The Role of Hydrogen in a Decarbonised Economy

Synthesis and recommendations of the Academy of Technologies

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Summary of the report and recommendations

In the universe, hydrogen is an atom as simple as it is abundant. Its chemical and energetic properties are manifold, which sometimes gives it the nickname "Swiss Army Knife". Hydrogen is widely used in industry ("raw material" hydrogen, hereafter in this report referred to as "*material hydrogen*"), notably in refineries to produce light or desulfurized fuels, in chemistry to produce ammonia and fertilisers, potentially in the steel industry to produce steels by reducing iron ore, etc. France produces and uses 922,000 metric tons of hydrogen per year and has several private hydrogen transport networks, more than 300 km long. World production, which is growing, is close to 70 million tons.

The objective of a drastic reduction in CO_2 emissions, or even carbon neutral by 2050, is sparking renewed interest in many countries, including France, in the energy applications of hydrogen whose combustion does not emit CO_2 or fine particles. New "energy" uses for hydrogen are being considered, such as injection of up to 20% into natural gas networks, conversion into methane or liquid fuels (e-fuels and in particular synthetic fuels for air transport), and the production of electricity through direct conversion in stationary fuel cells (FCs powering eco-districts or buildings) or in fuel cells on-board vehicles.

Hydrogen is sometimes referred to as a storage vector for intermittent solar and wind energy, after production by electrolysis and then reconversion into electricity in FCs (*Power-to-Gas-to-Power*).

The objective of the academy's **report** is to present the possible roles of hydrogen in the ecological transition, to propose an intensification of research and development (R&D) efforts in certain directions and to recommend avenues for industrial development. It includes an international benchmark.

The hydrogen value chain.

Production

Most of the hydrogen is currently produced by steam reforming of hydrocarbons. The processes are mature, but highly CO_2 emitting. Production processes by electrolysis (alkaline, or with proton exchange membranes "PEM") are mature, but significantly more expensive than steam reforming. Hydrogen produced by electrolysis is a decarbonated carrier only if electricity production is also decarbonated.

The cost of electrolytic hydrogen is determined by the price of electricity (75% of the total cost), far ahead of what is calculated for the depreciation of the facilities if they are used at least 3,000 to 4,000 h/year. Electrolytic hydrogen produced with renewable electricity will remain persistently more expensive (5 to 8 €/kg) than reforming hydrogen (3.0 to 4.5 €/kg including CO_2 capture and storage) as long as market prices for natural gas remain low. The exploitation of the energy properties of hydrogen produced by electrolysis can only be justified if the cost/penalty for the ton of CO_2 that would otherwise be emitted is significantly higher than 100 €/t.

The energy content of the hydrogen needed to decarbonate a significant proportion of French final energy consumption would mobilise more than 275 TWh of electricity if the hydrogen were produced exclusively by electrolysis. This increase of more than 50% in annual electricity production would require doubling the current installed capacity, if carried out solely by intermittent renewable energies (variable and noncontrollable).

It seems more realistic to envision that hydrogen production will be achieved by (1) electrolysis of water with nuclear electricity to ensure a high load factor of the electrolysers, (2) electrolysis of water with intermittent electricity, and (3) steam reforming with CO_2 capture and storage (CCS). French know-how in this field is significant, making it possible to envisage the development of an industrial sector. But it will only develop in France if it is accepted by society, and if the penalty for the ton of carbon emitted (EU-ETS price) increases significantly.

Transport and storage

Currently hydrogen must be compressed for transportation and storage. These operations have a direct impact on the hydrogen economy. For short distances, transport is carried out in pressurised tanks (currently 220 bars). Hydrogen pipelines are possible for large distances and quantities. On-board hydrogen storage for mobility (700 bars) has progressed thanks to carbon fiber composites (or others) which make it possible to reduce the weight of the tanks. However, their shape is cylindrical, which does not facilitate their integration in vehicles.

Uses

In this context where hydrogen presents multiple attractions, but also costs, its use should primarily concentrate on **two sectors, "material hydrogen" for industry and "energy hydrogen" for mobility.**

The most obvious and immediate need is the **substitution of carbonated hydrogen** from reforming processes with decarbonated hydrogen produced by electrolysis. This can be done quickly for the **territorially dispersed chemical industry,** which pays a high price for hydrogen due to the lack of real competition between suppliers and the high cost of packaging and transport. In addition, new uses must be promoted in order to decarbonate certain industries (steel and perhaps cement plants).

Hydrogen-based mobility provides a range that battery-based-only mobility cannot provide. Some forms of mobility (boats, trains, trucks and buses) can in any case not be decarbonated by electric batteries, whose density per mass and volume is too low.

