Hydrogen mobility in Europe and in the rest of the world

POLICY BRIEF 2015/01

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EXECUTIVE SUMMARY

Public policies implemented in Europe with the aim of decarbonising the economy and improving air quality in urban areas are gradually reducing the cost gap between the conventional powertrain, composed of an internal combustion engine paired with the transmission shaft, and other, more environmentally friendly solutions. These include hydrogen and fuel cell technologies for transport, now mature. Hydrogen, which falls within the scope of the recent 2014/94/EU Directive, appears likely to play an increasingly important role over the coming years.

Hydrogen and fuel cell vehicles are electric vehicles anyway, but they produce internally the electricity that is necessary for traction, through an electrochemical reaction. Compared to battery electric vehicles (BEVs), they have the advantages of long range and very short refuelling time. However, when compared to any other powertrain, they are reportedly expected to have a higher total ownership cost until the mid-2020s. Infrastructure investments needed to ensure a minimum number of hydrogen fuelling stations, on the other hand, are far less costly than those needed to ensure a minimum number of charging points for battery electric vehicles.

In the European Union, the hydrogen and fuel cell technology is one of the eight strategic priorities of the SET-Plan. There are several tools available to finance the infrastructure development for hydrogen mobility, starting with the TEN-T (Trans-European Transport Networks) and Horizon 2020 (multi-annual programme for research, development and demonstration) funds. In addition, some member states have allocated significant resources and rank among the pioneers of hydrogen mobility. Germany, in particular, is the country that has invested the most at global level and plans to have up to 1,800,000 hydrogen cars in its roads by 2030. Italy is the only major EU country having not yet developed a plan for hydrogen mobility, despite various significant initiatives in its territory.

Besides Europe, the most important deployment programmes are being developed in South Korea and Japan. The Japanese commitment for hydrogen mobility, in particular, is comparable to that of Germany, with about a thousand hydrogen fuelling points planned by 2025. In addition, Tokyo has launched an incentive scheme that partly compensates the price gap between hydrogen and fuel cell cars and the rest of the cars available in the market. In the United States, California is undoubtedly the most advanced State when it comes to hydrogen mobility, as 100 hydrogen refuelling points are expected to be available to the public by 2024.

Hyundai and Toyota have recently launched series production of hydrogen and fuel cell vehicles: the former for leasing fleets only, the latter also for individual sales. Other automakers that have invested in this technology and are planning to introduce their own models on the market over the coming years include Honda, Daimler, General Motors, BMW, and Volkswagen.

Hydrogen and fuel cell mobility is not limited to light-duty passenger vehicles (LDPVs) only, but it is already a well-established reality for urban buses and for forklift trucks. In addition, projects for hydrogen mobility are in the pipeline in the rail sector as well, which have the advantage of saving transport companies the

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costs associated with the installation and maintenance of power lines along railway tracks. Hydrogen transport in waterways also appears to be possible.

Business opportunities related to hydrogen mobility are very significant, since the turnover of this sector is estimated to reach € 60 billion by 2030. However, only those countries where hydrogen mobility planning tools will be developed in the short to medium term will allow their businesses to benefit fully from this new sector of the economy.

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1. BACKGROUND

1.1 – Car sector crisis and impacts of road transport on health and the environment

In several European countries, **the car market has undergone a severe crisis over the past few years**[1], while **traffic congestion** reduces dramatically the quality of life in urban areas. Moreover, the massive use of fossil fuels for transport (96 % in Europe) has a significant impact on the trade balance of all countries that have no large oil fields. In 2013, the European Commission estimated the value of imports of crude oil intended for transport in the EU-28 at **around € 1 billion a day**[2], a figure which highlights the **heavy energy dependency** of most EU-28 Member States from the supply of fossil fuels imported from third countries.

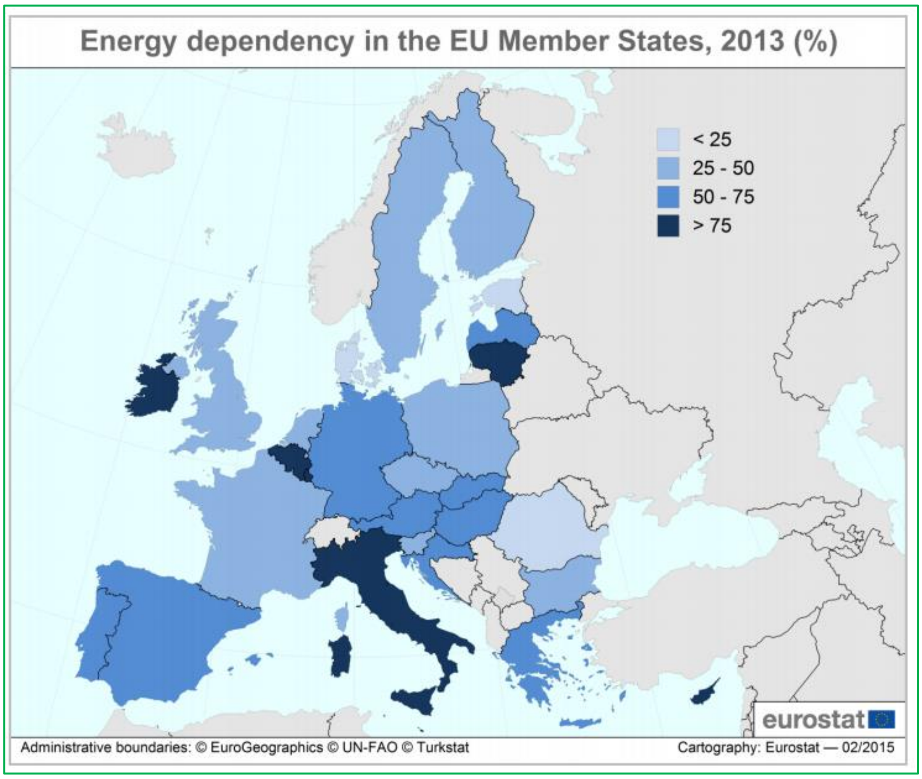

*Figure 1 – Energy dependency rate of EU Member States from third countries. Source: **Eurostat News Release 25/2015**, 9 February 2015.*

Internal combustion vehicles release **greenhouse gases and other substances harmful to humans and to the environment**. According to the **European Environment Agency**[3], the transport sector alone contributes to more than 20% of carbon dioxide (CO_2), 39% of nitrogen oxides (NOx) and 25% of carbon monoxide (CO) emissions, as well as 15% of fine particles ($PM_{2,5}$) across the 28 member States of the European Union. **More than 90% of Europeans living in**

[1] Annual sales of light-duty passenger vehicles in Europe decreased by around a quarter between 2007 and 2013, according to a report by Alix Partners quoted by the Financial Times. Cf. H. Foy, **Europe's auto market gloom to last until 2019**, Financial Times, 16 June 2013.
[2] Cf. **Clean Power for Transport: a European alternative fuels strategy**, COM(2013) 17 of 24 January 2013.
[3] **Air quality in Europe - 2014 report**, Copenhagen, European Environment Agency, 19 November 2014.

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urban areas are exposed to pollution levels well above the maximum thresholds set in 2005 in the **guidelines of the World Health Organisation** (WHO), resulting in **high levels of premature deaths** (400 thousands in 2011 alone) and in **high costs for national health systems**. This is why an increasing number of municipalities have adopted mobility plans aiming at limiting the access of private vehicles to ever larger areas around city centres. London appears to be the city that has adopted the most drastic measures through a **congestion charge**, a levy equivalent to around € 15/day, imposed on all vehicles emitting more than 99g CO_2/Km circulating in the city centre during office hours. Other measures promoted by public authorities to encourage the use of clean vehicles also include the partial or total exemption from payment of the annual car tax, as well as the partial or total exemption from the payment of parking.

1.2 –EU policies for Air Quality and Alternative Fuels

A set of increasingly strict standards for vehicle emissions and exhausts have been adopted at EU level. Euro 5 and Euro 6, entered into force in September 2009 and in September 2014 respectively, govern emissions of carbon monoxide (CO), non-methane hydrocarbons and total hydrocarbons, nitrogen oxides (NOx) and particulate matters (PM)[4]. As from 2015, stricter carbon dioxide (CO_2) emission targets apply for all new cars, as the average emissions of each car manufacturers' fleet cannot exceed 130 g/Km, a threshold that will be lowered to **95 g/Km by 2021**[5]. Similar thresholds will apply to light commercial vehicles, which will be subject to specific emission reduction targets by 2017 and by 2020[6]. To facilitate the achievement of such objectives, the system provides for a set of flexibility mechanisms that will be in place until 2023, including an initial bonus for car manufacturers that include very low emissions models (i.e. vehicles that emit less than 50 gCO_2/Km) in their own fleets. **A fine of € 95 per gCO_2/Km per car will apply from 2019, in case of non-compliance with the targets**. Over the longer term (2050), **the European Union aims at reducing CO_2 emissions in the transport sector by up to 60% from 1990 levels**, which corresponds to a reduction of about 70% from current levels[7]. Similarly, European legislation also regulates **noise pollution caused by traffic**, imposing limits to the noise of all new cars, with targets set for 2016, 2020 and 2024[8].

