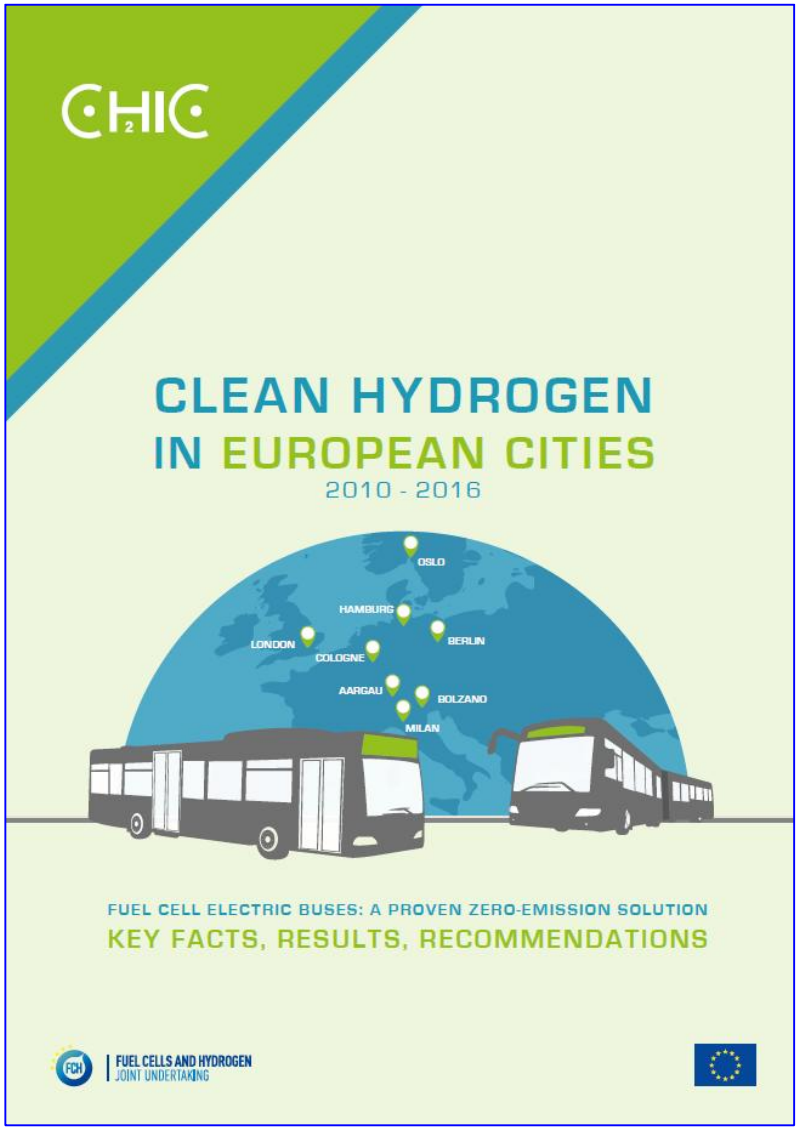
Opportunities and next steps suggested by CHIC

- 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 local emissions**, a contribution to transport decarbonisation and **satisfying the travelling public and the drivers**

Required next steps

- **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 process (see next slides)*
- **Regulations on hydrogen refueling stations construction and safety need to be further harmonised at EU and international level**– Key stakeholders are working *at European and international standards to simplify procedures and decrease costs*
- **Cost of hydrogen for buses needs to improve** – this requires attention to both bus efficiency AND low cost hydrogen at scale

CHIC brochure to be published next week



Final conference ahs become the Zero Emission Bus conference on 30th November to 1st December.

Over 200 attendees from around the world….

