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A European Approach for the Commercialization of Fuel Cell Buses in Public Transport

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Summary

Hydrogen fuel cell buses offer an interesting option for public bus operators on their way to zero emission mobility. They combine clean electric driving with the flexibility of a conventional bus: full day operating range, short refuelling times, and independence of infrastructure on the route. However, like battery buses their price premium in comparison to diesel buses is still a big hurdle for their market introduction. This paper introduces several major initiatives that seek to reduce fuel cell bus ownership costs and prepare for the commercialization of the hydrogen fuel cell bus sector.

Keywords: bus, fuel cell vehicle, hydrogen, market development, public transport

1 Clean Public Transport for Europe

1.1 Context

The European Union is pursuing an emissions reduction agenda as well as measures to improve local air quality and to reduce harmful noise levels in public transport. With Directives on Ambient Air Quality and Cleaner Air for Europe (2008), and on the Promotion of Clean and Energy-Efficient Road Transport Vehicles (2009), the EU has set first regulatory standards in this regard. Numerous European cities and regions have started initiating changes in their public transport systems, for example with the European Climate Change Statement 2015, or in the Clean Bus Declaration of the C40 Cities Initiative.

Seeking alternatives to diesel buses is crucial for realizing the emissions reduction agenda in public transport. While modern buses built to the EURO VI standard emit substantially fewer harmful emissions than older vehicles, there is a limit to achieving reductions in diesel bus emissions. Hence, cities and bus operators are under pressure to shift to electric, zero-emission powertrains such as tramways, trolley, battery and fuel cell electric buses (FC buses). Diesel buses currently dominate the public transport market due to their high productivity, low deployment costs, technological maturity, operational reliability and flexibility, e.g. high daily ranges, fast refuelling and no infrastructure requirement along the routes. Many cities and bus operators are struggling with the conflicting objectives of shifting to zero emission public transport while keeping operational flexibility and delivering increased services with limited budgets.

The hydrogen fuel cell (FC) bus is one of very few options for the elimination of both harmful pollutant and carbon dioxide emissions from public transport. Hydrogen can be generated from a range of low carbon sources and, when used in a fuel cell, the only emission is water. Fuel cell buses also offer an equivalent range and refuelling time compared with conventional buses, meaning that they can provide conventional public transport services without any loss of performance, operational flexibility or productivity, and with a reduction in noise. These benefits mean that the technology is very attractive to public transport operators, city administrations, and public transport service users.

The performance of fuel cell buses has been validated in Europe in recent years through various European demonstration projects (CUTE, HyFLEET:CUTE, CHIC, High V.Lo.City, HyTransit, 3EMotion), and the technology has reached a level of maturity where wider scale deployment by public transport operators is considered technically feasible. However, a number of actions are needed to allow the full commercialisation of FC buses, including (i) addressing the significant ownership cost premium relative to conventional vehicles, (ii) confirming that the vehicles can meet the very high availability levels demanded by public transport operations, (iii) developing larger hydrogen stations with lower cost hydrogen as well as high reliability, and (iv) increasing awareness of the potential of fuel cell buses to deliver zero emission public transport systems.

1.2 Potential of Alternative Power Trains

In 2012, the Fuel Cells and Hydrogen Joint Undertaking (FCH JU) started a FC bus commercialization effort by sponsoring a large study (executed by McKinsey) on alternative power trains [1] for urban buses with an industrial coalition composed of 40+ bus manufacturers, technology providers, infrastructure providers and bus operators (over 80 participants in total), with the aim of understanding which alternative power trains are most economic and suitable to decarbonise public transport in Europe. Powertrains examined included: diesel, serial and parallel hybrid, battery bus charging overnight, battery bus with opportunity charging, trolley buses and fuel cells buses. As a result, fuel cell buses and other electric buses were evaluated as potentially good candidates, whereby the first would give users more flexibility and are nearer to commercialization and the second offers less flexibility, has less operating experience, but may be lower in running cost (table 1).