Under the **Renewable Energy directive (2009/28/EC)**, at least 10% of final energy consumption in the transport sector will have to be ensured by **renewable energy** by 2020. In addition to this, under the **Fuel Quality Directive (2009/30/EC)**, by the same year suppliers will have to reduce the greenhouse gas

[4] Cf. EC Regulation 715/2007 of 20 June 2007 et seq.
[5] Cf. EC Regulation 443/2009 of 23 April 2009 and EU Regulation 333/2014 of 11 March 2014. The 2015 and 2021 targets represent respectively a 18% and a 40% reduction of the 2007 average (158.7 gCO_2/Km). Such levels do not refer to CO_2 emissions of single models, but to the average emission level of the whole fleet of models produced by a car manufacturer. In consumption terms, the 2015 target corresponds to a maximum of 5.6 litres of gasoline or 4.9 litres of diesel per 100 Km, whereas the 2021 target corresponds to a maximum of di 4.1 litres of gasoline and 3.6 litres of diesel per 100 Km.
[6] Limits for such vehicles are set at 175 g CO_2/Km by 2017 and at 147 g CO_2/Km by 2020. Cf. EU Regulation 510/2011 of 11 May 2011.
[7] Cf. White Paper – Roadmap to a Single European Transport Area: Towards a competitive and resource efficient transport system, COM(2011) 144 final of 28 March 2011.
[8] The threshold for production cars will be reduced from 74 db to 68 db in 12 years. The most powerful types of cars will have an extra margin of between 1 and 9 decibels. Cf. EU Regulation 540/2014 of 16 April 2014 on the sound level of motor vehicles and of replacement silencing systems.

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emissions caused by the **production, transport and use of their fuels** by 6%, compared to the 2010 EU average level. Furthermore, the **Clean Vehicles directive (2009/33/EC)** obliges public authorities and operators that perform public service duties to take into account factors such as emissions of CO_2 and other pollutants, as well as energy consumption, in the organisation of **tenders** for public fleets.

Finally, to promote the use of vehicles that use alternative fuels such as electricity, gas and hydrogen, **the development of fuelling infrastructure will also be harmonized at EU level**. Under the **Alternative Fuels Infrastructure directive (2014/94/EU)**, by 18 November 2016 all EU member States have to adopt and notify to the European Commission **national policy frameworks**, which may consist of several plans, strategies or other planning documentation developed separately or in an integrated manner, outlining their targets and objectives, with the aim of ensuring the proper **development of an alternative fuels market** and the construction of the fuelling infrastructure[9]. In fact, the **Trans-European Transport Network (TEN-T) guidelines** already provide that inland and maritime ports, airports and roads of the **core TEN-T network** should enable the decarbonisation of transport through energy efficiency improvements and through the construction of supply infrastructure for alternative fuels[10].

1.3 – Hydrogen ranks among the most important alternative fuels over the years to come

This complex regulatory framework aims on the one hand at limiting as much as possible the negative effects of fossil fuels on climate, environment and health; on the other hand, at **creating the conditions for the development of transport technologies** that, in addition to being cleaner, can also decrease Europe's imports dependence, thus increasing **energy security**. As a matter of fact, the technologies that are necessary to ensure the smooth transition to a more sustainable transport system could hardly be available on a mass scale, should their success rely on the market only. However, it has been observed that the long term goals set for the transport sector cannot be reached without a massive use of alternative fuels such as biofuels, methane from renewable sources, electricity and hydrogen[11]. Each of such alternative solutions can be more or less suitable, depending on the specific context and situation. For instance, it is likely that the greatest part of biofuels available will be used for long-haul trucking as well as for aviation, which will also rely on fossil fuels at least for a significantly longer timeframe than passenger vehicles. As a result, **the decarbonisation effort will mainly concern light-duty passenger vehicles**, which should be largely powered by hydrogen or electricity already by 2035 in order to get close to zero-emission

[9] The directive considers the following as alternative fuels: electricity, hydrogen, biofuels, synthetic and paraffinic fuels, compressed natural gas (CNG) and liquefied natural gas (LNG) including biomethane, and liquefied petroleum gas (LPG). EU Member States are free to decide whether or not to include hydrogen in their own National Strategic Plans. Electricity charging and CNG refuelling infrastructure available to the public in urban areas has to be built by 2020, whereas for hydrogen, for CNG outside urban areas and for other kinds of gases the deadline is 31 December 2025 (2030 in case of LNG for inland ports).
[10] Cf. **EU Regulation 1315/2013 of 11 December 2013 on Union guidelines for the development of the trans-European transport network**.
[11] Cf. Weeda, de Wilde, Wurster, Bünger, Schaap, Wallmark and Mulder, **Towards a comprehensive hydrogen infrastructure for fuel cell electric cars in view of EU GHG reduction targets**, HIT, Brussels, 8 October 2014.

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levels by 2050. For that reason, alternative fuels should not be seen as competing with one another, and have to be considered as **different tools available to achieve the same goals**.

Hydrogen and safety

Hydrogen is an odorless, colorless and highly flammable gas, which can lead to explosions in confined spaces where adequate ventilation is not provided. This is why hydrogen storage facilities having a capacity exceeding 5 tons fall within the scope of the **Seveso III directive**. However, hydrogen is neither more nor less dangerous than other gaseous fuels, such as natural gas or liquefied petroleum gas (LPG). It is true that the detonability limits of hydrogen are much wider than both natural gas and LPG, yet the latter two can produce an explosion at much lower concentrations (13-65% of volume in air for hydrogen, against 6.3-13.5% for methane and 3.1-7% for LPG). Furthermore, hydrogen has the double advantage of being non-toxic and of being fifteen times lighter than air, so in case of leakage it has no consequence on human health and dissolves very quickly in the atmosphere. The use of this gas in a number of industrial applications has allowed the development of safety standards and protocols that make it possible to handle safely this substance. In the transport sector, the research and development efforts have led to the design of tanks in reinforced composite materials, which are able to withstand very high pressures and provide adequate safety levels even in case of accident.

As demonstrated by the policy developments at national level that will be illustrated later in this brief, it is realistic to expect a **significant development of hydrogen fuelling infrastructure** in all those European countries that decide to promote hydrogen and fuel cells mobility over the next few years. In fact, **a 2010 McKinsey study**[12] demonstrates that the total ownership cost of hydrogen and fuel cell vehicles will converge with that of other powertrains available in the market in the upper vehicle segments (C, D, J) around 2025, when hydrogen and fuel cell cars will be produced on a mass scale. In addition to this, one has to underline that the comparison between different powertrains available does not take into account the **environmental, climate and health-related negative externalities** that are linked to the emission of greenhouse gases and of pollutants, in particular in urban areas: should such costs be internalised, the overall picture would look very different already today[13]. In fact, a recent study carried out by Stanford University scholars concluded that **an additional ton of carbon dioxide emitted in 2015 would cause up to US $ 220 worth of economic damages**. These are expected to take various forms, including decreased agricultural yields, harm to human health as well as lower worker productivity[14]. Furthermore, as a 2012 Bruegel study reveals[15], on the one hand hydrogen fuel is generally exempted from excise duties, yet on the other hand the cost of the electricity used to produce it through electrolysis is aggravated by a series of levies, on top of which one has to add the costs resulting from the

[12] McKinsey & Company, **A portfolio of power-trains for Europe: a fact-based analysis. The role of Battery Electric Vehicle, Plug-in Hybrids and Fuel Cell Electric Vehicles**, 2010. The study focuses on a scenario that assumes a 25% share of hydrogen fuel cell vehicles in Europe by 2050.
[13] Cf. I. Parry, D. Heine, E. Lis and S. Li, **Getting Energy Prices Right : From Principle to Practice**, Washington, D.C., International Monetary Fund, July 2014.
[14] F.C. Moore and D.B. Diaz, **Temperature impacts on economic growth warrant stringent mitigation policy**, Nature Climate Change, 12 January 2015.
[15] G. Zachmann, M. Holtermann, J. Radeke, M. Tam, M. Huberty, D. Naumenko and A. Ndoye Faye, **The great transformation: decarbonising Europe's energy and transport systems**, Brussels, Bruegel, 2012.

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inclusion of the power sector in the **Emissions Trading Scheme (ETS)**. Other forms of hydrogen production fall equally among the sectors covered by the ETS.

In 2013, over 250 billion cubic meters of hydrogen were market at global level, with a total value exceeding US$ 96 billion. Thanks to a number of measures adopted in various regions of the world, including in the transport sector, the global hydrogen market is expected to grow further, up to 324.8 billion cubic meters in 2020, with a value worth US $ 141.4 billion at current prices[16].

[16] **Global Market Study on Hydrogen: Electrolysis of Water Segment to Witness Highest Growth by 2020**, Persistence Market Research, New York, 5 March 2015.

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2. HYDROGEN CARS

2.1 – Types of hydrogen cars

When speaking about **hydrogen cars**, one has to distinguish between those powered by an internal combustion engine and those with an electric motor. The former burn hydrogen or a mix of hydrogen and other fuels, usually gasoline or natural gas (hydromethane). The latter are powered by the electric current resulting from an electrochemical reaction that takes place inside a **fuel cell**, between the hydrogen stored in the tank and the oxygen from ambient air. Fuel cells emit only water vapour, as underlined in a famous **Daimler TV spot**. In contrast, internal combustion engine vehicles powered by hydrogen and gasoline or hydromethane, although much cleaner than any other conventional vehicle, release greenhouse gases and other compounds resulting from the combustion process, such as CO_2, CO, unburned hydrocarbons and particulate matters. Finally, the development of internal combustion engine vehicles powered by liquid hydrogen seems to be abandoned at present, due to technical limitations as well as for safety reasons[17]. **Therefore, this report focusses only on hydrogen and fuel cell cars**, which will be available in the mass market as from 2015.

Fuel cells

Fuel cells are electrochemical converters that produce heat and electricity by oxidation of a fuel and reduction of oxygen. The chemical energy of the fuel, therefore, is converted into electricity and heat without combustion: the conversion process does not release any fine particles. In addition, the fuel cell conversion yields are higher than 50% and thus much better than those of any internal combustion engine. Besides hydrogen, other products such as natural gas, methanol, ethanol, biogas, LPG, gasoline or diesel may be used as a fuel, in both liquid and gaseous form. There are several types of fuel cells, which vary mainly depending on the electrolyte used and the temperatures reached in the process. Fuel cells can be used both for transport and for stationary applications, with capacity that can go from watts to megawatts. For instance, **a 360 MW fuel cell power plant** is expected to come into operation in 2018 to power an industrial district in Pyeongtaek, South Korea.

