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Prospects and impediments for hydrogen and fuel cell vehicles in the transport sector

A. Ajanovic [a],*, R. Haas [a]

[a] Energy Economics Group, Technische Universitaet Wien, Austria

HIGHLIGHTS

- Hydrogen could be a potential contributor to a more sustainable transport system.
- Major challenges are to reduce costs and to build up infrastructure.
- A stable policy framework with technical and environmental standards is essential.
- For electrolysers economies-of-scale and learning effects have to be harvested.
- The best prospects for hydrogen and fuel cells in mobility are in large capacity vehicles.

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ABSTRACT

Hydrogen and fuel cell vehicles are often discussed as crucial elements in the decarbonisation of the transport systems. However, in spite of the fact that hydrogen and fuel cell vehicles have a long history, they are still seen only as a long-term mobility option. The major objective of this paper is to analyse key barriers to the increasing use of hydrogen and fuel cell vehicles. A special focus is put on their economic performance, because this will be most crucial for their future deployment. Mobility costs are calculated based on the total cost of ownership, and future developments are analysed based on technological learning. The major conclusion is that to achieve full benefits of hydrogen and fuel cells in the transport sector, it is necessary to provide stabile, long-term policy framework conditions, as well as to harmonize actions across regions to be able to take advantage of economies of scale.

Introduction

The current transport system, relying mostly on fossil energy carriers, is not sustainable. The rising greenhouse gas (GHG) emissions from the transport sector are an increasingly important subject of discussions and regulations all over the world, particularly in Europe.

Moreover, reduction of the air pollution is becoming a regulatory priority, especially in urban areas. Currently, more than 80% of the world's urban population is exposed to air quality level below minimum standards. According to the World Health Organization, air pollution caused about 4.2 million premature deaths worldwide [1].

In Europe, the transport sector is responsible for about a third of total energy use and about a quarter of total

* Corresponding author.
E-mail addresses: ajanovic@eeg.tuwien.ac.at (A. Ajanovic), haas@eeg.tuwien.ac.at (R. Haas).
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greenhouse gas emissions. The largest amount of these emissions is coming from the road transport, especially passenger cars [2].

To reach a significant emission reduction in the transport sector, different policies and measures are already implemented and targets for the future are set. A major effort is put on the increasing use of energy efficient and alternative automotive powertrains, as well as low-carbon fuels. Among these, hydrogen and fuel cell vehicles are often discussed as crucial elements in the decarbonisation of the transport systems.

Over the last decade, the major attention has been given to electric vehicles (EVs). Since there are different types of EVs, their potential to the reduction of GHG emissions is very different. For the reduction of GHG emissions, of especial interest are battery electric vehicles (BEVs) and fuel cell vehicles (FCVs). These vehicles have zero emissions at the point of use, and could significantly reduce total emissions if electricity and hydrogen are produced from renewable energy sources [3]. In contrary, to BEVs, which are almost a mature technology used in many countries, FCVs are still seen as a future technology. Although the number of BEVs has been increasing over the last years, especially in China, the USA and the EU, there are still different weaknesses related to this technology. Most important are: (i) short driving range, (ii) long charging time, (iii) high investment costs, and (iv) limited infrastructure. In the case of BEVs, the battery is the major challenge. To increase the driving range of BEVs, it is necessary to increase battery capacity, and this lead to increasing weight of vehicles and consequently to efficiency reduction. The most significant advantage of hydrogen is high energy density.

Although, hydrogen and fuel cells are often seen as a future solution, it is important to state that they have a long history. Hydrogen was identified as a distinct element already in 1766. Almost since its discovery, hydrogen was seen as important part of the future energy system. Already in 1874, the French writer Jules Verne in his novel “The Mysterious Island” saw hydrogen and oxygen as the energy sources of the future [4].

The first demonstrations of water electrolysis were in the beginning of the 19th century. Hydrogen was used as fuel in one of the first internal combustion engine (ICE) vehicles, already over 200 years ago [5]. The major steps and milestones in the development of hydrogen and fuel cell vehicles are depicted in Fig. 1.

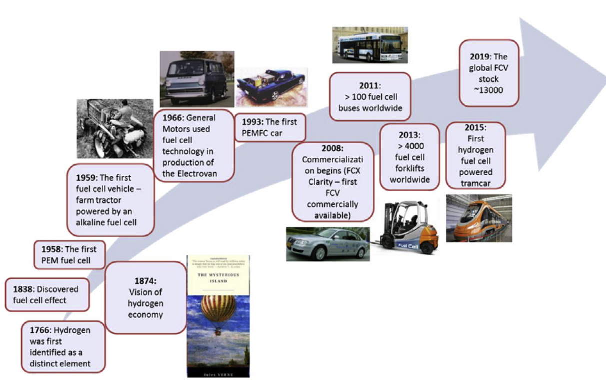

Fig. 1 – Major historical steps and milestones in the development of hydrogen and fuel cell vehicles.

Many times hydrogen was identified as a critical and indispensable element in the future low-carbon energy system [6–10]. Until now, there have been many “hydrogen hypes” but the reality is that hydrogen is currently used mostly just for different industry purposes. With the approximately 13 000 FCVs, hydrogen use in the transport sector can be neglected.

