Proceedings of 7th Transport Research Arena TRA 2018, April 16-19, 2018, Vienna, Austria

Fuel cell electric buses: Experience of a zero-emission solution

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Abstract

Mobility is at the heart of our society meanwhile the transport sector is responsible for about one third of Europe's greenhouse gas (GHG) emissions and the main cause of air and noise pollution, affecting citizens' health, especially in urban areas. What if we could find a way to move as flexibly, quickly and conveniently as today and at the same time keep our environment clean? Fuel cell electric buses are part of the solution and a commercialisation strategy is in place to bring the costs down, and this is what past deployments and the JIVE project are demonstrating across Europe.
After introducing the topic and explaining what fuel cell electric buses are, the paper will highlight the results and recommendations of previous and current fuel cell bus deployment projects to date – namely CHIC, High V.LO-City and Hytransit. The JIVE and MEHRLIN projects, which will deploy 139 new fuel cell buses and their hydrogen infrastructure will then be introduced along with the commercialisation strategy of fuel cell buses that started in parallel. The paper ends with a mention of the JIVE 2 project, which will add another 152 fuel cell buses in European cities, and will expend the deployment to new countries in Europe.

Keywords: public transport, zero emission, hydrogen, clean energy, decarbonization, air quality / noise / health issues, energy efficiency

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1. Introduction

Cities across Europe and beyond are facing common challenges: Increasing urbanisation & congestion, leading to a growing demand for transport services (and new mobility schemes); environmental challenges with poor air quality and associated health effects, with e.g. particulate matters 2.5 (PM 2.5) responsible for over 400 000 premature deaths according to the EEA (see 2016 "Air quality in Europe" report) along with GHG emissions; economic constraints: cities are looking for affordable, reliable, high quality and high tech services (digitalisation) with limited budgets.

These challenges are being tackled at local and national level by decision makers, with announcements to phase out diesel, plans to go for zero emission solutions and/or clean air schemes, such as in for example decisions taken in France, Netherlands, UK or at local level in cities like Hamburg, Oslo, Madrid. The European Commission is also addressing the issue with the launch of the Clean Bus Deployment initiative on 13th July 2017 and its plan to contribute to deploying at least 2.000 zero-emission buses by the end of 2019 in the EU. The "Clean mobility package", adopted on 8th November 2017, entails a revision of the Clean Vehicle Directive, setting up targets for clean bus fleets by Member State in 2025 and 2030.

The only long term viable option to decarbonise transport and deliver zero emission buses is the electrification of transport with two principal options: battery electric buses and fuel cell electric buses.

The JIVE project (Joint Initiative for hydrogen Vehicles across Europe) is a European project deploying 139 new zero-emission fuel cell buses across five member states, the first deployment of this scale in Europe. This project is co-funded by the European Fuel Cells and Hydrogen 2 Joint Undertaking (FCH 2 JU) under the Horizon 2020 programme and runs for six years from January 2017 onwards. The objective of the project is to enable the commercialisation of fuel cell electric buses across Europe through large-scale deployment of vehicles and infrastructure. JIVE build on previous experience with fuel cell electric buses, which have shown the readiness level of the technology, highlighted lessons learnt and recommendations. JIVE is a full part of a strategy for commercialising fuel cell bus technology for Europe that was launched in 2014.

2. What are fuel cell electric buses?

2.1. Fuel cell electric buses – what are we talking about?

A fuel cell bus is an electric bus that includes both a fuel cell and batteries. In such hybrid architecture, the fuel cell provides energy to keep the batteries charged, works with the batteries to provide peak traction power, and provides the energy necessary for the bus auxiliary loads. The fuel cell power module onboard the bus generates electric energy through an electro-chemical reaction leaving only water and heat as by-products. The electric energy is used to keep the batteries charged and the by-product heat is useful as a source of energy for maintaining passenger comfort, to improve vehicle efficiency. The batteries also provide storage for regenerated energy.
Hydrogen offers much higher energy density compared to electrical storage systems such as batteries, meaning that the battery system can be reduced in size, an improved fuel efficiency and operate for an entire day of service without refuelling.

