“Overview of the market segmentation for hydrogen across potential customer groups, based on key application areas”

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“Overview of the market segmentation for hydrogen across potential customer groups, based on key application areas”

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Executive Summary

The report assesses the current hydrogen market and its structure, the main players and how demand in going to evolve in the period 2015 to 2030. This exercise will help the project to understand and to identify the market opportunities for green hydrogen, encompassing the future volumes, prices and potential customers. The following table presents a synthetic summary of the content in this report.

- **Represents today more than 90% of hydrogen market share with a total consumption in Europe of 7 Mtons of H2**
- Main sub-segments: 63% Chemical, 30% Refineries, 6% Metal Processing, 1% others.
- **3.5%** hydrogen **annual growth** up to 2025.
- The **chemical sector** has the largest market share and its main sub-segments are: **84% Ammonia (3.6 Mtons of H_2)**, **12% Methanol, 2% Polyurethane, and 2% Nylon.**

  Refineries are the second largest market (**21.1 Mtons of H_2**). Here, hydrogen is used for hydrogenation process in order to produce lighter crudes.

- Key market to achieve a sustainable growth.
- EU agreed that CO2 emissions needed to be cut down by 80% in 2050, thus to achieve the target transport road sector requires a **95% of decarbonisation.**
- Transition to hydrogen will have the largest impact with passenger vehicles **(75% car fleet) through FCV.**
- Most HRS will be placed on existing conventional refueling stations; therefore, hydrogen will be more likely linked to today's petrol retailers.
- According to **Hyways, by 2030** EU could reach a penetration rate of FCVs around **9% – 13%** of the total fleet, which **represents 12 – 25 million vehicles .**
- According to **McKinsey, by 2030** the HRS network is foreseen to have 5.1 thousand retail stations **giving a total dispatch volume of about 2'615,000 tons of H_2 .**
- According to **Hinicio, and based on national H2 mobility scenarios**, **by 2030** EU could reach **786,000 H_2 tons** of consumption.
- Prices will gradually decrease as market achieves its maturity and the technology develops. **The retail price in 2015 will be around 10 €/kg and by 2030 it could reach a value of 5-7 €/kg .**

- Blending ratios defined in *NaturalHy project estimate* between 1%-15% (by volume) arises only minor issues, thereby current pipeline network may require only minor modifications.
- the natural gas demand in the grid all over EU for summer reached up to **1,721,921 GWh in 2013.**
- **Increasing pace of 1% annually** for natural gas demand.
- Hydrogen potential volume **by 2030:** injecting 1% the volume could reach around 170,000H_2 tons and injecting a maximum of 2% volume could reach **around 340,000 H_2tons.**

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List of Abbreviations

AFHyPAC	Association Française pour l'Hydrogène et les Piles à Combustible
CH_4	Methane
CO_2	Carbon Dioxide
CO_2eq	Carbon Dioxide equivalent
DSO	Distribution System Operator
ETS	Emission Trading System
EU	European Union
FCV	Fuel Cell Vehicle
FCEV	Fuel Cell Electrical Vehicles
FCH JU	European Fuel Cell and Hydrogen Joint Undertaking
GoO	Guarantee of Origin
GHG	Green House Gases
GW	Gigawatt
GWh	Gigawatt hour
H_2	Hydrogen
HENG	Hydrogen Enriched Natural Gas
HRS	Hydrogen Refueling Station
ICE	Internal Combustion Engine
kg	kilograms
km	kilometers
kW	Kilowatt
kWh	Kilowatt hour
MMBTU	1 million BTU (British Thermal Unit)
MW	Megawatt
MWh	Megawatt hour
NG	Natural Gas
NIP	National Innovation Program Hydrogen and Fuel Cell Technology
Nm^3	Normal cubic meters (0°C and 1 bar)
NOW	National Organization Hydrogen and Fuel cell Technology
P2G	Power to Gas
PEM	Proton Exchange Member
SMR	Steam Methane Reforming
TSO	Transmission System Operator
WE	Water Electrolysis
WP	Work Package

1 Introduction

The aim of this report is to deliver an overview of current and future hydrogen markets across the European Union. Having an understanding of future hydrogen markets, together with an assessment of the main policy drivers for green hydrogen (deliverable D1.3) will help the project assess the potential market for green hydrogen.

This deliverable will help the project to understand and to identify the market opportunities for green hydrogen, encompassing the future volumes, prices and potential customers. For this purpose, three market segments for hydrogen and their sub segments have been assessed. In the case of mobility, it was considered best to look into country specific outlooks given the available data and the ongoing H2 mobility programs.

The segments assessed are shown in **figure 1.**

For each sub-segment, the volume demand forecast, key applications area, potential customers and potential hydrogen prices in a timeframe of 2015 – 2030 have been estimated.

Additionally to the sector specific hydrogen forecasts, chapter 6 introduces the main drivers for green hydrogen demand that will be further explained in Deliverable 1.3.

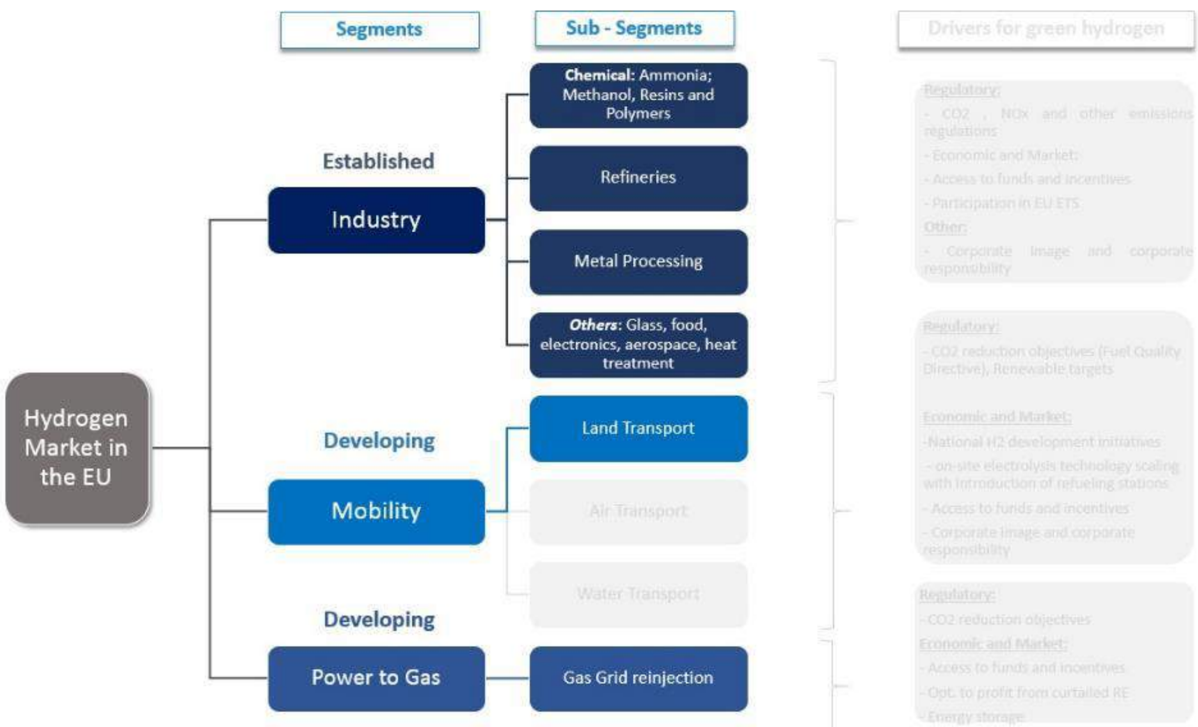

Figure 1 Hydrogen Market Segments and Sub-segments

1 Methodology

The methodology started with a synthesis and analysis of the bibliographic review gathered in deliverable 1.1, complemented through a search of information conducted via desk research. Only peer reviewed journal articles and conference proceedings publish within the last 7 years were considered to be reliable for most of the topics discussed.

The information was initially summarized and characterized according to the market segments identified. At the same time, Hinicio performed a number of informed hypothesis and calculations to complement the data gathered in the literature.

2 Hydrogen Market Segments

Hydrogen has long been known and utilized in the industry, either as feedstock (like for example in the oil and gas industry), or as a by-product of an industrial processes. Additionally, the use of hydrogen as an energy vector has been envisaged for a long time, and it’s expected to develop in other sectors of the economy.

The global demand for hydrogen in 2010 was around 43 Mtons[1] and is foreseen to reach 50 Mtons[2] by 2025, primarily as a result of demand from the production of ammonia, methanol and petroleum refinery operations. Asia and Pacific are the world’s leading consumers of hydrogen representing 1/3 of the global consumption; followed by North America and last but not least Western Europe with a 16% of share (7 Mtons of H_2)[1]. The hydrogen used can be produced by a variety processes, primarily by steam methane reforming (SMR) of natural gas, coal gasification and as a results of cracking of hydrocarbons (in refineries).