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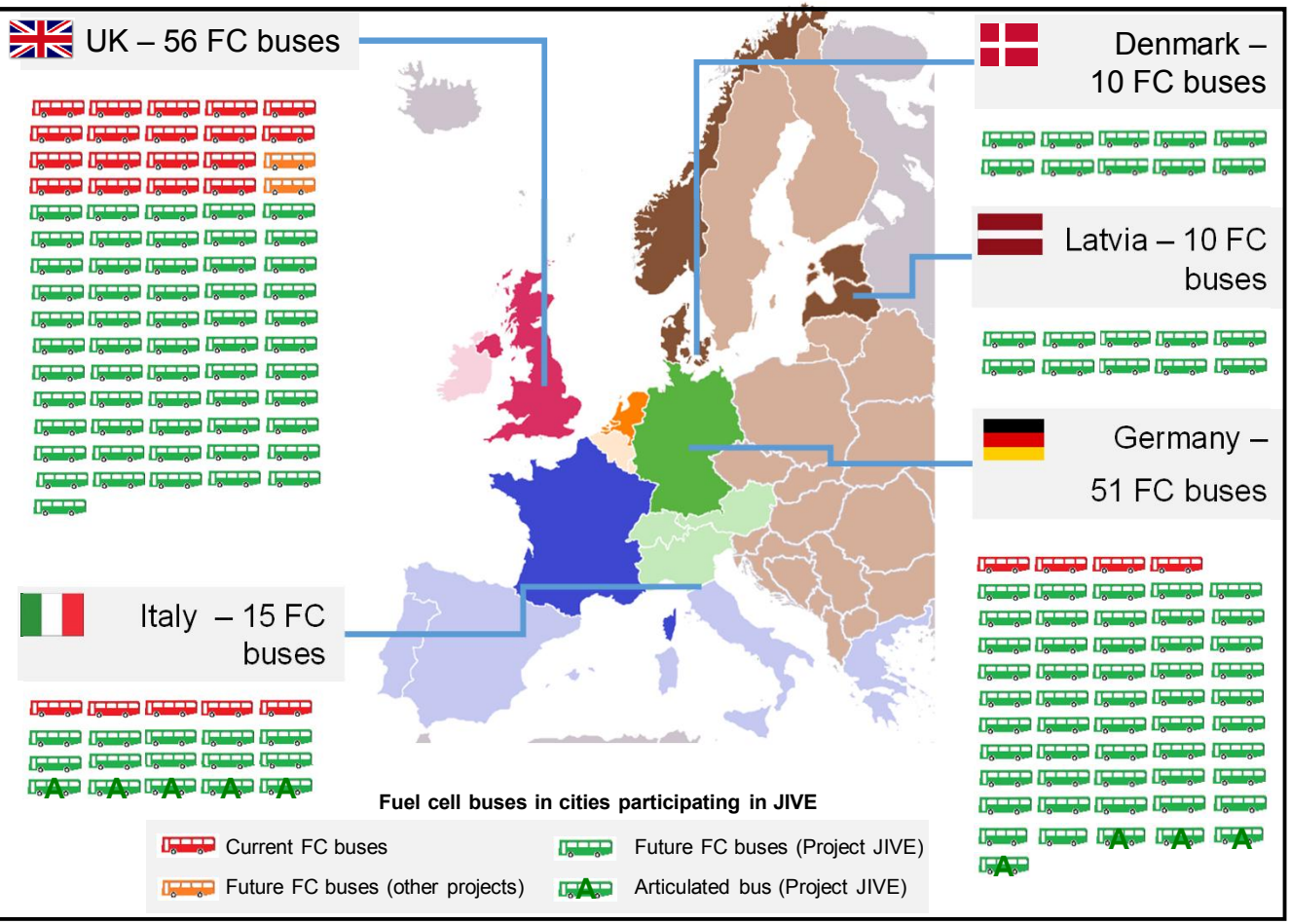
- Next steps – the JIVE project

The JIVE project will help commercialise fuel cell buses through a large-scale demonstration across five Member States

JIVE: Joint Initiative for hydrogen Vehicles across Europe

Objectives

- Deploy 142 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 will be a six year project, with an anticipated start date of early 2017

