

# Commercialisation of hydrogen fuel cell buses

Discussion paper

October 2017



## Summary

Buses are a central element of public transport systems. They are highly flexible while being a relatively low cost and efficient way of transporting people, especially in cities. While diesel still fuels most buses in operation worldwide, significant developments in alternative fuelled vehicles have been made in recent years and a range of ultra-low and zero emission options are now on the market. This paper focuses on hydrogen fuel cell buses, which are a form of electric bus, and summarises the findings of a focused study of the sector. Key conclusions include:

- Hydrogen fuel cell buses have been demonstrated in real-world operations over many years and are now on the cusp of a commercial breakthrough. This is not widely known beyond the fuel cell bus sector but is highly relevant for cities seeking versatile zero emission alternatives to diesel.
- Industry projections suggest that fuel cell buses will be competitive with battery electric buses on many routes within the next three to five years.
- Interest in battery electric buses from politicians in many cities has created market conditions that will allow fuel cell buses to compete economically without public sector subsidy in the near future, i.e. from the early 2020s.
- Fuel cell buses and battery electric buses are complementary technologies as they share a high proportion of common components; the most appropriate solution depends on the local context and constraints. With long range and short refuelling times, fuel cell buses offer a zero-emission solution on a wide range of routes, with particular advantages when fuelling heavier vehicles (articulated vehicles, double decks) with a high daily mileage, and challenging terrain, etc.
- Continued development of Europe's fuel cell bus sector will require (i) technology-neutral zero emission policies in cities / regions and at a national level; (ii) coordinated action to aggregate demands for vehicles that will unlock price reductions from economy of scale effects; and (iii) further development of the supply side, i.e. more manufacturers offering a wider choice of zero emission products that meet their customers' needs.

This document sets out a vision for large-scale deployment of hydrogen fuel cell buses on a commercial basis from the early 2020s and targets a broad audience: policy makers, regulators, investors, technology providers, bus operators, etc. The aim is to stimulate debate regarding how the vision could be delivered and to define next steps for the principal actors: policy makers, bus manufacturers, component suppliers, hydrogen infrastructure providers, and bus operators.

## Context

Cities across Europe and beyond are facing common challenges, including:

- **Increasing urbanisation & congestion** – leading to growing demand for public transport services.
- **Environmental challenges** – poor air quality that causes harmful health impacts, and a requirement to reduce greenhouse gas emissions to combat climate change. While significant progress in reducing surface transport emissions has been made in recent years, for example with the introduction of Euro 6 standards, moving towards a zero emission, sustainable future will require increased uptake of fully zero emission vehicles.
- **Economic constraints** – providing affordable, reliable, high quality services with limited budgets.

These challenges are leading an increasing number of cities to focus on their public bus fleets, as the early adopters of affordable and clean vehicle technologies. In this context, many of Europe’s larger cities have set out ambitious policies designed to stimulate a transformational shift in the dominant powertrain technology used in their bus fleets.

<b>National level plans</b>	<b>Norway</b>	All new urban buses sold in 2025 to be zero emission or use biogas. Aim to have a fully ZE transport system by 2030.
	<b>The Netherlands</b>	All new buses procured from 2025 to be ZE.
<b>City-specific commitments</b>	<b>Athens, Greece</b>	Commitment to remove all diesel vehicles from city by 2025.
	<b>Copenhagen, Denmark</b>	Phase out of diesel vehicles as part of plan to be carbon neutral by 2025.
	<b>Hamburg, Germany</b>	All buses purchased from 2020 to be ZE.
	<b>London, UK</b>	All new single deck buses to be ZE from 2020, all new single and double deck buses to be ZE from 2025.
	<b>Madrid, Spain</b>	Commitment to remove all diesel vehicles from city by 2025.
	<b>Paris, France</b>	Commitment to remove all diesel vehicles from city by 2025.

**Figure 1: Overview of illustrative announcements to accelerate uptake of zero emission buses in selected cities / countries across Europe (ZE = zero emission)**

The combined bus fleet size in this selection of European cities / countries that have indicated commitments to phasing out diesel vehicles totals almost 50,000 vehicles, which translates into a potential market of around 3,000 new buses per year as a minimum (assuming an average vehicle lifetime of fifteen years).

