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A. Le Duigou, M.-M. Quéméré, P. Marion, P. Houel, P. Menanteau, L. Sinegre, L. Nadau, A. Rastetter, A. Cuni, P. Mulard, L. Antoine, T. Alleau

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Aims and First Assessments of the French Hydrogen Pathways Project HyFrance3

Alain Le Duigou, CEA/DEN/DANS/I-Tésé, France
Marie-Marguerite Quéméré, EDF R&D, Département EPI, France
Pierre Marion, **Pascal Houel,** IFP, France
Philippe Menanteau, CNRS LEPII, France
Laure Sinegre, Lionel Nadau, GdF Suez, Direction Recherche et Innovation, France
Aline Rastetter, ALPHEA, URODEV CENTER, France
Aude Cuni, Air Liquide, France
Philippe Mulard, TOTAL France
Loïc Antoine, ADEME, France
Thierry Alleau, AFH2, France

Abstract

The HyFrance Group was originally formed in France to support the European project HyWays, by providing (former projects HyFrance1 and HyFrance2) the French data and possible hydrogen pathways according to national specificities. HyFrance3 is a new project that focuses on the economic competitiveness of different steps of the hydrogen chain, from the production to end usage, at the time horizon of 2030 in France. The project is coordinated by CEA with the other partners being: ADEME (co-funding), AFH2, CNRS, IFP, Air Liquide, EdF, GdF Suez, TOTAL, ALPHEA. The project is divided into 4 sub-projects, that address present and future French hydrogen industrial markets for chemical & refinery uses, the analysis of the interplay between wind energy production and storage of hydrogen for different automotive requirements (refuelling stations, BtL plants, H_2/NG mix), massive hydrogen storage to balance various offer and demand characteristics, and the supply network (pipeline option competitiveness vs. trucked in supply) to distribute hydrogen in a French region for automotive applications. Technical and economical issues, as well as GHG emissions, are addressed.

Keyword: HyFrance, Hydrogen, Roadmap, Techno-economy, storage, wind energy, industrial applications, infrastructure

1 Introduction

HyFrance3 is a ADEME funded French project, involving ten partners in an national consortium, that consists of major players from a range of energy, scientific, research and engineering institutions together with SMEs: ADEME (partner and co-funding), AFH2, CNRS, IFP, Air Liquide, EdF, GdF Suez, TOTAL, ALPHEA and CEA (coordinator). These partners have already achieved a high level of international visibility, recognition and acceptance within the framework of the former projects HyFrance1 and HyFrance2 [1]. Those projects partners contributed, together with other partners such as BRGM, Renault, PSA, to work out a French hydrogen energy roadmap, as a French application of the techno- and socio-economic methods and tools used in the European project HyWays [2] which aimed at developing a European hydrogen energy roadmap. As the aim of HyFrance is to identify the key issues, challenges, barriers and opportunities related to the development of hydrogen energy and its applications in France, HyFrance3 has been launched to focus on the economic competitiveness of different steps of the hydrogen value chain that had not been, or insufficiently, achieved in HyFrance1 and HyFrance2, from the production to end usage use, at the time horizon of 2030 in France.

This paper describes the topics addressed by this 18 months duration project that has been launched at the end of May 2009. The work is divided into 4 sub-projects, that cover both large scale systems (SP1, SP3, SP4) and a smaller scale one (SP2):

- SP1 : present and future French hydrogen industrial markets (merchant, captive and co-product), for chemical and refinery uses depending on different scenarios including the use of BtL,
- SP2 : technologies and costs of H_2 production from wind power for different transport requirements (refuelling stations, BtL plants, H_2/NG mix) with different grid configurations (isolated or connected wind power plants) and H_2 storage volumes,
- SP3 : relevance, dimensions and costs of centralized or decentralized hydrogen mass storage, to balance various offer and demand characteristics,
- SP4 : large scale infrastructure to satisfy massive demand vs. massive production or storage, by dimensioning the supply network (pipeline option competitiveness vs. trucked in supply) to distribute hydrogen in a French region for automotive applications.

Technical and economic issues, as well as GHG emissions, are addressed.

This national project aims also to pursue the French collective techno-economic expertise that emerged in the former HyFrance1 and HyFrance2 projects.

2 Present and Future French Hydrogen Industrial Markets

Similarly to the european and world markets, hydrogen in France is mainly produced for ammonia and refinery uses, both from fossil resources (captive and merchant supply) and as chemical processes co-product. In the short and medium term, given the prospects of an increasing hydrogen demand essentially for refinery use (desulfurisation, heavy crude oil processing, environmental requests), a progressive awareness of the limited fossil hydrocarbon reserves as well as increasingly stringent limitations of the emissions of greenhouse gases, low carbon content hydrogen production processes such as water electrolysis will appear relevant and long term candidate for hydrogen production. HyFrance3 aims to analyse the short and medium term hydrogen needs for a chemical and refinery use, up to 2030.