However, there are new prospects for hydrogen and fuel cell vehicles. Large-scale production of fuel cell has begun [11]. Hydrogen and fuel cells are being commercialised in several sectors, from portable electronica to forklift trucks [12,13]. Moreover, with the increasing use of renewable energy sources (RES) in electricity generation, as well as increasing need for flexible and storable energy carriers [14,15] hydrogen and fuel cell face again increasing popularity. Demand for hydrogen has grown more than three times since 1975 [5].

Over the last years, many aspects of hydrogen use have been analysed in scope of different studies, indicating its environmental benefits in the transport sector, as well as the high corresponding mobility costs in comparison to conventional and other electric vehicles. Miotti et al. [3] assessed the environmental impacts and costs of a polymer electrolyte membrane fuel cell system for use in passenger FCVs conducting a detailed cost- and life cycle assessment in two scenarios. According to the results of this study, FCVs can decrease life cycle GHG emissions by 50% compared to gasoline ICE vehicles if hydrogen is produced from renewable electricity. Ajanovic and Haas [16] have investigated the overall environmental impact of electric vehicles in different regions indicating relation between the environmental benignity of electric vehicles and electricity mix, travel activity, as well as emissions related to car production and recycling, showing that the highest sensitivity is with respect to the electricity mix. Moreover, Liu et al. [17] have shown that even when FCVs are fuelled by hydrogen produced via steam reforming of natural gas, 15%–45% lower well-to-wheels GHG emissions could be reached compared to conventional gasoline ICE vehicles. However, also here the results are sensitive to the source of electricity used for hydrogen compression or liquefaction. Some papers have investigated suitability of hydrogen use in the transport systems in specific countries or regions (e.g. Malaysia [18], China [19,20], Austria [21], Canada [22], Korea [23], Norway [24]) with the goal to provide recommendations to national policy makers and relevant government bodies. Moreover, some papers are providing assessment of hydrogen and fuel cells in the global energy system [25]. Common conclusion of most studies is that future role of hydrogen is very dependent on predictable and consistent policy framework.

Ajanovic et al. [26] provide a comprehensive review of the most important issues related to the economic and environmental assessment of battery electric- and fuel cell vehicles. Beside the transport sector, Staffell et al. [25] analyse possible role of hydrogen in the provision of also other energy services such as electricity, heat, and energy storage with the special critic on the stop-and-go policies.

The major objective of this paper is to analyse perspectives and key barriers to the increasing use of hydrogen and fuel cell vehicles with a special focus on their economic performance. Moreover, required policy framework and targets set for the uptake of hydrogen and FCVs are analysed and documented. Mobility costs are calculated based on the total cost of ownership, and future developments are analysed based on technological learning, as well as in harvesting economics-of scale.

Hydrogen and fuel cell vehicles: state of the art

For a long time hydrogen has been considered as a future energy carrier which can contribute significantly to the decarbonisation of the energy system. Its special role has been seen in its possible contribution to the transition towards a clean, emission-free and, hence, considerably more sustainable transport system. However, in spite of the fact that hydrogen and FCVs have some advantages in comparison to other fuels and automotive technologies, they are currently still rather a long-term option for mobility.

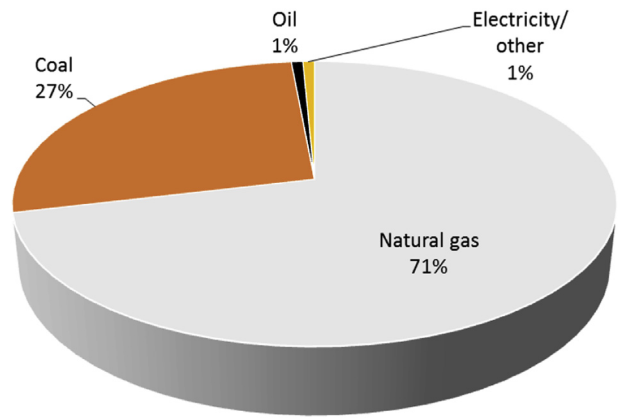

Fig. 2 – Hydrogen production worldwide by energy sources (Data source [5]).

Hydrogen production and use

Hydrogen is a secondary energy carrier, which can be produced from any primary energy source, e.g. fossil energy, nuclear or renewable. As an emission-free energy carrier, it can tackle some of the critical energy and environmental challenges. It can be produced using various energy sources and production methods, see Table 1. However, these different production methods are on different stages of maturity.

Currently, hydrogen production by steam reforming of natural gas is most widely used production method, see Fig. 2. About 71% of hydrogen is produced in this way. However, using this production method per every kilogram of hydrogen about 10 kg of CO_2 are produced [5].

For the future of special interest is hydrogen production from RES. Electrolysis is only mature technology, which can use RES for hydrogen production. Globally, this process accounts only for 0.1% of hydrogen production. Moreover, currently electricity used in this process is mostly not from RES. Besides electricity, this process requires also water. For every kg of hydrogen, about 9 L of water are needed, what can be an issue in water-stressed areas [5].

The major reason for the currently high use of natural gas in hydrogen production is the relatively low production costs. As shown in Fig. 3, the range of hydrogen production costs using steam reforming of natural gas is currently significantly lower than hydrogen production by electrolysis. This figure shows the range of the costs from literature [3–5,15] with different energy prices in different regions and different assumptions (e.g. for electricity price, natural gas prices, with or without costs for carbon capture and storage, etc.). The bold lines present the costs for hydrogen production by steam reformers and electrolysers resulting from own calculations based on Ajanovic/Haas [15]. Major input data used for our calculations are provided in Table 2. We did not consider carbon capture and storage costs.