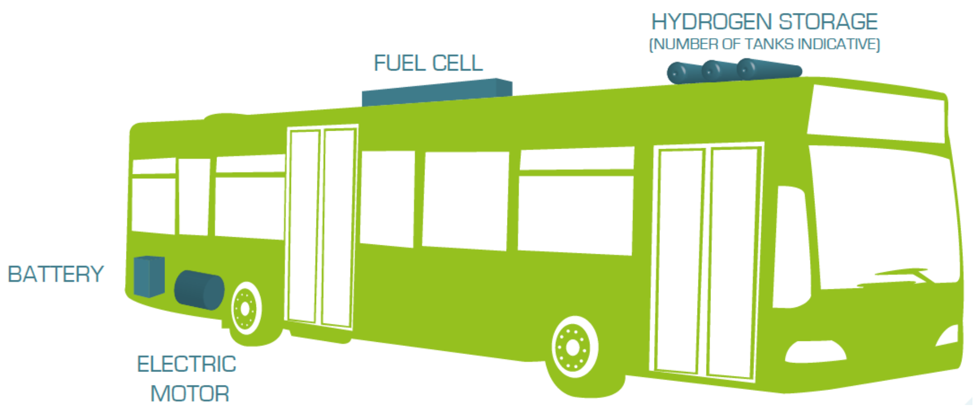

Figure 1 - Main components of a fuel cell bus

2.2. Refuelling a fuel cell bus and introducing hydrogen:

Fuel cell buses are refueled in a hydrogen refuelling station, usually located next to the bus depot. At the refuelling station, hydrogen is usually compressed, stored, and dispensed on demand to the buses. The equipment (e.g. gas-tight nozzles and receptacles) is comparable to that used for the refuelling of natural gas. It takes less than 10 minutes on average to refuel a bus after a full day of service. Hydrogen can be produced on-site or delivered depending on the way it is produced. The two main ways to produce hydrogen are steam methane reforming (when natural gas is used as the feedstock) and water electrolysis. In this case hydrogen is produced by using electricity to separate water into hydrogen and oxygen. "Green hydrogen" can be made through this process when the electricity is generated from renewable sources. There are other ways to produce hydrogen for example by using hydrogen originating from the chemical industry as a by-product.

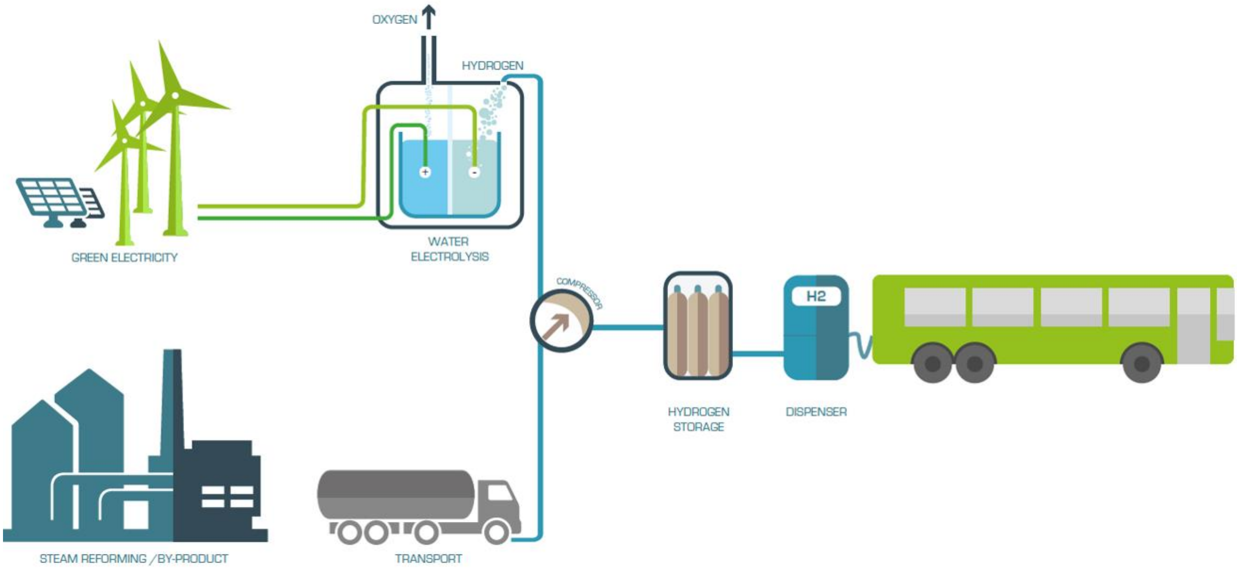

Figure 2 - Most common hydrogen supply pathways

3. Results and recommendations from previous trials

3.1. Results from the CHIC project

The European Union has funded fuel cell buses deployment projects for over a decade (CUTE, Hyfleet CUTE, CHIC, High V.LO-City, Hytransit, 3emotion). The largest one so far, the CHIC project (Clean Hydrogen in European Cities), ran from 2010 to 2016. Throughout the whole duration of the project, 56 fuel cell buses were demonstrated in eight cities with different climate and size.