A study has been carried out, based upon literature data and a complete survey of the French producers and consumers. It appears that by-product hydrogen share exceeds 50% (including steel industry coke oven gas) of the total hydrogen production, with a significant ratio being burnt, while those quantities could be considered as potentially available to supply car fleets for instance, but for a transition phase only. Almost all hydrogen is produced and consumed at the same location, and cross-border trade is negligible. In addition, emerging markets such as iron and steel industry could take benefit of a green hydrogen use, as foreseen for instance by the ULCOS (Ultra-Low CO_2 Steelmaking) project; this could represent very high supply requests, but rather in the long term. By and large, the French hydrogen industrial market should reasonably increase in the medium term. The CO_2 emissions associated to H_2 production are not very important (about 1 to 2% of the overall French emissions), but they could only be lowered either through expensive CO_2 capture and storage technologies (still to be demonstrated at a large scale) or by the use of nuclear or French electricity mix driven electrolysis.

As regards hydrogen needs for the refining industry, two petroleum scenarios are analysed. On the one hand, a "trend-setting" development scenario that perpetuate the current energy demand and technological progress foreseen together with an increase in bio-fuel use (10%, including a second generation allothermal bio-fuels ratio) hybridised cars and electrical vehicles (7.5% of the total number of cars in France). On the other hand, an "environmentally friendly" development scenario considers more ambitious hypothesis such as lower fuel consumptions (-20%), a strong increase in combined rail and road transport (20%), and 21% of cars without internal combustion engine: 15% electric vehicles (battery electric and hybrid), and 6% hydrogen fuel cell vehicles which corresponds to the HyWays "low" scenario for France in 2030. Calculations will use linear programming, to match the different fuels market demand with refinery scheme and crude oil supply, and therefore hydrogen requests, as a function of the scenarios and hypothesis chosen. Well-To-Weels BtL costs will be evaluated, taking into account the interplay with SP2 (above) when hydrogen is produced by electrolysis from wind energy. Overall CO_2 emissions will be estimated too.

3 Wind Energy Hydrogen Economics

Hydrogen production from wind energy often appears as a promising way to increase the renewable energy ratio in the energy mix, hydrogen being then developed as an electrical energy storage medium, as well as a very low CO_2 energy supply for a direct use in transports, together with an important energy security of energy supply. Different layouts may be considered: remote wind farms dedicated to hydrogen production on the one hand, and wind power systems connected to the grid, on the other hand, capable of providing a continuous electrolyser operation and possibly retailing electricity to the grid. Given the shape of hydrogen demand, different storage configurations may be necessary to guarantee continuous supply: irregular or regular requirements from refuelling stations, or continuous demand from a chemical process, for instance.

This topic aims at evaluating hydrogen production costs, given different types of demand, using wind power plants, electricity network, electrolysers, compressed hydrogen storage, and SOFC fuel cells to sell electricity to the grid. The simulation tool HOMER (NREL) is used to give the optimal techno-economic layout for each case, according to the components specifications and under the following economical assumptions: 3 MW wind systems, IHT S-556 electrolyser (760 Nm^3 H_2/h), 23 m^3 Air Liquide tube trailer storage (200 bar), 20 years lifetimes except for intermittently used electrolysers (10 years), and a 6% discount rate. The different cases considered are the supply of a hydrogen motorway service area in the south of France (important H_2 demand peaks), of a Hythane bus fleet (continuous supply of a binary mixture of 20% Hydrogen and 80% natural gas), and of a 2000 barrels per day BtL station. Unlike the refuelling station and Hythane bus fleet cases, the last one does not require any hydrogen storage capacity, which is provided there by the biofuel plant, and then considers a supply "with the current".

The first simulations show a large hydrogen production cost range, depending on the very different characteristics of the demand. The refuelling station requires a 28 MW isolated wind farm and the most important storage capacity. Hydrogen production is then the most expensive, in some cases over 20€/kg, but can be lowered by an appropriate overall system of management. Hydrogen production cost is barely cheaper in the case of a 3 MW isolated wind farm capable of supplying a 100 buses fleet (12.5 kg/h) because of H_2 storage. It is much different with the BtL station that can be supplied without H_2 storage. An isolated 48 MW wind farm could supply roughly 7% of a 2000 barrels per day BtL station, at an average cost of 9 €/kg. All these costs can of course be noticeably lowered when the system is connected to the grid, the lowest range of 4-5 €/kg being reached for the BtL station with grid connection.

4 Hydrogen Mass Storage

The former project HyFrance2 promoted a French strategy for hydrogen production with CO_2-free or CO_2-reduced emissions, i.e. mainly steam methane reforming SMR (assuming the availability of cost-effective techniques for CO_2 capture and storage), conventional water electrolysis using the French electricity mix (90% from non-fossil resources) and regional biomass gasification (large resources available). Whatever may be the future hydrogen production methods, large scale use of hydrogen will require massive storage comparable to natural gas to balance supply and demand. This is specifically relevant for the production of renewable hydrogen from intermittent sources such as wind energy, as described above. But storage remains essential to connect large scale hydrogen continuous production, as cited above, with seasonal demands. The mass storage will interact with the hydrogen grid similar to the buffering capabilities in the current natural gas grid, and the locations could be very similar. But technical requirements and strategy may strongly differ: natural gas storage in France responds to both winter/summer stationary use fluctuations and strategic choices, whereas H_2 mass storage would be linked to seasonal demand changes related to the variations in automotive uses.

