



## Working Paper

# Why local initiatives for the energy transition should coordinate The case of cities for fuel cell buses in Europe

Guy Meunier <sup>1</sup>, Lucie Moulin <sup>2</sup> and Jean-Pierre Ponssard <sup>3</sup>

January 2022

---

<sup>1</sup> INRA-UR1303 ALISS and CREST - Ecole Polytechnique

<sup>2</sup> Ecole Polytechnique

<sup>3</sup> CNRS and CREST - Ecole Polytechnique

## **La Chaire Energie et Prospérité**

La chaire Energie et Prospérité a été créée en 2015 pour éclairer les décisions des acteurs publics et privés dans le pilotage de la transition énergétique. Les travaux de recherche conduits s'attachent aux impacts de la transition énergétique sur les économies (croissance, emploi, dette), sur les secteurs d'activité (transport, construction, production d'énergie, finance), aux modes de financement associés ainsi qu'aux problématiques d'accès à l'énergie. Hébergée par la Fondation du Risque, la chaire bénéficie du soutien de l'ADEME, de la Caisse des Dépôts, d'Engie et de Renault.

*Les opinions exprimées dans ce papier sont celles de son (ses) auteur(s) et ne reflètent pas nécessairement celles de la Chaire Energie et Prospérité. Ce document est publié sous l'entière responsabilité de son (ses) auteur(s).*

Les Working paper de la Chaire Energie et Prospérité sont téléchargeables ici :

<http://www.chair-energy-prosperity.org/category/publications/>

## **Chair Energy and Prosperity**

The Energy and Prosperity Chair was created in 2015 to inform decisions of public and private actors in managing the energy transition. The Chair research deals with the impacts of energy transition on national economies (growth, employment, debt...), on specific sectors (transportation, construction, energy , finance), on acces to energy and with the associated financing issues. Hosted by the Risk Foundation, the chair has the support of ADEME, the Caisse des Dépôts, Engie and Renault.

*The opinions expressed in this paper are those of the author(s) and do not necessarily reflect the position of Chair Energy and Prosperity. It is therefore published under the sole responsibility of its author(s).*

Chair energy and Prosperity's working papers can be downloaded here:

<http://www.chair-energy-prosperity.org/en/category/publications-2/>

# Why local initiatives for the energy transition should coordinate The case of cities for fuel cell buses in Europe<sup>1</sup>

Guy Meunier (INRA-UR1303 ALISS and CREST - Ecole Polytechnique), Lucie Moulin (Ecole Polytechnique)  
and Jean-Pierre Ponsard (CNRS and CREST - Ecole Polytechnique)<sup>2</sup>

January 2022

To appear in the Revue d'Economie Industrielle

JEL Classification: Q55, Q42, C61

Keywords: Network effects; Experience effects; Public policies; Hydrogen deployment for mobility

## Abstract

Hydrogen is a possible alternative to the internal combustion engine, alongside battery-powered vehicles, in the context of reducing greenhouse gas emissions associated with transport activities. The costs associated with hydrogen vehicles are currently high, even when considering the greenhouse gas emissions and other pollutants avoided by their use. Efforts to reduce these costs, which will determine the social and environmental desirability of hydrogen vehicles, face two challenges: the high cost of refuelling, linked to the crucial problem of coordination between development of the vehicle fleet and refuelling infrastructure; and high purchase prices, which may decrease when sufficient quantities generate experience effects. This paper argues that each of these two handicaps calls for a specific policy design: at a local level for coordination between actors, and at a European level to generate sufficient volumes. The example of hydrogen-powered urban buses analysed through the Joint Initiative for Hydrogen Vehicles across Europe (JIVE) offers a telling illustration of these issues.

## Résumé

La filière hydrogène est une alternative possible au moteur thermique, aux côtés des véhicules à batterie, dans la perspective de réduire les émissions de gaz à effets de serre associées aux activités de transport. Les coûts associés aux véhicules à hydrogène sont actuellement élevés, même au regard des émissions de gaz à effet de serre et de polluants évitées par leur utilisation. Une diminution des coûts associés aux véhicules à hydrogène, déterminant de leur désirabilité sociale et environnementale, se heurte pourtant à des difficultés de deux ordres. D'une part un coût élevé de recharge, où le problème de la coordination entre développement de la flotte de véhicules et infrastructure de recharge est crucial. D'autre part, des prix d'achat élevés, susceptibles de diminuer grâce à des quantités suffisantes générant des effets d'expérience. Cet article argumente que chacun de ces deux handicaps appellent une politique publique structurée à un niveau spécifique : un niveau local pour la coordination entre acteurs, et un niveau européen pour générer des volumes suffisants. L'exemple des bus urbains à hydrogène étudié à la lumière du programme JIVE (the Joint Initiative for Hydrogen Vehicles across Europe) offre une illustration parlante de ces problématiques.

---

<sup>1</sup> Financial support from the Chair Energy et Prosperity at Fondation du Risque, ANR/Investissements d'avenir (ANR-11-IDEX-0003-02) and CELTE project (ADEME) is gratefully acknowledged. The paper benefited from suggestions and comments from Cyprien Bez De Berc, lawyer, Bernard Blez, Passion for Energy, Charlie Briggs, Element Energy, Julien Brunet, SymbioFcell, Lia Cairone, New York City Hall, Yann Francoise, Agence de l'écologie urbaine-Paris, Sophie Glemet, Toyota Motor Europe, Hervé Foucard, Department for transportation at Paris Council, Nicole Whitehouse, Thinkstep AG, as well as from the participants to Journées Hydrogène dans les Territoires 10 et 11 juillet 2019, Palais du Pharo, Marseille and the International Conference on Mobility Challenges, 5-6 december 2019, CentraleSupélec, Saclay. All errors remain the sole responsibility of the authors.

<sup>2</sup> Corresponding author [jean-pierre.ponsard@polytechnique.edu](mailto:jean-pierre.ponsard@polytechnique.edu)

# Why local initiatives for the energy transition should coordinate

## The case of cities for fuel cell buses in Europe

### 1. Introduction

Green technologies are characterized by high initial unit costs and high learning rates. Renewable energy through photovoltaic illustrates this phenomenon: the learning rate is estimated to be around 30%, i.e., the unit cost decreases by 30% every doubling of cumulative production (Elshurafa, 2018). Public subsidies are deployed to encourage the cost decrease of green technologies since it is argued that learning-by-doing is associated with externalities all along the production sector and not so much from each supplier individually. After some years, subsidies can be eliminated, market competition with mature fossil technologies can take place as it is nowadays the case for photovoltaic.

Fuel cell and battery electric vehicles (ZEV)<sup>3</sup> entered this route. Both technologies are expected to be competitive in the future. The larger capital cost of ZEV compared to ICE is a handicap for their deployment. These technologies face a second challenge known as the “chicken and egg issue”: their deployment needs the parallel deployment of a dedicated infrastructure. Without this infrastructure a ZEV is useless and vice versa. A third challenge comes from the fact that, given its high capital cost, the infrastructure should be developed in high density areas to maximize its utilization rate. But many such areas remain much too small to generate a high enough volume of ZEV to decrease their production costs. Furthermore, even in equipped area long distance travellers might be reluctant to adopt if charging/refueling is not feasible along their route. This suggests that some coordination process across local deployments may be worthwhile.

Public policies to promote clean transportation typically do not consider these issues jointly. Top-down approaches for price rebates, fuel efficiency standards, mandates... are elaborated at the national level or EU levels (Anderson et al., 2016, Littlejohn and Probst, 2019). Bottom-up approaches focus on specific geographic clusters in which the local actors elaborate ad hoc schemes to promote production, distribution and usages (mostly in transportation) of green energies (Meunier and Ponsard, 2018).

The potential benefit for coordinating these two approaches has been indirectly addressed in two recent papers. Zhou and Li (2018) empirically analyse Battery Electric Vehicle (BEV) deployments in 353 US cities from 2011 to 2013. Using a calibrated model, they compare the actual national public policy with a contingent one. The national policy selects an identical rebate for all cities while the contingent one adapts it to each city depending on relevant local market characteristics such as the level of population, the average household income and education level, the price of gasoline... The public support is assumed to be budget constrained so that it will disappear after some time leaving the situation to market forces. Zhou and Li (2018) show that the 353 cities are spread across three configurations. More precisely in a first group of cities the local market is too limited so that the level of deployment will reverse to no BEV once the public support is gone. In the second group of cities a sustainable market will perdure, the public support had been enough to pass what is called a tipping point. In the third group of cities, a sustainable market would have emerged anyway, public support has been wasteful. The uniform policy is more expensive than the contingent one.

---

<sup>3</sup> The list of acronyms is at the end of the paper.