2.2 –Advantages of hydrogen and fuel cell vehicles

In the past, high investment costs and a still unsatisfactory efficiency rate of fuel cells prevented the development and the subsequent market introduction of hydrogen vehicles, thereby preventing also the creation of a proper fuelling infrastructure network. Consequently, the few hydrogen cars manufactured so far essentially for demonstration purposes resulted far more costly than any other car produced on a large scale. Thanks to the great progress made in research and development over the last decade, however, **fuel cells are now much more efficient than in the past, contain much lower amounts of platinum and last several thousand hours**. According to a report of the French Parliament[18], in

[17] Liquid hydrogen has to be kept at -253°C temperature, which entails high costs and lower overall efficiency.
[18] L. Kalinowski and J.-M. Pastor, **L'hydrogène: vecteur de la transition énergétique?**, Paris, 19 December 2013.

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2013 their life cycle had indeed reached 25,000 hours, corresponding to a travel range of approximately 150,000 Km. As regards the costs, a report of the US Department of Energy[19] shows how, assuming a production of 500,000 units a year, the average cost of a fuel cell for transport produced in 2013 would have been more than 50% lower than in 2006 at 55 US $/kW. This value is not too far from 30 US $/kW, the target set to bring the price of hydrogen and fuel cell technology close to that of conventional cars with internal combustion engine. These assessments seem to be confirmed by recent statements of Toyota staff, who claim to have reduced the production costs of the propulsion system and of the tanks of its hydrogen vehicles of 95 % compared to 2002 levels. In this context it should be stressed that a fleet of 119 Chevrolet Equinox (General Motors group), put on US roads in 2007 in the framework of the Driveway project, has travelled so far nearly 5 million km, with some units having passed 200,000 Km range[20].

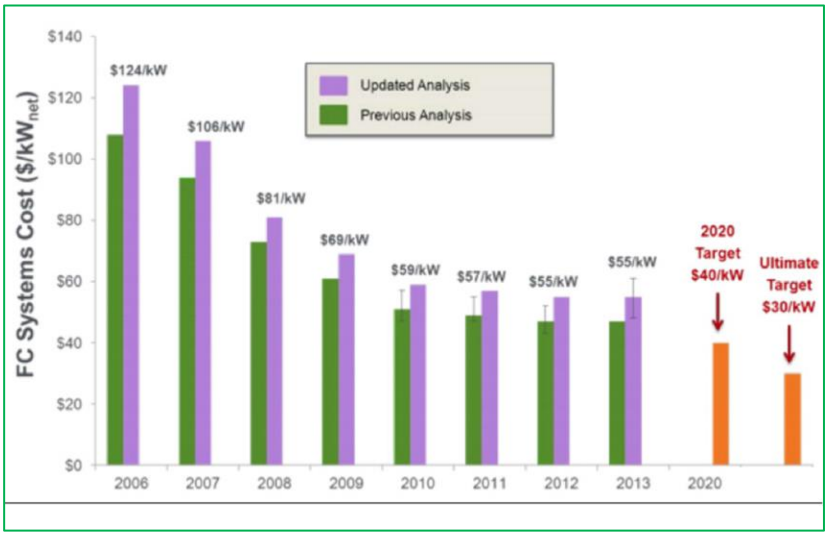

Figure 2 – Transport Fuel Cell System Cost Status and Targets, assuming a production of 500 thousand units per year. Source: U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy, ***2013 Fuel Cell Technologies Market Report****.*

In light of the above, it is not surprising that the McKinsey study cited earlier concludes that, **even in the absence of incentives, hydrogen and fuel cell cars can be competitive already in the medium term, also when compared to conventional powertrain cars**. The European Commission seems to share this view, as its **proposal for a directive on alternative fuels infrastructure**, transmitted to the European Parliament and to the Council in January 2013, required all those Member States where hydrogen fuelling points would be already available, to guarantee a minimum national coverage in order to allow the circulation of hydrogen vehicles within the entire national territory by 2020[21].

[19] U.S. Department of Energy, **2013 Fuel Cell Technologies Market Report**, Washington, D.C., November 2014.
[20] **GM Fuel Cell Fleet Tops 3 Million Miles. Chevrolet Equinox fuel cell vehicles driven in real world reach milestone**, 7 May 2014.
[21] Art. 5.1 of the directive proposal read as follows: "Member States on the territory of which exist already at the day of the entry into force of this Directive hydrogen refuelling points shall ensure that a sufficient number of publicly accessible refuelling points are available, with distances not exceeding 300 km, to allow the circulation of hydrogen vehicles within the entire national territory by 31 December 2020 at the latest".

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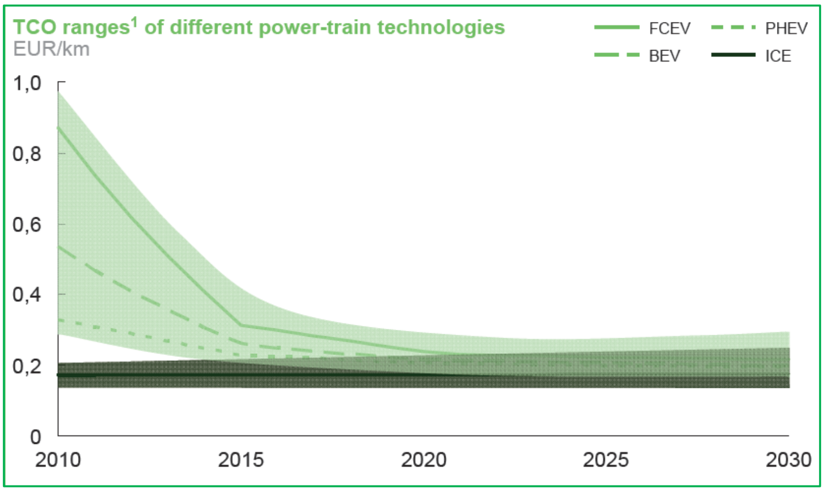

Figure 3 – TCO - total cost of ownersip – of different power-train technologies to 2030 in C/D vehicle category: fuel cell electric vehicles (FCEV), battery electric vehicles (BEV), plug-in hybrid electric vehicles (PHEV), internal combustion engine vehicles (ICE). Source: McKinsey study.

A hydrogen and fuel cell car is an electric car in all ways: it has an electric motor, it is quiet, it does not emit greenhouse gases, nor it emits other dangerous substances or fine dust. Hydrogen actually assumes the function of gasoline in a hybrid car: this saves significantly on the battery weight and volume. Furthermore, hydrogen cars provide a **travel range** and a **fuelling time** that are far better than any battery electric vehicles and are comparable to those of internal combustion engine vehicles of the same category. In addition, hydrogen fuel cell vehicles ensure satisfactory performances under **extreme temperatures**, unlike battery electric vehicles. In addition to the fuelling time, hydrogen cars have important advantages over battery electric vehicles, since they allow to travel even very long distances without fuelling and provide the same flexibility of use of traditional cars. Finally, if on the one hand battery electric vehicles have an efficiency rate "from well to wheel" better than any other powertrain, on the other hand the flexibility of the fuelling infrastructure of hydrogen vehicles make the latter way more suitable for a global market characterized by a **lack of sufficient smart grid infrastructure**, which is needed to ensure a mass deployment of battery electric vehicles and their proper integration into power management systems. In terms of infrastructure investment, also, even in countries having well developed electricity distribution grids, the **overall costs of fuelling infrastructure** for hydrogen prove to be less than those needed to develop the charging infrastructure of electric vehicles (battery or plug-in hybrids), following the mass deployment of hydrogen vehicles[22]. In preparing the Directive 2014/94/EU, the European Commission has shown how **the investments necessary to ensure a minimum number of fuelling points for hydrogen vehicles in Europe by 2020 are estimated at € 123 million**, compared to nearly € 8 billion necessary to ensure a minimum number of charging points for electric vehicles[23].

[22] McKinsey study quoted above.
[23] European Commission, Commission Staff Working Document - Impact Assessment Accompanying the document Proposal for a directive on the deployment of alternative fuels infrastructure – SWD(2013) 5 final Part I, Brussels, 24 January 2013.

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Which hydrogen for transport?

Hydrogen is generally considered as an energy carrier and not as an energy source, as it is rarely found in nature and must be derived from other molecules, thus consuming energy. In fact, in nature it is present in ophiolite or peridotite formations (which in Europe are mainly located in northern Italy, Greece, Cyprus, Turkey and Russia), but the real economic and environmental costs associated to the exploitation of these deposits are still being investigated. Most of the approximately 60 million tons of hydrogen produced annually worldwide is obtained through steam reforming of natural gas, liquid hydrocarbons or coal, a process that has the advantage of being cost-effective. However, steam reforming also releases greenhouse gases. In any case, the use of hydrogen produced in transport through steam reforming entails a significant reduction of emissions if compared to modern diesel cars. Moreover, hydrogen can also be produced through water electrolysis, using only electricity generated by renewable energy sources, thus ensuring zero emissions throughout the process. It is also worth noticing that the electricity required for electrolysis can also be produced by a plant that is not connected to the grid and is interlocked with one or more electrolysers: this may allow, among other things, to exploit the full potential of unpredictable renewable sources, also in regions without adequate electricity transmission and distribution infrastructure.