There are relatively few technical solutions for fully zero emission urban buses, with the principal options being battery electric or fuel cell electric vehicles, both of which use electrification of the drivetrain. Hydrogen fuel cell buses are an attractive solution in this space due to their:

- **Long range** – the amount of hydrogen stored on board can be tailored according to the operators’ needs, with ranges of 300+ kilometres achievable. The long range available from fuel cell buses is a unique advantage in the zero emission bus sector which means these vehicles offer flexibility and productivity benefits.
- **Short refuelling times** – fuel cell buses can be refuelled in approximately seven minutes, which means they are regarded as a direct replacement for diesel vehicles and can be offered as a zero compromise solution to operators. Depot-based refuelling means that these vehicles can deliver emission-free public transport services without the need for new refuelling / recharging infrastructure in public spaces.

- **Scalability** – the refuelling infrastructure for fuel cell buses is readily scaled up to accommodate growing fleets, thus avoiding some of the challenges related to upgrading the local electricity grid facing operators seeking to fully convert large depots to battery electric buses.
- **Potential to bring green energy into cities** – as cities struggle to meet the decarbonisation challenge, many sectors look to electrification, e.g. heat supply for buildings. This creates enormous pressure on cities' electricity grids as the only means of importing green energy into urban areas. Hydrogen provides an alternative option, which can complement green electricity and satisfy a range of end uses, starting with buses and moving to cover many aspects of mobility and eventually other sectors such as heating.

The technical performance of fuel cell buses has been validated in several demonstration projects<sup>1</sup>, and the technology is on a trajectory of rapidly decreasing cost. A fuel cell bus commercialisation strategy published in 2015<sup>2</sup> defined a pathway to large-scale uptake of these vehicles by the mid-2020s based on collaboration between cities / regions and ensuring supportive public frameworks are in place. Concerted efforts to aggregate demands for fuel cell buses<sup>3</sup> have led to the *JIVE* project, which is using joint procurement to bring about further cost reductions.<sup>4</sup> The *JIVE* project will lead to the deployment of close to 300 buses across Europe before 2020.

The key to the next step in the development of the sector will be increases in scale. This comes in two forms:

- Scale of bus orders to allow bus manufacturers to reduce prices to the point of commercial acceptability (without subsidy). This required orders of hundreds of buses per year per manufacturer.
- Scale of hydrogen bus fleets – large fleets are required to allow hydrogen providers to supply hydrogen at a price below the equivalent taxed diesel prices for the same routes. This implies at least twenty buses per depot and ideally more than fifty.

Achieving this scale will require further coordinated activity at a European level, both to group demand and to help cities and operators manage the risk associated with a large-scale commitment to the technology.

## Commercial deployment of fuel cell buses – the vision

The overarching vision for fuel cell buses in Europe from the early 2020s can be summarised as follows:

***Fuel cell buses become a mainstream choice for public transport providers in cities and regions across Europe as they provide zero emission transport at a total cost of ownership equivalent to or below that of battery electric buses, with no operational compromises for operators or passengers compared to incumbent diesel technologies.***

Achieving this vision will require several further developments (see following section), and crucially an increase in scale of deployment to reduce costs (capital and operating costs of the vehicles and associated

<sup>1</sup> Such as CHIC (<http://chic-project.eu/>) and High V.Lo-City (<http://highvlocity.eu/>).

<sup>2</sup> [www.fch.europa.eu/publications/fuel-cell-electric-buses-%E2%80%93-potential-sustainable-public-transport-europe](http://www.fch.europa.eu/publications/fuel-cell-electric-buses-%E2%80%93-potential-sustainable-public-transport-europe).

<sup>3</sup> Since 2015 the FCH 2 JU has funded a group of cluster coordinators to coordinate demands in geographic clusters across Europe and develop joint procurement strategies for fuel cell buses. See:

[www.fch.europa.eu/publications/strategies-joint-procurement-fuel-cell-buses](http://www.fch.europa.eu/publications/strategies-joint-procurement-fuel-cell-buses).