Summing up, the current costs of hydrogen production are lowest in large centralized gas reformers and they are more expensive in any electrolyser system. However, in the future, on the one hand, no remarkable further investment costs reductions are expected for the gas reformers due to the maturity level. Moreover, the prices for natural gas will be increasing, also due to higher CO_2 costs. On the other hand, significant learning effects for electrolysers are expected, and the electricity costs from the variable renewables could be very low, if the hydrogen production takes place at times of excess electricity.

However, currently about one-third of global hydrogen supply is covered with hydrogen produced as a by-product from facilities and processes designed to produce something else [5].

Since 1975 demand for hydrogen has been increasing continuously, see Fig. 4. Current demand for hydrogen in its pure form is around 70 million tonnes per year. As this hydrogen is almost entirely produced from fossil fuels,

Table 1 – Hydrogen production [27].

	Commercial availability	Feedstock/energy source	Production model
Steam reforming	Most common	Natural gas	Centralized or decentralized
Electrolysis	Special applications	Electricity	Centralized or decentralized
Gasification	R&D stage	Biomass	Centralized
Biological	R&D stage	Solar energy and/or organic waste	Centralized
Photochemical	R&D stage	Solar energy	Centralized
Thermochemical	R&D stage	Solar or nuclear energy	Centralized

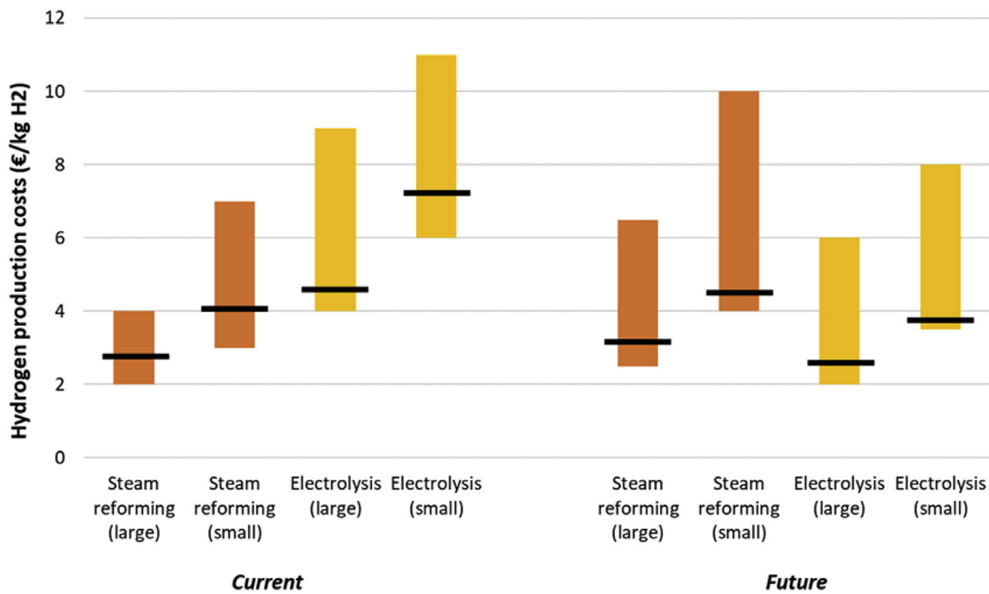

Fig. 3 – Range of current and future hydrogen production costs for small and large steam reformers and electrolyser systems (Data sources: [3–5,15], own analyses).

Table 2 – Input data for our calculation of hydrogen production costs in Fig. 3 (bold lines).

	Steam reforming		Electrolysis	
	Large	Small	Large	Small
Current investment costs (€/kW)	1400	2000	1550	2400
Future investment costs (€/kW)	1200	1500	1050	1600
Current O&M costs (€/kW)	30	60	15	30
Future O&M costs (€/kW)	24	50	12	25
Current full-load hours	6000	6000	2000	2000
Future full-load hours	6000	6000	2800	2800
Current efficiency	0.65	0.55	0.7	0.6
Future efficiency	0.7	0.6	0.75	0.65
Current energy price (cent/kWh)	3	3	2	2
Future energy price (cent/kWh)	5	5	2	2

production of hydrogen is responsible for about 830 million tonnes CO_2 per year [5].

Currently, the largest amount of hydrogen produced is used for different industry purposes, mostly oil refining and ammonia production. However, in principle hydrogen is a versatile energy carrier that can be used for very different purposes. It can enable diversification of energy carriers used in the transport sector, which is almost completely dependent on fossil fuels. Yet, current hydrogen use in the transport sector is less than 0.01 million tonnes hydrogen per year [5].

Fuel cell vehicles

Today, in the transport sector only a very small amount of hydrogen is used due to the low number of fuel cell vehicles. Globally, about 13 000 FCVs were in operation in the year 2019, mostly in the USA, Japan, China and Europe [28], see Fig. 5.

Fuel cell vehicles are currently neither economically competitive with internal combustion engine vehicles nor with other types of electric vehicles and powertrains. However, in opposite to electricity, hydrogen has potential to be used in different transport applications when longer driving range and higher load capacity are required.

Hydrogen in combination with fuel cell is already used in demonstration projects and niche markets for trucks and buses, as well as trains. Hydrogen fuel cell forklifts are already commercial and about 25 000 forklifts are already in use worldwide. The number of fuel cell buses is also increasing due to different demonstrations projects. Globally, more than 10 companies are producing fuel cell buses. Currently more than 500 buses, 400 trucks and 100 vans are in use [5].