The cost of hydrogen used for transportation may vary significantly, depending on the technology used for its production. The model of the McKinsey study cited earlier leads to the conclusion that **hydrogen can be produced and sold at competitive prices already in 2020**, and that in 2025 its cost will be 70% lower than in 2010[24]. The hydrogen distributed today in Bolzano is produced through electrolysis using electricity generated by hydro and is sold at € 13.98/kg, a value that makes the cost of a full tank roughly equivalent to that of a full tank of diesel. With an **incentive scheme** designed to promote the production of hydrogen from renewable sources, it would be possible to ensure a competitive market price, considering also the **possible use of hydrogen surplus in the framework of Power-to-gas projects (P2G)**[25]. In Germany, where the industry aims at developing up to 1,000 MW of P2G capacity by 2022, hydrogen produced through electrolysis is considered as biogas, and as such it benefits of a dedicated purchase tariff.

2.3 – Vehicle approval and fuelling infrastructure

In the European Union, hydrogen vehicles do not fall fully within the scope of the **directive on the approval of motor vehicles (2007/46/EC)**, as their technical characteristics are very different from those of conventional vehicles. This is why their approval is currently governed by the **EC 79/2009 Regulation** and by the **EC 406/2010 Regulation**, which provide for a **single authorization procedure** that is valid in all member states. As regards hydrogen fuelling infrastructure, the 2014/94/EU directive seen above establishes **minimum requirements** for their construction and imposes **common technical standards**[26].

[24] In the United States, hydrogen for transport is already today potentially cost competitive with gasoline, thanks to the shale gas bonanza. Cf. M. Kratochwill and H. Yang, **Shale gas could drive economics of hydrogen fuel-cell vehicles**, 1 August 2015.
[25] **Power-to-Gas (P2G)** is the process by which hydrogen is produced through electrolysis, mainly using energy from renewable sources, where it is abundant and cheap. This solution originates from the need to reduce imbalances between energy supply and demand in presence of unpredictable electricity generation from renewable sources, using excess electricity. Hydrogen can be stored and be used to generate electricity during peak times, as a transport fuel or as a gas to be injected into natural gas distribution grid.
[26] Cf. Annex II Directive 2014/94/UE.

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3. HYDROGEN TRANSPORT IN EUROPE

3.1 – Public support at EU level

As of today there are more than 500 hydrogen vehicles circulating in the world, which get the hydrogen at approximately 200 fuelling stations, generally built in the framework of demonstration projects. These include the **HyFIVE European project**: launched in April 2014, it provides for the deployment of 110 hydrogen cars and the opening of six new fuelling stations in the UK, Italy, Denmark, Austria and Germany, for a total investment of € 38 million, co-financed by the European Union with € 18 million. Car manufacturers who participate to the project with own models are BMW, Daimler, Honda, Hyundai, and Toyota.

At European Union level, hydrogen and fuel cell rank among the eight strategic technology initiatives developed under the **SET Plan (Strategic Energy Technology Plan**). In this framework, the research, development and demonstration funding available in the field of hydrogen and fuel cells, both for stationary and for transport applications, fall within the scope of **Horizon 2020**, the multiannual programme for research funding (2014-2020), which replaced the 7th Framework Programme on the expiry of the latter. However, the **€ 665 million of funds available for the co-financing of hydrogen and fuel cell projects** are neither managed directly by the European Commission, nor by the **EASME** (Executive Agency for Small and Medium-sized Enterprises), but by the **Fuel Cell and Hydrogen Joint Undertaking (FCH JU)**, a public-private partnership launched in 2003[27]. This allows to concentrate the allocation of funds on those sectors and applications that industry and research organisations consider priority and more likely to be developed at industrial scale.

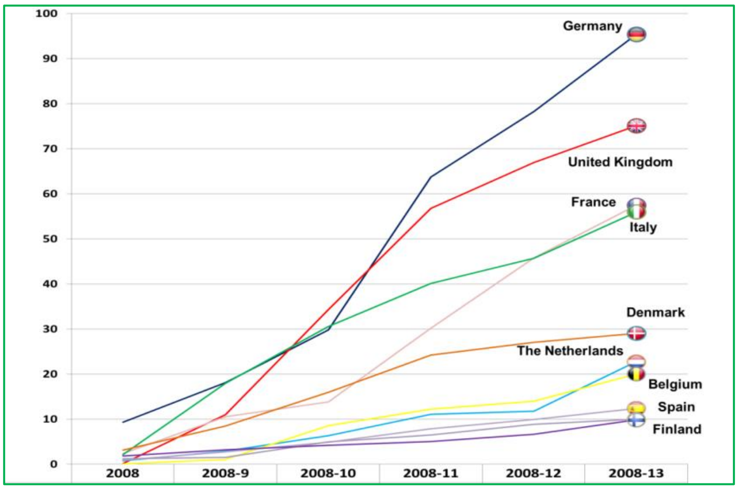

Figure 4 – FCH JU funding for R&D&D programmes by EU Member state, 2008-2013 (in million euro). Source: Fuel Cell and Hydrogen Joint Undertaking.

[27] As of today, the FCH JU has co-funded 155 projects for an overall value of 900 million euro. These include demonstration activities that have entailed the opening of 20 hydrogen fuelling stations, as well as the deployment of 260 cars and more than 74 buses.

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The **Connecting Europe Facility (CEF)**[28], with a **budget of over € 26 billion for the transport sector in 2014-2020**, makes eligible for grants the deployment on the TEN-T Core Network of new technologies, including infrastructure for alternative clean fuels. More than € 11 billion of the CEF are set aside for investments in those **Member States that are eligible for the Cohesion Fund**. In addition, the deployment of infrastructure for alternative clean fuels on the broader comprehensive network will be able to receive financial assistance from the CEF in the form of procurement and financial instruments, such as project bonds. Specific funding is equally available for actions that exploit the synergies of at least two sectors between transport, energy and telecommunications.

The **European Fund for Strategic Investment (EFSI)**, a key tool of the **"Juncker Plan"** for growth in Europe[29], will also combine up to € 21 billion already available between EIB funds, CEF and Horizon 2020 to stimulate up to € 252 billion of private investment in the areas identified as priorities. These include transport, including infrastructure for alternative fuels supply, renewable energy, broadband, training, research, development and SMEs. To be eligible for funding, projects will have to be launched within three years from the launch of the Fund, which will expectedly be operational by the summer 2015[30].

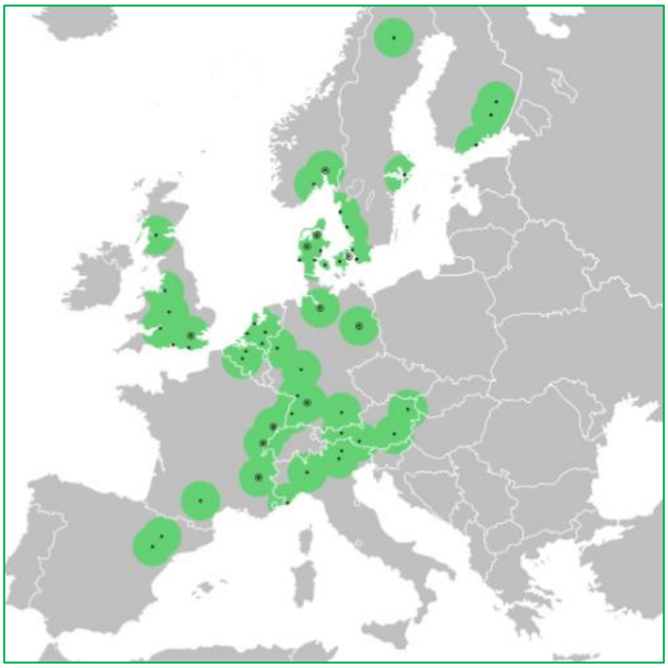

Figure 5 – Existing network of hydrogen fuelling stations and other stations already planned and financed for 2014-2015. Each dot represents one station, while dots with a small black circle around represent several HRS. Green areas represent a radius of 106 km from each fuelling station, which is considered to be a realistic distance for cars having a driving range of more than 500 Km. Source: HIT, ***Synchronised Implementation Plan****, December 2014.*

[28] Connecting Europe Facility (CEF), set up by **EU Regulation 1316/2013 of 11 December 2013** to co-fund projects in the transport, energy and broadband sectors.
[29] Cf. **European Council Conclusions**, Brussels, 18 December 2014.
[30] Cf. Sonja van Renssen, **Juncker's €300bn investment gamble – and what it might mean for energy**, Energy Post, 27 November 2014.

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3.2 – Public support at Member State level in the European Union

3.2.1 – Germany

The guidelines on State aid for environmental protection developed at the EU level recognize the opportunity to provide public support to promote the infrastructure development that is necessary for alternative fuels supply. Several European countries have adopted programmes to develop hydrogen mobility, which may be particularly ambitious, as it is the case for Germany. Since December 2002, the **Clean Energy Partnership** brings together 19 industrial partners, **coordinated by the Federal Ministry for Transport and Industry,** with the aim of testing and demonstrating the use of hydrogen as a transport fuel. The Federal Government, individual states (*länder*) and the industry have pledged € **1.4 billion over the period 2007-2016**, in the framework of the **National Innovation Plan (NIP)**. The hydrogen fuelling points available in the country will be **50 by the end of 2015**, for a total investment estimated at around € 40 million, and the hydrogen cars in circulation at that time should be about 5,000. Hydrogen station locations were determined as a function of potential demand, focusing initially in the metropolitan areas, which will be connected through special hydrogen corridors. Furthermore, the **Action Plan of the H_2 Mobility Initiative project (H_2MI)**, developed by Air Liquide, Daimler, Linde, OMV, Shell and Total, provides that the number of hydrogen refuelling points available at national level will have to reach **400 units by 2023, for an overall investment of around € 350 million**. Finally, **hydrogen refuelling points should be around 1,000 by 2030, when the number of hydrogen cars circulating at national level is expected to be around 1.8 million**. It is worth noting that, as it is the case in other countries, investment in hydrogen mobility does not exclude other commitments in public and private resources in favor of other forms of alternative mobility, including battery electric vehicles: the German government has indeed allocated substantial funds with the goal of having 1 million battery electric vehicles on the roads by 2020, a target which however seems unrealistic in light of recent findings[31].

