“Needs and benefits of “green” hydrogen in light of a market outlook”

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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
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 Objectives for the assessment of green hydrogen market

The aim of this work package is to assess the needs and benefits of “green” hydrogen in light of a market outlook, in order to provide evidence of a rational for adopting green hydrogen by policy makers and market players, and provide an insight of the potential penetration within the different market segments in Europe for the years 2015 – 2025 – 2030.

For this purpose, the work has been divided in 3 individual tasks, each one described in a separate deliverable:

D1.1. Bibliographic review of market outlooks for hydrogen in Europe.

D1.2. Overview of the market segmentation for hydrogen across potential customer groups, based on key application areas.

D1.3. Generic estimation scenarios of market penetration and demand forecast for “premium” green hydrogen in short, mid and long term

Figure 1 presents the schematic of the proposed distribution of tasks for WP1 as explained above, in order to demonstrate the narrow-down of the tasks from a global demand perspective of the hydrogen market, into a sector specific demand outlook of green hydrogen, including the evaluation of different roadmaps, policy drivers and considerations for each evaluated sector in the context specified.

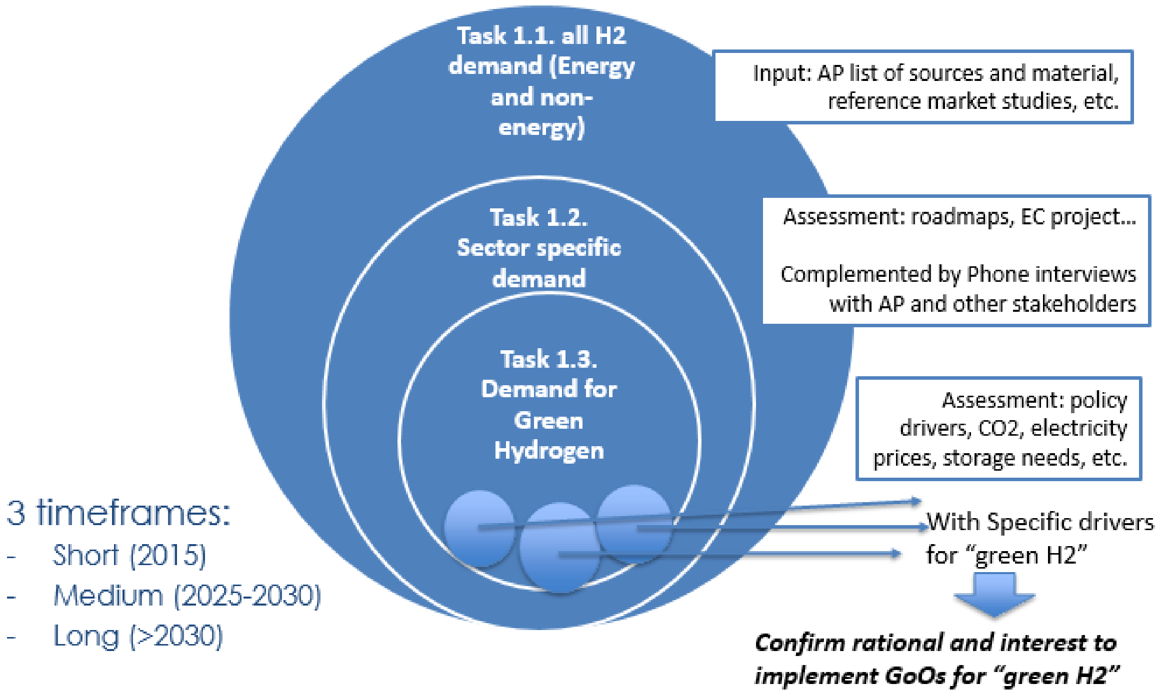

Figure 1 Schematic Representation of WP1 workflow (Source: Hinicio)

2 Introduction to D1.1: Rational, Contents and Methodology

2.1 Rational

Energy transition into low-carbon technologies has become one of the pillars on the quest to address some of the most immediate concerns that the world is facing nowadays: The depletion of fossil fuels, the security of energy supply, greenhouse gases emissions and a too- rapid climate change.