Meunier and Ponssard (2020) formalize the chicken and egg issue, namely the fact that infrastructure and cars are complementary goods. One objective of the model is to derive the optimal joint public subsidies for car rebates and retail stations depending on market characteristics. A context involving two markets is considered: the optimal set of subsidies is obtained under two configurations either autarky between areas or a global approach addressing the two markets with contingent policies. Using a numerical simulation, it is shown that the global approach significantly reduces the overall cost of public subsidies, allowing each market to benefit from the overall learning-by-doing effect.

Conceptually, the discussion about top-down versus bottom-up approaches can be related to the dichotomy between “comprehensive” versus “voluntary” approaches for international climate agreements (Morgenstern, 1991). The comprehensive approach favours agreements involving all parties and constraining policies. In a voluntary approach only a coalition of parties voluntarily coordinate their policies. These two approaches have been extensively discussed in the economic literature (for an early reference see Barrett, 1994). The efficiency of comprehensive approaches is limited by the lack of enforceability as demonstrated by the Kyoto protocol and more recently the Paris agreement. Voluntary approaches are self-enforceable, but the size of a stable coalition is typically very low. Still the Montreal protocol for the preservation of the ozone hole has demonstrated that under some circumstances combining both approaches, the initial size of the coalition may considerably be enlarged so that the whole process is quite efficient.<sup>4</sup> The ongoing collaboration of the C40 may be considered as a promising voluntary initiative for cities around the world to coordinate their efforts for addressing the climate change challenge.<sup>5</sup>

The objective of this paper is to empirically explore the potential benefit of combining the top-down and bottom-up approaches through a detailed case study. We have selected urban hydrogen Fuel Cell Electric Buses (FCEB) for the following reasons:

- Many city councils have been responding to the climate challenge by setting stringent objectives to decarbonize their transport system;
- Public transport (buses, rail, taxis ...) is a significant share of total transport and this share is expected to increase;
- Urban buses are operated by public or private companies in which city councils are influential;
- The price of FCEB is currently much higher than diesel or battery only buses, which is a strong barrier to their diffusion.

Consequently, there are both positive and negative aspects to the promotion of FCEB. It turns out that the EU has been promoting this technology since the beginning of the 2000s. The originality of the recent policy, compared to the usual subsidy policies, is to combine a uniform rebate for the acquisition of FCEB with local conditions for being eligible for these rebates. Schematically these conditions relate to securing local support for the infrastructure, as well as commitment to a long term FCEB plan. Only a limited, but growing, number of European cities have joined the EU program, through a form of self-selection process.

---

<sup>4</sup> <https://www.actu-environnement.com/media/pdf/news-32324-rapport.pdf>

<sup>5</sup> <https://www.c40.org/>

The paper will provide an evaluation of the EU policy towards FCEB. How much cost decrease would be necessary to obtain an economically meaningful abatement cost for FCEB so as to justify the deployment of this technology. Will the JIVE programs achieve the goal of providing visibility to the OEM's to engage in a substantial cost reduction process? Will it provide the appropriate incentive for the cities to coordinate the local players: municipalities, operators of public transport, energy providers, to get access to appropriate financial support? What is the overall assessment of the EU scheme?

Our analysis of the FCEB potential deployment in Europe and the associated EU policy relies on grey literature. It also builds on interviews with policy makers at various levels of authority (city council, regional, national and EU entities) and representatives from the hydrogen industry. Element Energy, a UK consulting firm in charge of monitoring the EU programs, provided detailed evaluation of these programs.

We also rely on the specialized academic literature on FCEB. Hua et al. (2014), summarizes the deployment and performance of FCEB in North America and Europe up to 2014. Stempien and Chan (2017) discusses the benefit of FCEB in Singapore through a detailed comparison of all pollutants for hydrogen, electric and diesel buses. Liu et al. (2018) cites the expected deployment of FCEB in Foshan and Yunfu (China) which expects to put 1000 buses and 20 HRS in operations in 2020 through the Synergy program.

The paper is organized as follows. Section 1 recalls the trend in urban transport towards zero emission in European cities and the role of FCEB. The cost analysis is continued in section 3. Section 4 provides an evaluation of the JIVE programs. Some comments conclude in section 5.

## 2. The FCEB market in Europe

### 2.1. The global demand, the role of cities and the trend towards zero emission buses (ZEB)

According to the *Europe Urban Bus Market Outlook Report 2017-2030*, the 2017 market size of the urban bus segment in terms of volume is estimated at 100,000 buses operating in 75 key cities in Europe. Of these, approximately 2% are hybrid/electric buses. In terms of value, the market value of buses in Europe ranges from \$ 28 billion to \$ 37 billion.<sup>6</sup> London, Paris, Madrid, Athens and Rome are the top five cities in terms of fleet size. These cities also have high population density and population levels.

The pressure to decarbonize urban buses comes from several sources. Urban buses are a component of heavy-duty vehicles which are the focus of recent EU regulation. From 2025 on, manufacturers will have to meet the targets set for the fleet-wide average CO<sub>2</sub> emissions of their new lorries registered in a given calendar year. The targets are expressed as a percentage reduction of emissions compared to the EU average in the reference period (1 July 2019-30 June 2020): 15% reduction from 2025 onwards, 30% reduction from 2030 onwards.<sup>7</sup>

---

<sup>6</sup> <https://www.researchandmarkets.com/reports/4432376/europe-urban-bus-market-outlook-report-2017-2030>

<sup>7</sup> [https://ec.europa.eu/clima/policies/transport/vehicles/heavy\\_en](https://ec.europa.eu/clima/policies/transport/vehicles/heavy_en)

At the local level cities are adopting future targets to decarbonize public transportation. Table 1 gives the fleet size and the commitments made for the top five European cities in 2018.

City	Fleet size	Commitments
London	9 142	From 2020 all single decks in central London are zero-emissions and from 2025 ZE purchase policy extended to double deck buses.
Paris	6 700	From 2025 all diesel vehicles will be removed
Madrid	2 600	From 2025 all diesel vehicles will be removed
Athens	2 526	From 2025 all diesel vehicles will be removed
Rome	2 522	N/A

Table 1: Fleet size and commitments made of major European cities

### The case of London

Former London Mayor, Boris Johnson, had set a target to reduce the city's carbon dioxide emissions by 60% of their 1990 level by 2025. His successor, Sadiq Khan, in his Mayor's Transport Strategy 2018, delivered his vision to improve air quality, which envisages among others that London's entire transport system will be zero emission by 2050. This includes delivering central London and town centre zero emission zones from 2025, creating a zero-emission zone in inner London by 2040 and a London-wide zone by 2050. Transport for London (TfL), the city's transit agency, is working towards the objective of the introduction of the Ultra-Low Emission Zone and the Toxicity Charge (T-Charge), using new alternatives to diesel buses, etc.

On the London City Hall's website<sup>8</sup>, it was announced that "from next year, all new double-deck buses will be hybrid, electric or hydrogen to focus on only buying the greenest, cleanest buses." By 2037 at the latest, the Londoner zero-emission bus market will represent 9,200 buses across London.

Through the Healthy Streets Approach, the Mayor has provided support to his strategy to re-shape the bus network and meets the 2037 goal. This strategy includes 12 Low Emission Bus Zones and one Ultra Low Emission Zone (ULEZ). The introduction of Low Emission Bus Zones means deploying the greenest buses on the capital's most polluted routes to cut harmful nitrogen emissions. To further support the ULEZ, TfL will ensure all double-decker buses operating in the ULEZ will be hybrid and all single-decker buses will be fully electric or hydrogen.

The new greener buses, which will be a combination of hybrid and clean buses that meet Euro VI standards, are part of an improvement programme to 3,000 buses outside central London. Moreover, TfL will introduce more than 250 zero emission single-deck buses into central London by 2020.

In 2019 the fleet of buses and the commitments can be summarized as follows:

- Hybrid: over 3,000 diesel-electric hybrid buses, making up 30% of TfL's bus fleet.
- Over 150, 100% electric buses are part of the growing fleet of greener buses and from 2020 all new single deck buses entering the fleet will be zero emission at tailpipe. They will be a mix of hydrogen buses and electric buses.

<sup>8</sup> <https://www.london.gov.uk/what-we-do/transport/green-transport>

- In the future London wants to be a world leader in hydrogen and fuel cell activity. Currently, 10 hydrogen buses are operating in London, the city ordered 20 double decker fuel cell buses from Wrightbus in May 2019 – they will be delivered in 2020. This produced one of the lowest prices since development began on the technology (£500,000 each bus).
- Inner and outer London by 2030: 90% of single decks electric or hydrogen and 60% of double decks hybrid; 40% electric or hydrogen.