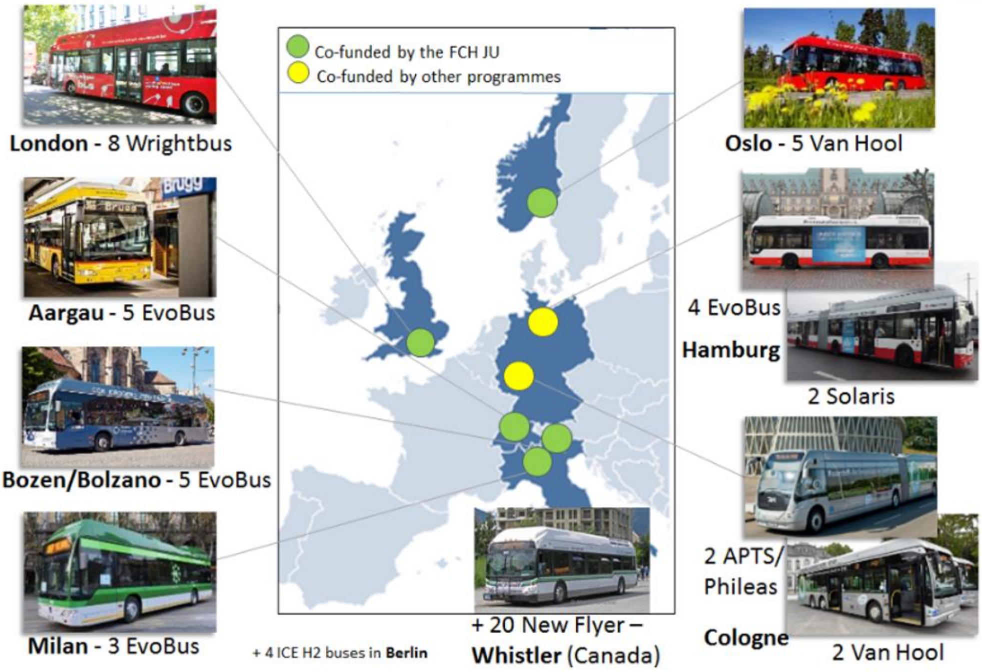

Figure 3- Deployment sites, number of buses and bus brands deployed within the CHIC project

The CHIC project demonstrated that fuel cell buses can be used as a day-to-day replacement of conventional buses as they can offer an operating range similar to that of a diesel bus, short refuelling times at hydrogen refuelling stations, high fuel efficiency with a consumption of 9 kg of hydrogen/100 km for 12 m buses, CO2 emissions reduced by 85% compared to diesel buses along the bus life cycle when the hydrogen fuel is produced from renewable energy sources. In addition, 6,800 tonnes of CO2 equivalent were saved within CHIC, and the use of over 4.3 million litres diesel was avoided.

The success of this initiative underlines the added value than fuel cell buses offer to phase out conventional fuels and improve air quality in the context of a strong European policy on emissions reduction. In public transport, finding an alternative to buses powered by conventional fuels has become a crucial issue: although modern conventional buses do deliver results in the struggle against harmful emissions, there is a limit to their potential as they still rely on fossil energies. The next step is the transition to zero-emission mobility, but many cities and bus operators struggle to reconcile this objective with their need to maintain operational flexibility and limited budgets. The European Commission has recently launched a Clean Bus Initiative with a view to foster the deployment of clean buses across Europe.

Fuel cell buses present a great potential to achieve this challenge as enabler of the elimination of both harmful pollutant and carbon dioxide emissions from public transport while providing public transport services with no loss of performance, operational flexibility or productivity, along with noise reduction. These characteristics make it a very attractive solution to cities and bus operators.

As one of the first projects providing regular deployment of fuel cell buses, the CHIC project delivered fact-based information about the advantages of the technology and delivered key recommendations for the uptake of the sector.

3.2. Key recommendations from the CHIC project

There are still some areas on which the fuel cell bus sector needs to improve in order to be commercially viable in the years to come.
The availability of the buses, especially at the beginning of the trial, did not fully match expectations. This was mainly due to the immaturity of the supply chain.. This has been partly solved by resolving the teething issues of the new drivetrains within CHIC. The availability will be further improved in next generation demonstration projects, where the increased scale in the supply chain will reduce waiting times for parts and ensure more trained specialists are available to diagnose and fix problems. These improvements to create a more mature and robust supply chain will be an essential part of commercialising the technology.