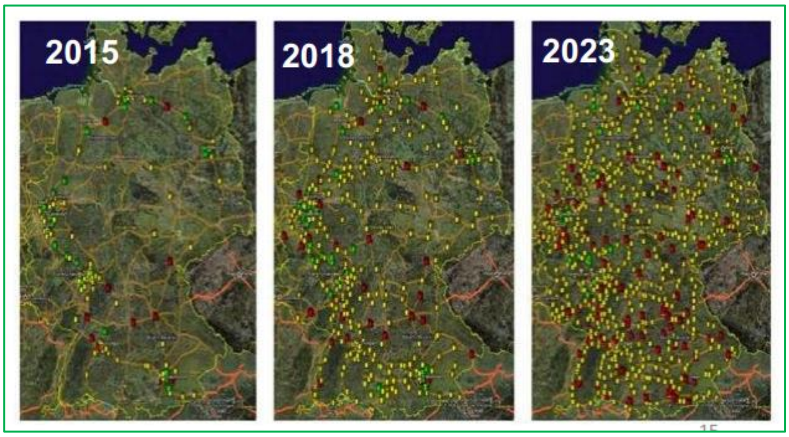

Figure 6 – Hydrogen fuelling infrastructure for transport in Germany between 2015-2023. Source: Fuel Cell and Hydrogen Joint Undertaking.

[31] **Germany to miss target for one million e-cars by 2020**, Euractiv, 3 December 2014.

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3.2.2 – United Kingdom

In the United Kingdom, with the **H_2Mobility** initiative, Government and industry have planned the opening of **65 hydrogen fuelling stations in the main British cities by 2020**, for an estimated investment of UK £ 62 million (equivalent to around € 78 million). In order to ensure adequate coverage of the territory at the moment hydrogen cars are expected to be deployed on a mass scale (about 1.6 million vehicles), **the refuelling points will have to be 1,150 by 2030**. The total investment needed for the refuelling infrastructure before reaching the break-even point between costs and revenues will amount to UK £ 418 million (about € 535 million). Fifteen of these refuelling points are expected to be operational by the end of 2015, also thanks to a UK £ 11 million (more than € 14 million) grant allocated by the Government in September 2014. **51% of the hydrogen used in transport should be derived from renewable sources through water electrolysis**, thus ensuring a 60% emissions reduction in 2020 and 75% in 2030, if compared to the use of an equivalent number of traditional powertrain cars.

3.2.3 – France

The French government did not mention hydrogen mobility among the measures listed in the **draft law on the energy transition**. The transport sector represents 27% of total greenhouse gases emissions in France and the Government has given preference to battery electric vehicles, given also that the Renault and PSA groups have invested heavily in this technology[32]. While public fleets will have to be composed at least by 50% of battery electric vehicles, plug-in hybrids or other low-emission vehicles by 2020, by 2030 some 7 million charging points for electric cars or plug-in hybrid cars have to be installed on public areas.

France, however, is also home to various companies that are investing heavily in fuel cell and hydrogen technologies and rank among the leaders of a number of projects aiming at promoting the development of mobility schemes based on alternative fuels. In 2011, a group of ADEME (Agency for the Environment and for Energy Management) experts developed a **strategic roadmap**, which provides four different scenarios for 2050 and identifies specific research and demonstration priorities for the industrial development of hydrogen technologies, for both stationary and transport applications. Following this study, in 2013 the ***Mobilité Hydrogène France*** consortium, bringing together a number of stakeholders and public bodies (including the Ministry of Ecology, Sustainable Development and Energy) started working on a **National Plan for the deployment of hydrogen fuelling infrastructure**, developed in the framework of the **Hydrogen Infrastructure for Transport (HIT)** project and finalized in 2014. In the absence of significant state funding for hydrogen fuelling stations, the development strategy for hydrogen mobility in France lays on the **progressive deployment of**

[32] With a market share of 31%, Renault is market leader in Europe for electric vehicles. To date, the Renault-Nissan Alliance has sold 200 thousand electric vehicles all over the world, around 75% of which were produced by Nissan. Nevertheless, actual sales have been much lower than previously expected: in October 2011, Carlos Ghosn stated that EV sales of the Alliance would reach 1.5 million by 2016. Cf. Alessandro Vai, **Elettriche, Renault-Nissan a quota 200 mila. Ma l'auto a batteria non decolla**, Il Fatto Quotidiano, 6 December 2014.

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corporate fleets, which justify investments in fuelling stations that can be opened to private vehicles as well. Besides the two hydrogen refuelling points available today, between 20 and 30 new stations should be inaugurated over the next months, with a target of reaching **150 refuelling points by 2020**.

3.2.4 – Italy

Despite two different attempts in the past (2004-2005 and 2009-2010), Italy remains the only major European country without a national platform promoting public-private partnerships in the field of hydrogen and fuel cells. This is partly due to substantial lack of interest demonstrated so far by the largest industrial groups and to the **priority given to natural gas and electricity as alternative fuels for transport**. As a matter of fact, Italy is the main market in Europe for natural gas vehicles, whereas Italian companies produce over 60% of the components in this sector at world level and export all over the world[33]. In order to encourage the use of biomethane in transport, the regions may adopt simplified authorization procedures for the construction of new refueling points and the adaptation of the existing ones[34]. In addition to this, in 2013 the Ministry of Infrastructure and Transport worked on a **National Infrastructure Plan for the recharge of electric vehicles (PNIRE)**, recently adopted by the government,[35] to ensure minimum uniform levels of accessibility to charging points throughout the country. Based on this, in the short term a network of charging infrastructure will be developed in urban and metropolitan areas, and should be extended later to suburban areas and highways. The charging points available to the public will have to be 130,000 by 2020. **For the PNIRE implementation, the Transport Ministry has set up a specific fund that will co-finance infrastructure investments, with a budget of more than € 47 million**.

Nevertheless, the **Italian Hydrogen Association (H_2IT)** is continuing to work towards establishing a national platform that is intended to serve as a **steering committee to coordinate the many research, development and demonstration initiatives underway in the country and to plan a coherent long-term strategy**. In this regard, in February 2014 the Industry, Trade and Tourism Committee of the Italian Senate issued a **resolution** which clearly stated that a national hydrogen platform should be launched as soon as possible, also with the aim of allowing Italian industry and research bodies to take full advantage of the EU funds available under Horizon 2020.

Six Italian regions (Piedmont, Lombardy, Veneto, Tuscany, Latium, and Abruzzo) as well as two autonomous provinces (Trento and Bolzano) adhere to **HyER**, a Brussels-based association that promotes battery electric and fuel cell vehicles across European regions, including through participating to demonstration projects as a partner. Various companies are working on the launch of the **Italian**

[33] Italy represents 77% of the European market for natural gas vehicles and 26% of Europe's LPG vehicles market. Cf. **Green economy e veicoli stradali: una via italiana**, Fondazione per lo Sviluppo Sostenibile, 16 December 2014.
[34] **Decreto legislativo 3 marzo 2011, n. 28**.
[35] Approved by a decree of the Prime Minister of 26 September 2014, published in Italy's official journal no. 280 of 2 December 2014.

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Initiative for Hydrogen Mobility (InIMI), which aims at developing an **Action Plan** for the deployment of a sufficient number of hydrogen refuelling points across the country by 2025.

Incentive scheme for sustainable mobility in Italy

In Italy, "hydrogen vehicles" fall within the scope of the **national incentive scheme for sustainable mobility**, managed by the Invitalia Agency on behalf of the Ministry of Economic Development. The current incentive scheme was launched by a 2012 Decree, which pledged up to 120 million euro between 2013-2015. The grants aim at encouraging the purchase of alternative fuel vehicles (electric, hybrid, methane, biomethane, LPG, biofuels and hydrogen) emitting up to 120 g/km CO_2. Half of the 2014 budget was set aside for company vehicles and for public transport, including car sharing and rental, but were available only provided that the buyer scrapped an older vehicle. This rule does not apply to the funds (around 50%) available for vehicles emitting less than a 95 g/km CO_2, open to all kinds of buyers, including individuals. However, the reduced availability of funds for individuals has resulted in a rapid depletion in both 2013 and 2014.

Despite the current lack of a coherent framework at the national level, various initiatives are underway to encourage the deployment of clean, hydrogen-based mobility solutions. **With the H_2Südtirol programme, Alto Adige-Südtirol aims at reaching energy self-sufficiency and at curbing transport emissions to zero by 2050**. An overall 24 hydrogen fuelling points are planned throughout the province of Bolzano over the next six years. As from 2017, another four hydrogen fuelling points are planned along the Italian branch of the "**Green Corridor**", which will allow travelling from Modena to Stuttgart via Bolzano and Munich with hydrogen vehicles.

The first hydrogen production and distribution facility in Alto Adige was inaugurated in June 2014. Hydrogen is produced by electrolysis using hydroelectricity generated in the area, while other planned stations will use electricity from unpredictable renewable energy sources, coupled with storage infrastructure. With a capacity of 1.5 million cubic meters of hydrogen produced every year, the Bolzano station is reportedly able to provide refuelling for around twenty buses or nearly a thousand cars. To date five Daimler buses entered service with the local public transportation company SASA SpA, together with ten Hyundai ix35 FC SUVs, available for leasing. Most of the project was financed through regional funds of the 2007-2014 ERDF, while the purchase of the vehicles was co-financed by the FCH JU in the framework of the **CHIC (Clean Hydrogen in European Cities)** and of the **HyFIVE (Hydrogen for Innovative Vehicles)** projects, to which various other European cities participate.