## 2.2. The prospective demand for FCEB

The two technologies which will be deployed in response to the general trend towards zero-emission buses in cities are battery electric buses (BEB) and Fuel cell electric buses (FCEB). These two technologies differ in several characteristics. We shall come back to cost issues shortly. The other main issues are summarized as follows:

- From the start it should be clear that fuel cell vehicles have a handicap relative to battery vehicles in terms of energy efficiency: around 25-35% for fuel cell compared to 70-90% for battery.<sup>9</sup> FCEB must have other advantages to compete with BEB.
- With a bus range of 450 km compared to 200 km for BEB (under standard topographic and climate conditions, see next item), FCEBs are well suited for cities in which the average daily route of a bus may be longer than 200 km.
- Demonstrations have taken place on challenging topographies, with or without heating / cooling systems on. FCEBs have been deployed in many different places with extreme weather conditions and unlike BEBs, the performance of FCEBs is not affected by weather conditions. They operate from -30°C to +50°C ambient temperature<sup>10</sup>, without altering the autonomy, whereas such conditions can cause deep discharge cycles in BEBs.
- With fast refuelling and route flexibility, FCEBs do not affect bus operators' service or current operation processes, as no roadside infrastructure or change to operational processes is required. From a technology point of view, they are the easiest ZE transport to deploy, as they do not limit productivity and quality of service. On the contrary, opportunity-charging of BEB on-route is tied to the specific route where chargers are located. Frequent compulsory charging can also cause schedule or operational issues for BEB.
- As regards infrastructure there are a number of factors that enter into the comparison: a significant local H2 demand through different usages such as trains, taxis, forklifts... is essential to justify the deployment of a H2 supply infrastructure. For BEB a large local fleet may be a handicap since the parallel charging of many BEB's may require a high set-up investment cost to provide the adequate power.
- Refurbishing and recycling processes are easier for FCEBs. Rechargeable electric batteries (Li-ion, Ni-Zn, Ni-Cd) can also be recycled. Because of their electrical residual

<sup>9</sup> <https://insideevs.com/news/406676/battery-electric-hydrogen-fuel-cell-efficiency-comparison/>

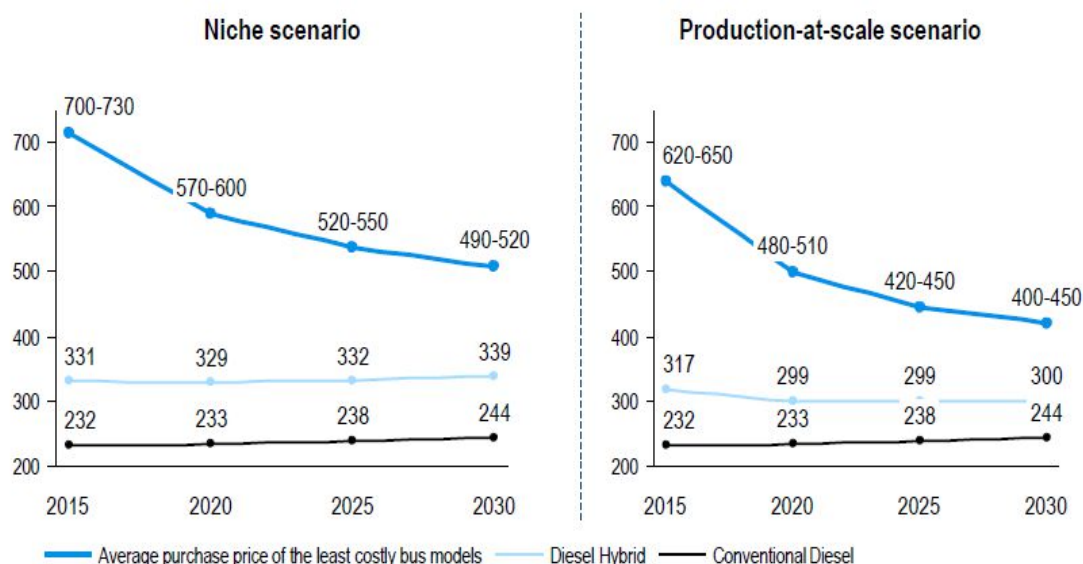
<sup>10</sup> Ballard, 2019.



power that can cause fire or explosion, recycling those batteries is not an easy, energy-friendly process. Fuel cell stacks are easier to recycle. One of the largest manufacturers, Ballard, certifies “the customer can return the fuel cell stack so that the membranes can be replaced while the existing hardware and plates are reused. “[..] More than 95% of the precious metals are reclaimed during this process. We refurbish and recycle 1000’s of fuel cell stacks every year.”<sup>9</sup> Ballard fuel cell stacks use no cobalt, lithium or rare earth materials.

- Another key element that can negatively influence the market share of FCEBs: the social acceptance of the hydrogen technology, which mostly depends on the public trust in hydrogen safety. Some passengers don’t feel reassured with hydrogen storage in tanks on the roof of the bus.<sup>11</sup>

Altogether the FCEB market is expected to remain much lower than the BEB market. Two scenarios (volume and price) for the deployment of FCEB in Europe over the period 2015-2030 have been elaborated (Roland Berger, 2015).<sup>12</sup> A niche scenario and a production-at-scale scenario by 2025. The niche scenario is characterized by a cumulative number of 1,200-1,800 FCEB deployed on Europe's roads in total while the production-at-scale scenario is characterized by a cumulative volume of 8,000-10,000. According to Roland Berger, “the latter represents about 7-9% of the expected total cumulative urban bus purchases in Europe in the period 2015-2025”. Figure 1 gives the corresponding projections for the purchase prices of FCEB over 2015-2030. It is expected to decrease to approximately €490k - €520k in the niche scenario and to €400k- €450k in the production-at-scale scenario.<sup>13</sup>



<sup>11</sup> This has been subject of a significant amount of research. It would appear not to be as big a problem as once was thought; indeed, some might suggest not a problem at all. People generally just expect that the authorities will only provide safe vehicles for them to travel in.

<sup>12</sup> Roland Berger GmbH, 2015.

<sup>13</sup> Recently G. Topham, a specialised journalist for *the Guardian*, reported an order by London (TfL) of 20 hydrogen-powered double-decker buses with a unit price around €550,000. This is consistent with the target price announced by Roland Berger for 2020 in the niche scenario

- Figure 1: Purchase price of standard FCEB according to different scenarios [€ x10<sup>3</sup>].

### 3. Cost analysis, CO2 and local pollutants emissions

Based on these scenarios and other more recent data we can estimate the total cost of ownership (TCO) of FCEB versus BEB and diesel bus in 2020. The TCO is a convenient way to analyse the costs incurred by a durable good, using a discount rate for aggregating capital and operating costs. The TCO components can be divided into five categories: fixed capital (purchase price), maintenance, fuel (running cost), personnel costs and disassembly cost (end-of-life cost).<sup>14</sup>

We use various sources to estimate the TCO of FCEB, BEB and diesel bus.<sup>15</sup> The results are summarized in Table 2 and reference the standard 12 m bus. The gap between the TCO of the clean technologies and the fossil one appears quite large.

<b>TCO 2020</b>	<b>FCEV</b>	<b>BEB</b>	<b>Diesel</b>
<b>1 Fixed capital (€/km)</b>	<b>1,71</b>	<b>1,23</b>	<b>0,55</b>
Purchase price (€)	650 000	470 000	210 000
<b>2 Maintenance (€/km)</b>	<b>0,40</b>	<b>0,80</b>	<b>0,30</b>
<b>3 Personnel costs (€/km)</b>	<b>2,63</b>	<b>2,63</b>	<b>2,63</b>
<b>4 Fuel (€/km)</b>	<b>0,80</b>	<b>0,31</b>	<b>0,48</b>
Unit price (€/kg H2, €/kWh, €/L)	10,00	0,24	1,60
Consumption per 100km ( kg H2, kWh, L)	8,00	1,30	30,00
<b>Total 1+2+3+4 (€/km)</b>	<b>5,53</b>	<b>4,97</b>	<b>3,96</b>

Table 2: Estimates of the TCO for FCEB, BEB and diesel bus

Here are some details for the calculations:

- Fixed costs per year (capital, maintenance, personnel) are converted per km assuming a yearly mileage of 40 000 km/year;
- The purchase price is annualized assuming a 12-year duration and a discount rate of 4.5 %;
- Maintenance depends for the most part on variables such as the technology as well as vehicle age, duty cycle, topography or fleet maintenance practices; the corresponding numbers are global estimates;
- Personnel costs are based on annual salaries over a 12-year duration and a discount rate of 4.5 %;
- Fuel costs are based on the unit price of the energy, the efficiency of the technology and the average yearly mileage for a bus (40 000 km/year).