Table 1: Comparison of Electrical Drive Trains for Buses

Drive Train Concept	Daily Range	Route Flexibility	Charging/ Refueling time	Productivity
Battery bus with opportunity charging	+	-	+	-
Battery bus with overnight charging	-	+	-	-
Trolley bus	++	-	n/a	+
Fuel cell electric bus	++	+	++	+

1.3 The "Commercialization Study"

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 second study (executed by Roland Berger) showing scenarios for the development of the total costs of ownership for FC buses [2]. The study "Fuel Cell Electric Buses – Potential for Sustainable Public Transport in Europe" concluded that (i) FC buses are crucial for reducing emissions while meeting operational requirements; (ii) 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; and (iii) large-scale, coordinated deployment (300–400 buses in Europe by the early 2020s) is a logical next step for continued development of the sector.

Further deployment of FC buses is mainly an issue of cost – at the time of the study, fuel cell bus costs were 3–4 times those of conventional buses, and operational costs are also higher. The main driver for 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. There will also be advantages from synergies with fuel cell electric car development.

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 cost premium is driven by the costs associated with the introduction of a new technology, mainly reflected in a higher FC bus purchase price and thus, higher financing costs. In the first years of deployment, the costs of infrastructure for the hydrogen refuelling system, bus maintenance, and hydrogen add to the premium until 2020. From 2020, bus maintenance costs are expected to converge to diesel bus levels and hydrogen fuel costs are assumed to be even lower than diesel costs on a per kilometre basis. Hence, in the medium term, reducing the purchase price of FC buses as well as providing affordable infrastructure solutions for large FC bus fleets and competitive hydrogen prices is crucial to bringing costs down. This is reflected in a "best case scenario" (lower hydrogen and higher diesel prices, high number of FC buses, making use of synergies by using FC stacks from automotive industry etc.) in which FC bus total cost of ownership (TCO) is equal to or even lower than that of a diesel bus.

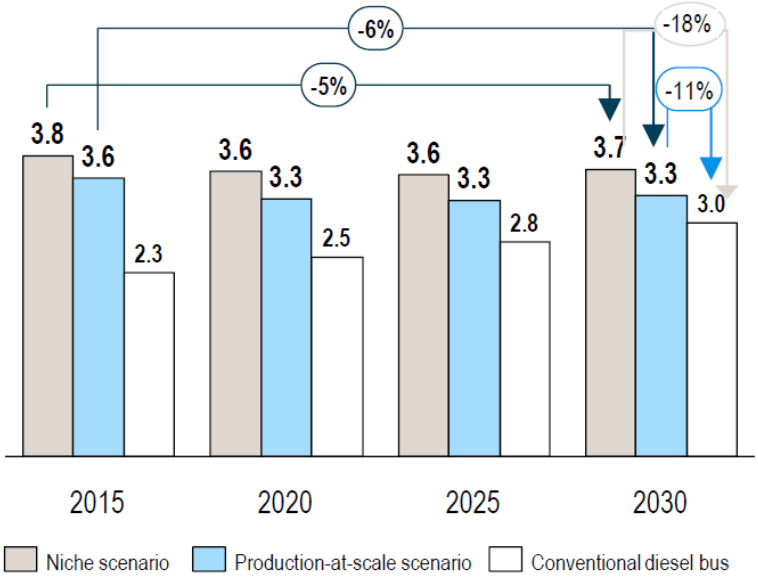

Figure 1: TCO Development (Euro/km) [2]

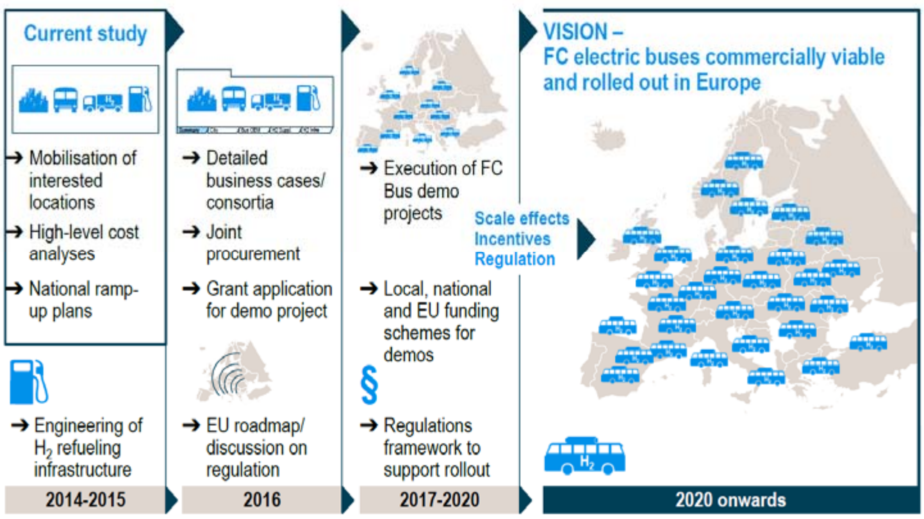

Figure 2: FCH JU Commercialization Vision [2]

1.4 Setting up Procurement Clusters

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. This initiative builds on and takes forward the recommendations from 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.