Apart from Bolzano, hydrogen fuel cell buses have been acquired by the municipalities of **Milan** (3) and **Sanremo** (5), also in the framework of the CHIC project. Another 5 hydrogen fuel cell buses will soon be deployed in **Rome**, in the framework of the 3Emotion European programme. In **Val di Fiemme** (Province of Trento), two minibuses assembled by the local firm **Dolomitech** are also in use. Finally, following the successful demonstration of the **Mhybus project**, a fleet of

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10 **BredaMenarinibus** buses powered by hydromethane will soon enter service in **Ravenna**.

3.2.5 – Other European countries (EU and extra-EU)

Denmark, Sweden and Norway adhere to the **Scandinavian Hydrogen Highway Partnership**, a public-private partnership that aims at making Scandinavia one of the first regions in Europe to develop a comprehensive network of hydrogen refueling stations. The target is to open **45 hydrogen refuelling stations by the end of 2015,** that should serve around 100 hydrogen buses, 500 vehicles and 500 special vehicles. In this context, Denmark has adopted its own **National Plan** for the deployment of hydrogen fuelling infrastructure for transport, developed under the **Hydrogen Infrastructure for Transport (HIT)** project, funded through the TEN-T budget.

Under the same project were also developed the **national plans of Sweden and of the Netherlands**[36], where the number of hydrogen fuelling stations is expected to be 5 by 2016 and 30 by 2017 respectively. In addition, under the new HIT-2-Corridors project the national Plans of **Finland, Poland and Belgium** will also be developed, together with a Plan for the **region of Riga (Latvia)**.

In **Switzerland**, finally, the H_2-Mobility Initiative consortium plans to begin the market introduction of hydrogen vehicles throughout the country by 2016, with the aim of having **between 500 thousand and 800 thousand units along Swiss roads by 2030**, with 15 hydrogen fuelling stations entering into service over the next few years[37].

[36] As seen above, the Hydrogène Mobilité France plan was also developed under the HIT project.
[37] A. Martin, P. Dietrich, **Analysis of the Situation to Realize an Initial Market for H2-Vehicles in Switzerland**, H2-Mobility Swiss, 2013.

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4. HYDROGEN TRANSPORT IN THE REST OF THE WORLD

4.1 – East Asia: South Korea, Japan, China

Outside Europe, the most important programmes are being developed in **South Korea** and in **Japan**. The Seoul government, which has allocated the equivalent of over € 470 million between 2004 and 2011, plans to open **500 hydrogen fuelling stations by 2020**, by which year the number of hydrogen vehicles in circulation should reach 50 thousand units. This move should lead to create around 560 thousand new jobs. Tokyo, which has allocated the equivalent of about € 800 million between 2008 and 2012, plans instead of reaching the number of **one thousand fuelling stations by 2025, by which year the number of hydrogen cars circulating in Japan should be around one million.**

In the absence of a mass production and of economies of scale, the price of the first hydrogen cars produced in series will necessarily be high. To facilitate the development of a market, the Japanese government has therefore recently announced a policy of **generous subsidies and fiscal incentives**, in the framework of a **Roadmap aiming at promoting the hydrogen economy**, following the adoption of the **4° Strategic Energy Plan** (April 2014). Announced measures include the renewal of public fleets with hydrogen cars and a **grant scheme of 2 million yen (around € 14 thousand) for each new hydrogen vehicle sold**[38]. The goal is to make sure that the purchase price of a hydrogen car falls to the equivalent of about € 15 thousand by 2025. This measure in fact appears to be compatible with projections developed by the industry, which in the absence of incentives foresees a drop in hydrogen car prices of C/D segment from an average of € 60 thousand in 2015 to € 30-35 thousand in 2020 and € 21-25 thousand in 2030[39].

In **China**, 5 hydrogen fuelling stations are planned for the thousand hydrogen cars that should be in circulation in the country by the end of 2015. In the course of 2014, a small fleet of three hydrogen cars of **SAIC Motor Corp.** travelled through 64 cities and 15 provinces, covering 10,000 km in 52 days[40]. To effectively tackle the high levels of air pollution in urban areas, **the government aims at having in circulation in the country up to 5 million "new energy" cars by 2020**. This category includes only battery electric, hybrid and hydrogen fuel cell vehicles, which benefit of a system of incentives until 2020 and a purchase tax exemption until 2017. Furthermore, by 2016 at least 30% of newly registered vehicles available to public authorities must run on "new energy" technology[41].

[38] Japan Moves to Fast-Track Cars Powered by Hydrogen Fuel Cells, New York Times, 26 June 2014.
[39] Cf. McKinsey quoted above.
[40] Record in China: 10,000 km traveled by three cars fueled with hydrogen provided by Air Liquide, 17 December 2014.
[41] China Requires 30% of State Cars Use Alternative Energy, Bloomberg, 14 July 2014.

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4.2 – United States

There are other examples of government activities in support of hydrogen cars and zero-emission mobility in general. In the **United States**, the Bush administration strongly supported the development of hydrogen-based clean transport, but the focus switched to "zero emissions vehicles" more in general over the past years, with the aim of including other forms of clean vehicles, in particular battery electric vehicles. The target at federal level is to cut net oil imports by 50% by 2020[42]. By the same year, CO_2 emissions will have to be 17% lower than in 2005, whereas in the long term the emissions reduction will have to reach 83% by 2050[43]. New standards introduced at the federal level in 2012, also involve **doubling the efficiency of light-duty passenger vehicles**, which on average will have to emit no more than 90 g CO_2/km and will have to be able to travel more than 23 km per liter of fuel by 2025[44]. Eight States, representing around 23% of the car market at federal level (California, Oregon, Connecticut, Maryland, Massachusetts, New York, Rhode Island, and Vermont) have agreed on an ambitious **Action Plan**, aiming at creating the regulatory and market conditions that are necessary to have 3.3 million zero emission vehicles on the roads of these States by 2025, against the 200 thousand available today at federal level. **California** adopted a policy by which at least 15% of all newly registered vehicles will have to be zero emission by 2025. A **Roadmap** was adopted in 2012 in the framework of the ***California Fuel Cell Partnership***, providing for the opening of at least 68 hydrogen fuelling stations by early 2016, with the aim to reach **100 hydrogen stations by 2024**. At least US $ 20 million will be made available every year by the local government to finance investment and running costs of new stations, until the target is reached. **At least one third of the hydrogen for transport will have to be produced from renewable energy sources**, and **hydrogen cars circulating in California should be 50 thousand by 2017**. Finally, in March 2013 was set up **H_2 USA**, a public-private partnership that includes the US Department of Energy, which aims at coordinating the initiatives for infrastructure deployment needed to develop hydrogen mobility throughout the country.

[42] **Reducing America's Dependence on Foreign Oil As a Strategy to Increase Economic Growth and Reduce Economic Vulnerability**, The White House, 29 August 2013.
[43] Cf. **President to Attend Copenhagen Climate Talks**, The White House, 25 November 2009; **Cutting carbon pollution, protecting American communities, and leading internationally. President Obama's Climate Action Plan Progress Report**, The White House, Washington, D.C., June 2014.
[44] **Obama Administration Finalizes Historic 54.5 MPG Fuel Efficiency Standards**, The White House, 28 August 2012.

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5. HYDROGEN CAR MANUFACTURERS

5.1 – The development programmes of the main car manufacturers

After over a decade of research, development and demonstration investments, **hydrogen and fuel cell technology for transport applications is now ready to move to the marketing stage**[45]. From what seen above it is not surprising that automakers having invested the most on hydrogen mobility are Hyundai, Toyota, Daimler, Honda, General Motors and BMW[46]. In 2013, **Hyundai** was the first car manufacturer starting series production of the hydrogen version of one of its models, the ix35 (a SUV known as Tucson in North America). Initially intended only for leasing to public or business fleets, the ix35 FC are produced at the rate of one thousand units per year and the production should increase to 10 thousand units per year, after 2015. During the summer 2015 **Toyota** will start selling outside Japan its first hydrogen sedan available in the market, the **Mirai**[47], whereas the **Lexus** brand should propose a hydrogen version of its LS model in 2017. During the spring 2016 **Honda** should also introduce a hydrogen model for the mass market, having also concluded an agreement for the development of fuel cells and new generation tanks with **General Motors**.

Toyota Mirai: the sedan of the future

Mirai ("Future" in Japanese) is the first car powered by hydrogen to be produced in series and to be officially put on sale to the general public.
The 154 horsepower car, which has a 0-100 Km/h acceleration of 9.6 seconds and a range of over 650 Km, is produced in the Motomachi factory (Japan), previously used for the production of the Lexus LFA. The road tests began in 2008 and led 100 prototypes to travel at least 20,000 km each along the roads of Japan and of the US, for an overall distance of over 2 million km. Following these tests, the Toyota technical staff concluded that the Mirai is at least 1.7 times more efficient than a hybrid car.
The Mirai has been available in Japan from December 15, 2014 and will be for sale in Denmark, Germany and the UK as of summer 2015, while sales in the United States are planned to begin in autumn 2015. The sale price will be different depending on the market: in Japan it is equivalent to about 49 thousand euro including taxes, but with government incentives it falls to just over 35 thousand euro; in the United States it will be equal to approximately 46 thousand euro, but also in this case it will go down to about 36 thousand euro, thanks to the incentives available at state's and federal level; in Germany it should instead be sold at around 66 thousand euro (plus VAT). As for the expected sales, the goal is to reach 400 units in Japan by the end of 2015, between 50 and 100 cars a year in Europe in the early years and not less than 3,000 units in the US by the end of 2017. The Mirai will also be available for leasing, a formula that will include fuel costs. The warranty provided covers eight years or 160 thousand km. Toyota plans to produce up to 700 units by the end of 2015 and increase production later, depending on how the demand evolves. The goal is to sell tens of thousands of units in all regions of the world where refuelling infrastructure is available by 2020.