[1] World Hydrogen Industry Study 2010 by Freedonia and Production and Utilization of Green Hydrogen by The Linde Group. It was converted to metric tons by considering an H_2 density of 0.0899 kg/m^3

[2] Praxair 2013 Outlook

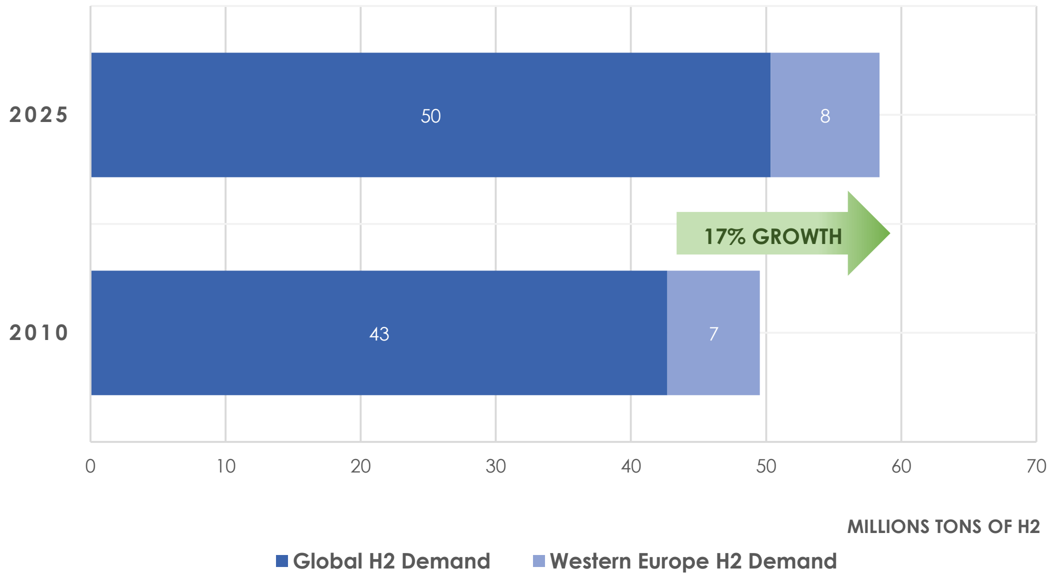

Figure 2 Hydrogen Volume Consumption in 2010 and 2025. Source: Hinicio and data from: **(Freedoni_Group, 2010)**

In the future, the main energy networks will possibly include electricity, gas, liquid fuels and gaseous fuels. Within this last one (gaseous fuel) is located the hydrogen vector, which may ultimately be used for the industry (including chemicals and petro-chemicals), for mobility, electricity network (including storage of excess renewables) and heating. A schematic of an example of such configuration is presented in **figure 3.**

Figure 3 Hydrogen Layout Economics (Source **(Toyota, 2014)***)*

The industrial sector represents more than 90%[3] of today's hydrogen consumption, thus policies may play a strategic and crucial role to shift the fossil economy into a hydrogen based economy. On the

[3] Source: (Guy Maisonnier, 2007) and Hinicio's internal data

other hand, although not very significant today, the mobility market is foreseen to be the fastest growing and most important market in the horizon 2025 – 2030, thus clearly relevant in the context of a ‘green hydrogen’ study. In addition, hydrogen injected into the natural gas grid will be mostly of renewable origin, thus it requires a deeper analysis. For this reason, the backbone of this analysis will consist on further sub-segmentation and outlooks for these three specific sectors.

2.1 Industry sector

With more than 90% of hydrogen market share, the Industry is currently the largest producer and consumer of hydrogen amongst the EU28, with a total consumption **of 7 Mtons of H_2. Figure 4,** based on (The_Linde_Group, 2013), displays a snapshot of the different hydrogen segments in the industry sector. The main segments and sub-segments of the industry are: chemical, refineries, metal processing and others such as aerospace, glass, food (sorbitol and fat processing) and heat treatment for electrical generators (namely in the nuclear power plants). Each of these will be further analysed in sections 2.1.2 to 2.1.5 of this chapter.

INDUSTRY & MARKET SHARE	KEY APPLICATIONS	SUPPLY SYSTEM	H2 DEMAND
General Industry 1%	• Semiconductor • Propellant Fuel • Glass Production • Hydrogenation of Fats • Cooling of electrical Generators	• Small on-site • Tube trailers • Cylinders • Liquid H2	LOW >0.07 Mtons
Metal Working 6%	• Iron Reduction • Blanketing gas • Forming gas	• Cylinders • Tube trailers	MEDIUM 0.41 Mtons
Refining 30%	• Hydrocracking • Hydrotreating	• Pipeline • Large On-site	2.1 Mtons
Chemical 63%	• Ammonia • Methanol • Polymers • Resins	• Pipeline • Large On-site	HIGH 4.3 Mtons

Figure 4 Industry Sector Snapshot (Source: Hinicio)

The chemical sector is the most important hydrogen consumer (accounting for 63% of the market share (**4.3 Mtons of H_2**), followed by the refinery sector, which accounts for 30% of the market share. It is worth to mention that ammonia alone accounts for more than **50% (3.6Mtons of H_2)** of the **total industry volume consumption**.

It is foreseen that up to the year 2025 there will be more or less constant global growth at the current rate of 3.5%[4] per year. Assuming a similar tendency for Europe for the years 2025 - 2030 a snapshot of hydrogen demand in industrial sectors could be as described in **figure 5.**

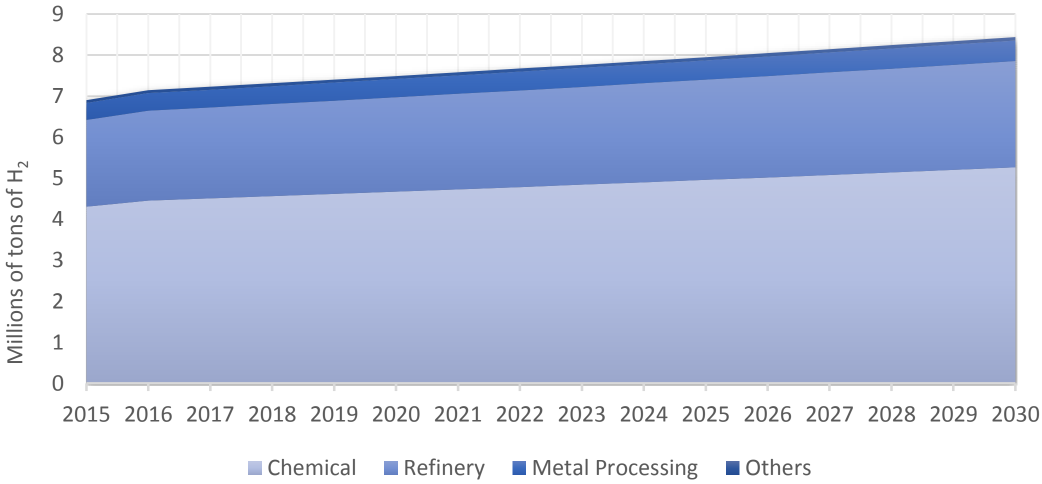

Figure 5 Hydrogen Demand for Industry Sector. Source: Hinicio based on data from **(Freedoni_Group, 2010)**

2.1.1 Hydrogen price analysis

Currently, the hydrogen production in Europe is led by a few large industrial actors who play a key role in establishing internally a market price. In general, we may describe the commercial transaction, as a bilateral hydrogen transaction between two industries, which is defined by a high price elasticity that are portray with different parameters. Firstly, the inexistence of a global price database which leads the market to a lack of traceable information. Additionally, prices depend on “buyers” location that defines how hydrogen will be delivered (liquid or gas), thereby transport and distribution of hydrogen is especially important when hydrogen is produced in large scale from centralised production sites to points of use. Moreover, the purity levels plays an important role since higher purity levels imply higher hydrogen costs. Thus, having a reliable market price is extremely challenging, nevertheless it is known that prices vary from 10€/kg to 60€/kg[5] . Finally, encompassing these factors, a more reliable approach to forecast hydrogen price in the industry is by analysing its production cost.

There are many ways of producing hydrogen, each yielding to a very different cost scheme. Nonetheless, only one production method prevails as the most widely used the industry. This is the steam methane reforming (SMR) of natural gas (NG). Since this technology is mature, we can conclude that the variations of hydrogen production cost are largely dependent on the price of the NG.