It is reasonable to assume that hydrogen mobility will initially develop only from a limited number of distribution points, effectively reserving its use for heavy transport and local vehicle fleets. Finally, rail traction and ships (over short distances, but also stationary in port) will be able to use hydrogen as a substitute for hydrocarbons and notably for heavy fuel oil.

The injection of decarbonated hydrogen into existing gas infrastructures as a substitute for natural gas should be a third lever to boost demand and create reliable sources of production, as the IEA points out. Admittedly, the cost of avoided CO_2 is high, but this is because natural gas is cheap and has low CO_2 emissions.

The massive use of hydrogen as an intermediate storage of intermittent electrical energy (wind and solar) in the ***Power-to-Gas-to-Power*** chain faces daunting obstacles due to the considerable volumes required for the underground storage of hydrogen and the low load factor of the electrolysers and fuel cells in the "conversion-storage-conversion" chain, which places a considerable burden on costs.

The **various possible uses of hydrogen will be in competition,** since production capacities by electrolysis are necessarily limited. For example, producing only half of the hydrogen currently consumed in France (922 kt) would require nearly 50 TWh of electricity; this hydrogen could alternatively power some ten million light electric vehicles, i.e. about a third of the total number of vehicles in France; hydrogen could also be used to decarbonate certain industries or to produce gas and synthetic fuels. These different uses could require nearly 300 TWh of electricity, which far exceeds the intermittent electricity surpluses of a 100% renewable mix. The different electricity, gas and hydrogen sectors are interdependent and a systemic approach to the production and uses of hydrogen is necessary.

The development of the hydrogen sector will require the creation of considerable infrastructures for its production, delivery to vehicles, transformation into methane or synthetic liquid fuels or, after storage, into electricity, etc. These investments will have to be made when there is no demand for it: only the State will be able to take this risk.

Security

The deployment of hydrogen outside the industrial sector will be associated with consumer uses, increasing the potential for accidents, particularly in the mobility, residential and tertiary sectors. This new risk will have to be taken into account and existing standards and regulations that are based on significant feedback from experience acquired in another context will have to be adapted.

Industrial demonstrators; research and development

We must take advantage of the strong motivation of the territories to initiate "demonstrators". Some projects are part of larger research and development programmes. But others aim essentially to be showcases for known and often imported technical solutions; they must be supervised at the national level, and a periodic and transparent assessment of these operations must be carried out.

French public research has identified many promising technologies with variable *Technology Readiness Levels* (TRL), such as high-temperature reversible electrolysers, plasma torches, native hydrogen, hydrogen from bacterial activity and/or 2nd generation biogas-type processes, all of which are promising avenues; the development of these technologies is insufficiently supported, and their passage to the industrial pilot stage should be encouraged. The same is true for transport techniques, where French R&D is present, but sometimes not on the national territory due to a lack of an adequate regulatory framework.

Towards a French/European Hydrogen Industry

The key technologies (electrolyser, fuel cell, on-board hydrogen reservoirs, etc.) exist; almost all of them are mature and can be industrialised.

The French ecosystem of equipment manufacturers is alive and well and covers these key technologies and has the required components (connectors, valves). Nevertheless, these companies are small or even very small enterprises and will therefore find it difficult to apprehend the market, which, being global, implies very high commercial prospecting costs. Consolidation of the sector will impose itself sooner or later; in the meantime, small players will need the support and credibility of more powerful actors, while avoiding the drying up their creativity and agility. This ecosystem must benefit from targeted calls for tender in France and Europe to help companies grow. Furthermore, as at this stage of development these companies are confronted with the well-known problems of growth management and difficult access to equity capital, such support is an opportunity for France to develop a new industry in a timly manner.

The major French integrators (Air Liquide, Engie, EDF, Total...) are present, particularly in terms of the orders they place and the operations - some of them of significant size - that they often initiate or announce with the support of public authorities. Their knock-on effect on **French and European** industry is not always sufficient.

International Benchmarks

Many countries are committed to the hydrogen challenge with a national strategy, stimulation of the demand for decarbonated hydrogen, incentives for hydrogen mobility, risk coverage for early investors and finally research programmes. Among the most dynamic countries and in descending order of effort outside Europe: Japan, Korea, China, the United States (California in the lead), Australia; and in Europe: Germany, the Nordic countries, France and the United Kingdom.

Several of these countries (Germany, Japan, Korea, etc.) consider that they have limited potential for national production of decarbonated hydrogen, and are considering, despite the difficulties of maritime transport of hydrogen, its massive import from countries that would produce it from natural gas or coal and capture CO_2 (Australia for Japan, Russia for Europe), or from electrolysis in countries where renewable energies can be very competitive.) The geostrategic implications of these policies are complex.