Thank you for your attention

www.chic-project.eu

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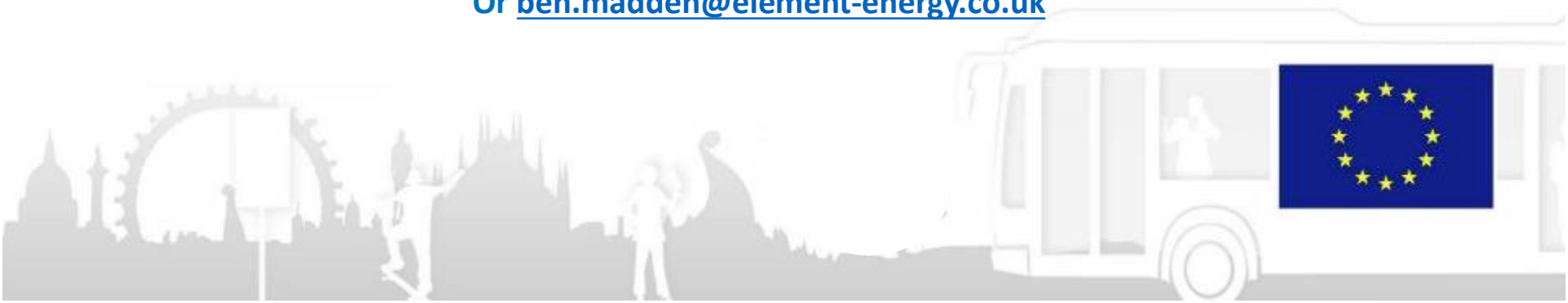


NewBusFuel project

1 Aberdeen
- Linde
- Aberdeen City Council

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

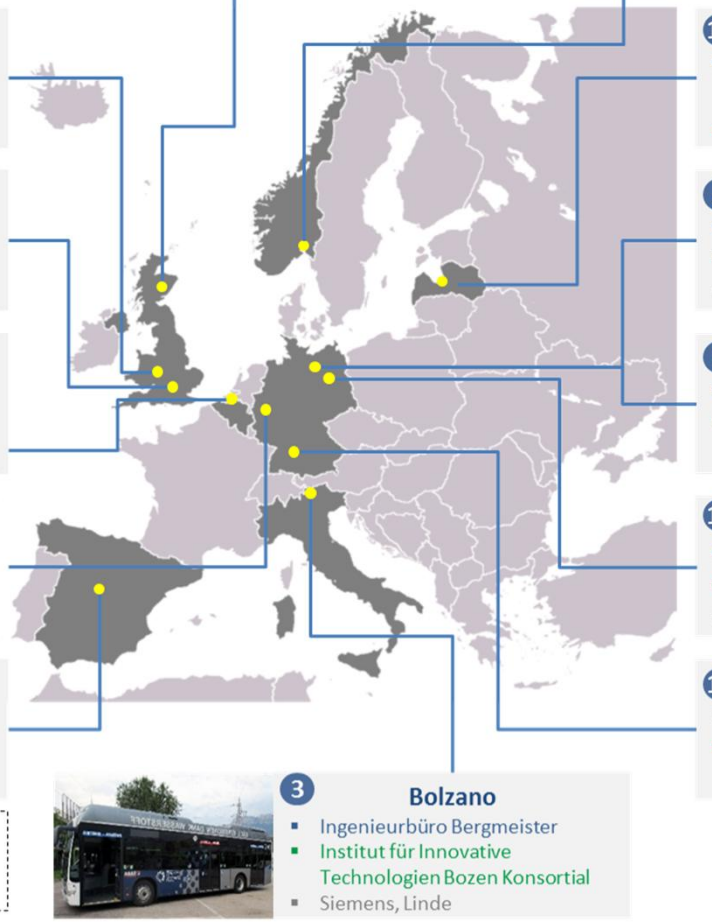
2 Birmingham
- ITM Power
- Birmingham City Council

7 London
- Air Products
- London Bus Services Limited

4 De Lijn
- Linde
- De Lijn

13 Wuppertal
- Hydrogenics
- Wuppertaler Stadtwerke

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



Industrial lead
Operator lead
Other industrial

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

11 Riga
- Industry role to be tendered
- Riga Satiksme

5 Hamburg 1
- Vattenfall Innovation
- Hamburger Hochbahn
- Siemens

6 Hamburg 2
- Air Products
- Hamburger Hochbahn

10 Potsdam
- McPhy Energy
- ViP Potsdam
- H2 Logic

12 Stuttgart
- Siemens
- Stuttgarter Strassenbahnen

Inter-study partners: Element Energy, thinkstep, EvoBus