The technology costs will need to be reduced : The CHIC project reports a 50% reduction of the purchasing costs of the buses, but this will not be sufficient to achieve a mass market breakthrough. Fuel cell buses are still an expensive alternative to both conventional buses and buses from alternative fuels. A commercialisation strategy has been set up to tackle this issue, with a view to get economies of scale through increased volume of demand and technology improvements (see next chapter).

In addition, some of the cities encountered delays due to lengthy permitting procedures for their hydrogen refuelling infrastructure. This underlines the need for specific documents which support both the operator, who has to obtain approvals, and the authorities considering granting them. The project has gathered best practices that will be helpful for fuel cell bus deployments in other cities. Additionally, further Europe-wide harmonisation of regulations, codes and standards (RCS) are ongoing. Key stakeholders in the sector work on a common framework to simplify procedures and thereby reduce costs.

3.3. Results and recommendations from the High V.LO-City & HyTransit projects

After the CHIC project, three more demonstration projects were co-funded by the FCH-JU to accelerate the commercialisation of fuel cell buses in Europe. Sister projects High V.LO-City and HyTransit started in 2012/2013 and are deploying a total of 20 fuel cell buses and their associated refuelling infrastructure in four cities: Aberdeen in Scotland (10 buses), Groningen in the Netherlands (2 buses), Antwerp in Belgium (5 buses) and San Remo in Italy (3 buses).

Building on the findings of the CHIC project, the High V.LO-City and HyTransit projects have set ambitious targets to improve the technical availability of the buses and to reduce the total cost of ownership of the buses.
As 15 buses have been in full operation for about three years with more than 1.5 million km driven, first conclusions can be drawn. A reduction in capital costs has been achieved compared to the CHIC project, demonstrating that volume is essential for manufacturers to achieve price reduction. The availability of the buses has also greatly improved, with several buses reaching 100% of technical availability over the past few months. This is proving the maturity of the technology and is paving the way to the introduction of larger fleets of buses in Europe. It is important to note that the fuel cells are highly reliable (97% availability of the fuel cells) and that an important part of the failures are “normal” bus failures (normal wear of components).

The hydrogen refuelling infrastructure is performing well in the projects, with an average availability of the refuelling stations above 97%. A refueling event typically takes between 10 and 12 minutes, which close to the refueling time of a conventional fuel bus.

The acceptance of the buses in the cities where buses are deployed is very good and both passengers and drivers enjoy the buses. While bus drivers had some reservations about the technology early in the projects, a second assessment after two years of operation shows that these reservations have largely decreased at the same time as the availability of the buses has increased. The projects have also identified training a being of great importance both for the optimal operation of the buses and for the acceptance of the buses by the drivers.

While the supply chain can still remain an issue, the High V.LO-City and HyTransit projects have enabled bus manufacturers and public transport operators to come up with efficient solutions at the local level. The supply chain maturity has gradually improved since the start of the projects and is expected to continue to do so through the rest of the projects and in future deployments.

While the High V.LO-City and HyTransit projects are demonstrating that the technology is reaching its maturity, the CAPEX and OPEX cost of the buses and the refuelling stations remains a challenge, even though savings have been achieved. Similarly, the cost of producing green hydrogen remains very high. A further reduction in prices is essential for the operation of the buses to become economically viable.

Knowing about all of these challenges, the JIVE project (and its infrastructure counterpart MEHRLIN) is initiating the next step towards commercialising fuel cell buses in Europe.

4. The deployment of a fuel cell bus fleet in Europe

4.1. The JIVE & MEHRLIN projects

The JIVE (Joint Initiative for hydrogen Vehicles across Europe) project seeks to deploy 139 new zero emission fuel cell buses and associated refuelling infrastructure across five countries; this is the largest deployment of this scale to date. JIVE will run for six years from January 2017 and is co-funded by a 32 million euro grant from the FCH JU (Fuel Cells and Hydrogen Joint Undertaking) under the European Union Horizon 2020 framework programme for research and innovation. The project consortium comprises 22 partners from seven countries. The regions and cities involved are Region of Köln, Wuppertal and Rhein-Main in Germany, London, Birmingham, Dundee and Aberdeen in the United Kingdom, South Tyrol in Italy, Riga in Latvia and Slagelse in Denmark.