Hydrogen represents a reliable alternative, as it doesn’t produce polluting emissions when used. For this reason, many believe that this energy vector could revolutionize the way we will manage the world’s energy resources, having a huge growth potential in the upcoming years to guarantee energy security in Europe and redeem the GHG emissions. For this to be true, the introduction of hydrogen will need to prove a positive impact and emissions reduction, not only when used, but in a whole life-cycle context. In order to achieve this, there is a need for introducing a ‘sustainable’ pathway for the development of the hydrogen infrastructure and its introduction in the economy. This is the rational of studying and placing ‘green hydrogen’ in a real economical context within the EU.

2.2 Contents

Section 3 of this report contains a review and synthetic description of the relevant sources consulted. A diagram is presented to show the market’s divisions in its different segments and sub-segments with the main drivers for changing to green hydrogen in each segment can be found in section 4, together with a brief analysis and the main conclusions that can be drawn from the literature review and each of the segments. The conclusions of this work package will help provide a starting point for D1.2 and provide the tools needed to create a final market overview in D1.3.

The identified demand segments for hydrogen in Europe were: Industry (including petro-chemical), Mobility, Power (electricity) and Heating. After assessment, considering their relevance (volumes) and potential future development, two were selected to perform an in-depth analysis: the industry and the mobility hydrogen markets. Additionally, an insight to a possibly relevant emerging application is presented: “Power to gas” for hydrogen gas grid injection. Even though a ‘proper demand for hydrogen’ cannot be analyzed in this case, this application could be key for introducing green hydrogen in the economy, as it could be the key to help the introduction of new hydrogen technologies and help to profit from curtailed renewable energies.

2.3 Methodology

Figure 2 presents a schematic of the work undertaken during D1.1 and D1.2. This approach required a comparison and synthesis of the different market projections available: total volumes and prices, associated emissions, type of market (merchant, captive), and a characterization of the hydrogen marketable product parameters for the different applications (kgH2, MWh, Liquid/gaseous, purity levels, application areas, etc…).

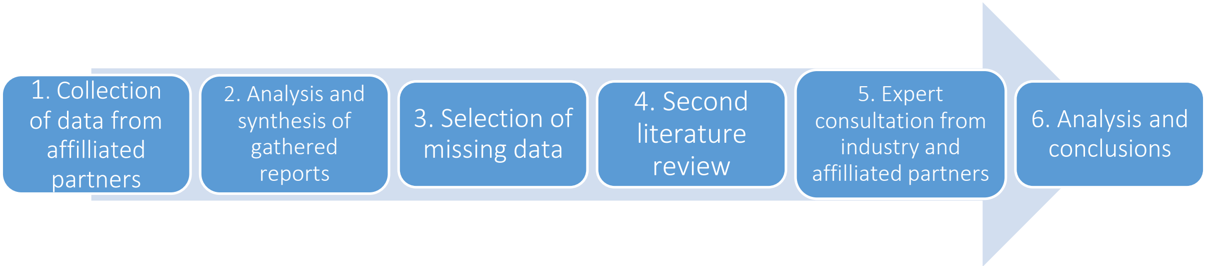

Figure 2 Schematic Representation of methodology for task 1 (Source: Hinicio)

The methodology for task 1.1 started with a bibliographic review. At this stage, the consortium reached out to the affiliated partners to collaborate in performing a collection of relevant data and sources. After being evaluated, the sources were complemented through a second literature research.

An initial summary was carried out, which was finally complemented with expert consultation from affiliated partners. Additionally, in order to complement the information in deliverable D1.3, Hinicio presents a set of different scenarios based on possible hypothesis for the penetration of green hydrogen in the different segments, which will depend on several specific drivers that were identified during this literature review and are mentioned in this document.

3 Summary of relevant sources analysed

Table 1 Source Summary (Source: Hinicio)