A compilation of information of the different cost ranges for the same technology in several industries was conducted by the Department of Energy of The United States (Sara Dillich _. R., 2012). The report proposes 5 different scenarios (considering different NG prices), which were modelled by a tool called

[4] Source: World Hydrogen Industry Study 2010 by Freedonia
[5] Source: Internal information from Hinicio

H2A[6]. The main results of these simulations are shown in Figure 6. The first scenario uses Annual Energy Outlook (AEO) 2009 prices for industrial NG as a production feedstock; the second scenario uses the same principle but with AEO 2012 prices. Then, the report conveys a sensitivity analysis by setting up three flat prices: 2 USD/MMBTU, 3 USD/MMBTU and 4 USD/MMBTU.

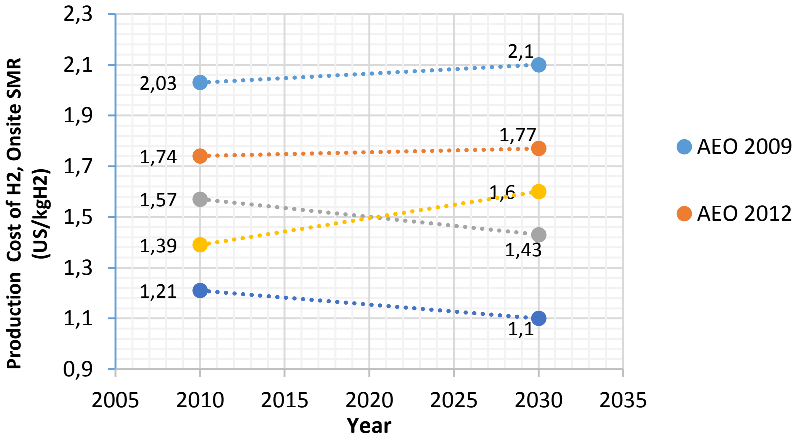

Figure 6 Hydrogen from SMR Cost Evolution Sensitivity Analysis (Source: Hinicio and data from **(US_Department_of_Energy, 2015)**

2.1.2 General characteristics of hydrogen in the industrial sector

Logistics

Although hydrogen production costs from SMR of NF are expected to vary little within a 25 year time frame, considering the 5 different scenarios described in the previous section, it is very important to note that hydrogen costs at the point of use are extremely dependent on volumes and logistics between the point of production and the point of use.

Most of the hydrogen consumed in the industry is sold within a captive market or produced on-site (64%). ‘Fatal hydrogen’, which is the name given to hydrogen that is produced as by-product of some industrial processes is also commercialized, and it constitutes 27%[7] of the market. The remaining 9%[8] consists in merchant hydrogen commercialization.

Table 1 Hydrogen production by market sector. Source: **(Guy Maisonnier, 2007)**

Market sector	H_2 production (MTons/year)	H_2 production (Billion Nm^3/year)
By-Product	18.87	21
Captive	43.15	48
Merchant	6.3	7

[6]Source: (US_Department_of_Energy, 2015)

[7] (The_European_Comission, Hyways The European Hydrogen Roadmap, 2008)
[8] (The_European_Comission, Hyways The European Hydrogen Roadmap, 2008)

Total	**68.32**	**76**

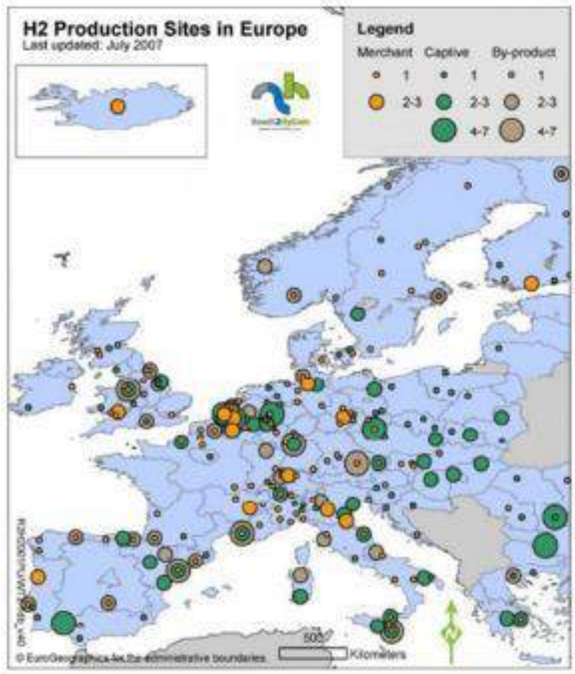

Figure 7 Geographical Distribution of H_2 production among European Union on 2007. Source: **(The_European_Comission, Hyways The European Hydrogen Roadmap, 2008)**

Purity Levels

Hydrogen purity levels vary within industry segments and does have a direct impact on the cost of production of hydrogen to meet certain market expectations. The hydrogen quality verification level is determined depending on whether the hydrogen is in liquid or gaseous state, as described in **tables 2 and 3**. Hydrogen for a specific industrial application must always comply with its determined classification.

Table 2 Gaseous Hydrogen Purity Levels Classification

GASEOUS (Type I)		
Quality Verification Level	**Typical Uses**	**Hydrogen purity**
B	General industrial applications	99.95%
D	Hydrogenation and water chemistry	99.99%
F	Instrumentation and Propellant	99.995%
L	Semiconductor and specialty applications	99.999%

Table 3 Liquid Hydrogen Purity Levels Classification

LIQUID (Type II)		
Quality Verification Level	**Typical Uses**	**Hydrogen purity**
A	Standard Industrial, fuel and standard propellant	99.995%

B	High Purity: industrial, fuel and Propellant	99.999%
C	Semiconductor	99.9997%

2.1.3 Description of industrial markets by sub-segments

2.1.3.1 Chemical: Ammonia; Methanol, Resins and Polymers

The chemical industry represents **63% of the total industrial hydrogen demand**. The main sub-segments, shown in **figure 8,** are *ammonia, methanol, polymer and resin production*. ***Ammonia*** is by far the largest consumer in the **chemical sector**, representing 84% of the total demand.

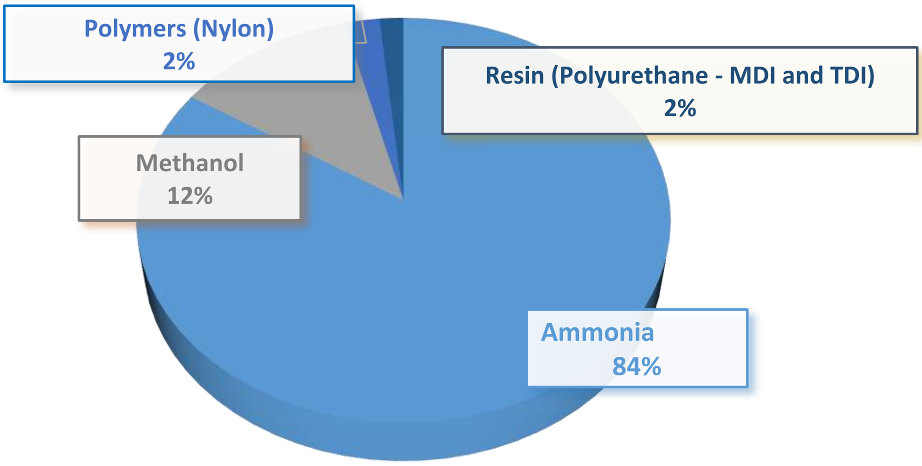

Figure 8 Chemical Industry demand by sub-segments. Source: Hinicio and data from **(The_Linde_Group, 2013)**

The synthesis of ammonia is carried out by a catalytic reaction which requires high volumes of hydrogen recovered from natural gas.

A typical ammonia plant has the capacity to produce between 1000 to 2000 tons/day of this product, needing a hydrogen feedstock to operate ranging from **57,500 to 115,000 tons/year**[9] **.** The ammonia market in Europe is driven by the biggest fertilizer supplier: **Yara.** The global ammonia market is **expected to be relatively stable with an annum rate growth of 0.1%**[10] however environmental pressures in Europe could challenge industry players to come up with more sustainable agribusiness food processing alternatives, either creating opportunities for green hydrogen, or limiting the market development.

- **Methanol**, accounting for **12% of market share** is the second largest hydrogen consumer in the chemical sector. Since it is a mature market, it is forecasted that it will maintain a stagnant growth in the next years. The methanol production entails two steps: Steam reforming and Methanol Synthesis. The steam reforming is led by an endothermic reaction, which involves a catalytic conversion of methane and steam into syngas. Then, the methanol synthesis involves a catalytically conversion of syngas into methanol via an overall exothermic reaction, ending

[9] Source: (Air_Liquide, 2004), in terms of volume is 80,000 to 160,000Nm3/h. It was considered a Hydrogen density of 0.0899 kg/m^3

[10] Source : (ICIS, 2014)

with hydrogen separation and methanol purification. The average plant capacity is around **5,000 tons/day with a yearly hydrogen consumption of 266,104 tons**. The key industrial players are **Methanex and Sabic[11].**

- **Nylon and Polyurethane** each represent a 2% of the market share. These processes do not require such high volumes of hydrogen.
- A typical **Nylon** plant capacity is 180,000 ton/year and the main actors in Europe are **DuPont, BASF, Lanxess and DSM**. This is a very competitive market that has recovered in 2014. It has estimated an **annual pace growth around 3.5% - 5%** [12] driven mainly by macroeconomics recovery.
- For **Polyurethane**, the typical plant capacity has a production of 240,000 ton/year and there are 4 main players that covers almost the whole market, these are: **Bayer Material Science, BASF, Dow Chemical PU, and Huntsman Polyurethanes**.