The overall objective of JIVE is to advance the commercialisation of fuel cell buses through large-scale deployment of vehicles and infrastructure so that by the end of the project, fuel cell buses are commercially viable for bus operators to include in their fleets without subsidy, and that local and national governments feel empowered to regulate for zero emission propulsion for their public transport systems.

JIVE will introduce new fleets of fuel cell buses into urban and regional bus operations at an unprecedented scale. This will be made possible by multiple cities and regions collaborating in joint procurement processes, allowing large orders to be placed with single bus suppliers. The procurement activities are organised into three clusters and by clustering geographically, it is possible to provide common specifications for the buses, which is essential to unlock the economies of scale.

Specifically, JIVE plans to achieve a 30% cost reduction versus state of the art, to operate 50% of the vehicles for at least 36 months, to deploy the largest capacity hydrogen refueling stations in Europe and achieve near 100% reliability, to demonstrate the technological readiness of fuel cell buses and hydrogen refueling stations and encourage further uptake.

The project provides foundation for a continued growth of the fuel cell bus sector in Europe. By working together over the coming months and years, bus suppliers, public transport authorities and operators can realize the vision of fuel cell buses becoming a mainstream choice delivering zero emission public transport across Europe.

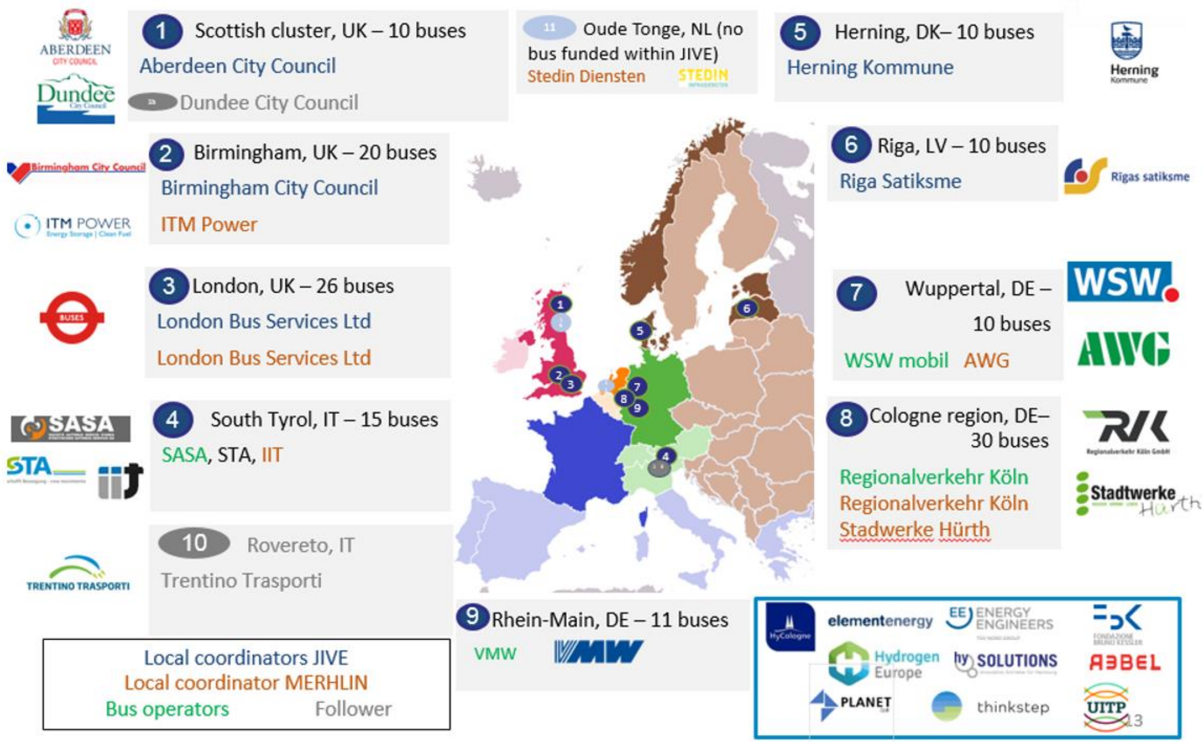

Figure 4 - Partners in JIVE and MEHRLIN projects and deployment sites

Alongside JIVE, the MEHRLIN project will deploy seven hydrogen refuelling stations serving bus fleets in cities across Europe, in the UK, the Netherlands, Italy and Germany. MEHRLIN began in July 2017 and will run until the end of 2020. The MEHRLIN project is co-funded by the European Commission's Connecting Europe Facility (€5.5M) and the support is managed by the Innovation and Networks Executive Agency.

