Hydrogen, distinguishing myth from reality

By

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The joint challenges of energy and climate currently occupy economic, geopolitical and media debate. Like always, a work of analysis is indispensable to sort between good ideas and "false good ideas". The challenges related to hydrogen, which is back in fashion, are no exception to this rule.

Here we preview some myths and realities on the subject.

A "zero-emission energy source"?

Who hasn't heard the laudatory characteristics often used in reference to hydrogen? In a context where we are facing serious threats concerning, on the one part, the provision of energy, and on the other, a changing climate caused by the emission of CO_2, hydrogen is sometimes presented as a silver bullet, a "source of energy with zero CO_2 emissions", that is to say an evident solution to these two problems. However:

Hydrogen is not a "source" of energy.

Hydrogen (or, to be precise dihydrogen H_2) does not exist in this state in nature in a form that is available and in significant quantity. It must therefore be produced from a true source of primary energy. Remember that, to date, the principal source of energy used to produce hydrogen is of fossil origin (natural gas principally).

Hydrogen is not "zero emission".

It all depends on its mode of production (Table 1.). The principal technology used to date involves the reformation of gas, thus generating 11 tonnes of CO_2 for every 1 tonne of hydrogen product – that's a lot. Instead, the idea of producing hydrogen using "low-carbon" electricity (by hydrolysing water) is clearly more virtuous. But it's not "zero emission" either. The production of 1 tonne of hydrogen corresponds to a generation of around 2.6 tonnes of CO_2 with the electricity source being solar photovoltaic panels; 0.8 tonnes with wind; and 0.2 tonnes with nuclear.

Hydrogen in "clean mobility"

In a country like France with an electricity mix close to 70% nuclear (so low emissions of CO_2), the main source of direct CO_2 emissions is provided by the transport sector (Table 2.). (This will be different for other countries, such as Germany, where the energy mix generates much higher CO_2 emissions from industry and the production of electricity). *Thus, it is pertinent in France to tackle the decarbonisation of this sector as a priority.*

Remember that CO_2 emissions in the transport sector concern the "mobility" of people (cars, diesel buses, planes, trains, …), but equally that of freight (lorries, boats, planes, trains, …). In France where electricity is "low-carbon", the train (electric) is a "low-carbon" mode of transport, and the priorities of decarbonization in the transport sector (by hydrogen or otherwise) concern first cars and lorries. In other countries, where the production of electricity is not "low-carbon", the decarbonization of rail can equally be a challenge.

According to expert estimates, the development on a global scale of hydrogen vehicles across all categories (cars, lorries, trains) could see strong growth in the next decade, around 40% per annum. That's a strong growth rate, but from a non-existent start.

- Table 1 -

Hydrogen is not « zero emission ». It all depends on how it is produced

Production modes of dihydrogen

"Grey"	**"Green"**
Currently ≥ 95% of global dihydrogen production	**Currently ≤ 5% global dihydrogen production**
• **From Gas (Methane CH_4)**	• **From water electrolyze with Nuclear / Solar PV / Wind electricity**

CH_4 + $2H_2O$ → $4H_2$ + CO_2

Methane (gas) | Water | Dihydrogen | Carbon dioxide

$2H_2O$ → $2H_2$ + O_2

Water | Dihydrogen | Dioxygen

- **To produce 1 ton of H_2**
  - **SMR (1):** **11 tons of CO_2 (2)**

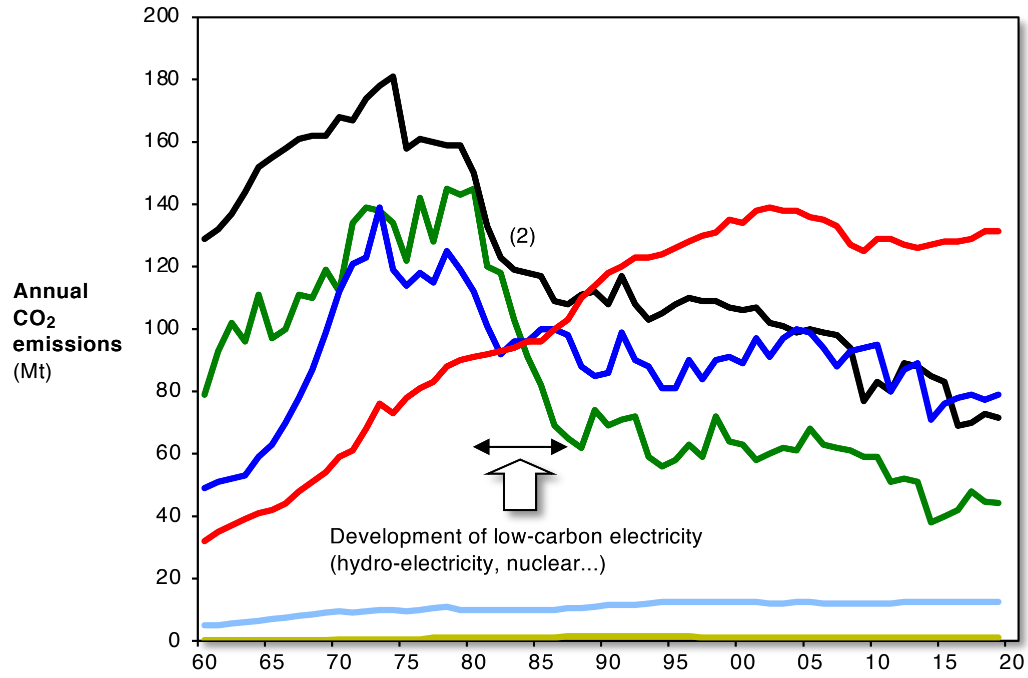
- **To produce 1 ton of H_2**
  - **Nuclear:** **0,2 tons of CO_2**
  - **Wind:** **0,8 tons of CO_2**
  - **Solar PV:** **2,6 tons of CO_2**