2.1.3.2 Refineries

Refineries represent the second largest consumer of hydrogen within the Industry segment, with a market share of **30% (2.1 Mtons of H_2 demand annually).** In refineries, hydrogen is used for hydrogenation processes to crack the heavier crudes as well as increase the hydrogen ratio in the molecules and thus produce lighter crudes. These processes are called 'hydro-cracking' and 'hydro-treating desulphurization units', and it is extremely important for the feedstock that the hydrogen is of high purity.

The hydrogen volume consumption of a refinery site depends strongly on the processes involved and products generated. Therefore, it may change greatly from refinery to refinery and cannot be calculated from the production volumes alone. In general terms **a typical plant operates with hydrogen production capacities in a range of 7,200 tons/year – 108,800 tons/year and for new and complex large scale refineries up to 288,000 tons/year**. The main actors in the European market are **BP, Total, Shell and EXXON** (the latter with a small participation).

2.1.3.3 Metal Processing

Metal processing encompasses the use of hydrogen to yield iron reduction. The market share for the metal processing industry is **6% (410,000 tons).** The typical hydrogen consumption in this type of plant is rounded between 36 tons/year – 720 tons/year[13].

The activity in the metal processing sector has decreased since 2009 as a result of the financial crisis. According to NASDAQ[14], the annual **decrease is around 2.7% for Europe**. The main player in the metal processing sector in Europe is **Arcelor Mittal**.

2.1.3.4 Other segments in the industrial sector

Several other industrial processes use hydrogen but all together just account for 1% of the industry market share. They are listed in the following.

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[11] Source : (Methanex, 2014)
[12] Source: (ICIS, 2014)
[13] Source: (Air_Liquide, 2004) in terms of volume is: **50-1,000 Nm^3/h**. For computing to metric tons it was considered a hydrogen density of 0.0899 kg/m^3
[14] Source : (NASDAQ, 2013)

Table 4 Hydrogen market for other segments

Segments	Sub-segments	Volume (m^3/y)	Typical plant capacity	Growth per year	Main consumers
Electronics (Liquid Hydrogen)	Semiconductor	380 mill	50-1,000 Nm^3/h	2.3%	Intel, Samsung, STMicroelectronics
Aerospace	Rocket propellant	380 mill			Haltermann Solutions
Glass	Glass production		44 [15]	3.4%	Pilkington, Saint-Gobain, Guardian Glass, AGC Glass Europe
Food	Hydrogenation of fats		320 [16]	-0.3%	ADM, Desmet Ballestra, AGA, Roquette, Tereos Syral
Heat Treatment	Cooling of electrical generators		>300MW		Areva, Gamesa

Figure 9 shows graphically a scale of the typical production volumes in the different industrial sub-segments)

[15] Considering 300 kgH_2/day and glass density of 2,52 g/cm^3
[16] Considering 800 kgH_2/day and average fatty acids density of 0.9131g/mL

2.2 Mobility

2.2.1 Generic hydrogen market outlook: FCVs and retail networks

The mobility sector is potentially one of the key sectors that may generate sustainable growth and demand for ‘green hydrogen’. This sector could be of paramount importance to achieve significant GHG emission reductions. In 2010 transport emissions were responsible for 32% of the annual GHG emissions in Europe according to European Energy and Transport Directorate General[17]. This alarming proportion is due to an accelerated increase of passenger vehicles. By 2009, the total amount of passenger cars rose to 273 million in the EU according to Parc Auto Survey[18], and it is foreseen to keep growing at the same rate. In September 2009, the EU agreed that the CO_2 emissions needed to be cut down by at least 80% by 2050. In order to achieve this target, the road transport sector requires a 95%[19] of decarbonisation. This reduction would imply a complete removal of light and medium gasoline vehicles and only a partial removal of ICE for heavy-duty vehicles (less than 45%). The European Union has therefore set up strong regulations in order to contribute to the decarbonisation of the road transport sector. The set of policies and regulations are further explained in *D1.3 “Generic estimation scenarios of market penetration and demand forecast for “premium” green hydrogen in short, mid and long term”*[20].

The demand for hydrogen in the transport sector will be coming mainly from passengers’ cars, due to the fact that it represents 75% of the total vehicle park. This category encompasses sizes from small (A/B), medium (C/D) and larger (SUV) cars, typically called “light duty vehicles”.

Fuel cell vehicles (FCV) are at the gates of commercialization, but due to the slow introduction of this technology and the related infrastructure, H2 mobility is currently limited to a few demonstration projects throughout Europe, which are heavily depending on public subsidies. Hence, the hydrogen demand for the transport sector is today almost negligible. However, it is expected to increase significantly as a larger number of hydrogen vehicles begin to enter the market and the refuelling infrastructure builds up.

A number of studies have proposed market outlooks for the dimension and impact of the penetration of this technology in the EU. These studies are based on different scenarios, using different hypothesis on fuel and technology price evolution and policy support.

The Hyways roadmap study[21] considers 4 different scenarios: The first and most optimistic one is characterized by a “very high policy support”, that considers an optimal timing of policy implementation and serial car production in 2013. In the same report, there is a high policy support scenario but with a car serial production starting in 2016. A third one, “high policy support” contemplates a scenario where policy instruments are implemented just after specific technological and market barriers are encountered. And the last one is the “modest policy support”, which considers policies are implemented until problems are clearly visible and targeted support actions for hydrogen

[17] Source: (EU_Comission, 2010)
[18] (McKinsey, A portfolio of power trains for Europe: a fact based analysis)
[19] Source: (McKinsey, Roadmap 2050, s.d.)
[20] www.certifHy.eu
[21] Source: (The_European_Comission, Hyways The European Hydrogen Roadmap, 2008)

and fuel cells are introduced. A summary of the results in a timeframe 2010 – 2050 is shown in **figure 10**.

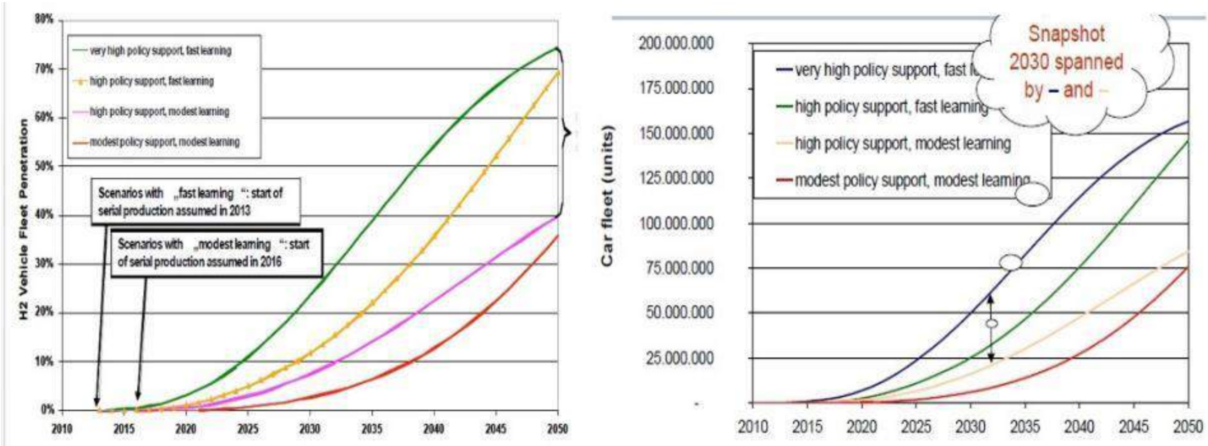

Figure 9 Development of the penetration rate of hydrogen vehicles for passenger transport. Source: **(The_European_Comission, Hyways The European Hydrogen Roadmap, 2008)**

According to this outlook, by 2025, EU could reach a penetration rate around 3% with a high policy support modest learning and 7% with a high policy support fast learning in the mobility sector for FCV, which would **represent 5 – 7 million vehicles.** And for 2030, EU could reach 9% – 13% of penetration rate in the mobility sector for FCV, which would **represent 12 – 25 million vehicles[22] (about 1.4 mill – 3 mill ton H2 per year[23]).**

McKinsey[24], on the other hand, shows a more optimistic scenario of penetration rate for FCV and retail network for EU 28 from 2020 to 2050. The study describes as well the retail network, explaining that there will be three types of HRS systems determined by hydrogen demand requirements and coverage areas. A small[25] station having a maximum capacity of 400kgH_2/day, a medium[26] station with 1 tonH_2/day and finally a large[27] HRS, being able to deliver 2.5 tonH_2/day. **Figure 11** shows an outlook in thousands of retail stations in Europe for the years 2020 – 2050.