In order to deliver this ambition, the *cluster coordinators* have developed five regional procurement clusters, where a number of bus operators and cities agree to work together to procure large numbers of fuel cell buses. The clusters cover 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.

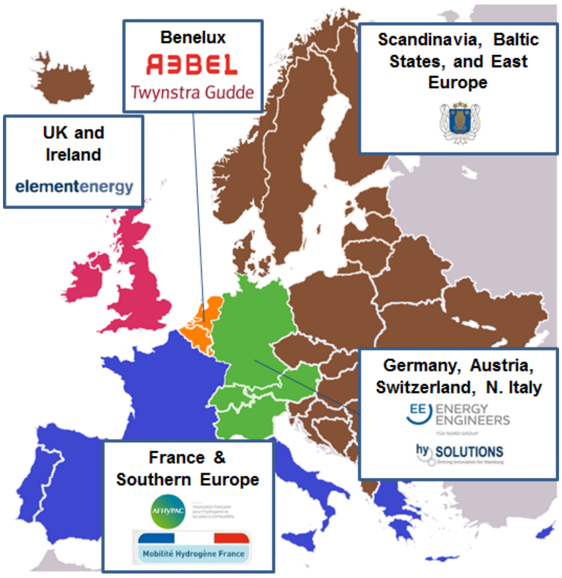

Figure 3: Clusters in which demands for FC buses are being aggregated across Europe

The main objectives of the clusters are to identify and help develop demand for FC buses, define common technical standards for the vehicles, and to organize coordinated joint procurement of large numbers of buses (c. 100+). This large and simultaneous procurement of FC buses will support bus manufacturers to source components at lower costs and thus contribute to significant price reductions for FC buses. The cluster members have already started a series of projects for the further commercialization of fuel cell buses in public transport (see following sections), and potential demand for hundreds of vehicles has been identified.

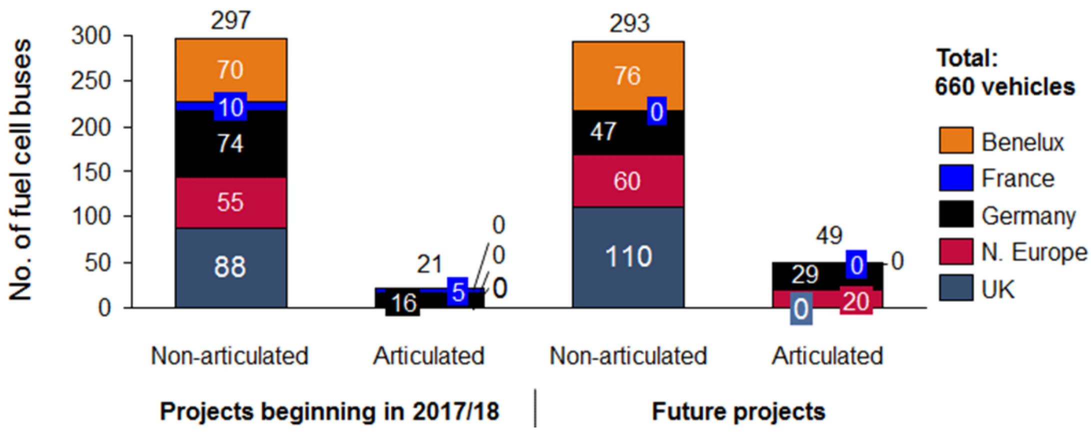

Figure 4: Potential demand for FC buses in the pre-2020 period

Note that the numbers shown in fig. 4 are estimates based on the work of the cluster coordinators to date. Funding is in place for some but not all buses represented here. While the cluster coordinators have sought to provide realistic and relatively conservative deployment numbers, in practice these figures may change as more detailed local feasibility work is undertaken.