<sup>14</sup> The disassembly cost will be assumed not to vary significantly between technologies and will be ignored. It actually might be cheaper for Electric Buses when compared with diesel buses.

<sup>15</sup> Roland Berger GmbH, 2015. Ballard, 2019. Eudy, L., Post, M. 2019.

The respective TCO can be used to derive the marginal abatement cost defined as the cost increase for reducing one-ton of CO<sub>2</sub> emissions when a cleaner, presumably more costly, technology is substituted for a dirtier one.<sup>16</sup>

To apply this calculation to the substitution of diesel bus by BEB or FCEB one needs to compare the TCO and the CO<sub>2</sub> emissions for each technology. The emissions for FCEB and BEB depend on a number of factors: the most important one is the technology to produce H<sub>2</sub> (steam reforming versus electrolysis) and the source of electricity (from the grid or from renewables). We assume that renewables generate no emissions and that the emissions from the grid come from the European mix.<sup>17</sup> For Diesel buses the emissions are directly related to its fuel consumption (under normal traffic conditions).<sup>18</sup> Note that we do not take a full life cycle analysis such as is done in the more recent publication of Carbon4.<sup>19</sup>

Table 3 gives the result with different technologies. The abatement costs suggest that neither FCEB nor BEB are worth implementing to reduce CO<sub>2</sub> emissions.

	FCEV			BEB		Diesel
TCO	5,53			4,97		3,96
Technology	Hydrogen Electrolysis	Hydrogen reforming	Hydrogen Electrolysis	Electricity European mix	Electricity Decarbonized	ICE
emissions gCO <sub>2</sub> /km	0	320	0	720	0	1 200
Abatement cost €/tCO <sub>2</sub>	1 312	1 789	675	2 113	845	

Table 3: Abatement costs for FCEB and BEB in 2020 versus diesel bus

Note however that TCO and abatement costs are time dependent. They depend on the technologies available and on the “experience” accumulated at that time. It is noteworthy that “learning-by-doing” is a major factor that explains the decline in unit cost over time of new products so that the concept of TCO needs be used with care.<sup>20</sup>

To illustrate this point let us carry on some simple calculations. Firstly, we revisit the TCO and abatement cost for FCEB assuming a purchase price of 450 k€ and a fuel cost of .56 €/km (corresponding to a H<sub>2</sub> price of 7 €/kg), both assumptions in line with the production at scale scenario from Roland Berger (2015). The results are displayed Table 4. Even with these optimistic assumptions it remains unjustified to deploy FCEB to reduce CO<sub>2</sub> emissions.

<sup>16</sup> This indicator has been extended to industrial items involving complex clean production processes such as offshore wind power or carbon, capture and sequestration. One may then order the different technologies by increasing abatement costs and infer the optimal launching date as the social cost of carbon increases (see for instance

[https://www.mckinsey.com/~media/mckinsey/dotcom/client\\_service/sustainability/cost%20curve%20pdfs/p athways\\_lowcarbon\\_economy\\_version2.ashx](https://www.mckinsey.com/~media/mckinsey/dotcom/client_service/sustainability/cost%20curve%20pdfs/p athways_lowcarbon_economy_version2.ashx)).

<sup>17</sup> Source for FCEB and BEB emissions: Nylund, N-O, Koponen K. 2012.

<sup>18</sup> Source for diesel bus emissions: Mahmoud et al. 2016.

<sup>19</sup> <https://www.carbone4.com/publication-transport-routier-motorisation-alternatives>

<sup>20</sup> See Creti et al. 2018 for a detailed analysis of this issue.

<b>TCO FCEB</b>	<b>2020</b>	<b>2025</b>
<b>1 Fixed capital (€/km)</b>	<b>1,71</b>	<b>1,18</b>
Purchase price (€)	650 000	450 000
<b>2 Maintenance (€/km)</b>	<b>0,40</b>	<b>0,40</b>
<b>3 Personnel costs (€/km)</b>	<b>2,63</b>	<b>2,63</b>
<b>4 Fuel (€/km)</b>	<b>0,80</b>	<b>0,56</b>
Unit price (€/kg H2, €/kWh, €/L)	10,00	7,00
Consumption per 100km ( kg H2, kWh, L)	8,00	8,00
<b>Total 1+2+3+4 (€/km)</b>	<b>5,53</b>	<b>4,77</b>
<b>Technology</b>	<b>Hydrogen Electrolysis</b>	<b>Hydrogen Electrolysis</b>
emissions gCO2/km	0	0
<b>Abatement cost €/tCO2</b>	<b>1 312</b>	<b>675</b>

Table 4: Target cost analysis for FCEB in 2025

Secondly, we introduce the social costs of local pollutants that is, NOx and PM 2.5 emissions. These costs are estimated through their impact on health. They could vary considerably depending on the area under consideration. We have considered dense urban and very dense urban areas (Quinet, 2013, page 45). This increases the fuel cost of a diesel bus from .48 €/km to .75 €/km for dense urban and to 1.84 €/km for very dense urban. Then we revisit the CO2 abatement cost. The results are displayed Table 5. The abatement cost comes within a reasonable range as the local social cost is taken into account (it even becomes negative in very dense urban areas!).

<b>Technology</b>	<b>Hydrogen Electrolysis</b>	<b>Hydrogen Electrolysis</b>
emissions gCO2/km	0	0
<b>Abatement cost €/tCO2</b>	<b>1 312</b>	<b>675</b>
With local social cost in dense urban	<b>1 087</b>	<b>450</b>
With local social cost in very dense urban	<b>74</b>	<b>-191</b>

Table 5: Abatement costs for FCEB in 2020 and 2025 with local pollutants

Thirdly, to get some feeling about the credibility of the 450 k€ target price we calculate the impact of a reasonable 10% learning rate under two different scenarios. Suppose that the yearly production in 2020 is 185 while the cumulated production is 860 and the unit cost 650 k€. Table 6 shows that approximately 450 k€ would be achieved in 2025 with the production at scale scenario (the figure is 455 363). But it also points out that this scenario relies on an annual growth rate of 50%, which is far off current deployments. The niche scenario, which is more in line with current deployments, assumes 6% as an annual growth rate. With this scenario and a learning rate at 10% the unit cost would be approximately 450 k€ only in 2041 (the figure is 453 297).

			scenario	
		Assumptions	prod at scale	niche
year	2020	2025	2041	
learning rate	10%			
annual growth rate		50%	6%	
yearly production	185	2 819	630	
cumulated production	860	8 463	8 720	
unit cost	650 000	455 363	453 297	

Table 6: Implied learning rate for the target cost analysis for FCEB in 2025

This analysis points out clearly that if a decrease in the cost of FCEBs is a prerequisite for its deployment to make economic sense, it remains challenging objective.

## 4. The coordination schemes among European cities for FCEB

Over the years, the European Union has introduced new pieces of legislation to tackle transport challenges and meet its climate and energy targets. In addition, the EU has been a driver of hydrogen deployment programs, funded by European entities such as the Fuel Cell and Hydrogen Joint Undertaking (FCH JU) or the EU Connecting Europe Facility (CEF). These programmes have been accompanied by a series of initiatives to bring together all stakeholders around the establishment of a low-carbon European bus system. This section will review these positive incentives the EU developed to deploy the hydrogen technology.

The programs will be classified according to a typology that relates which public policies are best suited to match the structural characteristics of each phase of deployment towards clean transportation. This ideal deployment would typically go through three successive phases: take-off, powering-up and cruising (Meunier and Ponssard, 2018). The take-off phase takes place in clusters through demonstration projects supported by local public-private partnerships and joint ventures between manufacturers and energy providers. Then the coordination among clusters is critical to move to the powering up phase to cash-in the benefit of learning-by-doing. Competition should be encouraged, and exclusive deals be eliminated while joint subsidies for infrastructure and vehicles remain necessary. Eventually subsidies are eliminated and market forces will allocate the available technologies to the relevant segments, this is what we call the cruising phase.

The FCEB deployment went through the take-off phase and we shall investigate whether it has now entered the powering-up phase.

### 4.1. The initial coordination schemes for demonstration projects

We have identified 6 major coordination schemes that have supported demonstration projects across European cities (CUTE, HyFLEET:CUTE, Clean Hydrogen for European Cities (CHIC), HIGHVLOCITY, HyTransit, 3Emotion). The first one emerged in 2001 and the latest one, which is still ongoing, in 2017. Table 7 gives the time span covered by each scheme, the cities that benefited, the total number of FCEBs involved, and the associated budget with the FCH JU part.