[22] Source: (European Comission, 2008)
[23] Assuming that an average passenger vehicle in the EU travels about 12,000 km/year, and that the FCV consumes about 1 kg H2 / 100 km
[24] Source: (McKinsey, A portfolio of power trains for Europe: a fact based analysis)
[25] 70- 100 cars per day (2 dispensers)
[26] 150 – 250 cars per day (4 dispensers)
[27] 450 – 600 cars passengers per day (10 dispensers)

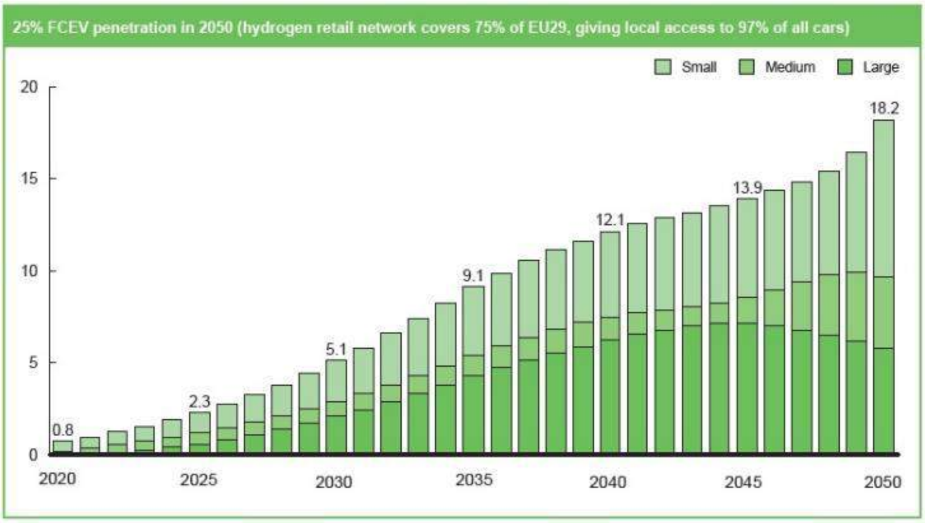

Figure 10 Penetration rate of Hydrogen Retail. Source: **(McKinsey, A portfolio of power trains for Europe: a fact based analysis)**

Considering a 25% penetration of FCV by 2050, a total number of 2,300 retail stations are already foreseen for 2025 (50% "small", 25% "medium", 25% "large"), **giving a total H_2 volume capacity of about 330,000 tons of H_2 available for distribution in the EU.** In the year 2030, the network is foreseen to count with 5,100 retail stations (45% small, 45% large, 10% medium), **giving a total H2 volume capacity of about 980,000 tons of H_2 available for distribution in the EU.**

2.2.2 Price evolution

The hydrogen price evolution, as it has been explained for the industry, is directly dependant on production and distribution cost. The cost of dispensed hydrogen at the refuelling station is expected to be high in the first few years of deployment due to the underutilisation of retail stations. As retail stations and FCVs are expected to spread out after 2020, the hydrogen cost is also expected to decrease.

Different studies analyse the hydrogen retail price evolution with the gradual introduction of demand from the mobility sector and technology development. **Figure 12** displays a comparative of the different results considering different FCV market penetration rates and hydrogen production technology choices.

The Fuel Cell and Hydrogen Joint Undertaking (a public-private partnership between industry and the European Commission) has set as the target that for 2025 the retail price of H_2 should be between 4.5 euro/kg and 7 euro/kg. The 3 studies converge on the conclusion that retail price will gradually decrease and it will be around 5 – 7€/kg by 2030.

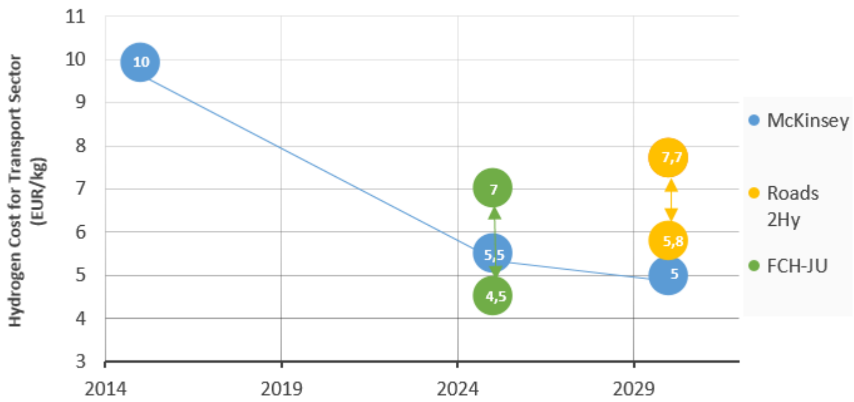

Figure 11 Hydrogen Cost development from 2015 to 2030. Source: Hinicio based on different technology and market roadmaps

2.2.3 Characteristics of H2 for Mobility

The transport sector has high hydrogen purity quality standards which are specified in ISO 14687 [28]in a level of 99.995% purity.

Compressed hydrogen storage (700 bars / 350 bars) is the current standard storage technology. And thanks to the technological improvements, the storage capacity on board is increasing without compromising the volume requirements, thus resulting in driving ranges that approach those of gasoline ICEs.

2.2.4 National H2 initiatives

After looking into EU-wide scenarios, individual national roadmaps for the introduction of hydrogen have also been assessed (for those countries which already have H2 mobility programs in place). In concrete, this report examines the outlooks for H2 mobility in Germany, France, UK and the Scandinavia initiative. Table 5 summarizes these programs.

[28] (ISO, 2012)

COUNTRY	PROGRAM	FINDINGS	2015	2025	2030	2050
	H_2 Mobility	HRS	90	500	1,000	NA
		FCVs	200	500,000	1,87 mill	NA
		H2 (tons)	24	60,000	216,000	NA
	Mobilité Hydrogène France	HRS	NA	355	600	>1,000
		FCVs	NA	167,000	773,000	7.3 mill
		H2 (tons)	NA	22,000	89,000	880,000
	UK H_2 Mobility	HRS	65	380	1,150	NA
		FCVs	<500	255,000	1,27 mill	NA
		H2 (tons)	<100	30,600	152,000	NA
	H2moves.eu SCANDINAVIA	HRS	12	185	NA	450 - 1000
		FCVs	26	87,000	NA	3,3 mill – 7,3 mill
		H2 (tons)	3.2	10,400	NA	394,000 - 880,000

Table 5 H2 Mobility public-private partnerships. Source: Hinicio analysis based on: **(Mobilité_Hydrogène_France)**, **(McKinsey, UKH2 Mobility, 2012)**, **(EUDP_Transnova, 2012)**, *and* **((NOW), 2013)**. *Information of **2015** is based on expectations taken from the Reports of H2Mobility Program*

2.2.4.1 Germany

This is the country that has foreseen the highest penetration rate for FCV. Since 2008 a national program was launched and coordinated by The National Organization Hydrogen and Fuel cell Technology (NOW)[29] in order to decrease the GHG emissions coming from transport sector. The program is called *The National Innovation Programme Hydrogen and Fuel Cell Technology* (Germany_Trade_&_Invest, s.d.). And this was founded by the Federal Government represented by the Federal Ministry of Transport, Building and Urban Development. The program intends to speed up the market penetration of fuel cell technology.

The current hydrogen volume consumption and projection for 2025 and 2030 was calculated by Hinicio based on the size of the car fleet[30] projected by ((NOW), 2013) (like in the previous section: assuming an average distance and consumption for a particular vehicle of 12,000 km/year and 1 kg H_2 / 100 km). Figure 13 shows a possible scenario of hydrogen volume consumption evolution up to 2030.