The overall objective of MEHRLIN is to demonstrate a financeable demand-led business model for hydrogen refuelling stations in order to further boost the deployment of hydrogen as an alternative fuel in the EU. The project consists of a study with a real-life trial of large hydrogen stations in 7 different locations. By building and operating these stations, the MEHRLIN project will not only contribute to the expansion of the hydrogen refuelling station network in Europe, but will allow a test, under real conditions, of the technical and economic performance of refuelling stations under high load and daily utilization. Using this evidence, MEHRLIN will undertake an assessment of the financing case for hydrogen refuelling stations using a demand-led business model to further boost the deployment of hydrogen as alternative fuel in the EU. This business model will be defined through study and seminars to be carried out jointly with key finance providers.

Joint procurements have been launched by the UK and the German cluster in May and June 2017 and outcomes of the tender are expected to be made in the first quarter of 2018, to be followed by the first orders.

4.2. The commercialisation study

JIVE is part of a larger process aimed to commercialized fuel cell buses and thus offer affordable zero emission solutions for cities across Europe. The strategy started in 2014. The FCH JU gathered a large coalition of cities and regions, bus operators, bus manufacturers, technology providers and hydrogen suppliers, and produced a study (executed by Roland Berger) showing scenarios for the development of the total costs of ownership for FC buses. The study "Fuel Cell Electric Buses – Potential for Sustainable Public Transport in Europe" concluded that :

- Fuel cell buses arecrucial for reducing emissions while meeting operational requirements;
- Vehicle costs are on a downward trajectory but further work is needed to reduce costs of not only the buses, but also the refuelling infrastructure and fuel
- Large-scale, coordinated deployment (300–400 buses in Europe by the early 2020s) is a logical next step for continued development of the sector.

The main driver for the capital cost reduction is expected to be volume, which allows economies of scale in the bus production, for component suppliers, and in the support systems for the vehicles in the field. The study showed that overall costs for these buses are expected to decrease to a cost premium of about 11–18% compared to conventional diesel buses on a per kilometre basis by the year 2030.
The fuel cell bus commercialisation vision is highlighted in the figure 2.