Segment	Title	Author	Year	Subject	Reference
Industry	Part II: Industrial Surplus Hydrogen and Market Production	Roads2HyCom project members	2007	Hydrogen Industrial Market segments: "Industrial surplus hydrogen and markets and production"	[1] ***Guy Maisonnier, J. P. (2007). European Hydrogen Infrastructure Atlas. PART II: Industrial surplus hydrogen and markets and production. HyLights***
Industry	Hydrogen-Based Energy Conversion. More than storage: system flexibility	SBC Energy Institute	2014	Hydrogen-Based Energy Conversion: Market segment descriptions and scenarios	[2] ***Benoit Decourt, B. L. (2014). Hydrogen Based Energy Conversion. SBC Energy Institute***
Industry	Hydrogen Production Cost Using Low-Cost Natural Gas PRAXAIR	Praxair	2011	Hydrogen Outlook: current consumption and projections	[3] ***Angel, S. (2011). Global Hydrogen Investor Day. Global Growth Outlook. USA: Praxair***
Industry	Hydrogen Production Cost Using Low-Cost Natural Gas	Sara Dillich, DoE USA	2012	H2 production cost by SMR injecting NG. Sensitivity analysis	[4] ***Sara Dillich, T. R. (2012). Hydrogen Production Cost Using Low-Cost Natural Gas. Department of Energy United States of America***
Industry	World Hydrogen Industry Study with Forecasts for 2013 and 2018	Freedonia	2014	World Hydrogen Demand 2013 and Regions' market share	[5] ***Group, F. (2013). World Hydrogen Industry Study with Forecasts for 2013 and 2018. Cleveland, OH.***
Industry	Methanol Industry Presentation	Methanex (Brad Boyd)	2011	Methanol market outlook	[6] ***Methanex. (2014). Methanex Investor Presentation. Texas: Methanex***
Industry	HyWays Potential for by-product hydrogen and possible	HyWays	1995 - 2003	Germany: Current potential for by-product hydrogen and possible production extension. Inventory of plants and	[7] ***Comission, T. E. (1995 - 2003). Hyways: Potential for by-product hydrogen and possible production extension.***

	production extension			amounts, segmentation by amount / type of industry	
Industry	Hyways. The European Hydrogen Energy roadmap	HyWays	2008	An action Plan features the detailed conditions for FCV penetration including: timelines needed to overcome the initial barriers to facilitate H2 technologies deployment.	[8] ***Comission, T. E. (2008). Hyways The European Hydrogen Roadmap. Belgium***
Industry	Global Green House emission Data	USA Environmental Protection Agency	2007	Global emission by source	[9] ***Agency, U. S. (2007). Global Greenhouse Emissions Data. Retrieved from http://www.epa.gov/climatechange/ghgemissions/global.html***
Industry	Hydrogen - Making a Transition from Industrial Chemical to Energy Carrier	Air Liquide	2004	Air Liquide corporate presentation, Current industrial Hydrogen applications and status of the use of H2 as energy carrier	[10] ***Liquide, A. (2004). Making the Transition from Industrial Chemical to Energy Carrier. Texas: Air Liquide***
Industry	DOE H2A Production Analysis	DoE	2012	Models to provide transparent reporting of process design assumptions and a consistent cost analysis methodology for the production of hydrogen	[11] ***Energy, U. D. (2015, 02 25). Hydrogen and Fuel Cell Program. Retrieved from http://www.hydrogen.energy.gov/h2a_production.html***
Industry	Metals & Mining Stock Outlook	NASDAQ	2013	Metals & Mining Stock Outlook	[12] ***NASDAQ. (2013, February 14th). Metals & Mining Stock Outlook - Feb 2013 . Retrieved from http://www.nasdaq.com/article/metals-mining-stock-outlook-feb-2013-industry-outlook-cm217862***
Mobility	H2-Mobility penetration EDF R&D Evaluation Model:	EDF	2014	H2 mobility penetration in France: Hydrogen mobility toward low carbon technologies. Model for hydrogen price, regulation	[13] ***Dominique LAFOND (EDF R&D) (2014), H2-Mobility penetration EDF R&D Evaluation Model: Presentation and***