By 2015 the car fleet number was expected to reach **200 vehicles**, as part of the demonstration project for fuel cell cars and buses, with the objective of demonstrating the technical feasibility of hydrogen technology. According to NOW program, the hydrogen refuel station network could have reached **90 units by 2015** to ensure a driver supply for FCVs. Likewise, this network could help the commercialization ramp up; moreover, by 2025 based on ((NOW), 2013), Germany could expect to have **500,000 vehicles on the road** and **500 HRS**, representing **60,000 tons of hydrogen**. Completing

[29] ((NOW), 2013)
[30] 200 passenger cars in 2015
500,000 passenger cars in 2025
1.8 mill passenger cars in 2030

the project **by 2030, the retail's expansion could be expected to increase up to 1000 HRS, allowing a good coverage for the estimated car fleet of 1.8million vehicles, representing around 216,000 tons of hydrogen demand.**

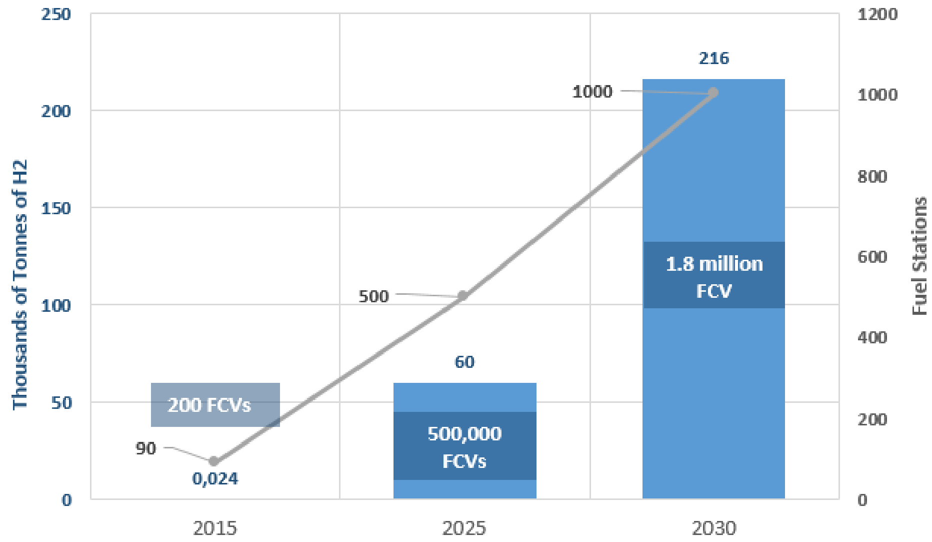

Figure 12 Annual Hydrogen Consumption of FCVs. Source: Hinicio and data from **((NOW), 2013)**

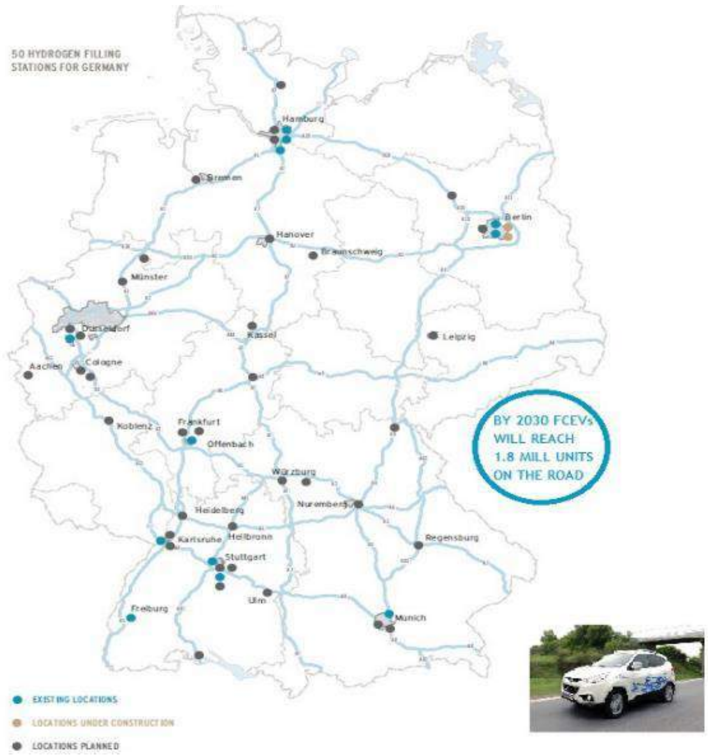

Figure 13 Hydrogen Filling stations in Germany 2013. Source: NOW

2.2.4.2 France

H2 Mobility France is a consortium that was created by the French Hydrogen and Fuel Cells Association (AfhyPac, 2015), to help France achieving its CO_2 targets.

The association has set the objective of CO_2 emissions savings of 1.2Mton[31] by 2030 through the introduction of FCVs. The objective by 2050 is to reach accumulated savings of 10.4 Mton of CO_2.

Based on H2Mobility France, by 2025, the FCV fleet is expected to reach **167,000 vehicles, for which this program calculated a total demand of 22,000 tons of hydrogen, and a retail network of 355 HRS**. Similarly, the H2Mobility program **foresees 773,000 FCVs by 2030, representing a demand around 89,000 tons of hydrogen on that year and a network of 600 HRS**. If this trend continues, the number of vehicles could even increase up to 7.3 million[32] units in 2050. **Figure 15** shows a summary of the outlook performed in terms of numbers of vehicles, annual hydrogen consumption, electricity demand and HRS.

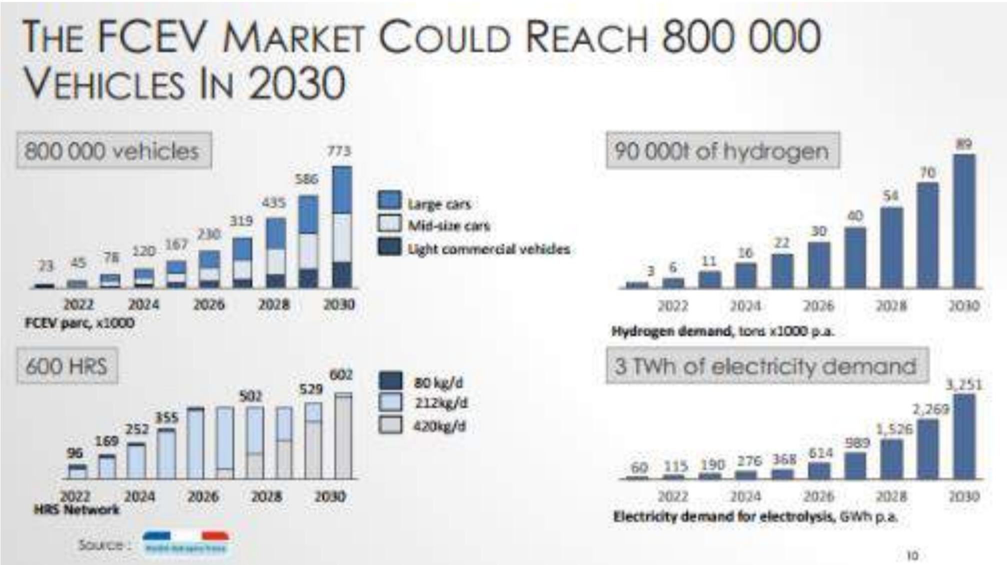

Figure 14 Hydrogen Penetration Breakdown from 2022 to 2030. Source **(Mobilité_Hydrogène_France)**

In terms of production, an outlook was made in the same study considering mainly three production technologies: SMR of NG, water electrolysis (WE) and by-product hydrogen from industry. The hydrogen production is expected to be progressively decarbonised[33] by shifting from SMR of NG to WE, since most of the electricity in France comes from Nuclear power. Biogas reforming could as well diminish the SMR process footprint. **Figure 16** shows the shares of hydrogen production by technology. By 2030 the hydrogen could be mostly produced from WE (73%).

[31] Equivalent to 780,000 diesel vehicles. Source H2 Mobilité France
[32] (Mobilité_Hydrogène_France)
[33] Electricity production in France is dominated by nuclear power with a 75% of the stake share. This way to produce electricity is a low carbon technology, nevertheless France has been looking for alternative options to produce electricity because this is considers as a controversial technology.

Figure 15 Hydrogen breakdown production. Source **(Mobilité_Hydrogène_France)**

2.2.4.3 United Kingdom

The H_2Mobility UK[34] aims to evaluate the potential for hydrogen FCVs in order to provide environmental and economic benefits to the country. The project brought together industrial participants from the fuel cells industry, energy utilities, industrial gas companies, fuel retailers and automotive OEMs in partnership with three UK government departments. The main FCVs producers involved in the UK H2 Mobility project are **Daimler, Hyundai, Nissan, and Toyota.**

The UK roadmap expects savings of 1.2 tonsCO_2/year by 2030 by introducing FCVs. **Figure 17** shows the FCVs market penetration. Here it can be seen that from 2022 to 2030 the UK parc is expected to have a fast paced growth due to the fact that technology could reach its breakeven point. In consequence the FCVs prices could decrease, which could help to speed up FCVs sales. Regarding refuelling stations, the UK roadmap predicts that thestarting point begins on 2015 with 65 stations that could provide sufficient initial coverage. **By 2030 the national coverage it is expected to reach up 1.150 stations[35].** The initial phase (until 2022) encompasses only small stations followed by a ramp up of medium size stations from 2023 to 2030. Only from 2028, UK roadmap foresees an introduction of large stations that could have only a small market share.

