

A hydrogen refuelling stations infrastructure deployment for cities supported on fuel cell taxi roll-out

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ABSTRACT

A shift towards lower-carbon fuels is mandatory to achieve the decarbonisation of the transport sector, which is responsible of 14% of world greenhouse gas emissions. Despite to the fact that fuel cell electric vehicles are zero tail-pipe emissions vehicles, their use is presently residual. A massive integration of fuel cell vehicles faces a “chicken-egg dilemma”: vehicles need a proper refuelling infrastructure to provide a safe and continuous hydrogen supply, but a viable deployment of the refuelling infrastructure needs the support of an initial market of vehicles.

In this article, we design a feasible strategy for overcoming the dilemma, using the local taxi fleet as a stable market of hydrogen consumers to start up a retail hydrogen supply infrastructure in high-populated cities. The design is based on three objectives: ensuring hydrogen supply, having throughout the city a nearby alternative for refuelling and maximizing the infrastructure utilisation rate.

The strategy applied to the city of Madrid show that \$415 million of public funds allocated along 25 years would provide in six years a network of 112 hydrogen refuelling stations, able to supply the hydrogen needs of 15,000 new fuel cell electric taxis what would cut the emissions of 300 kt CO₂ yearly.

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1. Introduction

In 2010, transport-related GHG emissions reached 7 GtCO₂eq, what represents 14% of total. Among them, 72% corresponded to road transport [1]. Without the implementation of mitigation measures, global emissions from transport would reach 12 GtCO₂eq by 2050, but in the scenarios aimed to achieve the 2 °C limit, emissions should be around 6 GtCO₂eq, what in fact means lower levels than in 2010 [1].

Most developed countries are the major GHG producers [2]. In 2014, in the US, the transport was responsible of 26% of the total emissions [3]. In the same year the transport sector produced in the EU-28 countries 25.5% of emissions, of which 73% came from road transport and among them 44% were emitted by passenger cars [4].

The practical implementation of mitigation measures is not showing the expected performance. According to the International Energy Agency (IEA) in 2016 several countries were on track, and

some of them even exceed, many of the targets set in their particular Paris Agreement pledges [5]; but it would not be nearly enough to limit warming to less than 2 °C [6].

Three main fundamentals lead the GHG emissions mitigations measures focused on transport: increasing the efficiency of the vehicles, changing the transport habits and shifting to lower-carbon fuels [7].

In the ambit of fuel shifting, high-emission fuels can be replaced for electricity and hydrogen, both used in EVs, and for biofuels used in ICEs. Fig. 1 illustrates the main characteristics of EVs and ICEs.

The use of biofuels reached 3% in 2015 and it is foreseen a marginal increase up to 4% by 2021 [8]. Similar advances have been seen in PHEV and BEV integration. In 2015, there were 1.26 million EVs running, meaning 1% of penetration and reaching high shares of 23% in Norway and 10% in the Netherlands [9]. Multiple research is ongoing to boost the penetration levels, favouring the integration [10] and improving the recharging conditions [11].

The integration of hydrogen presents the lower advance. Hydrogen can be used in vehicles equipped with hydrogen internal combustion engines (HICE) or in EVs equipped with hydrogen fuel cells (FCEV). In comparison with the other types of EVs, FCEVs offer a lower GHG emission level than PHEVs and lower recharging time

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Nomenclature		Financial	
<i>General</i>		<i>IRR</i>	Internal Rate of Return
<i>BEV</i>	Battery electric vehicle	<i>K</i>	Discount rate for NPV calculation
<i>EV</i>	Electric vehicle	<i>TDEP</i>	Asset depreciation period
<i>FCEV</i>	Fuel cell electric vehicle	<i>RPI</i>	Retail price index (%)
<i>FCET</i>	Fuel cell electric taxi	CF_z	Cash flow for year z
<i>HICE</i>	Hydrogen internal combustion engine	CFA_z	Cumulative cash flow for year z
<i>HRS</i>	Hydrogen refuelling station	<i>NPV</i>	Net present value
<i>IEA</i>	International Energy Agency	z	Ordinal indicating the number of years the asset has been operating
<i>PHEV</i>	Plug-in Hybrid electric vehicle	<i>FL</i>	Financial Leverage
	<i>SMR</i> Steam methane reforming	<i>VAT</i>	Value added tax (%)
<i>TCO</i>	Total cost of ownership	<i>TAX</i>	Incomes taxes (%)
<i>WE</i>	Water electrolysis	<i>ADSCR</i>	Annual debt service coverage ratio