<sup>4</sup> [www.fch.europa.eu/news/launch-project-jive-large-scale-deployment-fuel-cell-buses-europe](http://www.fch.europa.eu/news/launch-project-jive-large-scale-deployment-fuel-cell-buses-europe).

refuelling infrastructure). The challenge faced and an illustration of fuel cell bus pricing dynamics are summarised below.

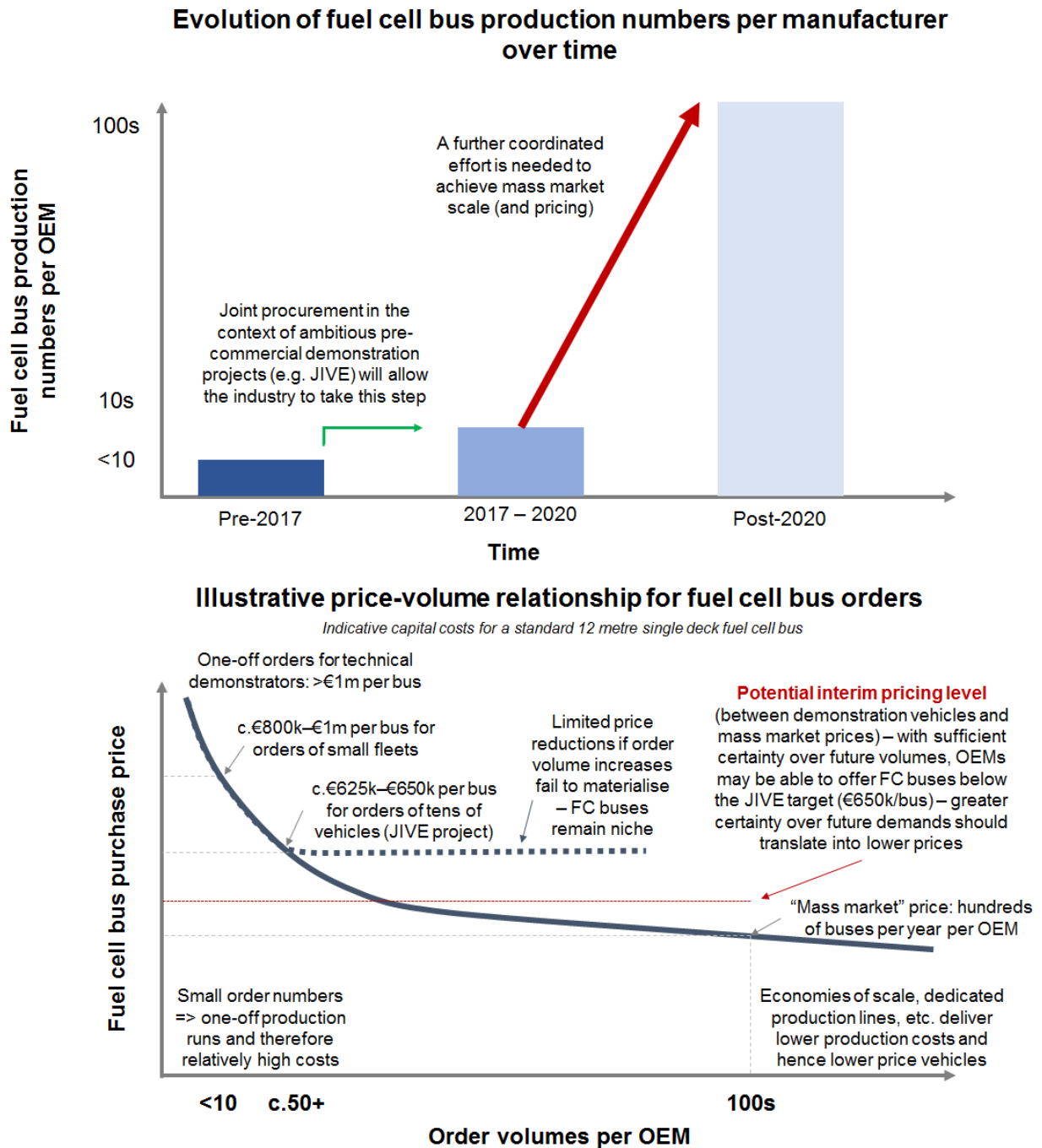


Figure 2: Illustration of scale-up in production numbers and price-volume relationship for fuel cell buses (note that these graphs are purely illustrative and not based on empirical data)