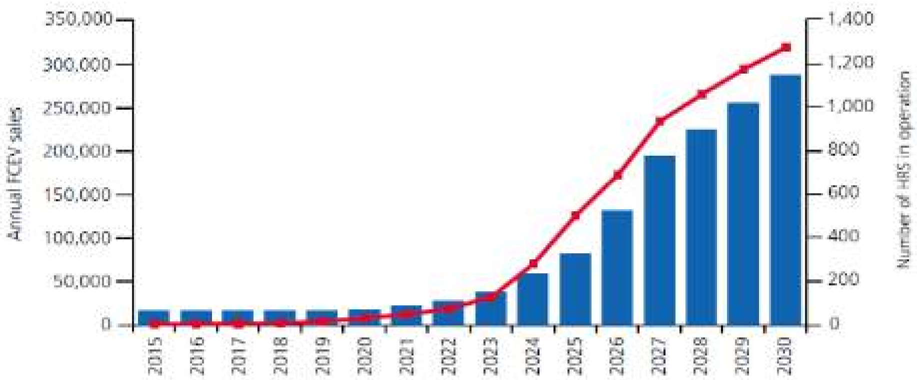

Figure 16 *UK consumer demand for FCVs and HRS in operation. Source:* **(McKinsey, UKH2 Mobility, 2012)**

[34] (McKinsey, UKH2 Mobility, 2012)

[35] Roadmap considers three HRS sizes. Small Station: 80 kgH_2/day and 16 FCV fills/day. Medium: 400kgH_2/day and 80 FCV fills/day. Large: 1000kgH_2/day and 200 FCV fills/day

Based on UK roadmap, the annual hydrogen consumption is less than **100 tons per year in 2015. By 2025** the hydrogen consumption could reach **around 30,600 tons per year**[36]. And for **2030** an annual hydrogen consumption could achieve **152,400 tons per year**[37]**.** According to UK roadmap, this will be mainly supplied by a mix of SMR oand WE. By 2030 the UK Mobility roadmap believes that hydrogen could come primarily from WE (51%) followed by SMR (47%), as it shown in **figure 18**. And it will include both, on-site production at the HRS and centralised production with distribution to the HRS.

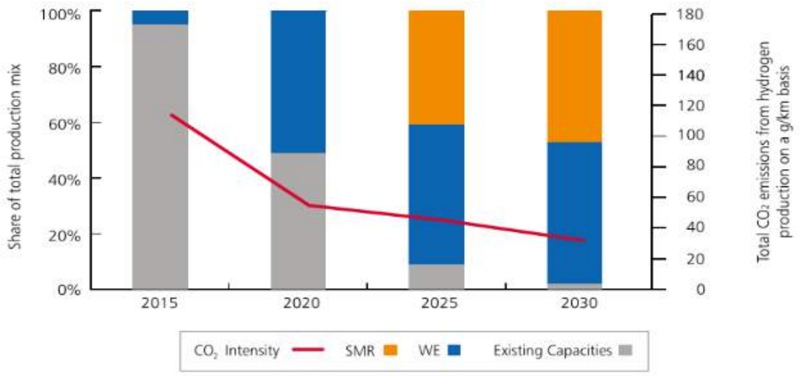

Figure 17 Hydrogen breakdown production. Source: **(McKinsey, UKH2 Mobility, 2012)**

2.2.4.4 Scandinavia

The H2moves Scandinavia[38] project objective is to mitigate GHG emissions and increase the share of renewable energies in these countries throughout the deployment of H2 infrastructure. The Consortium is formed by public and private entities. The aim of the project is to demonstrate the aptness of FCVs and the refuelling stations required to contribute for the diminishing of GHG emissions coming from road transport. H2 Scandinavia owns and operates 1 HRS; the hydrogen is produced on-site via water electrolysis**.** They owned as well 19 FCVs that helps to trace the benefits of these vehicles.

The project has helped encourage the deployment of HRS which entails the increase of FCVs units on the road. **Figure 18** portrays the actual and planned HRS without giving details about the year scope. According to H2 moves Scandinavia, each of the HRS can perform 350 refuelling per week, thus encompassing the **current 12 HRS in operation** it is possible to calculate the actual capacity (4200 FCVs per week) by assuming small stations[39]. Hence, the supply capacity of the whole network could be around **350 tons H_2/year.**

[36] The car fleet will be around 255,000 units. This number was gotten from Figure 17. By summing the annual sales of FCVs up to 2025
[37] Car fleet: 1.27 mill units. This number was gotten from Figure 17. By summing the annual sales of FCVs up to 2030

[38] (EUDP_Transnova, 2012)
[39] Small Station: 80 kgH_2/day and 16 FCV fills/day

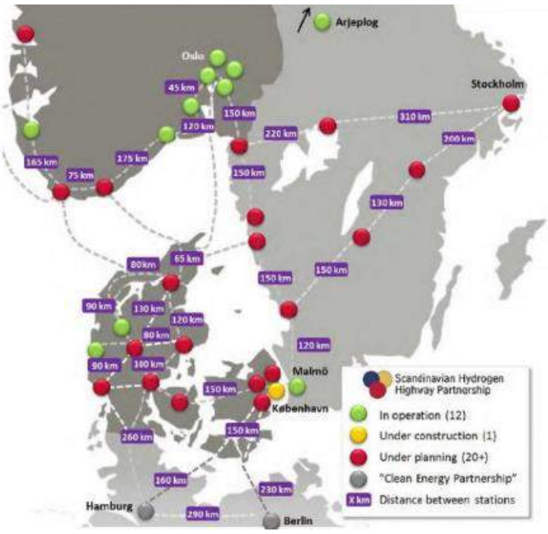

Figure 18 HRS Scandinavia/ Source: H2 moves Scandinavia 2012

Additionally, Denmark has put a lot of efforts to introduce FCVs and increase HRS network. In 2012 the country developed an outlook for HRS for a timeframe of 2015 – 2050, as displayed in **figure 19.**

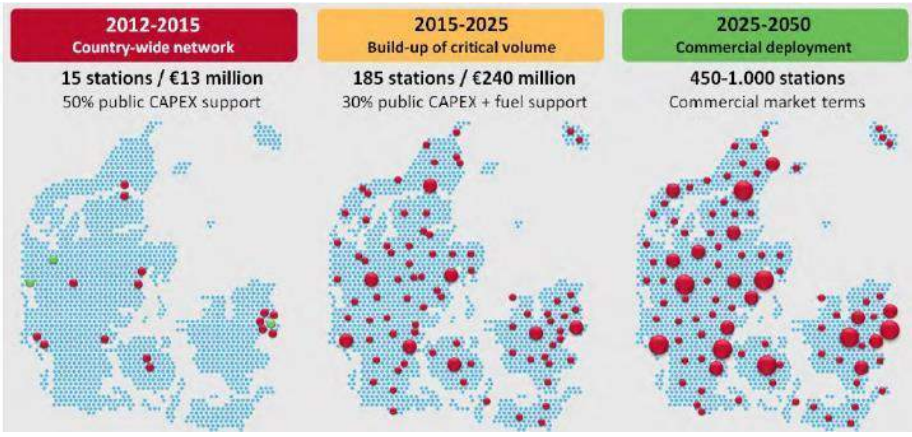

Figure 19 Denmark HRS outlook network

By assuming the same parameters stated aforementioned, it can be calculated the HRS supply capacity for the whole network. In the **timeframe of 2015 – 2025** (base on Figure 20) it is foreseen to have a coverage of **185 HRS** amongst the country, leading to **an annual H_2 supply capacity of around 27,000 tons**[40]. With this same information Hinicio assumes a possible FCV flee of around **87,000 vehicles**[41] . Then, for the horizon **2030 – 2050** it is envisaged a HRS deployment of **450 – 1000** [42], reaching a hydrogen supply capacity around **95,300– 277,700 tons per year and a deployment of FCV between 3.28 mill and 7.3 mill**[43]**.**

[40] Medium stations: 400 kgH_2/day

[41] Calculate with the lowest ratio of FCVs/HRS amongst UK, France and Germany. This relation is 470.2 cars per station on 2025

[42] Conservative scenario: *Medium stations: 400 kgH_2/day and Large stations 1000 kgH2/day*

[43] Calculate with the lowest ratio of FCVs/HRS amongst UK, France and Germany. This relation is 7300 cars per station on 2050

2.2.5 Analysis of the H2 mobility projections and conclusions

It can be observed that the more recently developed national H2 mobility programs are more conservative than the EU-wide scenarios analyzed (McKinsey report and Hyways project) dated in 2010 and 2007 respectively. Indeed, the Hyways project scenarios are quite optimistic, because they do not reflect the economic slowdown faced since 2008 nor the changes of the policy frameworks (e.g. introduction of the 2020 climate and energy package).