	Presentation and first results			and hydrogen penetration in the market	***first results. EDF R&D, France***
Mobility	Roads2HyCom Reports in Detail	Roads2HyCom project members	2007	Website contains detailed information on the results generated within the Roads2HyCom (R2H) project. More projects such as HyTRAN have joined this wiki to create and maintain a reliable source of information. It is edited by technology experts only	**[14] *Roads2Hy Official project website (2015). Retrieved from:* *http://www.ika.rwth-aachen.de/r2h/index.php/Roads2HyCom_Reports_in_Detail***
Mobility	A portfolio of power trains for Europe: a fact-based analysis	Consortium : Zero Emission Vehicles.eu (supported by McKinsey)	2010	Hydrogen for transport sector: segmentation and projections	**[15] *McKinsey. (2010). A portfolio of power trains for Europe: a fact based analysis***
Mobility	UKH2-Mobility Phase 1 Results April-2013	UKH2 Mobility Project (McKinsey)	2013	fact based analysis of the potential for hydrogen fuel cell electric vehicles (FCVs) in the UK	**[16] *McKinsey, E. E. (2012). UKH2 Mobility***
Mobility	NOW Annual reports 2012 and 2013	NOW project	2012 - 2013	Modeling of electro mobility in Germany	**[17] *(NOW), N. O. (2013). Annual Report. Germany: NOW.***
Mobility	German National Hydrogen and Fuel Cell Technology Innovation Programme	Project website	2015	German National Hydrogen and Fuel Cell Technology Innovation Programme	**[18] *Invest, G. T. (n.d.). www.gtai.de . Retrieved from National Hydrogen and Fuel Cell Technology Innovation Programme: http://www.gtai.de/GTAI/Navigation/EN/Invest/Industries/Smarter-business/Smart-mobility/national-hydrogen-and-fuel-cell-technology-innovation-programme.html***
Mobility	FCH-JU Urban buses alternative powertrains	FCH JU - NEW IG	2012	Urban buses alternative powertrain for europe	**[19] *FCH-JU. (2012). Urban buses: alternative powertrains for Europe. FCH JU.***

	for Europe 2012				
Mobility	German Efforts on H2 Transport LBST report	LBST	2011	Germany Hydrogen Transport Sector: Project update upto 2011	**[20]** ***GmbH, L.-B.-S-T. (2011). German efforts on hydrogen for transport. Ottobrunn***
Mobility	Towards a European Hydrogen Roadmap	Matthias Altman, LBST	2004	Mobility and drivers towards hydrogen: Description of projects	**[21]** ***Matthias Altman (2004). Towards a European Hydrogen Roadmap. Hyways Project. LBST***
Mobility	H2MOVES Scandinavia 2012 third part	H2moves Scandinavi a	2012	Project Outlook 2012: Results and projections	**[22]** ***Transnova, E. (2012). H2moves Scandinavia Technical Reporting. Oslo***
Mobility	H2 Mobilité France. Study for a Fuel Cell Electric Vehicle national deployment plan	Mobilité Hydrogène France	2010	Hydrogen Mobility implementation plan: FC Vs market outlook in France from 2010 - 2030	**[23]** ***France, M. H. (n.d.). H2 Mobilité France. Study for a Fuel Cell Electric Vehicle national deployment plan***
Mobility	AfhyPac official website	AFHYPAC	2015	Website of the French association of hydrogen and fuel cells	**[24]** ***AfhyPac. (2015). Retrieved from http://www.afhypac.org/fr/accueil***
Mobility	ISO 14687-2:2012	ISO 14000	2012	Hydrogen fuel -- Product specification -- Part 2: Proton exchange membrane (PEM) fuel cell applications for road vehicles	**[25]** ***ISO. (2012). ISO 14687-2:2012. Retrieved from http://www.iso.org/iso/catalogue_detail.htm?csnumber=55083***
Mobility	JEC - Joint Research Centre-EUCAR-CONCAWE collaboration reports	European Commission's Joint Research Centre, EUCAR and CONCAWE	2014	Vehicles and powertrains, energy and fuels in Europe: Well-to-Wheels Analysis of Future Automotive Fuels and Powertrains in the European Context	**[26]** ***Joint research center JEC, report website (2015à. Retrieved from: http://iet.jrc.ec.europa.eu/about-jec/welcome-jec-website***