1.5 The "NewBusFuel" Study

The "New Bus Refuelling for European Hydrogen Bus Depots (NewBusFuel)" project is an engineering study on hydrogen bus refuelling stations (HRS), funded by the FCH JU. The overall aim of NewBusFuel was to fill a significant knowledge gap around the technologies and engineering solutions required to refuel large numbers of FC buses at individual depots. HRS for buses differ from those for passenger cars. Beside the lower pressure level (35 instead of 70 MPa) the main differences are the higher flow rate and the daily amount of hydrogen provided. In case of a larger bus fleet (e.g. 100 vehicles), hydrogen demand can reach two to three tonnes per day, while current passenger car stations have capacities of around a tenth of this level. Thirteen case studies were examined in this study, based on different sites and considering different ways of providing the hydrogen to the station: centrally produced and then trucked in (either gaseous or liquid), or produced on site at the station via electrolysis or biogas reforming. The project ended in May 2017.

The study's principal recommendations for bus operators include:

- Establish an appropriate initial fleet size
- Ensure infrastructure sizing and procurement is adequately linked to growing bus fleets
- Chose a modular HRS design
- Find the right balance between reliability and cost

Hydrogen prices at the stations will depend on the hydrogen supply method. In general, on-site production via electrolysis or steam reforming of biogas leads to higher hydrogen costs. Especially in the case of electrolysis the production costs not only depend on the capital investment required, but also on the price of the electricity. In order to keep capital costs low, the study recommends a modular approach in HRS size tailored to the demand of the fleet. Electricity prices depend very much on local conditions such as legal framework and surcharges (e.g. the German feed-in compensation and grid usage fees). These surcharges make electricity and hence the hydrogen unnecessarily expensive. Nevertheless, even under German tariff conditions prices between 5 and 6 €/kg can be reached which can offer bus fuel costs equivalent to diesel (on a per kilometre basis). Trucked-in hydrogen is usually cheaper especially if the hydrogen stems from by-product overcapacities. Prices below 4 €/kg are possible. But often, by-product hydrogen is not from renewable sources.

For fuel cell buses to realise their full potential in terms of supporting decarbonisation of the transport sector, these vehicles will have to use very low or zero carbon hydrogen (often termed "renewable" or "green" hydrogen). This fact is widely acknowledged within the hydrogen sector and work is underway to identify fuel supply solutions that meet the often conflicting demands of low cost and low carbon hydrogen.

1.6 The "MEHRLIN" Project

The "MEHRLIN" project (Models for Economic Hydrogen Refuelling Infrastructure) covers the installation, operation and economic evaluation of hydrogen refuelling stations for buses. The MEHRLIN project, supported by a grant from the European Commission's Connecting Europe Facility (Transport) programme managed by the Innovation and Networks Executive Agency, aims to demonstrate a new demand-led commercial model for the deployment of hydrogen refuelling stations. The project involves a study of the real-life operation of large-scale hydrogen stations in seven different locations; with stations in Germany (Hürth, Wermelskirchen [Cologne Region] and Wuppertal), Italy (Bruneck/Brunico), the Netherlands (Oude Tongue – South Rotterdam), and the UK (London and Birmingham). The studies will focus on the financing of stations (bankability) and on technical, environmental, economic and regulatory performance of hydrogen refuelling stations. The station designs will reflect the results of the NewBusFuel study. The project started in January 2017 and will run until December 2020, with the commissioning of the first stations expected in mid-2018.

1.7 The "JIVE" Project

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. JIVE will run for six years from January 2017 and is co-funded by a 32 million EURO grant from the FCH JU under the European Union Horizon 2020 framework programme for research and innovation.

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. The FCH JU defined in their project call a maximum price for FC buses in the range of 650,000 EURO in order to be eligible for funding. Assuming these price targets will be achieved, this represents a cost reduction of almost 40% relative to the prices of FC buses in 2014.

JIVE not only includes the procurement and operation of fuel cell buses, but also their technical validation and a comprehensive dissemination of the results to bus operators, cities, regions and bus manufacturers.