In order to derive to an EU-wide market projection for mobility hydrogen, the CertifHy project bases its projection on the national H2Mobility programs because they reflect recent market conditions.

We assume that the 4 country/regions which launched the H2Mobility programs (France, UK, Germany and Scandinavia) will represent 100% of the total FCV fleet in Europe by 2015. This market presence will progressively decrease as other countries initiative investment programs in this technology (Austria, Netherlands, Italy, Spain, etc.). By 2030 market share of the 4 countries/regions would represent around 60%.

By 2030, we can estimate a European H2 consumption of around **786,000 tons/year.**

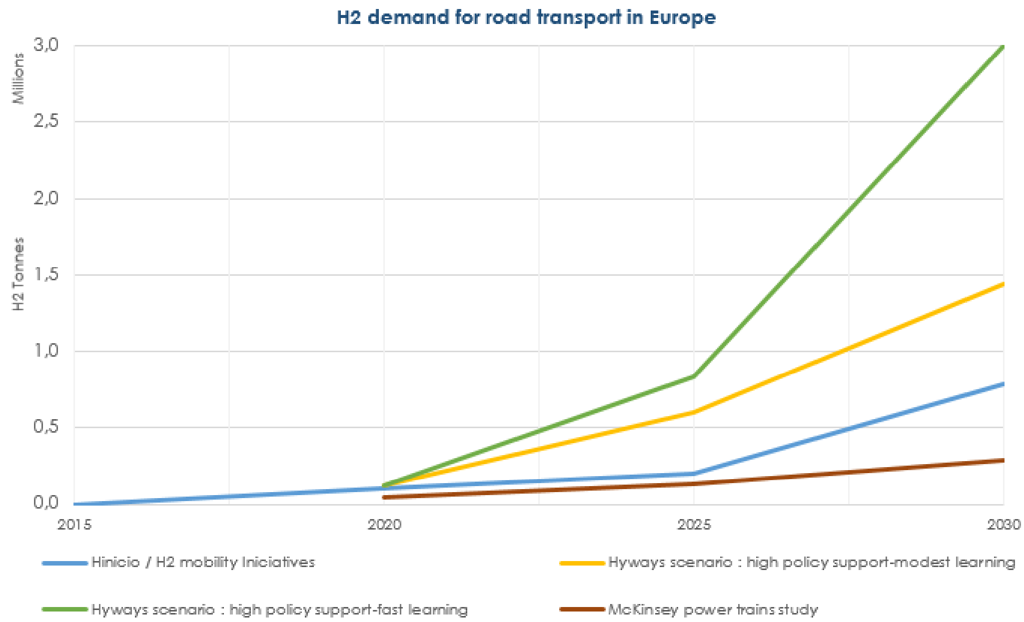

Figure 20 Comparative analysis of existing roadmaps for FCEV and H2 demand for transport. Source: Hinicio's analysis based on national H2 mobility roadmaps, Hyways project, a portfolio of power-trains for Europe (McKinsey)

2.3 Power-to-gas ("P2G") - Injection of H2 into the natural gas grid

Blending hydrogen into the existing natural gas pipeline networks has some benefits, like allowing to transfer renewable electricity from the power to the gas grid at times when there is oversupply of electricity. This could help to avoid curtailment of renewable energy and contribute reducing GHG emissions of the overall energy system. The rationales and drivers for introducing to P2G market will be further explained in ***Deliverable 1.3*** "*Generic estimation scenarios of market penetration and demand forecast for "premium" green hydrogen in short, mid and long term*".

For the purpose of the report, this chapter will help to provide an estimation of the hydrogen volume that could be injected into the grid.

The amount of hydrogen injected today into the natural gas grid is negligible. However, over the coming years the network could facilitate the integration of renewable energy through hydrogen gas.

The blending percentages were defined by The NaturalHy [44] study, which states that blending between 1% -15% (by volume) offers minor issues, therefore the current pipeline network may require only minor modifications to the operation and maintenance. In the graph, it is also displays the maximum theoretical percentage (**20%**), nevertheless this ratio seems to be extremely high and could cause some damage for gas appliances end users (boilers, gas turbines and combustion engines).

In **2013** the natural gas (NG) demand in the grid all over the EU reached to **4,955,421 GWh[45]** and it was projected to keep an increasing pace of 1%[46] annually. To size the hydrogen blending that could be injected direct into the grid, it needs to be bounded by the pipeline flow rate during low consumption periods. Thus, NG consumption during summer (**1,721,921 GWh**) was used to calculate and size the maximum hydrogen volume consumption. Therefore, 3 scenarios were proposed: ***Low (1%), Medium (2%) and High (5%)*** **hydrogen volume blending**. For computing Natural Gas volume, it was assumed that is composed mainly of methane (CH_4). Then, with the volumetric energy content[47] of this component it was possible to get the "Natural Gas" volume**.** **Figure 21** shows an outlook in tons of hydrogen that could be injected into the grid, for the timeframe of **2015 – 2030** without considering the hydrogen penetration rate into the market nor the grid locations and end users.

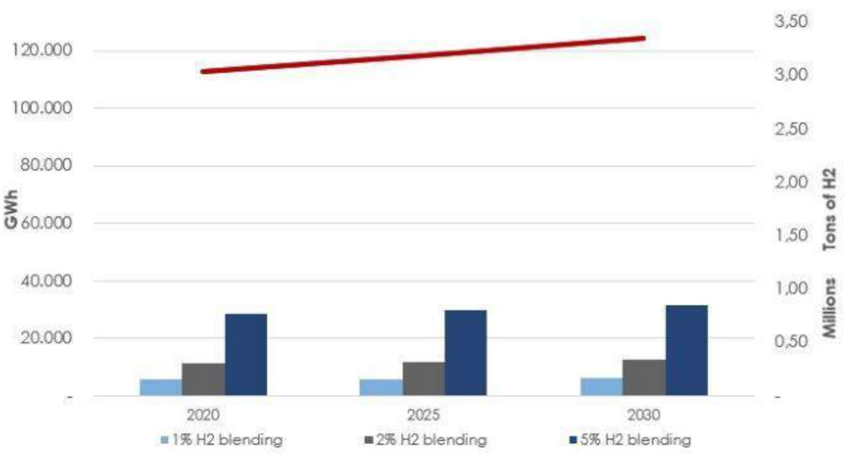

Figure 21 P2G Hydrogen volume opportunity. ***Source: Hinicio***

Table 6 *Potential H2 injected into the grid in Tons.* ***Source: Hinicio***

SCENARIOS	2020	2025	2030

[44] (Florisson, A step towards the hydrogen economy by using the existing natural gas grid (the NATURALHY-project), 2005; Florisson, http://energy.gov/sites/prod/files/2014/03/f9/05_florisson.pdf, s.d.)
[45] Source: (Europe, 2013)
[46] (Entsog, 2013)
[47] Source: (Benoit Decourt, 2014). Volumetric Energy content 10,8 kWh/m^3

Low	307,350	323,000	340,000
Medium	769,000	807,561	848,800
High	1,536,700	1,583,300	1,697,500
Maximum theoretical	3,073,500	3,230,250	3,395,021

In conclusion, we assume that a hydrogen injection **volume ratio between 1% up to a maximum of 2% of hydrogen blending could be feasible without major technical consequences.** Of course, this figure does not consider the local specification of the gas grid. And it assumes that all grids (including transport and distribution) in Europe will be doped with up to 2% of hydrogen.

3 Towards the use of green hydrogen

As global energy consumption continues to rise, it is imperative to develop new alternatives to fossil fuels that nowadays moves our world. The impending GHG emissions growth and the strong dependency of exhaustive sources limited by fossil energy present some of drivers to switch to new alternatives and to encourage industry players to invest on different technologies. Hydrogen is a promising energy carrier, nevertheless the way that is currently produced is not in line with long-term climate and energy goals. In the long-term hydrogen, if based on sustainable source, could contribute to reduce CO_2 emissions, local pollution, ensure energy independence and will help to achieve sustainability goals.

The introduction of hydrogen as an energy carrier is not only a technology challenge, but it also requires the convergence of many political and socioeconomic factors. Political will and improved regulatory and policy regimes could lead to an uptake of green hydrogen. The rational for the use of green hydrogen will be further developed in Deliverable 1.3, covering 2 main driver categories (regulatory and market). There are many benefits behind green hydrogen; but it is imperative to set up policy initiatives that help reduce its cost and remove market barriers. The policies can be classified as those to: a) reduce local emissions; b) reduce greenhouse gas emissions; c) increase energy security through the use of local resources and through distributed energy; d) develop new industries for growth and job. In addition to the policies, the ability of the industry to reduce technology cost will be of paramount importance for the future of the sector.

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