Coordination scheme	horizon	#FCEB	Cities	Funding Total/FCH-JU
CUTE	2001-2006	27	Reykjavik, London, Amsterdam, Porto, Madrid, Barcelona, Luxembourg, Stuttgart, Hamburg, Stockholm	
HyFLEET:CUTE	2006-2009	47	Amsterdam, Barcelona, London, Luxemburg, Madrid, Hamburg, Berlin	43.16 M€
CHIC	2010-2016	26	London, Aargau, Bolzano, Milan, Oslo, Hamburg, Köln,	81,8M€ / 25,8M€
HIGHVLOCITY	2012-2019	14	Antwerp, Aberdeen, San Remo, Groningen	30M€ / 13M€
HyTransit	2013-2019	6	Scotland (Aberdeen)	£19M / £8,3M
3Emotion	2017-2022	21	Rotterdam, Aalborg, London, Roma, Versailles, Pau	39,2M€ / 14,9M€
Total		114		217M€

Table 7: The initial coordination schemes for take-off

We can see that these demonstration schemes took place in more than a dozen cities scattered all over Europe. Typically, such a project involved only a limited number of FCEBs and its goal was to demonstrate the feasibility of the deployment, to identify the possible challenges and avenues to solve them. The coordination between the deployment of the buses and the availability of the H2 production and delivery was also at stake.

A detailed evaluation of these programs has been made.<sup>21</sup> The following conclusions emerged:

- Successful tests on range, energy efficiency, CO2 emissions, bus availability and HRS access;
- Need to reduce prices to achieve commercialization;
- Need to increase social acceptability among regional stakeholders through adequate safety regulation and production of green hydrogen.

Table 8 gives in more detail, the technical and economic objectives of each scheme and provides an evaluation of its main achievements and pending issues.

<sup>21</sup> Source: Dolman and Skiker, 2019.

Project	Objectives	Success/ Achievements	Lessons learnt
HyFLEET:CUTE	<p>Develop fuel cell buses to reduce the consumption of fuel and energy in the whole transportation system</p> <ul style="list-style-type: none"> <li>-Develop efficient and sustainable ways to produce hydrogen</li> <li>-Inform the community and key decision-makers about the potential advantages of a hydrogen-based transport system</li> </ul>	<ul style="list-style-type: none"> <li>-more than 2,5 million km travelled</li> <li>-no accidents</li> <li>-Bus availability &gt; 89%</li> <li>-Stations availability &gt;90%</li> <li>-Share of renewable energy used for on-site H2 generation</li> </ul>	<ul style="list-style-type: none"> <li>-Optimizing existing FC buses for energy efficiency</li> <li>-Development and build of next generation of FCEB</li> <li>-Optimizing existing H2 refuelling systems for efficiency and reliability</li> <li>-Create a global hydrogen bus platform for dissemination and exchange of information, forum for debate, education of decision makers</li> <li>-Study the socio and macroeconomic implication of H2 technology</li> <li>-The purchase price of the buses must be significantly reduced to achieve commercialisation</li> </ul>
CHIC	<p>Demonstrate:</p> <ul style="list-style-type: none"> <li>-Operating range &gt;350km</li> <li>-Short refuelling times (&lt;10min)</li> <li>-High fuel efficiency (9kg/100km) for 12m buses</li> <li>-CO2 emissions reduced by 85% compared to diesel buses along the bus life cycle (green hydrogen)</li> </ul>	<ul style="list-style-type: none"> <li>-Operating range equivalent to that of diesel buses (&gt;350km)</li> <li>-Refuelling time &lt;10mins</li> <li>-Satisfaction for end users</li> <li>-6,800 tonnes of CO2 equivalent saved compared to diesel buses</li> <li>-Survey results show that CHIC regional stakeholders, bus drivers and passengers support the technology and a move to zero emission public transport</li> </ul>	<ul style="list-style-type: none"> <li>-Improve bus availability through resolving technical 'teething' issues and increasing scale</li> <li>-Reduce bus and hydrogen prices through commercialisation</li> <li>-Harmonise regulations</li> <li>-Importance of green hydrogen – social science research suggested, that hydrogen should be fully sustainable to be fully accepted by society</li> </ul>
HIGH V.LO.City and HyTransit	<ul style="list-style-type: none"> <li>-Increase energy efficiency of buses;</li> <li>-Reduce the total cost of ownership;</li> <li>-Increase the life time of the fuel cells;</li> <li>-Reduce life cycle costs and more specifically the cost of hydrogen;</li> <li>-Define concrete economic early markets</li> </ul>	<ul style="list-style-type: none"> <li>-14 buses in full operation with &gt;85% availability</li> <li>-97% availability of stations</li> <li>-good customer acceptance</li> <li>-1.5million km driven</li> <li>-9-10 kg hydrogen per 100km</li> </ul>	<ul style="list-style-type: none"> <li>- Ensure high availability of supply chain</li> <li>- HRS can easily be scaled up when the fleet is growing and should be located at the bus depot, more efficient if used at full capacity</li> </ul>

3Emotion	-Reduce TCO, capex and fuel cost - (<10kg/100km) -Increase lifetime and warranties -Availability > 90%	On going	On going
----------	---	----------	----------

Table 8: The objectives and achievements of the take-off schemes

#### 4.1. The coordination schemes for the take-off phase: JIVE 1 and JIVE 2

Launched at the World Economic Forum 2017, in Davos, The Hydrogen Council involves 60 major companies. Its mission is to be: “a global initiative of leading energy, transport and industry companies with a united vision and long-term ambition for hydrogen to foster the energy transition”. The year 2017 may be considered as a kick-off date for the large-scale commercialization of clean hydrogen solutions across industries world-wide.

Simultaneously, also in 2017, the European Commission launched the Clean Bus Deployment Initiative. This initiative is based on the following 3 pillars:<sup>22</sup>

1. *A public declaration* endorsing a common ambition of cities and manufacturers to accelerate roll-out of clean buses: The signatories commit to jointly deploy 2,000 clean buses by the end of 2019 in the EU
2. *Creating a deployment platform* where public authorities, public transport operators, manufacturers and financial organisations can come together with the aim to:
  - better exchange information,
  - better organize relevant actors and create coalitions,
  - leverage potential investment action,
  - issue recommendations on specific policy topics.
3. *Creation of an expert group* bringing together actors from the demand and supply side. This expert group will benefit from consolidated expertise on technological, financial and organisational issues.

In this favourable context two new schemes dedicated to FCEB were launched, labelled as the Joint Initiative for Hydrogen Vehicles across Europe (JIVE and JIVE 2). Table 9 gives their main characteristics. It clearly appears that they have much larger targets than the demonstration programs.

<sup>22</sup> [https://ec.europa.eu/transport/themes/urban/cleanbus\\_en](https://ec.europa.eu/transport/themes/urban/cleanbus_en)



Coordination scheme	horizon	#FCEB	Cities and regions	Funding Total/FCH-JU
JIVE 1	2017-2022	139	London, Birmingham, Aberdeen, Bolzano, Herning, Region Köln, Wuppertal, Region Rhein-Main	106 M€ / 32 M€
JIVE 2	2018-2023	152	Benelux, France, Germany North Italy, Northern and Eastern Europe, UK	225M€ / 25M€

Table 9: The JIVE coordination scheme for powering-up

The JIVE schemes are organized along administrative regional “clusters”. Each cluster coordinates the cities within its region. The management is carried out by associated existing organizations as follows: Benelux: Rebel (twynstra Gudde); UK: Element Energy; France: Afhypac & Mobilité hydrogène France; Germany/ Italy: Energy Engineers & hySolutions; Northern/ Eastern Europe: Latvian Academy of Sciences.

In each cluster, the JIVE coordinator entity will support the participating cities in the initial transition phase and give advice for a long-term FCEB deployment. More specifically, these missions involve:

- Increase the number of affiliated cities within the cluster;
- Support each affiliated city in its development plans for FCEB;
- Facilitate the analysis of their financing needs and the access to subsidies for the first wave of deployments;
- Provide advice and support for the corresponding procurement processes;
- Develop strategies for financing the future deployments beyond the current subsidised phase.

As of 2019 the five regions which cover all Europe (see Figure 2) operate under the overall coordination of Element Energy, an energy consultancy based in the UK, which directly reports to the FCH JU. Element Energy relies on partners (Thinkstep and PLANET) to carry out the performance assessment.