At the same time, at least some progress in the deployment of hydrogen infrastructure can be noticed. Japan, Germany and the USA are the countries with the highest number of hydrogen refuelling stations (HRS) worldwide. Many European countries have at least few hydrogen refuelling stations, see Fig. 6.

Major reasons for emerging expectations regarding hydrogen

Recent developments, such as the slow penetration of battery electric vehicles, the unsolved problem with battery recycling, the imbalance between electricity supply and demand due to the increasing use of variable renewable energy sources, demonstrate the urgent need for additional technologies, measures and policies to be on track with the emission reduction targets set by policy makers.

In the following we explain the two major reasons for recently increasing expectations with respect to hydrogen which are: (i) the need to find solutions for the looming excess electricity generation from variable RES and (ii) the restricted capability of EVs to provide solutions in the large vehicle segments.

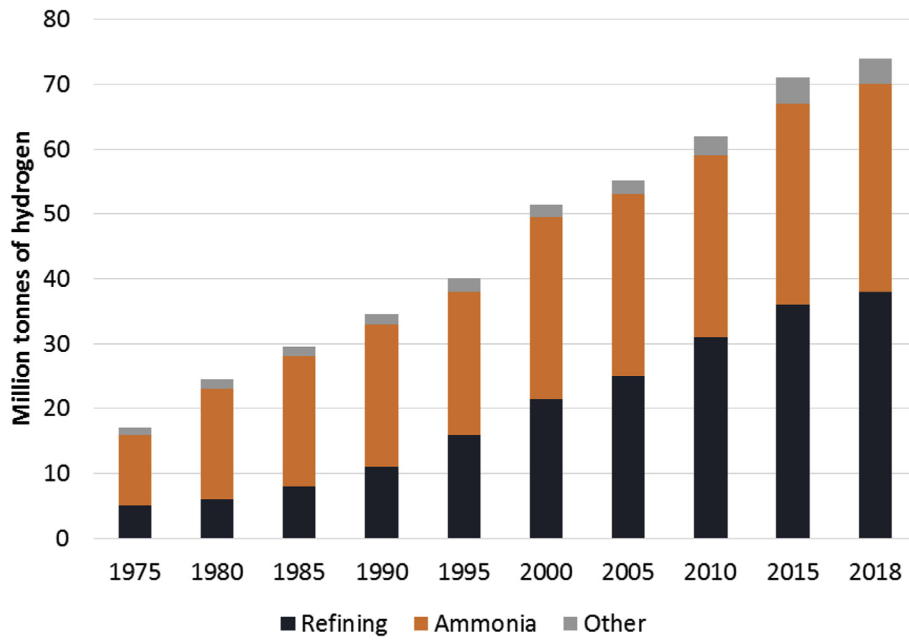

Fig. 4 – Development of the demand for hydrogen since 1975 by type of use (Data source [5]).

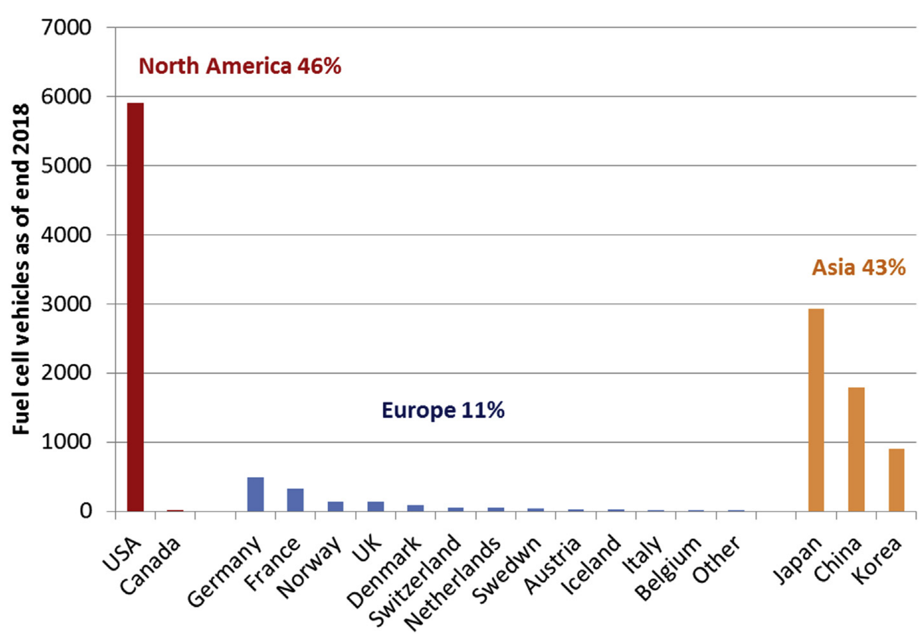

Fig. 5 – Fuel cell vehicles as of end 2018 (Data source [28,29]).

RES integration

Looking at the worldwide future GHG emissions expected it is obvious that emission reduction goals are ambitious. Huge additional efforts are needed for a profound transformation of the energy system including transition from carbon-based energy sources to clean and sustainable ones. Hydrogen has the potential to be a powerful enabler in this energy transition, as it offers a clean, sustainable, and flexible option for overcoming multiple obstacles that stand in the way of a resilient and low-carbon economy [8].