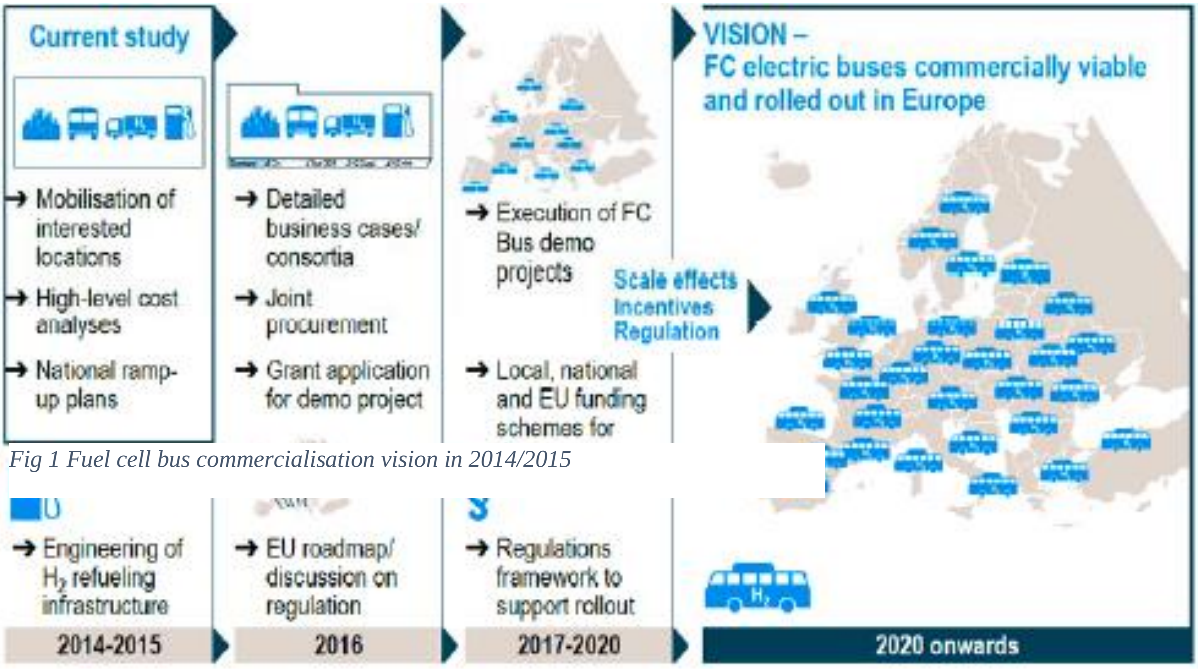

Fig 1 Fuel cell bus commercialisation vision in 2014/2015

Figure 5 Fuel cell bus commercialisation vision in 2014/2015

4.3. The joint Procurement strategy: geographical clustering

In September 2015, the FCH JU commissioned a group of consultants to help initiate and coordinate a new wave of fuel cell bus procurement activity across Europe, as a continuity of the work undertaken within the *Commercialization Study* described above, which mapped out a strategy for commercialising fuel cell bus technology for Europe. The first phase of this strategy is to ensure a step change in the level of demand for fuel cell buses, with a target of 300–400 new buses deployed by 2020.

Five regional procurements clusters were identified covering the UK, Germany, France, the Benelux region, Scandinavia, Latvia, Austria and Northern Italy. Almost 60 bus operators and transport agencies are members of these clusters, which remain open for other interested parties to join. The geographical coverage is highlighted in the figure 3.

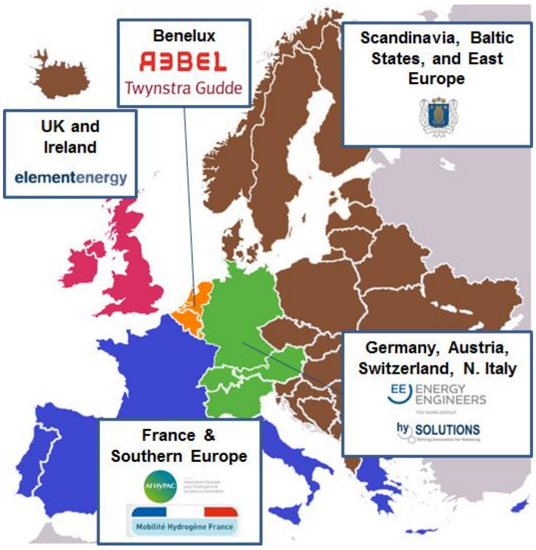

Fig 2 Five clusters looking at demand aggregation and match funding

Working with city representatives, the cluster coordinators identified demand for over 600 fuel cell buses across Europe.

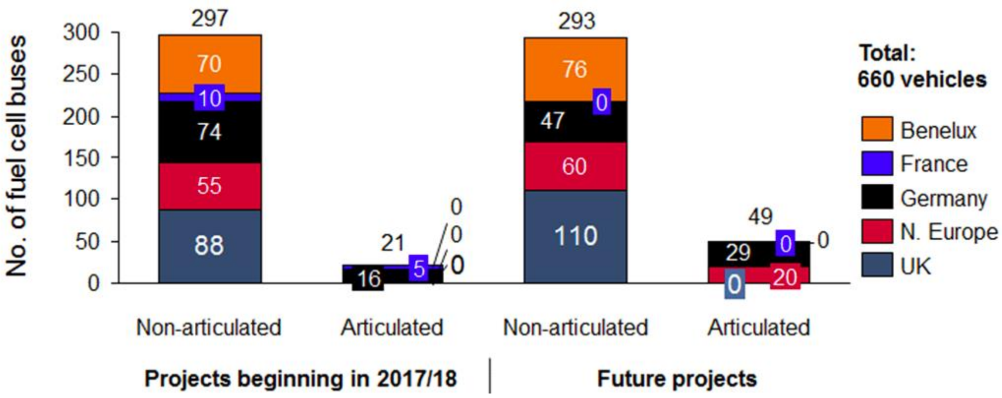

Fig 3 Potential demand for fuel cell bus in the pre-2020 period

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.

In parallel with the identification of demand, the current and planned deployments are expected to deliver 400 fuel cell buses in Europe by 2020, and thus match the ramp up scenario as identified in the commercialisation study – see figure