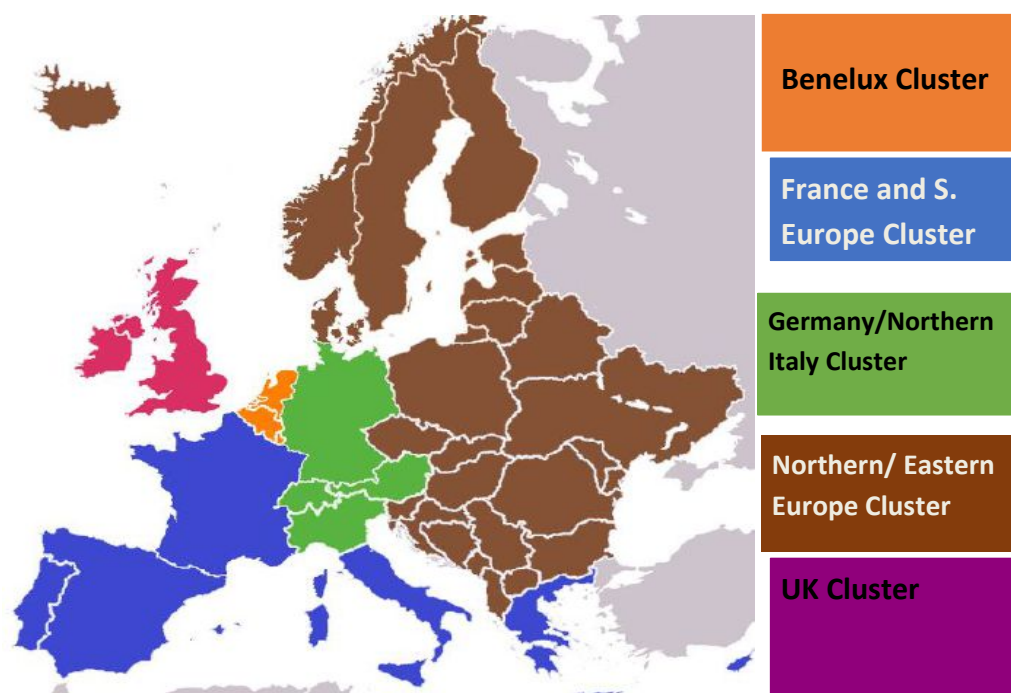


Figure 2: Cluster coordination and location as wished in the future

Moreover, JIVE 2 encourages new entrants in the FCEB market (industry suppliers and HRS) to stimulate technological innovation and large-scale uptake.

We now turn to the evaluation of JIVE.

## 5. Analysis of the JIVE<sup>23</sup> coordination schemes

The two questions of interest are the following:

- Is the JIVE/2<sup>24</sup> scheme an efficient self-selecting process to elicit the cities that are likely to pursue a sustainable FCEB deployment in the future and eliminate the cities only looking for a short-term financial wind fall profit;
  - in the former case one would expect that the JIVE/2 cities are indeed required to present and detail their plans for the future, in line with the project's work programme, in/after 2020;
  - furthermore, one would expect that these cities would have made earlier commitments to FCEB such as getting involved in demonstration programs and incurring some sunk costs for the provision of green hydrogen;

<sup>23</sup> The JIVE and JIVE2 projects have received funding from the Fuel Cells and Hydrogen Joint Undertaking under grant agreement No 735582 and 779563. This Joint Undertaking receives support from the European Union's Horizon 2020 research and innovation programme, Hydrogen Europe and Hydrogen Europe Research.

<sup>24</sup> For notational simplicity JIVE/2 refers to JIVE and JIVE 2.

- finally, that the JIVE/2 program does provide potential benefits which override its constraints, for instance benefits in relation to the design of the procurements and participation in the exchange of information along the process.
- Is the JIVE/2 process successful enough in terms of volumes to generate substantial learning-by-doing returns leading to reduced prices of FCEBs in the near future?
  - JIVE/2 provides monetary and non-monetary incentives, such as a flat 200 k€ subsidy for the acquisition of a FCEB and assistance to cities with their development plan for FCEB acquisition, their financing, the tender process... Are these incentives strong enough to generate the desired volumes; could these incentives have been designed differently?

Our answer to these questions is based on different sources: Quantitative analysis of questionnaires regularly handed out as part of the JIVE/2 process;<sup>25</sup> Interviews of representatives from AFHYPAC, Element Energy, EU Commission; Interviews of professionals: city officers, managers in companies operating along the value chain (OEMs, Energy providers...), specialized lawyers.

## 5.1. JIVE/2 as an efficient self-selecting process

### Quantitative analysis of questionnaires

The answers have been classified under two categories:

- The reasons for being involved in clean transportation in general, in FCEB in particular, and in JIVE/2;
- The main benefits at this stage.

A total of 13 cities provided answers to the first item. The results detailed in Table 9 confirm that the cities involved in JIVE/2 have a long-term commitment towards clean transportation and FCEB, but joint commitments of their local and national Governments to this technology are a prerequisite. The absolutely vital importance of Government Policy Frameworks that incentivize or mandate Zero Emission public transport is a constant refrain when it comes to cities' willingness to find the funds to subsidize the new technology to encourage transport operators.<sup>26</sup> The cities engage in demonstration projects to gain experience in operating BEBs and/or FCEBs. In particular, they need confirmation of the credibility of both FCEB and HRS. Note that the current price of FCEB is a major concern.

---

<sup>25</sup> The JIVE/2 information cited in this paper was gathered by PLANET GbR Engineering and Consulting, thinkstep AG and Fondazione Bruno Kessler on behalf of the JIVE and JIVE 2 Projects. We are indebted to them for their assistance.

<sup>26</sup> The EU Clean Vehicles Directive as revised in spring of 2019 will also be a powerful driver. See [https://ec.europa.eu/transport/themes/urban/vehicles/directive\\_en](https://ec.europa.eu/transport/themes/urban/vehicles/directive_en) It requires that a certain share of vehicles bought by the public sector MUST be emission free and that, from 2026, this explicitly means battery or fuel cell electric only (0 g CO<sub>2</sub> at the tailpipe).

For the second item we have 16 answers [out of 18 cities involved in the JIVE/2 projects. To date, the benefits from JIVE/2 are accruing through ‘best practice’ information gathered along three stages: Financing, Planning the HRS, Planning the Bus Operations. These results are detailed in Table 10. Access to better information about funding resources at all levels (EU, national including regional/local) is a major benefit for the cities. JIVE/2 also provides enhanced opportunities for exchanges with industry (HRS and bus operators) or with the experienced JIVE/2 project coordinator. Note also there are substantial benefits from exchanges (formal and informal) with other cities involved in JIVE/2 and the dissemination of information from earlier EU programs.

It should be noted however, that interviews suggest that the involvement of cities in JIVE/2 has not been a smooth road for all. Problems relating to sufficient/timely financing and poor industry response to tenders have led to significant delays. Long delays in demonstration projects cannot always be accommodated, while in cities without these constraints, an innovation such as this might be given the time it needs – but without the subsidies of the project environment.

JIVE/2 also opens the opportunity for coordination between regions with experience of FCEB fleets deployments (e.g. Köln) as well as between regions seeking to build their knowledge and experience by demonstrating FCEB buses in small fleets (e.g. Auxerre, Gävleborg) as long as they commit to extend their fleets, if the initial demonstrations are successful.

Altogether there is a significant number of cities (7 out 18) engaged in JIVE/2 which had gained previous experience in FCEB through earlier EU programs (a striking example being London, see Table 6) while some others are using JIVE/2 to get into a demonstration stage building on the experience of early adopters.

What are the major reasons for the city involvement in clean transportation					
City looking for alternative to current public transport fuel options		77%			
City wants cleaner air		62%			
City committed to combatting climate change		46%			
Part of the City's general environmental programme		46%			
Funds became available from sources outside city		46%			
Why selecting FCB		Is your involvement in FCB part of a national/local plan ?		What do you expect from JIVE	
Will your transportation plan involve both BEB and FCB	100%	Does your national government support a wider deployment of fuel-cell buses?	88%	The refuelling technology will prove to be highly reliable and relatively maintenance free	62%
main drawback of FCB is higher price	77%	Does your local government support a wider deployment of fuel-cell buses?	69%	The bus technology will prove to be highly reliable and relatively maintenance free	54%
main advantage of FCB is range	54%			The city will have a clear idea of future public transport bus	54%
				The city will commit to a future hydrogen fuel cell bus technology in the short term	38%

Table 9: Cities 'expectations from clean transportation, FCEB and the JIVE programs

What information did you find helpful?					
<b>Financing</b>		<b>Planning the HRS</b>		<b>Planning the Bus Operations</b>	
Knowledge of European sources of money	94%	Talking to HRS suppliers	94%	Talking to city sites with operating FC Buses	50%
Knowledge of National (including local/regional)	88%	Talking to city sites with operating HRS	75%	Talking to FC bus suppliers	50%
Previous experience in preparing funding proposals	75%	Talking to JIVE/JIVE 2 project coordinator	69%	Talking to JIVE/JIVE 2 project coordinator	44%
A local politician who was committed to the idea	69%	Written resources: NewBusFuel Reports	69%	Written resources: Reports from CHIC	44%
Working with another site to jointly seek finance	13%	Written resources: Reports from other ongoing or completed projects	50%		
		Written resources: Reports from CHIC	31%		