The increasing electricity generation from variable RES in the power sector, which is necessary for the transformation of the energy system towards a more sustainable one, lead to an increasing imbalance between supply and demand. One of the options to solve this challenge is to use hydrogen as a long-term electricity storing option, see Fig. 7.

Hydrogen has potential to improve economic efficiency of investments in renewables, enhance security of power supply and serve as a carbon-free long-term storage [8]. In the energy transition, it could enable large-scale, efficient renewable energy integration, and link different energy sectors,

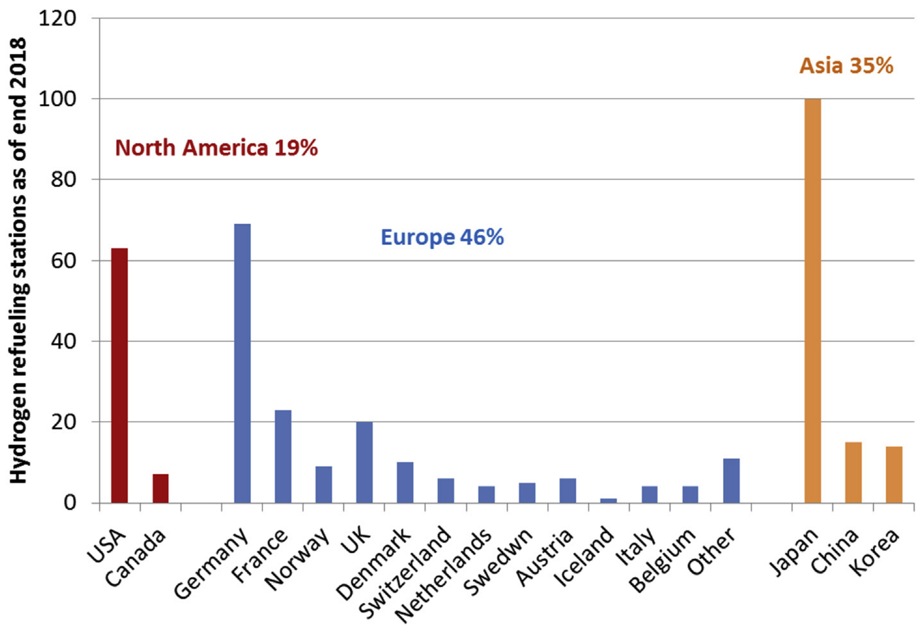

Fig. 6 – Number of hydrogen refueling stations at the end of 2018 (Data source [28]).

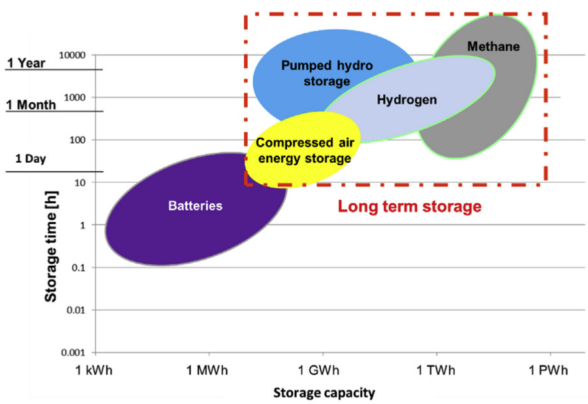

Fig. 7 – Different storage options [30,31].

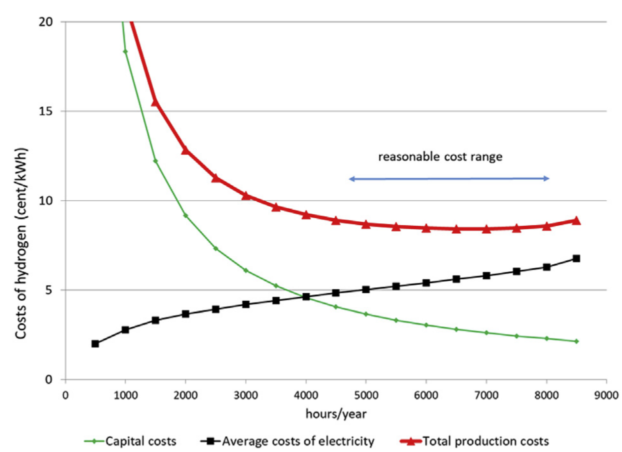

Fig. 8 – Hydrogen production costs depending on full-load hours.

providing needed flexibility to maintain the resilience of the system.

One of the major challenges related to hydrogen-based energy storage systems is rather low efficiency over the whole conversion chain, mostly about 20%–30% [32], due to several energy transformation steps. Other important challenge is to have enough full-load hours per year to make hydrogen-based energy storage system economical. Electrolysers have significant investment costs, and to make them cost effective they have to be operated for a sufficient number of hours per year. However, the basic idea is to store surplus electricity from RES, and periods of availability of surplus electricity are occurring for a limited amount of time.

The relation between hydrogen costs, electricity price and full-load hours of electrolyser is depicted in Fig. 8. The hydrogen costs are calculated as:

$$C_{H_2} = \frac{\frac{C_c + C_{O\&M}}{T} + C_E}{\eta} \ (\mathrm{EUR/kWh}) \tag{1}$$

where, C_C is the capital cost, $C_{O\&M}$ are the operating and maintenance costs, T is the number of full-load hours per year, C_E is the electricity costs, and η is the efficiency of the electrolyser, see Refs. [33].