We evaluate hydrogen mass storage dimensioning and costs connected with an infrastructure network to be developed in a couple of French regions during the next decades (up to 2050), as described below. In the literature, four underground facilities are considered in which natural gas can be stored under pressure: depleted oil fields, aquifers, excavated rock mines, and salt caverns. Given the French geological layout, we consider the latter as the cheapest most convenient in principle. Thick salt deposits are located in the south and east of France, and salt caverns have the advantage of good performances in terms of filling and emptying (cycling), working volumes, reasonable depths and cushion gas needs. As said below, both south-east French administrative regions named Rhône-Alpes and PACA have been selected for this study. Hydrogen quantities to be stored have been evaluated, roughly at a few tenth of thousands tons, as well as filling and emptying rates which may have a strong impact on the dimensioning. This fits on the one hand the demands in 2050 for personal cars and light duty vehicles with a hydrogen fuel cell or internal combustion engine, evaluated by two scenarios of the French project PROTEC H_2 (see below), and on the other hand a continuous hydrogen supply which considers a possible break (maintenance) for a whole month.

5 Hydrogen Infrastructure and Transport in a French Region

Currently, existing hydrogen production, storage and infrastructure is mostly used for the chemical and refining industries, and as said above, even if nearly 1600km of hydrogen pipelines in Europe have been identified, almost all hydrogen is produced and consumed on-site. In the future, hydrogen use will be spread all over the country, therefore a distribution infrastructure will be necessary. Its design and costs will be of a primary importance for the global use and acceptance of this energy carrier, case specific and strongly dependent on the scenarios of demand, essentially for transportation, delivery options and geographic locations (production, storage, refuelling stations).

Various projects such as HyWays and Roads2HyCom evaluated the technological developments and related costs of hydrogen infrastructure for transport and distribution. HyFrance3 aims to analyse the hydrogen infrastructure development in two French regions, selected on the basis of criteria such as industrial and research capacities, massive geological gas storage opportunities, and initiatives in hydrogen projects and demonstrations. South-East French administrative regions named Rhône-Alpes and PACA have been selected, which gather almost 20% of the French population. Deployment scenarios given by the recent French project PROTEC H_2 (calculated by the POLES code) have been selected to characterize hydrogen demands up to 2050: penetrations rates of 16% and 40% at that time horizon for passenger cars and light duty vehicles, together with somewhat lower penetration rate values, less than 2%, in 2030. The ECOTRANSHY code will be used to work out an economic model that can provide the main optimal features (trucks or pipelines? where? when?) of a hydrogen network originating from large-scale facilities (production and mass storage) and supplying a set of GPS-located delivery points with given demands (refuelling stations), at various time steps from 2010 to 2050. The approach has the advantage to mix in a unified framework economical issues (estimation of capital and operational expenditures), physical features pertaining to hydrogen (trucks characteristics, hydraulics of pipelines and compression stations), and geographical constraints (location of sources and consumptions). With regard to the supply, salt caverns mass storage locations inside the Rhône-Alpes and PACA regions will be considered at first, as well as long distances mass storage locations in the case of French regions lacking of geological mass storage capacities. Hydrogen transport between large scale production and geological mass storage facilities will be evaluated too.

6 Conclusion

This project aims to assess different steps of the hydrogen chain at the time horizon 2030 in France, from the production to the final use. Industrial markets (chemistry, refinery) should reasonably increase in the medium term, mainly due to refinery use; steelmaking could represent very high supply requests, but rather in the long term. As regards hydrogen needs for the refining industry, two petroleum scenarios are analysed: a "trend-setting" one, and an "environmental" one that considers a 6% penetration rate of hydrogen fuel cell uses in vehicles in 2030. The wind energy hydrogen production first simulations show a large cost range: from 4-5 €/kg when the system is connected to the grid for a supply "with the current", up to over 20€/kg for an isolated refuelling station. As regards hydrogen massive underground storage, salt reservoirs located in the south and east of France will be considered; hydrogen quantities to be stored have been evaluated, roughly at a few tenth of thousands tons to balance supply and demand in the Rhône-Alpes and PACA regions. Those two French administrative regions have been selected to evaluate the 2 deployment scenarios given by the recent French project PROTEC H_2: penetrations rates of 16% and 40% at the time horizon 2050, together with somewhat lower penetration rate values, less than 2%, in 2030. ECOTRANSHY code will be used to work out an economic model that can provide the main optimal features of a hydrogen network originating from large-scale facilities to supply refuelling stations, at various time steps from 2010 to 2050. In addition to the technical and economic data that will be given, HyFrance3 offers, as a continuation of HyFrance1 and HyFrance2, the opportunity of a national debate on hydrogen by gathering the major French public and industrial research partners. Large scale analysis developed in HyFrance3 address practical topics that could lead to detailed developments in future projects, to evaluate for instance hydrogen scenarios that consider intermittent energy sources, massive production and hydrogen storage, and national transport and distribution infrastructures.

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