The large-scale demonstration activities now underway (e.g. the JIVE project) will lead to large cost reductions compared to previous projects. However, at the cost levels envisaged a substantial premium relative to alternative powertrain choices will remain. Discussions with several European bus OEMs suggest that at sufficient scale of production (minimum 100 buses per year) fuel cell bus costs can fall to a level at which they will be competitive with other zero emission options, as illustrated in the economic analysis that follows.

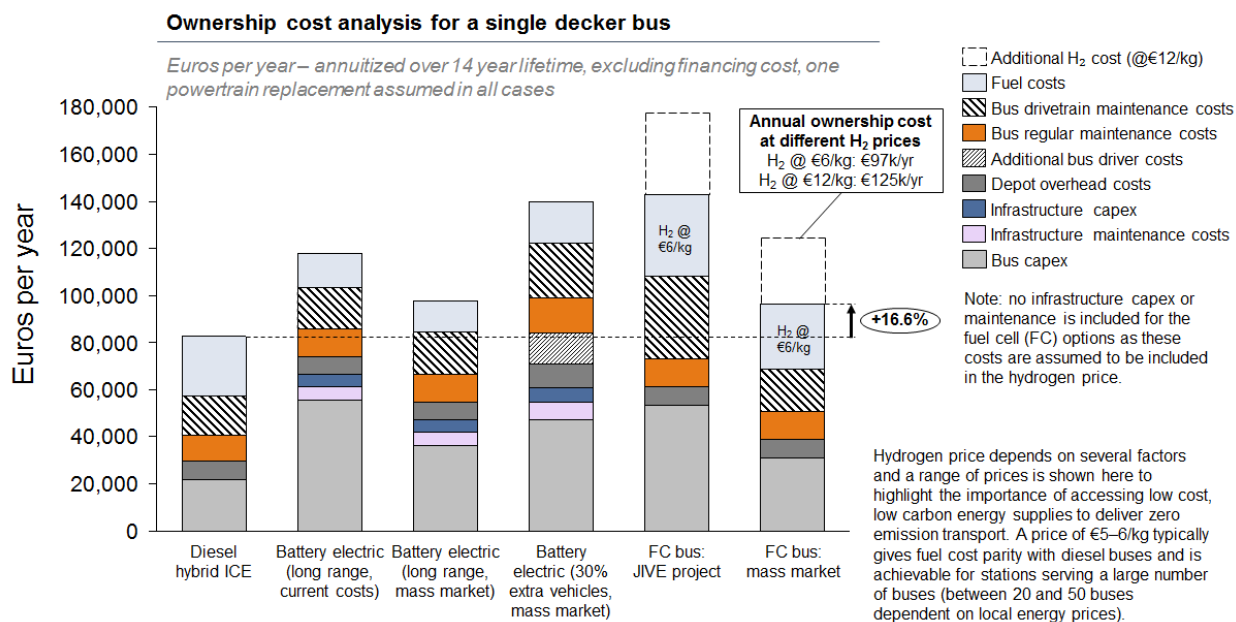


Figure 3: Ownership cost analysis for a typical 12m single deck bus (excluding financing costs)

The analysis above shows that while at current pricing levels fuel cell buses come with a high cost premium relative to diesel hybrid vehicles, at *mass market* prices this technology can compete with other zero emission alternatives. Note that in this context, *mass market* refers to low hundreds of vehicle orders per manufacturer per year. This level of demand is consistent with even a small share of the potential zero emission market of around 3,000+ new buses per year in European cities that have indicated commitments to phasing out diesel vehicles, as highlighted above. Although the indicative prices used here are not specific to any individual manufacturer, all assumptions used have been validated by several OEMs independently.

This is a profound conclusion – fuel cell buses can provide zero emission public transport at ownership costs competitive with battery electric buses and with relatively modest premiums relative to incumbent diesel vehicles (c.15–20%). This fact should provide reassurance and confidence to any municipality considering legislating for zero emission buses. It should also encourage public transport operators and authorities to ensure that zero emission tenders remain technology neutral and allow local providers to consider the hydrogen option alongside the all-battery electric options.