[45] According to the McKinsey study quoted above, in 2010 demonstration fleet had travelled more than 15 million Km all around the world.
[46] In September 2009 the main world car manufacturers (Daimler AG, Ford Motor Company, General Motors Corporation/Opel, Honda Motor Co., Ltd., Hyundai Motor Company, Kia Motors Corporation, Renault SA/Nissan Motor Co. Ltd. Alliance and Toyota Motor Corporation) signed a letter of understanding where they announced the objective to begin hydrogen car sales by 2015, should enough hydrogen fuelling stations be available.
[47] Until 2020 Toyota will share free of charge around 5,680 licenses on its own fuel cell patents, with the aim of encouraging the rollout of hydrogen vehicles.

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Daimler should begin mass production of hydrogen models for the general public in 2017, under an agreement with **Ford** and **Nissan**, starting with 50 thousand units per year. Fuel cells will be produced in the Burnaby factory in British Columbia (Canada), in which the German group has invested the equivalent of about € 36.5 million. As for **BMW**, despite the Bavarian manufacturer having developed liquid hydrogen solutions for internal combustion engine vehicles, it will use under license the fuel cells drive system developed by Toyota and will introduce its own models on the market by 2020. Other car manufacturers that will introduce their own hydrogen and fuel cells models in the market over the next few years include **Kia** (Hyundai Group) and **General Motors**. The **Volkswagen/Audi Group**, which will start mass production and marketing of hydrogen vehicles after 2020, concluded a multi-year contract for fuel cells development with the Canadian company Ballard, valued between € 42 and 70 million[48]. Volkswagen has also concluded an agreement with the Chinese group **SAIC** on hydrogen supply infrastructure and fuel cells standards[49]. For the time being, the **French groups** seem to focus exclusively on battery electric cars, despite the partnership agreement concluded by Nissan with Daimler, while **the Anglo-Dutch group FCA** focusses on the development of natural gas and LPG technologies[50].

5.2 – Niche hydrogen vehicle manufacturers

Given the high price of hydrogen cars, in the early years the only models available on the market will be sedans or SUVs, which will compete with models falling within the middle and upper market segments. In addition to large manufacturers, however, **small independent producers** have developed compact cars that are the result of research and development carried out for over a decade. These include **Microcab**, a spin-off of Coventry University, in the United Kingdom. Other small firms include **Riversimple** (United Kingdom) and **Elano Mobile** (Germany).

Niche producers do not point necessarily on sales to end customers, but target a niche market, that of **public or private fleets in urban areas**, such as taxis, vehicles for the transport of goods in cities (mini-van), or even car sharing and short term rental. It is in this context that Microcab is working on the development of an **innovative and integrated sustainable mobility concept for urban areas**, using hydrogen produced exclusively from renewable energy sources, which it intends to implement in the Mediterranean region. Combining a fleet of 200 hydrogen vehicles deployed for a free-floating car sharing scheme to a small fleet of five hydrogen buses or trams for public transport, in a city of no more than 300 thousand inhabitants, Microcab expects to be able to cut at least 4,000 tons of CO_2 in just five years.

[48] Cf. Ballard Signs Long-Term Engineering Services Contract To Advance Volkswagen AG Fuel Cell Automotive Research Program, 6 March 2013.
[49] SAIC Motor, Volkswagen cooperate on fuel cell and hybrid tech, 28 March 2014.
[50] In the past FIAT built a few prototipes of hydrogen fuel cell vehicles using two of its existing model, such as the Seicento and the Panda, in the framework of demonstration projects funded by the Italian Ministry of the Environment. Over the last years, however, the Fiat Research Centre (CRF) has stopped any activities in this field.

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Microcab: the city car for all seasons

Microcab has developed a hydrogen vehicle for 4 people for an essentially urban use, a total weight of 750 kg, a top speed of 90 km/h and a range of about 280 km. The car is not the adaptation with hydrogen and fuel cells of an existing model already available in the market, as it is the case for most of the hydrogen vehicles currently circulating, but was designed and built around the 350 bar compressed hydrogen tank and the fuel cell. This resulted in an effective optimization of space and weight balance. The chassis, made of aluminum, is produced by Lotus, one of the project partners. Unlike other manufacturers, Microcab also offers the possibility to recharge the car battery to make it work even in the absence of hydrogen fuelling infrastructure: it can therefore be considered as a plug-in hybrid vehicle, where the extended range is ensured by hydrogen instead of gasoline, and a fuel cell and an electric motor instead of an internal combustion engine. To date Microcab has deployed a dozen cars in the region of the English Midlands, in the framework of **SWARM** (*Demonstration of Small 4-Wheel fuel cell passenger vehicle Applications in Regional and Municipal transport*), a project co-financed by the FCH JU. SWARM promotes the demonstration of 90 small hydrogen and fuel cell vehicles as well as the opening of three new hydrogen fuelling stations in three regions of Belgium, England and Germany, aiming also at establishing a hydrogen corridor between Scotland, Germany, Belgium and Scandinavia. Microcab is also involved in the **LREV** project (*Hydrogen for Long-Range Electric Vehicle*), which investigates the possibilities offered by the use of advanced materials to refuel hydrogen without compression.

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6. BUSES, FORKLIFTS AND OTHER TYPES OF TRANSPORT

6.1 – Hydrogen buses

Besides cars, it is worth noting that hydrogen and fuel cell buses are already a reality in several urban areas, usually as part of demonstration projects. **There are about 50 buses running on hydrogen in the world today**, mostly in European and North American cities. Nevertheless, about 75% of the buses available in the world circulate in developing countries, which represent the biggest market for these vehicles today. Demonstration projects therefore can also be run in other geographical areas: three hydrogen fuel cell buses are currently in the roads of **São Paulo, Brazil**, in the framework of a **project for urban emissions reduction** funded by the UNDP. More generally, the largest hydrogen and fuel cell bus fleet, consisting of 20 units, was until recently in service in the city of Whistler, British Columbia (Canada). The bus fleet, manufactured by New Flyer, was inaugurated on the occasion of the Winter Olympics of 2010 and was used until March 2014, as part of a **demonstration project** worth the equivalent of more than € 63 million. **Norway** will soon take the lead in hydrogen bus transport: 30 hydrogen buses will indeed be deployed in the streets of Oslo by 2030.

The main hydrogen bus manufacturers include Ford, Hyundai and Toyota, besides the European groups Daimler, MAN, Solaris, Van Hool and VDL Bus & Coach. During the **FCH JU 2014 Stakeholder Forum**, the latter companies signed a **letter of understanding** on the development and market introduction of fuel cell buses, paving the way for the **deployment of 500 to 1,000 hydrogen buses across Europe between 2017 and 2020**. In the absence of mass production, the current price of hydrogen and fuel cells buses is still much higher than that of diesel buses of the same category, averaging around € one million.

Automotive groups have adopted a **standard for compressed hydrogen** at 70 MPa (700 bar), in order to reduce the tank size, while keeping the vehicle safe. However, high compression rates also imply high costs for hydrogen as a transport fuel. This is why hydrogen buses use lower compression tanks of 35 MPa (350 bar), as the tank size is not an issue. Such standard is also being used for small cars and for forklifts, which have a largely sufficient range even at a 350 bar pressure.

6.2 – Hydrogen forklifts

Another type of hydrogen mobility is also practiced in the production sites of large companies or in sorting centers of several large retail chains. **In North America alone around 5,400 hydrogen fuel cell forklifts are currently in use**, as they have a much longer range than battery electric forklifts and can be refuelled in only three minutes. Industrial groups such as Walmart, Coca-Cola and Nestlé, among others, have switched to hydrogen, which they found more convenient also given the lower costs for energy and maintenance.

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6.3 – Other hydrogen transport modes

It needs to be emphasized that hydrogen mobility is not limited to road transport only, but can be applied to various other modes as well. The French group **Alstom** intends to launch the production of 40 hydrogen and fuel cell trains for regional transportation in its Salzgitter factory (Germany), following an agreement with the transport authorities of four different German states (*länder*). Hydrogen and fuel cells would in fact be an innovative solution available to local rail companies to eliminate the emission of greenhouse gases, particulate matters and other harmful substances at the time of **replacement of diesel locomotives** currently in service along non-electrified railway tracks. This would allow transport companies to **save on the costs associated with the installation and maintenance of power lines along the railway tracks**, while maintaining a zero emissions level. The investment should be completed in 2020, following a test phase with two prototypes for passenger transport in 2018[51]. Also, **by the summer 2015 will be circulating in Dubai so-called *train trolleys***, double-decker, single-wagon trams with no doors, which will be powered by hydrogen and fuel cells and will be used by tourists and residents alike[52]. However, it is China that seems to be a particularly promising market for hydrogen fuel cell trams: **CSR Sifang** has developed the **first HFC tram intended for mass production in the world**. The tram, which has over 60 seats and can carry more than 380 passengers, can be refilled with hydrogen in three minutes and can then run for 100 km at speeds as high as 70 km per hour[53].

Finally, hydrogen and fuel cells can be a solution for **zero-emission transport along inland and sea waterways**. In addition, the pollution caused by the reversal of fossil fuels in the ports may gradually decrease through the use of these technologies. In Venice, in the autumn of 2015 is expected to come into service **Hepic (Hydrogen electric passenger boat Venice)**, a 40-seat boat similar to those currently in service from the local airport to the historical centre, which will be equipped with a hydrogen fuel cell propulsion system[54].