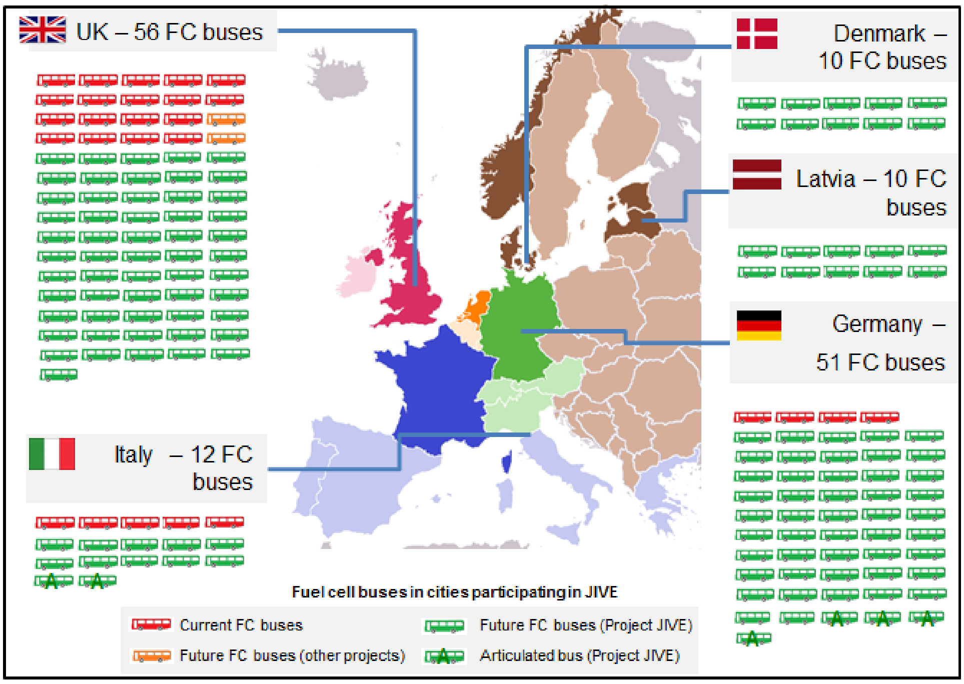

Figure 5: Fuel Cell Buses in JIVE

In spring 2017, the first tenders for the procurement of the fuel cell buses were launched and bus manufacturers were invited to bid. Before that, the partners in the regional clusters developed common specifications for the FC buses. This procedure will help to bring prices down by buying the same bus in larger numbers. The tenders caused a significant rise of interest among bus manufacturers to supply fuel cell buses and initial indications are that several European bus OEMs can supply fuel cell buses in the short term. Additional OEMs are expected to begin offering FC buses to customers in Europe over the coming years, including some Asian bus manufacturers.

1.8 Medium-term outlook for Europe's fuel cell bus sector

The subsidised projects described above, along with related initiatives, are expected to lead to around 400 FC buses operating in Europe by the early 2020s. However, for this technology to fulfil its potential in terms of contributing to environmental objectives, deployment of increasing numbers of these zero emission vehicles will be needed in the post-2020 period. The cluster coordinators are now working with city representatives and bus operators on developing business cases and financing plans for larger-scale deployment of fuel cell buses beyond 2020. In the context of the potential demand for fuel cell buses summarised above, the cluster coordinators are also consulting with bus manufacturers to explore the best next steps to link supply and demand in a way that triggers the cost reductions required to ensure commercial uptake within the next decade. This involves working with bus manufacturers and other supply chain partners to understand the conditions needed to enable different production cost trajectories for fuel cell buses, and the creation of sustainable businesses in the zero emission public transport sector.

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Authors

Dr Frank Koch has for more than 17 years been working in the fuel cell business. Since 2000 he has been manager of the Fuel and Hydrogen Network North Rhine-Westphalia as part of the EnergyAgency.NRW. Here he is responsible for the topics hydrogen mobility and hydrogen infrastructure set-up and coordinates an expert group "hydrogen for public transport". Frank Koch also coordinates the German Fuel Cell Bus Procurement Cluster. This institution was installed by the FCH JU and brings together bus operators from Germany and Northern Italy in order to discuss fuel cell bus topics and launch joint projects. Frank holds a doctoral degree in chemical engineering.

Michael (Mike) Dolman is a Principal Consultant at Element Energy and has a decade's experience working across the low carbon energy sector. In recent years Mike's work has focused on hydrogen transport and he has led many of Element Energy's activities in this area, which include project initiation, consortium building, and securing funding, through to project implementation, monitoring and data analysis. Since 2015 Mike has managed a number of projects aimed at delivering coordinated deployment of fuel cell buses across Europe as part of efforts to commercialise this zero emission technology. Mike holds a Master's degree in engineering from the University of Cambridge.