## Pre-requisites, risks, and next steps

Several further developments are required for the vision outlined above to be realised. The large-scale collaborative initiatives such as the JIVE project will lead to hundreds of fuel cell buses operating in daily service in tens of cities / regions by around the end of the decade, thus expanding the evidence base on technical readiness of vehicles and refuelling infrastructure. It is essential that these deployments succeed and demonstrate the ability to operate with a high level of reliability on challenging routes across Europe. This will then provide a firm foundation for the additional actions required, which are summarised in the (non-exhaustive) lists below.

### Policy makers

- Continue to develop and implement suitable policies to create favourable market conditions for zero emission buses. These zero emission policies should be technology neutral, acknowledging that hydrogen fuel cell vehicles offer a proven technical solution alongside battery electric buses.

### Bus manufacturers / component suppliers

- Bus manufacturers need to work with supply chain partners to achieve further cost reductions (capital costs and maintenance costs) for fuel cell buses to a level where the need for public subsidy is significantly reduced / eliminated in some of the most environmentally sensitive areas. The potential for synergies with other sectors (e.g. fuel cell solutions for other heavy duty vehicles, passenger cars) should also be considered. Bus manufacturers will need to target a 12m single deck bus cost well below €450k per bus.
- Additional efforts are required to offer maintenance solutions at a comparable cost to diesel vehicles and to reduce fuel consumption ideally below 7kg/100km for a typical flat urban route.
- Continued development of the supply side is also needed – e.g. an expanded range of fuel cell bus models available, improvements in fuel efficiency and lifetimes of key components, more mature supply chains, and greater capacity of suppliers to support increasingly large fleets in service. A truly commercial fuel cell bus market requires multiple OEMs competing to offer a range of vehicle types, from urban buses (single / double deck, articulated / non-articulated), to minibuses, to coaches. Urban buses are likely to remain the focus in the near term, but there will be a need for a wider range of zero emission options in the coming years.

### Hydrogen infrastructure providers

- Continue efforts to develop cost effective, reliable, low carbon hydrogen supplies for large fleets of buses. Previous studies have demonstrated that engineering solutions to refuel large fleets of fuel cell buses exist<sup>5</sup>, opening up the option of *hydrogen depots*. However, these types of solutions are yet to be demonstrated in practice. The choice of hydrogen supply method typically depends on a range of factors and is likely to be location-specific.
- Hydrogen supply prices are very dependent on local energy economics. However, for the bus market to prosper, suppliers will need to develop solutions which offer hydrogen at, or ideally below, €6/kg.

---

<sup>5</sup> See for example the *NewBusFuel* study: <http://newbusfuel.eu/>.

## Bus operators

- Bus operators will need to develop plans to deploy hydrogen buses on a larger scale. This will involve a considerable technological risk. The bus operator industry will need to make early plans for increased scale of deployment and ensure all local actors are bought into their plans. Furthermore, there are likely to be issues associated with managing technological risks (e.g. a requirement for leasing of vehicles) which the operator industry needs to consider and then communicate to the hydrogen supply sector.

## Providers of subsidy and soft debt

- The requirement for subsidy for larger scale hydrogen bus deployment is expected to be dramatically reduced. Instead, the focus should be on helping manufacturers and (more importantly) operators manage the risks around moving to larger scale deployments. Here, there is a role for soft finance providers to help finance these early deployments when they are perceived as too risky for the banks. Subsidy providers might direct their interventions at providing small incentives to operators who are prepared to take the risks associated with moving to scale rapidly and / or to help underwrite some of these risks in loan structures.

The nature of the bus industry means that a transition to high uptake of fully zero emission vehicles is unlikely to be stimulated by the vehicle manufacturers alone: a combination of aggregating demands for these types of vehicles and specific local policy measures that create attractive market conditions will be needed for continued growth of this sector. While several ambitious projects that are underway / planned will lead to hundreds of these buses operating across Europe within the coming years, further action is needed from the supply and demand side (including local / national policy makers) for this growth to continue.