[51] Fuel cells to power regional trainsets, Railway Gazette, 24 September 2014.
[52] Dubai Trolley: new rail link to connect downtown, Gulf News, 4 January 2015.
[53] World's first hydrogen tram rolls off assembly line, Xinhuanet, 19 March 2015.
[54] Hepic: battello a zero emissioni per Venezia, Orizzonte Energia, 11 March 2015.

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CONCLUSIONS

Hydrogen mobility is going through a development phase in the most advanced regions of Europe and of the world. The **unique features of hydrogen and fuel cell vehicles** – ability to contribute significantly to the reduction of greenhouse gases and air pollution, electric powertrain associated with quick refuelling and long travel range, possibility of using a clean fuel produced domestically - generated high expectations in the early years of last decade, but the interest quickly vanished in the absence of models available on the market, giving way to disillusionment and skepticism. Meanwhile, the first battery electric cars were introduced in the market. The perception that hydrogen is a fuel for a future still very far in time was then widespread, to the detriment of new initiatives and new investments in the sector. The fact that **in Italy alone at least three hydrogen fuelling points, built using regional or EU funds, were dismantled following the end of demonstration activities**[55], while other fuelling stations were announced and financed but were never built[56], demonstrates to what extent the interest on this technology could have vanished.

However, **the situation has changed radically over the past few years**. The 2009 agreement of major car manufacturers, as well as the involvement of State or regional authorities in new public-private partnerships aiming at developing new strategies for refuelling infrastructure deployment, paved the way for the mass market introduction of hydrogen vehicles. This makes it possible to launch large scale production, which is indispensable to reduce production costs. It also adds to the progress made in terms of vehicle performance and lifecycle, to the incentives and other support programmes, to the fall of natural gas price in the United States, to new rules on greenhouse gas emissions and on air pollution, as well as to the **growing interest for hydrogen as a carrier for the storage of electricity generated from unpredictable renewable energy sources**[57]. Therefore the years ahead to 2025 will be key to overcome the so-called “death valley” and for the further development of these technologies. **The general expectation is that hydrogen and fuel cells will replicate the success of hybrid technology**, which had a strong impact on the transport sector, despite the wide initial scepticism.

In light of the above it is not surprising that the preliminary results of a study by the International Energy Agency (IEA) to be published later this year show that **hydrogen fuel cell cars circulating in France, Germany, Italy and the United Kingdom might be around 40 million by 2050**[58].

[55] Such facilities are the following: hydrogen fuelling point at Bicocca (Milan), inaugurated in September 2004 and dismantled shortly afterwards; hydrogen fuelling point at the ENI multienergy station in Mantova (Valdaro), opened in September 2007 and closed down in 2010; mobile liquid hydrogen fuelling point at the ENI/Agip station at Magliana Nord (highway Rome-Fiumicino Airport), used in 2007 to refill a small fleet of BMW Series 7. A fourth fuelling point, opened in July 2006 at the ENI multienergy station of Grecciano (highway Firenze-Pisa-Livorno), is still operational but has been closed for long.
[56] Examples include the Porto Marghera Hydrogen Park (Venice), for which 4 million euro of public funds were allocated in 2003, and the 6 hydrogen fuelling stations announced in Apulia, for which 5 million euro were allocated in 2008.
[57] Cf. J. Ogden, C. Yang, M. Nicholas and L. Fulton, **NextSTEPS White Paper: The Hydrogen Transition**, Institute of Transportation Studies, University of California at Davis, 29 July 2014.
[58] **IEA Hydrogen Technology Roadmap**, to be published in June 2015. The study assumes that in 2050 the taxation level of oil products used in transport will be 30% higher compared to hydrogen, whose production will rely almost entirely on zero emission processes.

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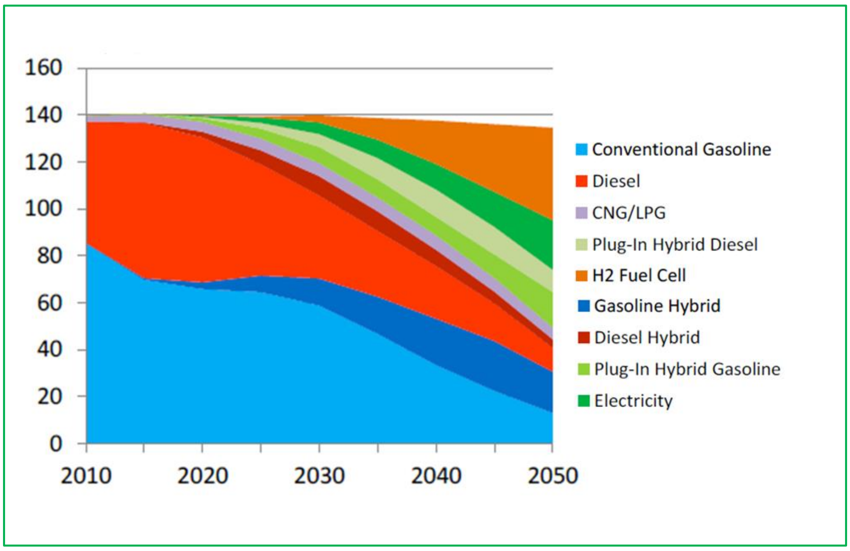

*Figure 7 –Stock of light duty passenger vehicles in EU-4 (France, Germany, Italy, United Kingdom) between 2010 and 2050, based on the 2DS-High H_2 scenario developed by IEA. Data in million. Source: International Energy Agency, **Hydrogen Technology Roadmap**.*

The opportunities in industrial and commercial terms will consequently be significant: according to the strategy consulting firm Navigant Research, **the global turnover of hydrogen and fuel cell cars will increase from about € 155 million expected for 2015 to about € 60 billion in 2030**[59]. From the employment point of view, the impact of this new market segment will only be positive: the European Climate Foundation has indeed estimated that **the increasing use of electricity and hydrogen for transport will produce a net increase in employment in Europe of about 660 thousand units by 2030**. As for state budgets, in European countries **the decline in revenues from excise duties resulting from the decrease in imports of oil products will be more than offset by the revenues of additional ordinary taxation of economic activities**[60].

In this context, in accordance with Directive 2014/94/EU, **hydrogen refuelling infrastructure for transport will be eligible to receive European and national support**, with the aim of pooling public support for the coordinated development of alternative fuels market. Contrary to the recommendations of the European Commission, however, the Directive leaves the Member States free to choose whether or not to include hydrogen in the list of alternative fuels to be submitted to Brussels by November 2016.

This option involves at least **three important consequences for the development of hydrogen mobility in Europe in the short to medium term**. First, the Member State which does not include hydrogen in its national programme will not be required to open a sufficient number of hydrogen refuelling

[59] **Fuel Cell Vehicles. Light Duty Vehicles, Transit Buses, and Scooters: Global Market Analysis and Forecasts**, Navigant Research, 2013.
[60] P. Harrison (ed.), **Fuelling Europe's future. How auto innovation leads to EU jobs**, Brussels, European Climate Foundation, 2014.

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points on its territory, which therefore cannot in any way be subject to the assessment that the European Commission will have to perform by November 2017. Moreover, **lacking such commitment, projects for the development of hydrogen mobility infrastructure will not be eligible for funds potentially available neither at the national, nor at the EU level**, as the latter will be allocated exclusively to the technologies expressly provided in the national plan of each EU Member state. In fact, when funding requests are submitted to the attention of project evaluators, it is necessary that proposed projects are implemented across territories that committed to the development of the technologies in question, **in order to avoid funding projects with no future**. Finally, businesses and other organisations that are willing to run transport projects or investment based on hydrogen would be in real difficulty against competitors operating in countries that have included hydrogen in their alternative fuel mix.

In light of the above, it is clear that **at least until the mid-2020s, hydrogen mobility in Europe will develop properly only in those EU countries that have chosen to include this carrier in their plans for alternative fuels infrastructure development**. As a result, companies in these countries will benefit from the comparative advantage resulting from their early movers position, at the time hydrogen mobility becomes a mass reality at global level.

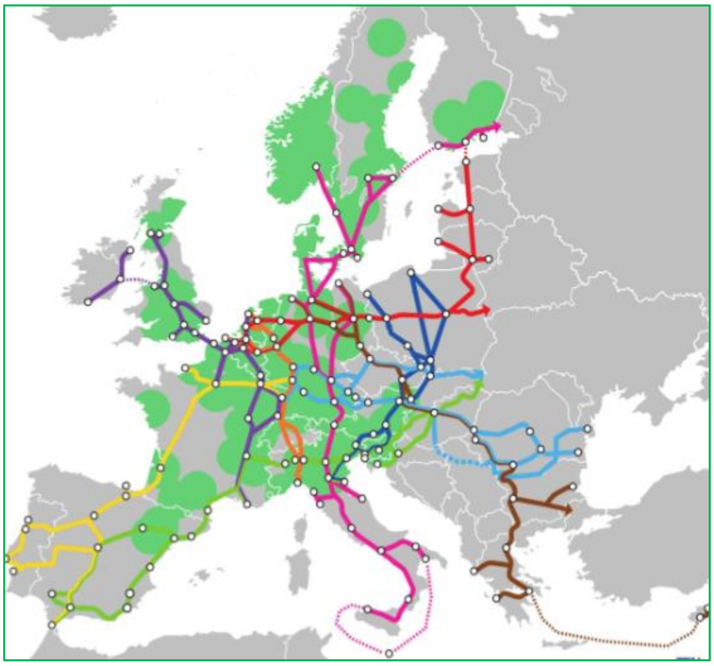

*Figure 8 – Hydrogen fuelling stations in Europe in 2020 (green areas) linking existing national and regional networks and the TEN-T core network. Source: HIT, **Synchronised Implementation Plan**, December 2014.*

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