For this calculation, large-scale electrolyser with investment costs of 1550 EUR/kW, a depreciation time of 25 years, and an efficiency of 70% is taken. The average electricity costs are calculated from the electricity market prices in Germany (EPEX) from 2015 to 2018, calculating the average of prices below specific full-load hours.

As seen from Fig. 8 the capital costs per kWh produced are declining, and the average electricity costs are increasing with full-load hours. Below 2000 full-load hours per year, hydrogen costs are extremely high. The curve starts to become rather flat starting from about 3000 full-load hours per year. However, the cheapest hydrogen costs could be reached between about 4500 and 8000 full-load hours.

To make the energy supply chain more energy efficient, re-electrification of hydrogen can be replaced with the direct use of hydrogen in the transport sector. Hydrogen in combination with fuel cell vehicles could have an important role in the transport decarbonisation. In contrary to BEVs, which are most suitable for small cars, FCVs can be easily used in much broader car-segments, e.g. medium to large cars, buses, trucks, fleets, etc., where a large number of kilometres per day is required.

Limits and restrictions for BEVs

In principle rechargeable EVs could be a good solution for the future. Yet, there is one considerable problem, or at least a challenge: the battery. The battery performances have to be improved and costs reduced. The major problems related to battery are high sensitivity, long charging time, low energy density, and resulting high weight. Actually, there are few problems.

For example, to have vehicle with the range of about 500 km, with BEVs, lithium-ion battery system has a weight of 830 kg, and with FCVs and hydrogen (compressed to 700 bar), energy storage weigh is about 125 kg. Weight of energy storage system of BEVs and FCVs in comparison to conventional ICE vehicles is shown in Fig. 9.

Moreover, an important challenge for the future will be sustainable battery production and recycling [16]. However, thanks to overhead lines electricity use in the transport sector, e.g. in trains or trolleybuses, have already long and successfully tradition.

Major impediments for hydrogen and fuel cell vehicles

Hydrogen has some very good characteristics and a significant potential to contribute to the energy transition and emission reduction, especially in the transport sector. However, there are some key barriers that have to be overcome before the full benefits of hydrogen and FCV can be materialized. The major challenges for hydrogen and FCVs could be divided in the three major categories: (i) economics, (ii) infrastructure, and (iii) policy framework.

Economics

Affordability is one of the major barriers for the broader use and faster penetration of FCVs. Mobility provided by FCVs and hydrogen is still very expensive and not competitive with conventional cars, as well as with other alternatives such as rechargeable electric vehicles.

For the commercialization of FCVs most important is to reduce investment costs. Assuming ambitioned diffusion of alternative automotive powertrains announced in policy targets (e.g. The Paris Declaration on Electro-Mobility and Climate Change and Call to Action [35]) and depicted in scenarios (e.g. Ref. [36]), it can be expected that a further cost reduction of FCVs through technological learning will take place. Technological learning is calculated using following equation:

$$IC_{New}(t) = IC(t_0) \cdot \left(\frac{x_t}{x_{t_0}}\right)^{-b} \tag{2}$$

Where $IC_{New}(t)$ is investment cost of new technology, b is a learning index, $IC(t_0)$ is investment cost at the time t_0, and x refers to cumulative capacities installed at time t and t_0, see Ref. [15].

Since for conventional car further technological learning is not expected, the price difference between ICE vehicles and FCVs will decrease over time, see Fig. 10.

Total mobility costs of FCVs per kilometre driven are dependent on purchase price of vehicles, hydrogen costs and other operating and maintenance costs, energy efficiency of vehicles, specific number of kilometres driven per year, lifetime of vehicles, as well as interest rate. Currently, the largest impact on the total mobility costs has purchase price of vehicles. Fig. 11 shows current and future total mobility costs of FCVs in comparison to conventional ICE vehicles. Driving range of 12 000 km per year over 7 years is assumed. A sensitivity analysis is documented in Ajanovic and Haas [26].

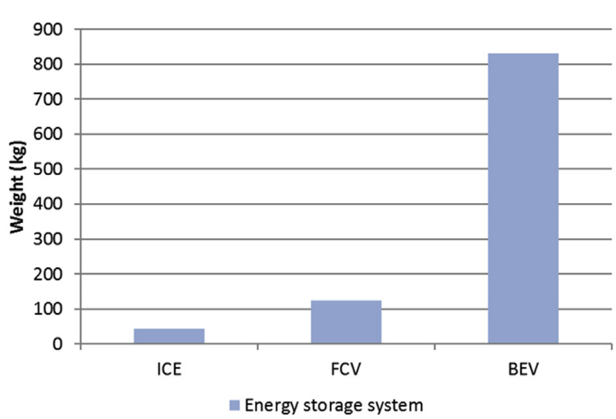

Fig. 9 – Weight of energy storage system in vehicles, driving range 500 km (Data source:[34]).