Recommendations

Based on these observations developed and supplemented in the report, the main recommendations of the National Academy of Technology of France are as follows. Barring duly noted exceptions, they are addressed to the public authorities.

RECOMMENDATION 1: Prioritise and promote hydrogen applications for the energy transition by considering the cost per tonne of carbon that is avoided in this way.

1.1: Decentralised production of hydrogen by electrolysis for uses in territorially dispersed industries, rather than by natural gas reforming, has a positive carbon balance at no additional cost to the consumer. This should be made a priority.

1.2: The Academy recommends making the distribution of hydrogen for mobility the subject of a national policy like in Germany. Transport (trucks, buses and coaches, rail, river and sea transport) and local urban and suburban vehicle fleets should have priority. This calls for the establishment of a national co-ordination structure for public and private actors from all sectors of the hydrogen industry. Priority should be given to equipping the vicinity of the major regional capitals, especially where there are logistics centres. The network will further develop along the main corridors and as a fleet of hydrogen vehicles develops. Particular attention must be paid to safety issues.

1.3: France has an extensive natural gas network. The Academy recommends that, in a phase of development of the hydrogen economy, the injection of decarbonated hydrogen into gas networks should be encouraged, despite the high cost per ton of CO_2 thus avoided, to sustain demand and in this way benefit from economies of scale in production.

1.4: The Academy recommends the development of industrial demonstrators of 100% hydrogen storage and distribution systems, especially for energy supply to non-interconnected areas (NIAs) or for export. However, massive storage of hydrogen for huge amounts of electricity generation in the Power-to-Gas-to-Power logic has no convincing business model by 2050.

RECOMMENDATION 2: Develop a supportive policy framework

2-1: Like the major countries with which it is in competition, France must have a vision and an ambitious, shared and clear hydrogen industrial policy. The initiatives of the territories, and in particular the regions, often involve industrial demonstrators. The Academy recommends encouraging these initiatives with the aim of contributing to the industrial development of the French hydrogen industry: hydrogen policy cannot result from the mere aggregation of regional initiatives and must be driven and supervised by the government at the national level.

Public authorities could, in full transparency and independently of hydrogen promoting bodies, assess the coherence of the overall policy and the results achieved.

2-2: The Academy recommends that public authorities, in liaison with industry, universities and research laboratories, should produce System Analyses and overall scenarios, coupling in particular the electricity and gas sectors, including hydrogen and CO_2 emissions, and thus making it possible to appraise the opportunities, costs and time horizons of the various options.

2-3: Pre-normative, normative and regulatory efforts should be continued, particularly for the safety of consumer or semi-consumer applications at the European level. By continuing current practices, regulatory work must involve the administration and all stakeholders (firefighters, technical centres, equipment manufacturers, operators, users, etc.).

2-4: The European Union must establish a classification of the different types of hydrogen based exclusively on CO_2 emissions during its production. The qualification of green hydrogen must be reserved for decarbonated hydrogen (electrolysis with decarbonated electricity or reforming with CO_2 capture and storage or use).

RECOMMENDATION 3: Promote a French and European industry encompassing the entire hydrogen chain.

Beyond the electrolyser, the main elements are storage, transport, distribution and consumption. These elements interact to form a system, the operation of which is dictated by the intermittenct of certain renewable sources of electricity (variable and non-controllable) and the variability of consumption.

3.1: There are mainly two modes of production of decarbonated hydrogen: 1) hydrocarbon reforming and water reduction with CO_2 capture and storage or utilisation (CCUS), 2) electrolysis of water by decarbonated electricity. The reforming/CCUS path should be developed when the economic conditions are right, especially since France has players of international stature.

It is up to the public authorities to promote a French and European electrolyser/fuel cell industrial sector with a view to reducing costs and achieving the required functionalities (variable electrolyser load, etc.).

3.2: A policy of business support should be put in place in all areas of the hydrogen sector, especially the value-added links in the chain, giving priority to French equipment manufacturers by stepping up equity investments, equity support, repayable loans and cash flow support, and by encouraging cooperation between French or at least European-based and -governed players.

3.3: Demonstration, pre-deployment and deployment operations organised by territories create demand. They must be valorised by ensuring that they do not have as their main consequence the importation of equipment produced in Asia or North America.

3.4: The exploration for native geological hydrogen must be encouraged.

RECOMMENDATION 4: Preparing the future through an increased French and European R&D effort

4.1: Research and development must be stepped up to help launch the industrial sector and the emergence of French groups with global ambitions. The entire chain must be supported in parallel: hydrogen production (many alternative processes are possible), transport, storage and use, particularly for mobility. Public funds should be made available to support as a priority the potential levers for change at the intermediate (3 to 6) or low TRL (*Technology Readiness Levels*). This should be done in order to build prototypes and then move on to pilots and industrialisation.