Table 10: Current stage of implementation and main benefits from JIVE

Additional information from cities not affiliated with JIVE/2 either from interviews conducted or from Dolman and Madden (2018) includes:

- EU funding only covers a part of the costs, without national, regional or private investments, it is impossible to commit to sufficient volumes. In the French cluster for example, some cities (Nantes, Rouen, Le Havre, Belfort) are waiting for a net FCEB price below 450 k€ and an effective strategy in place for vehicle maintenance. They will consider purchasing fuel cell buses after 2020.
- Paris is not a member of JIVE/2. RATP, which operates the urban buses, announced an ambitious plan of 4,500 bus renewal before 2025 with 80% electric and 20% CNG. In their ZE original plan FCEBs were not considered due to high costs. RATP considers that if an experiment with fuel cell buses occurs, the feasibility of a whole depot based on hydrogen (200 buses) must also be determined. Nevertheless, the bus routes in Paris have a mileage below 180 km, which is below the mileage suited to FCEBs (300 km). BEBs perform better on mileages below 200 km. So efforts are focused on deployment of this technology.

It can be observed that there is some geographic bias in the cities that benefited from JIVE/2. They are more likely to be part of the Northern clusters (UK, Benelux, Germany...) than the Southern ones (notably France). This problem arises mostly from the selection process for the participating cities. Element Energy organised a call to candidacy, to which the cities can respond within two/three months. This time period is particularly short, and disadvantages cities that are not related to important national OEMs committed to hydrogen (Figure 3 gives the distribution of OEMs among clusters). Van Hool, arguably the leading manufacturer of FCEBs as they get almost 90% of the European FCEBs orders, lobbies a lot of Belgian and Dutch cities, so that their candidacy documents are likely to be better prepared than those of the French cities, which are underrepresented in the project. However, this under representation can also be explained by a different level of maturity of

the market between the countries. German, British, Dutch and Belgian cities had previous experiences with FCEBs, whereas France has only more recently shown interest.<sup>27</sup>



Figure 3: Distribution of European OEMs among JIVE/2 clusters

## 5.2. JIVE/2 as a scheme to trigger a high demand for FCEB

The level of the demand aggregated by JIVE/2 is detailed in Table 11.

<sup>27</sup> Note that European recovery plans announced in 2020, in particular in Germany and France, have allocated significant resources for the deployment of hydrogen in heavy duty vehicles. The precise impact of these plans on FCEB would be worth studying. The so called plan Hulot to deploy hydrogen for the energy transition announced on June 1 2018 provided a much more limited push for this technology <https://www.ecologie-solidaire.gouv.fr/plan-hydrogene-outil-davenir-transition-energetique>

Cluster	#FCEB in JIVE	#FCEB planned after 2020
Benelux	50	136
France	15	49
Germany/Italy	88	177
N/E. Europe	50	147
UK	88	136
Total	291	645

Table 11: The level of demand directly induced by JIVE/2

Aggregation of the overall demand suggests about 1 000 FCEB to be deployed in the coming years as compared to only 114 FCEB for the demonstration programs. This number is substantial but remains closer to the niche scenario than to the production at scale scenario envisioned by the Roland Berger study (cf. section 2.2). This is confirmed by the observation that the price for standard 12 m single deck buses is expected to be around €650k / €625k in 2020. Still some suppliers have indicated far lower prices (e.g. well below €450k) for customers willing to commit to enough volumes (sustained orders of at least 100 buses per year per OEM).

Figure 4 depicts the relationship between the price evolution and the phasing of the different coordination projects implemented in Europe.<sup>28</sup>

<sup>28</sup> *Fuel cell bus joint procurement clusters*, Element Energy Ltd, Nov 2017 in FCH JU Stakeholder Forum

\* <http://hydrogenvalley.dk/white-paper/>

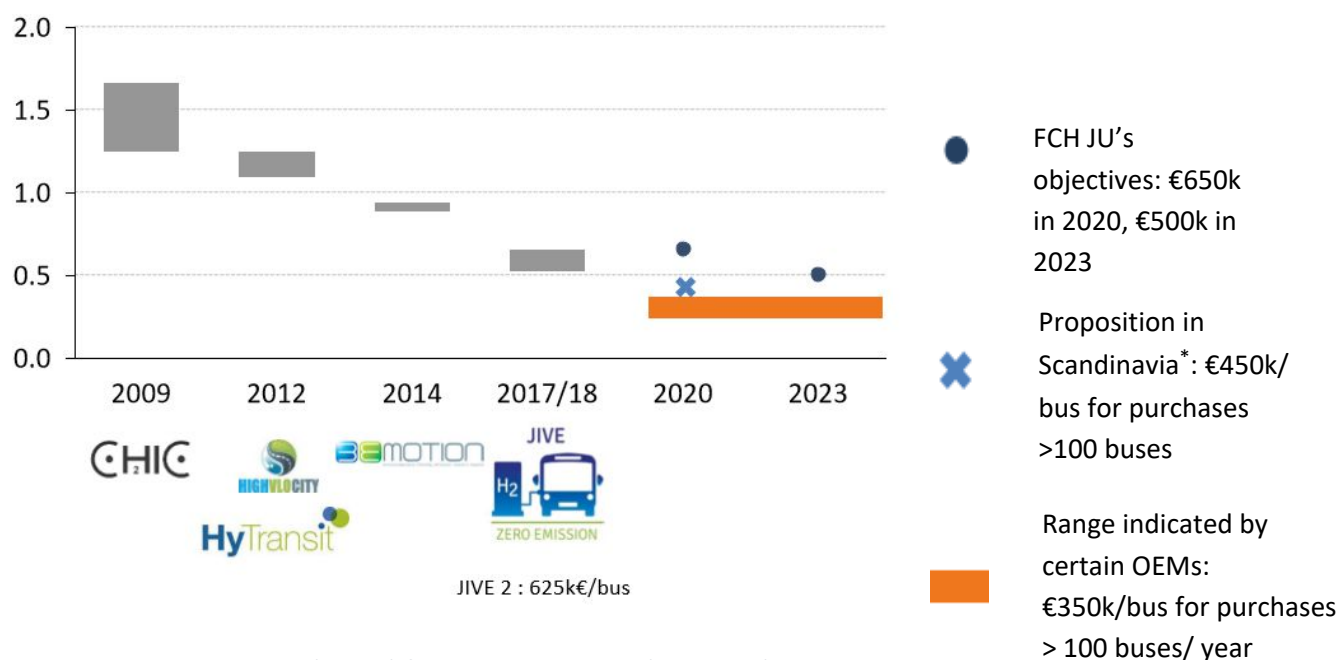


Figure 4: Capex evolution (in €M) for a standard FCEB (12 metre) in Europe without subsidy

Altogether it seems that the JIVE/2 program remains short relative to the objective of triggering a high enough demand, but this conclusion may be wrong. We may just be at the beginning of the powering-up phase and future programs may consolidate FCEB deployment. On the 3<sup>rd</sup> June 2019, the latest deployment program H2Bus Consortium was announced by Everfuel, Wrightbus, Ballard Power Systems, Hexagon Composites, Nel Hydrogen and Ryse Hydrogen. Through this consortium, they are committed to deploying 1,000 FCEBs, along with supporting infrastructure in European cities. In the press release, we can read “the first phase of the project, totalling 600 buses, is supported by €40 million from European funding. This will enable the deployment of 200 hydrogen fuel cell electric buses and supporting infrastructure in each of Denmark, Latvia and the UK by 2023”.<sup>29</sup> New EU programs are under way and will take the baton from JIVE/2.<sup>30</sup>

## 6. Concluding comments

The example of hydrogen-powered buses is highly instructive. It clearly shows the interest of policy coherence between the local level to control network effects and a macro level that is large enough to generate the volumes that alone can reduce costs thanks to the experience effect. This example can be used as a reference to evaluate current hydrogen deployment strategies in other cases.

Our analytical framework suggests the systematic combination of two levels. On the one hand, a local level at which network effects are analyzed to potentially reduce the costs of coordination between infrastructure and hydrogen use, integrating transport (e.g. commercial vehicles, taxis, ambulances, trucks, dump trucks, trains...) and other hydrogen uses into gas networks for heat production and industrial uses (e.g. steel plants, cement plants, chemical complexes...). On the other hand, a macro level at which experience effects are analyzed, both in terms of the industrial costs on the components of added value but also the costs generated by the initiation of local projects (legal set-up, application process for obtaining public aid, etc.).