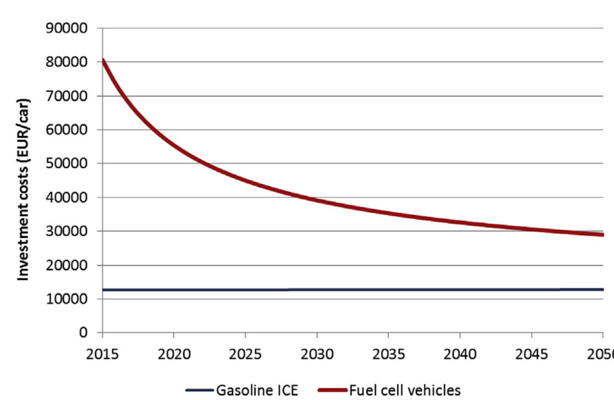

Fig. 10 – Development of the investment costs of vehicles due to technological learning (for average car size of 80 kW) [15,37].

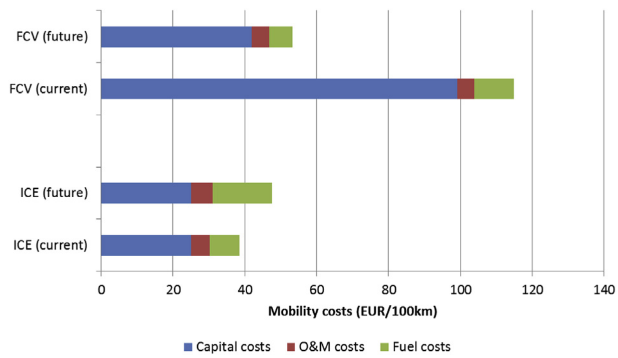

Fig. 11 – Total costs of mobility with FCVs in comparison to ICE vehicles (car power: 80 kW) incl. taxes.

Although, total mobility costs of FCVs are currently very high compared to conventional ICE vehicles, some car manufactures have already moved from prototypes to products. Different models of FCVs are already available on the market (e.g. Toyota Mirai, Honda Clarity, Hyundai Tucson, etc.) With the exception of costs, FCVs are comparable to conventional fossil-fuelled vehicles with respect to driving range, which is between 400 and 550 km per tank, as well as regarding the refuelling time of 3–5 min. In addition, FCVs are quiet and have zero-emissions at the point of use. Even, if hydrogen produced by steam reforming of natural gas is used, FCVs could have compete with emissions from ICE vehicles [3,17].

Deployment of infrastructure

Another important barrier for the adoption of FCVs is requirement for new and expensive infrastructure. Currently there are worldwide just 376 hydrogen refuelling stations. As shown in Fig. 6, there are just five countries with more than 20 HRS.

Moreover, also the utilisation of HRS is currently low, mostly in the range from 10 to 90 FCVs per station [5]. In the future, 2500–3500 FCVs per station are expected [38].

The current deployment of infrastructure is limited mostly to different pilot projects. At this early development stage, it is easier to enable infrastructure for FCV fleets, such as buses and different kind of delivery and service vehicles, which have determined driving routes and can use a central location to refuel. These local infrastructure and related knowledge gained should be used in the development of a broader cross-countries infrastructure network. To achieve this it is important to develop common standards and regulations regarding safety, maintenance, payment, etc. Through the modularisation of technical components and by series production, infrastructure costs could be significantly reduced. However, in the early stage major risk is that refuelling stations will be under-utilized, so that financial support for the deployment of infrastructure is essential.

As discussed by Ogden [39] hydrogen refuelling infrastructure should offer: (i) coverage – enough stations to enable convenient travel, (ii) capacity to meet growing hydrogen demand, (iii) positive cash flow for station owners and network-wide supply, and (iv) cost competitiveness with gasoline (on an EUR per kilometre bases). To meet these goals, coordinated deployment actions, geographically and over time, are needed.

Policy framework and future targets

The future role of hydrogen and fuel cell applications in the transport sector is very dependent on the policy framework and future targets. However, implemented policies, investments, as well as future targets differ significantly from country to country. A relatively low number of policies is applied directly to hydrogen and fuel cell technologies. The policy support for hydrogen and fuel cell vehicles as well as corresponding infrastructure is driven mainly by different national priorities such as air quality, climate change, energy security, etc. [25]. There is also broad portfolio of policies that indirectly support use of hydrogen and FCVs, e.g. standards for CO_2 emissions from new cars, ban of ICE vehicles, etc.

The major problem for the faster and broader deployment of hydrogen and FCVs is a lack of regulations as well as coordinated action between different stakeholders. In addition, technology standards are needed, which would drive economies of scale and reduce risks of the investment. There is still lack of investments in hydrogen and fuel cells in most of countries and regions. Although, the European Commission acknowledges that the market uptake of alternative vehicles and infrastructure roll-out are fundamentally connected, its proposal for post-2021 CO_2 targets for passenger cars and vans does not link the availability of charging and refuelling infrastructure to the future CO_2 targets. However, to be able to reflect the reality of the market, Europe's long-term climate objectives should be linked to future infrastructure availability and consumer acceptance [40].

Further research and developments projects are needed to learn about new technology and increase public acceptance. However, from societies point of view most important is to have clear long-term vision and a stable policy framework. Major elements of needed policy framework are depicted in Fig. 12.