Policies	The Revised FQD: weakened proposal must still be implemented	Transport and Environment	2014	EU policy: Drivers for clean fuel	[27] **Website "The revised FQD: weakened proposal must still be implemented". (2015) Retrieved on** **http://www.transportenvironment.org/publications/revised-fqd-weakened-proposal-must-still-be-implemented**
Power to Gas	A step towards the hydrogen economy by using the existing natural gas grid (the NATURALHY-project)	Onno Florisson	2005	Power to Gas project description: Definition of hydrogen blending	[28] ***Florisson, O. (2005). A step towards the hydrogen economy by using the existing natural gas grid (the NATURALHY-project). Retrieved from http://energy.gov/sites/prod/files/2014/03/f9/05_florisson.pdf*** [29] ***Florisson, O. (n.d.). Retrieved from: http://energy.gov/sites/prod/files/2014/03/f9/05_florisson.pdf. Retrieved from http://energy.gov/sites/prod/files/2014/03/f9/05_florisson.pdf***
Power to Gas	Ten year network development plan 2013 - 2022	Entsog	2013	Provides a view of how European gas infrastructure could develop over the next ten years	[30] ***Entsog. (2013). Ten year network development plan 2013 - 2022. Brussels.***
Power to Gas	System Development Map 2013	Entsog & GIE	2013	Euroepan Natural Gas Infrastructure	[31] ***Europe, G. I. (2013). www.gie.eu. Retrieved from http://www.gie.eu/download/maps/ENTSOG-GIE_SYSDEV_MAP2013.pdf***
Green Hydrogen	Hydrogenics_ Company presentation	Hydrogenics	2014	Hydrogenics company presentation: Electrolyzers and uses. Includes industrial uses and PtG projects	[32] ***Hydrogenics (2015). Company Presentation. Oevel, Belgium***
Green Hydrogen	Production and Utilization of Green Hydrogen	Mathias Mostertz Linde	2013	Green hydrogen in the industry	[33] ***Mathias Mostertz, Group, T. L. (2013). Production and Utilization of Green Hydrogen. The Linde Group***

Green Hydrogen	Green Hydrogen: green at the source	The Linde Group	2014	Green Hydrogen applications: Two Green Hydrogen demonstration projects	[34] ***Group, T. L. (2014). Green Hydrogen: green at the source. The Linde Group***
Green Hydrogen	GT AFHYPAC 1.3 / Garantie d'Origine H2 renouvelable	ADEME, AG AFHYPAC	2013	Action plan for consortium, regarding project for GoOs for green Hydrogen	[35] ***Ademe, GT AfHyPAC (2013). 1.3 / Garantie d'Origine H2 renouvelable. AfHyPAC***
Green Hydrogen	Water Electrolysis Status and Potential for Development	Fraunhofer ISE	2014	Electrolysis and PtG: Describing Water Electrolysis, coupling with renewable energies.	[36] ***Tom Smolinka , Fraunhofer ISE (2014). Water Electrolysis Status and Potential for Development. Joint NOW GmbH – FCH JU, Water Electrolysis Day, Brussels (BE)***
Green Hydrogen	Hydrogen- overview of European initiatives	Hinicio	2014	Green Hydrogen Initiatives in Europe: Summarized	[37] ***Hinicio (2014). Hydrogen- overview of European initiatives. Brussels***
Green Hydrogen	Erzeugung von grünem Wasserstoff (GreenHydrogen)	TÜV Süd	2011	"Green Hydrogen" standard from TÜV Süd for green hydrogen from bio-methane, glycerin or renewable electricity	[38] ***Erzeugung von grünem Wasserstoff (GreenHydrogen), TÜV Süd Standard CMS 70 (Version 12/2011)***
Other	ROADMAP 2050 A practical guide to a prosperous, low-carbon Europe	McKinsey	nd	CO2 emmission reduction roadmap for europe	[39] ***McKinsey. (n.d.). Roadmap 2050. Retrieved from http://www.roadmap2050.eu/attachments/files/Corepresentation.pdf***

4 Assessment of the literature review: Contents and key findings

After assessing the sectors and sub-sectors of hydrogen markets in Europe through existing studies and relevant reports available in the literature, we have decided to select those markets which are potentially the largest ones within the considered timeframe.

Figure 3 shows a diagram of EU hydrogen market's segments, sub-segments, and main influencing factors for moving into green hydrogen.

For the mobility market, it has been considered more relevant to assess the outlooks for each country, rather than other criteria, such as the type of vehicle. The four countries considered are retained due to their existing H2 mobility programs or similar initiatives in place:

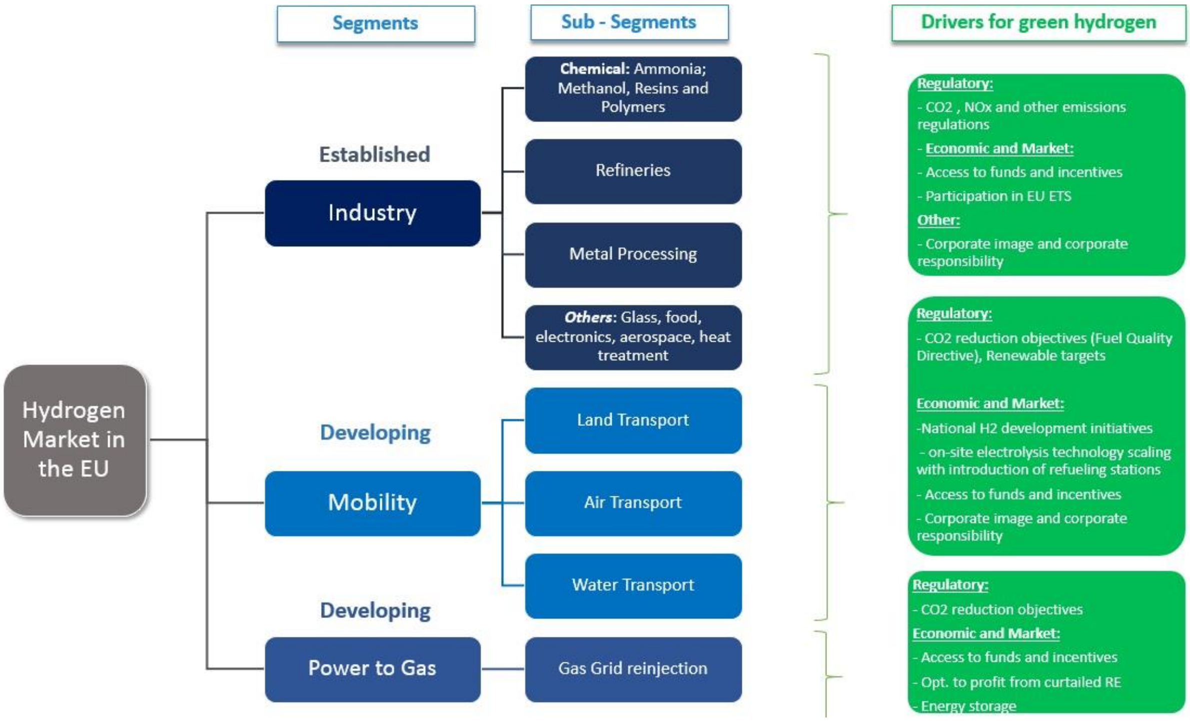

Figure 3 Main segments and sub-segments and influential factors for green Hydrogen. (Source: Hinicio)

The most important factors to consider in order to move ahead in our analysis for each segment are the current and forecasted market shares, volumes and price ranges; as well as the volume and price dynamics, and the characteristics of the hydrogen for each segment. Some of this information is available in the literature and relatively easy to find, but some was difficult to obtain.

4.1 Hydrogen market in the industry segment

This segment is the only one to have today an existing measurable and relatively predictable demand. For the immediate and short term, volumes are simple to estimate. Nonetheless, price targets are not as evident, given that hydrogen in the industry is a less transparent market, therefore prices are not published nor available in publicly accessible databases. For this reason, the most reliable information found on the literature which could yield an appropriate estimate of these prices are hydrogen production cost (ranges). These costs are associated to the method of production of the gas, but in the case of industrial markets, it is widely accepted that 'Steam Methane Reforming' (SMR) is the main production method, and will continue to be so for years to come.

In contrast, it is very challenging to foresee what will be the evolution of the Industry market in the longer term. No forecasts are found on the literature beyond 2018, for which a growth estimate had to be considered.

4.2 Hydrogen market outlooks in the mobility segment

Different approaches are made to produce generic hydrogen market outlooks in the mobility segment. In order to be able to produce a reasonable estimate of the evolution of the volumes, country-based outlooks have considered relating these amounts with a forecast of FCVs sold in the country in this period of time, and creating a set of possible scenarios for the average yearly consumption for these vehicles.

In the case of the whole EU, no such forecast is available in the literature, for which capacities, rather than volumes consumed are considered. In this case, the outlook is made by predicting possible scenarios for the evolution of the infrastructure, and calculating the average amount of hydrogen distributed daily by every different type of HRS. An alternative way to perform this calculation is by forecasting possible scenarios for the total penetration of FCVs in the EU automotive park (in percentage), and calculate based on the complete vehicle sales, the amount of FCV penetration for the EU territory. Putting together these volumes, and other factors such as economies of scale, different production techniques and the evolution of the available technology, price forecasts are produced. Each study proposes a different methodology, getting different results, for which a price range is produced for every year. These ranges are compared with the EU targets set for hydrogen price until 2030.