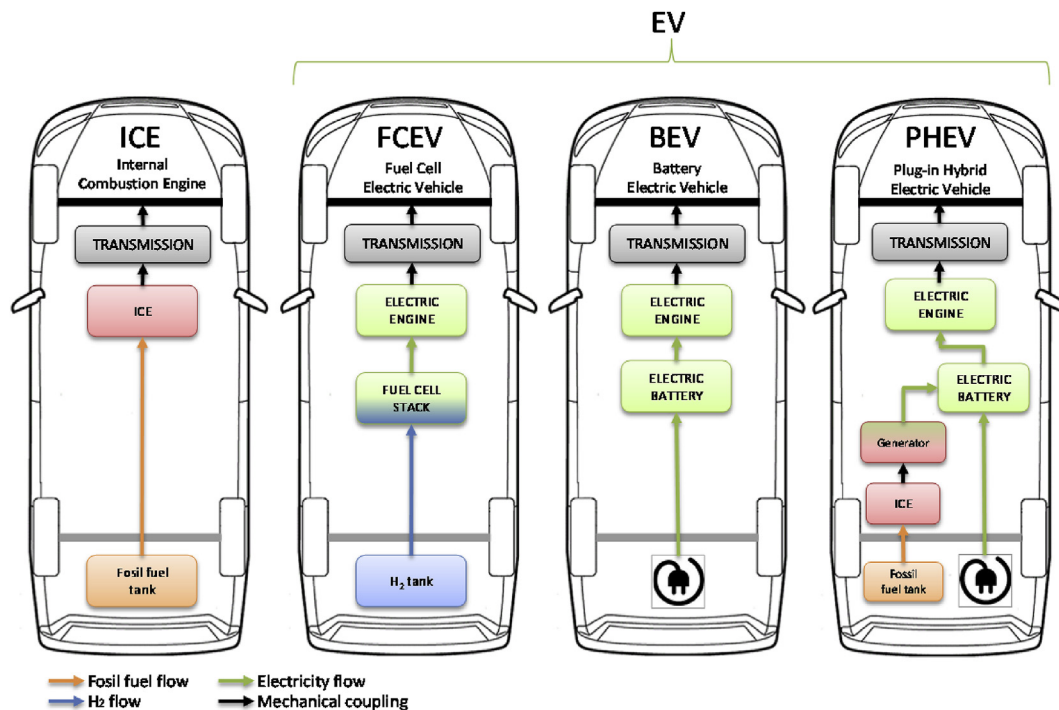


Fig. 1. EVs and ICEs functioning principles.

and greater range of autonomy than BEVs. Therefore, FCEVs present a mobility similar to present conventional ICE vehicles [12].

Well-to-wheel FCEV emissions depend on the hydrogen production mix and the share of RES in the generation of the electricity involved, but generally is well below ICE and PHEV and around BEV levels [12–15]. Recent research focused on taxi life cycle analysis has determined lower energy consumption and CO₂ emissions of FCEV in comparison with BEVs [16].

With regard to fuel prices, though the costs for PHEV and BE are currently lower, in terms of total cost of ownership¹ (TCO), both

FCEVs and BEVs show comparable values and slightly higher to PHEV [12,13,17].

All the GHG reduction strategies include the integration of FCEVs in vehicle fleets. The IEA includes in the pathway to achieve 2DS scenario,² a 25% share of FCEVs in 2050, which would contribute to get 10% reduction of transport-related emissions [12]. The EU HYWAYS project [18], estimates 2.5 million FCEVs by 2020. In California is projected the integration of 10,500 FCEVs in 2018 and more than 34,000 units by ending 2021 [19]. A minimum of 10 million vehicles and a maximum of 40 million in the best scenario are planned for the US by 2035 [20].

¹ Total Cost of Ownership considers all the costs related with the purchase and use of the vehicle, including fuel cost so that takes into account the vehicle fuel economy.

² The IEA 2DS scenario sets up strategies to achieve the goal of limiting the global mean temperature increase to 2 °C.

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