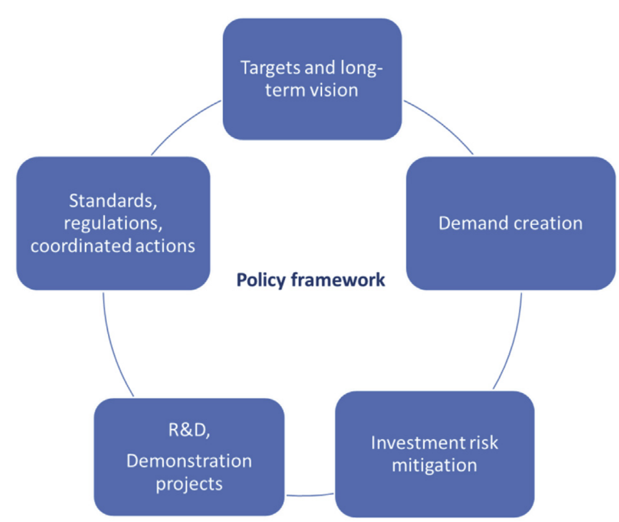

Fig. 12 – Policy framework required for a further uptake of FCVs.

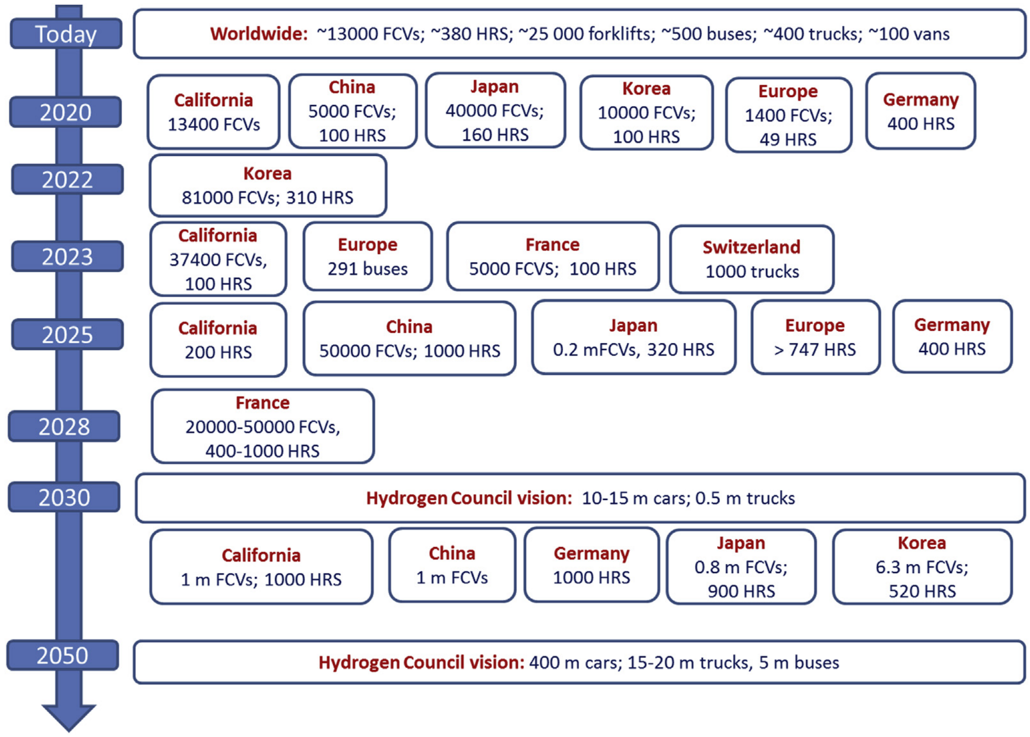

Fig. 13 – Announced targets and visions for fuel cell vehicles [5,25,28,29].

Due to the currently high costs of hydrogen and FCVs, their market uptake is directly correlated to GDP per capita. The highest investment in hydrogen and FCVs are currently concentrated in few countries, the USA, Japan, China, Korea and few EU countries.

The major visions and announced targets for FCVs and HRS are depicted in Fig. 13. The highest future targets regarding the number of FCVs are set in California and China, 1 million FCVs by 2030, followed by Japan and Korea.

Conclusions and outlook

Hydrogen in combination with FCVs is seen as a potential contributor to the transformation of the current fossil fuels based transport system towards a more sustainable one. Interest in this technology had already many ups and downs over time. However, with the increasing use of variable RES and consequently increasing need for additional storage- and sector coupling options, interest in hydrogen and fuel cells rise again.

In the category of passenger cars, FCVs are in strong competition with conventional ICE vehicles, as well as with other electric vehicles. There are still three major challenges, which have to be solved in the future: reduction of investment costs of cars, infrastructure development and stable policy framework conditions that give predictable support to emerging technologies and can reduce risks related to long-term investments. Appropriate policies should increase confidence in alternative technologies, and including externalities, they should make low-carbon transport options more competitive.

From the current point of view, fuel cells could have best prospects in vehicles with high capacities such as trucks and buses, where they have a better performance in comparison to BEVs. Although, the current market share of fuel cell busses is still very small (just about 500 around the world), recent investments and goals set indicate a shift of mass transit to fuel cell mobility solutions. Fuel cell trains are already cost competitive with diesel trains [8].

However, to achieve full benefits of hydrogen and fuel cells in the transport sector, it is necessary to provide stable, long-term policy framework conditions along the whole energy system, as well as to harmonize standards across regions and sectors to be able to take advantage of economies of scale.

Nomenclature

BEVs	Battery electric vehicles
CO_2	Carbon dioxide
EVs	Electric vehicles
EPEX	European Power Exchange
FCVs	Fuel cell vehicles
GDP	Gross domestic product
GHG	Greenhouse gas emissions
HRS	Hydrogen refuelling station
ICE	Internal combustion engine
RES	Renewable energy sources
R&D	Research and development

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