4.3 The ‘Power to Gas’ role in the future hydrogen market

Hydrogen gas grid injection is difficult to assess in the light of a demand outlook, taking into account that there isn’t a ‘specific demand’ for the time being for this application, thus such outlooks are not yet widely available. Instead, literature in general details existing and planned projects in the short term, their location and technical specifications. The longer term is less evident to assess, as many assumptions need to be made. To date, gas grid injection is not widely spread, and volumes of hydrogen produced and injected are negligible. Nonetheless, we need to keep in mind that in many countries in the EU it already has a commercial value (namely, the price paid for the natural gas).

The amount of hydrogen that can be injected in the natural grid is limited by the maximum allowed volumetric concentration for injection in the grid at a specific point. This amount, different in each country, can be used to calculate the technical capacity limit of hydrogen injection in the gas grid country by country to assess the maximum possible hydrogen that can be injected in the grid for a specific year, taking into account outlooks for infrastructure. This capacity is different from the outlooks for gas grid injection in the EU. These outlooks are dependent on other factors. Power to gas has the added value of helping to valorize what is today curtailed renewable energy, by giving it a potential value in the form of the gas and can be key in the introduction of new hydrogen technologies. Considering the amount of curtailed renewable energy each year in the EU could provide an approach of the amount of “green hydrogen” that could be injected in the natural gas grid. Nonetheless, such forecasts are as well very numerous and variant, as they consider very different scenarios.

4.4 How much of the hydrogen in the different segments will be ‘green’?

Regarding this subject, publications are less specific, and there hasn’t been a clear consensus on the definition and outlooks for the penetration of the same in the EU. The main influencing factors remain the economic and regulatory framework. It is important to note that through the EU ETS, the production of green hydrogen could actually represent an economic benefit. This is relevant, given that as from 2013, the scope of the ETS has been extended to include other sectors such as the chemical and petrochemical industry. Still, there are large uncertainties regarding the green hydrogen demand evolution possibly driven by the ETS.

Many different production methods have been considered in the literature. Nonetheless, it is most common to find allusions to by-product hydrogen and water electrolysis[1] as main sources of green hydrogen. While biomass gasification is still under debate, other methods like the organic production of hydrogen, e.g. with algae or bacteria, as well as the direct splitting of water, using sunlight, are still topics for basic research and they are not expected to have a large impact before 2030. To proof that the hydrogen is originating from renewables and reduces CO2 compared to fossil production methods, standards and certification processes as used in other areas, will be necessary. Already established is the “Green Hydrogen” standard from TÜV Süd for green hydrogen from bio-methane, glycerin or renewable electricity [38]. Additional added values such as corporate responsibility and company image are factors mentioned to increase the penetration of green hydrogen in the industry and mobility for the years to come. These will be further studied in D1.3.

5 Conclusions on initial results of literature review for green hydrogen markets

1. **Hydrogen markets in the industry** are overall well referenced, having enough information elements to describe the current situation and make accurate forecasts in the short and medium term, and create hypothesis to produce outlooks for the long term. Some reports state that the value added for green hydrogen in the industry is still not significant enough to ensure large penetration, for which action may need to be taken. The information gathered evidences the need to have a project like CertifHy, as one of the required measures to develop the market of green hydrogen in the EU for the upcoming years.

[1] Water electrolysis can only be considered ‘green’ if produced with a low-carbon based electricity (not based on fossil fuels). In reports such as *[15]* (McKinsey. (2010*). A portfolio of power trains for Europe: a fact based analysis.)*, it is considered that by 2030 most of the electricity sources will be decarbonized in the EU.

2. Independent of the large variation on the results of the different outlooks for hydrogen in the **mobility segment**, it can be stated that 'green hydrogen' will be more important in the emerging mobility market, than for industry, given that the main driver for the development of the mobility market is the reduction of greenhouse gas emissions and local emissions. It is therefore expected for the long term, that a **large percentage of the hydrogen for mobility will be green.**

3. **For power-to-gas, 100% of the H_2 produced to be injected in the grid will be green**, due to the very nature of this application.

In conclusion, the literature review conducted in D.1.1 confirms the rational and interest both for market players and policy makers to have a green hydrogen GoO in place in Europe.