<sup>29</sup> <https://www.greencarcongress.com/2019/06/20190604-h2bus.html>

<sup>30</sup> See for instance <https://www.fch.europa.eu/news/fch-ju-launches-new-call-project-proposals>



The deployment of the hydrogen sector will also depend on the national public policies as a response to the climate challenge, and in particular on the specific measures adopted in the recent recovery plans (see for instance Meunier and Ponssard, 2020 for discussion of the French hydrogen plan). There is the desire and hope to make European manufacturers “world champions” in this field. Some European industrialists are indeed well placed at the international level, but competition will be tough against companies such as Ballard, Hyundai, Toyota, BYD to name but a few. And Europe is not alone in developing an industrial policy. There is Japan, China, Korea...

A formal normative analysis of a support program like JIVE still need to be done to improve similar programs. Subsidies to low carbon technologies are usually justified by learning externalities. The case of hydrogen buses shows that i) learning takes place not only within manufacturing plants but also among users, and ii) the commitment of cities helps reduce the future costs. Future research would need to formalize these processes to better design policies and their coordination among multiple jurisdictions (cities, countries, EU).

## References

Anderson, S., Fischer, C. and Egorenkov, A., (2016), Overlapping strategies for reducing carbon emissions from the personal transportation sector, *Energy and Climate Conference* 14-15 October CESifo, Munich.

Ballard, (2017), *Economic Case for Hydrogen Buses in Europe*.

<https://cdn2.hubspot.net/hubfs/2007428/Premium%20Content/Economic%20Case%20Hydrogen%20Buses%20Europe/PT-Ballard-Fuel-Cell-Buses-in-Europe-Summary.pdf>

Ballard, (2019), *Fuel Cell Electric Buses – Proven Performance and the Way Forward*.

<https://info.ballard.com/fuel-cell-electric-buses-proven-performance-white-paper>

Barrett, S., (2018), Climate treaties and the imperative of enforcement, *Oxford Review of Economic Policy*, 24-2, 239–258.

Barrett, S., (2014), *Why have climate negotiations proved so disappointing?*

[www.pas.va/content/dam/accademia/pdf/es41/es41-barrett.pdf](http://www.pas.va/content/dam/accademia/pdf/es41/es41-barrett.pdf)

Creti, A., Kotelnikova, A., Meunier, G and Ponssard, J-P., (2018), Defining the Abatement Cost in Presence of Learning-by-doing: Application to the Fuel Cell Electric Vehicle. *Environ Resource Econ*, 71(3), 777-800 (2018). <https://doi.org/10.1007/s10640-017-0183-y>

Dolman, M., Skiker, S., (2017), *Fuel cell buses: a flexible and zero emission public transport – Fuel cell buses in Europe* <https://www.fch.europa.eu/sites/default/files/selection.pdf>

Dolman, M., Skiker, S., (2019), *Presentation of the JIVE Project – Joint Initiative for hydrogen vehicles across Europe*,

[https://www.fch.europa.eu/sites/default/files/documents/ga2011/4\\_Session%201\\_JIVE\\_Michael%20Dolman%20%28ID%204811591%29.pdf](https://www.fch.europa.eu/sites/default/files/documents/ga2011/4_Session%201_JIVE_Michael%20Dolman%20%28ID%204811591%29.pdf)

Dolman, M. Madden, B., (2018), *Strategies for joint procurement of fuel cell buses – a study for the FCH-JU*,

[https://www.fch.europa.eu/sites/default/files/Strategies\\_%20for\\_joint\\_procurement\\_of\\_FCEBuses\\_final\\_report.pdf](https://www.fch.europa.eu/sites/default/files/Strategies_%20for_joint_procurement_of_FCEBuses_final_report.pdf)

Elshurafa A. M., Albardi S. R., Bigerna, S., Bollino, C., A., (2018), Estimating the learning curve of solar PV balance-of-system for over 20 countries: Implications and policy recommendations, *Journal of Cleaner Production*, Volume 196, 122-134.

Eudy, L., Post, M., (2019), *Fuel Cell Buses in U.S Transit Fleets: current status 2018*, National Renewable Energy Laboratory. <https://www.nrel.gov/docs/fy19osti/72208.pdf>

Frost and Sullivan, (2013), *Strategic Analysis of Global Hybrid and Electric Heavy-Duty Transit Bus Market* (NC7C-01). Frost & Sullivan Publication. <https://fr.slideshare.net/FrostandSullivan/strategic-analysis-of-global-hybrid-and-electric-heavy-duty-transit-bus-market>

Hua T, Ahluwalia R, Eudy L, Singer G, Jermer B, Asselin-Miller N, Wessel S, Patterson T, Marcinkoski J, (2014), Status of hydrogen fuel cell electric buses worldwide, *Journal of Power Sources*, 269, 975-993.

Littlejohn, C., and Probst, S., (2019), What Role for Electric Vehicles in the Decarbonization of the Car Transport Sector in Europe?, CESifo Working Paper Series 7789, CESifo Group Munich.

Liu, Z., Kendall, K., Yan X., (2018), China Progress on Renewable Energy Vehicles: Fuel Cells, Hydrogen and Battery Hybrid Vehicles, *Energies*, 12, 54, 1-10.

Mahmoud, M., Garnett, R., Ferguson, M., Kanaroglou, P., (2016), Electric buses: A review of alternative powertrains. *Renewable & Sustainable Energy Review* 62, 673-684, DOI: 10.1016/j.rser.2016.05.01

Meunier, G., Ponssard, JP., (2018), What policy should be adopted to encourage deployment of hydrogen vehicles in France? <http://www.chair-energy-prosperity.org/en/publications-2/politique-encourager-deploiement-vehicules-a-hydrogene-france/>

Meunier, G., Ponssard, JP., (2020), Optimal Policy and Network Effects for the Deployment of Zero Emission Vehicles, *European Economic Review*, Vol 126, <https://www.sciencedirect.com/science/article/abs/pii/S0014292120300817>

Meunier, G., Ponssard, JP., (2020), Hydrogen-France has still many challenges to face. Invited paper I4CE <https://www.i4ce.org/hydrogen-france-climate/>

Morgenstern, R. D., (1991), Towards a Comprehensive Approach to Global Climate Change Mitigation *The American Economic Review* Vol. 81, No. 2, 140-145.

Nylund N-O, Koponen K., (2012), *Fuel and Technology Alternatives for Buses – Overall Energy Efficiency and Emission Performance*. <https://www.vtt.fi/inf/pdf/technology/2012/T46.pdf>

Quinet E., (2013), *L'évaluation socioéconomique des investissements publics*, Tome 1, page 45.

Reuter, B., Faltenbacher, M., Schuller, O., Whitehouse, N., Whitehouse, S., (2017), *New Bus ReFuelling for European Hydrogen Bus Depots* [http://newbusfuel.eu/wp-content/uploads/2017/03/NewBusFuel\\_D4.2\\_High-level-techno-economic-summary-report\\_final.pdf](http://newbusfuel.eu/wp-content/uploads/2017/03/NewBusFuel_D4.2_High-level-techno-economic-summary-report_final.pdf)

Roland Berger GmbH, (2015), *Fuel Cell Electric Buses – Potential for Sustainable Public Transport in Europe*, A Study for the Fuel Cells and Hydrogen Joint Undertaking,  
[https://www.fch.europa.eu/sites/default/files/150909\\_FINAL\\_Bus\\_Study\\_Report\\_OUT\\_0.PDF](https://www.fch.europa.eu/sites/default/files/150909_FINAL_Bus_Study_Report_OUT_0.PDF)

Stempien J.P., Chan S.H , (2017), Comparative study of fuel cell, battery and hybrid buses for renewable energy constrained areas, *Journal of Power Sources*, 340, 347-335.

Transport & Environment, (2018), *Electric buses arrive on time*  
<https://www.transportenvironment.org/publications/electric-buses-arrive-time>

Zhou, Y. and Li, S., (2018), Technology adoption and critical mass: The case of the us electric vehicle market, *The Journal of Industrial Economics* 66(2): 423-480.

## Acronyms

BEB = Battery Electric Bus

CEF EU = Connecting Europe Facility

FCEB = Fuel Cell Electric Bus

FCEV = Fuel Cell Electric Vehicle

FCH JU = Fuel Cell and Hydrogen Joint Undertaking

HRS = Hydrogen Refuelling Station

JIVE = Joint Initiative for hydrogen Vehicle across Europe

OEM = Original Equipment Manufacturer

PEM =Proton Exchange Membrane

SMR= Steam Methane Reforming

TCO = Total Cost of Ownership

ZEV = Zero Emission Vehicle

ZE = Zero Emission