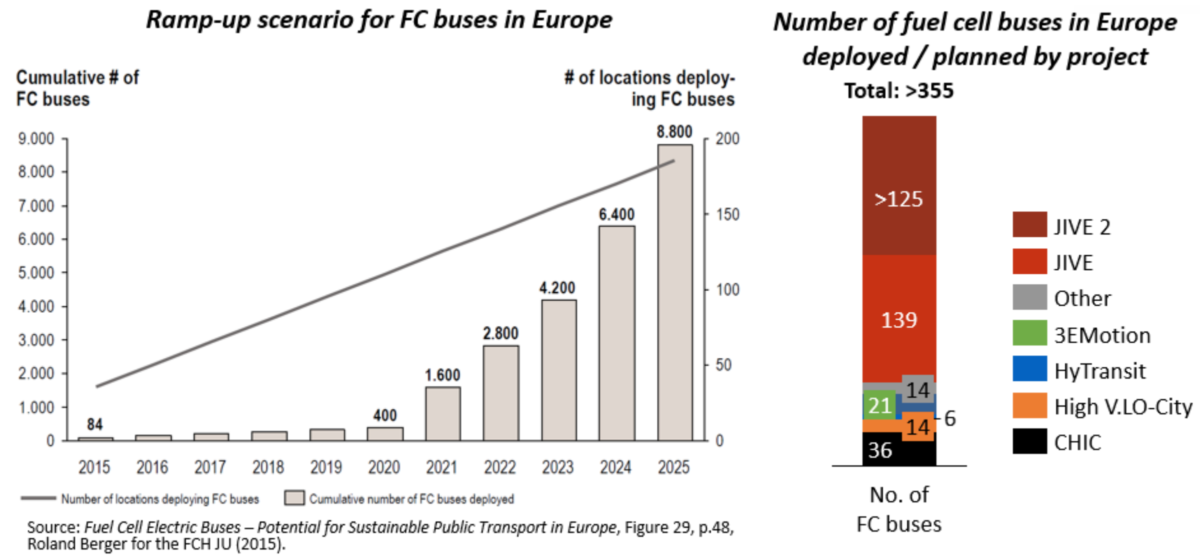

Fig 4 Ramp up scenario for fuel cell buses in Europe and number of buses planned by project

JIVE builds a key part of the commercialisation process, and the overall objective is to reach the next phase of the commercialization of fuel cell buses, thus make the technology commercially viable for bus operators to include in their fleets without subsidy, and empower local and national governments to regulate for zero emission propulsion for their public transport systems.

4.4. JIVE 2 :

The upcoming further fuel cell bus project JIVE 2 is another key element of the commercialisation process. This project – which is due to start in January 2018 – will add another fleet of 152 fuel cell buses. The figure below highlights the deployment sites and the fact that thanks to the JIVE and JIVE 2 projects, a total fleet of 291 new fuel cell buses will operate on European roads, in line with the ramp-up scenario foreseen as part of the 2015 Commercialisation study (see figure 5).

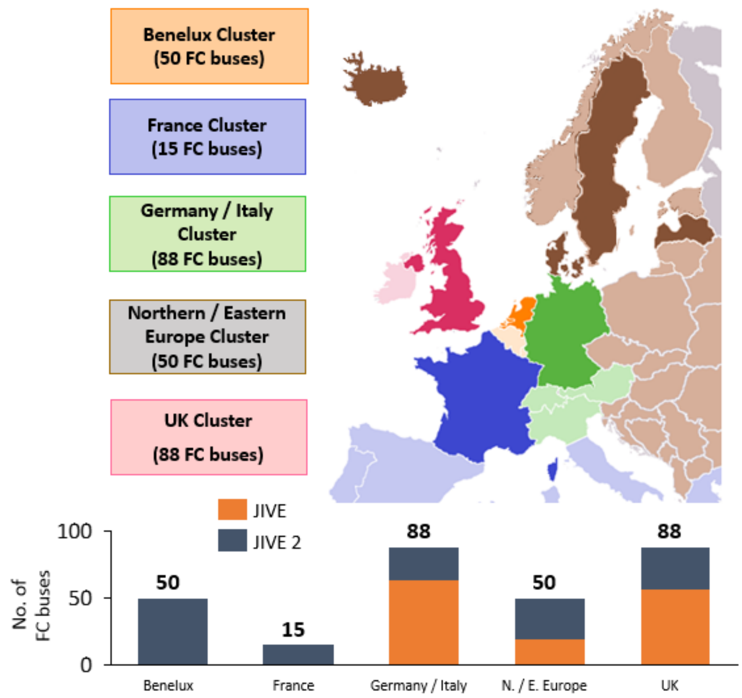

Figure 6 - JIVE 2 deployment sites and number of buses by cluster (JIVE /JIVE 2)

5. Acknowledgements :

The JIVE project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking under grant agreement No 735582. This Joint Undertaking receives support from the European Union's Horizon 2020 research and innovation programme, Hydrogen Europe and N.HERGY. The MEHRLIN project is co-financed by the European Union's Connecting Europe Facility.

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