(1) Steam Methane Reformer ; (2) Carbone Capture and Storage might be considered and referred to as "blue hydrogen"
Sources: ADEME, Estin & Co analyses and estimates

- Table 2 -

In a country like France, the main source of CO_2 emissions is the transportation sector

France – Excluding CO_2 from importations – Million tons – 1960-2019



	CAGR 60-80	CAGR 80-00	CAGR 00-19
Transportation (3)	5%	2%	0%
Building Heating	4%	-1%	-1%
Industries	1%	-2%	-2%
Energy industries (1)	3%	-4%	-2%
Agriculture (4)	4%	1%	0%
Waste management	7%	0%	0%

(1) Mainly electricity production; (2) Impact of relocation in other manufacturing countries; (3) Mainly road transportation (cars, commercial vehicles, trucks) ; (4) Including emissions methane, agriculture represents 20-25% of greenhouse gas total emissions in France; Sources: CITEPA, Estin & Co analyses and estimates

The development of hydrogen vehicles will remain, at least on the horizon of the next 5-10 years, a phenomenon of "diversification" rather than large-scale "substitution". Even in the most optimistic projections, the proportion of hydrogen vehicles produced annually by 2030 will stay well below 5%. One of the reasons resides in the energy yield of the system, between the production of electricity and the mechanical energy finally transferred "to the wheel" of the vehicle. The yield is estimated at around 30% for hydrogen vs 75% for a simple electric car, all other things being considered equal.

For the production of fuel-tanks there can however be an attractive additional factor. Given that hydrogen is a gas, it is necessary to develop, for reasons of safety, more elaborate fuel-tanks for automobiles. In general, this necessity lends considerable appeal to composite materials (Table 3.) that are more resistant than classic plastic materials. The fuel-tanks for hydrogen will therefore have a higher unit cost than that of classic petrol tanks (by a factor of around 10-20x, even more if we consider the opportunity of integrated systems including the motor / hydrogen fuel cell). But this increase in value will not compensate the narrowness of the market in the next 5-10 years.

The challenge is to properly calibrate the investments – not too little, nor too much – to benefit from a significant relay of growth, without risking reliance on capacities that prove to be too ambitious.

Illustrative examples are the development of the A380 and TGV at its start, are some examples of initial oversizing.

A challenge of production method…

The "low-carbon" production of electricity is the first challenge. A country like France has some strong assets in this domain due to nuclear, hydroelectric, and renewable production capabilities. It will be, and it is already, possible to produce "low-carbon" hydrogen by plugging into the electricity grid.

This is not true in other countries where the production of electricity is a lot less "low-carbon" compared to France (for example with a significant usage of coal or natural gas).

Attention should also be paid to renewable electricity production assets (solar photovoltaic, and wind) dedicated to hydrogen production. They are structurally intermittent, with a utilisation rate that is low and variable, thus negatively impacting the cost competitiveness of hydrogen production.

It is worth noting that, in certain countries the production of hydrogen is envisaged as a mode of storage for intermittent energy, without giving explicitly the energetic yield (low by construction) for this type of cycle.

... and of storage and distribution infrastructure

The second challenge concerns storage and distribution infrastructure, that is equivalent to a network of "petrol stations" for hydrogen and the associated logistics. Firstly, hydrogen while also a gas, has different properties to those of natural gas (inflammability, light weight), thus the infrastructure and logistics that exist for petrol/diesel and natural gas are not reusable. It's necessary to develop new ones. Equally, the size and location of the "hydrogen stations" should be planned intelligently.

The initially limited penetration rate poses a question for the coverage of costs of such a network. It is necessary to initially target several large points of passage of lorries, professional cars, etc… Here also, the corresponding calibration and build-up of investments are critical and probably differ by country, which adds a constraint to the rapid development of a fleet of cars or lorries at a European scale.

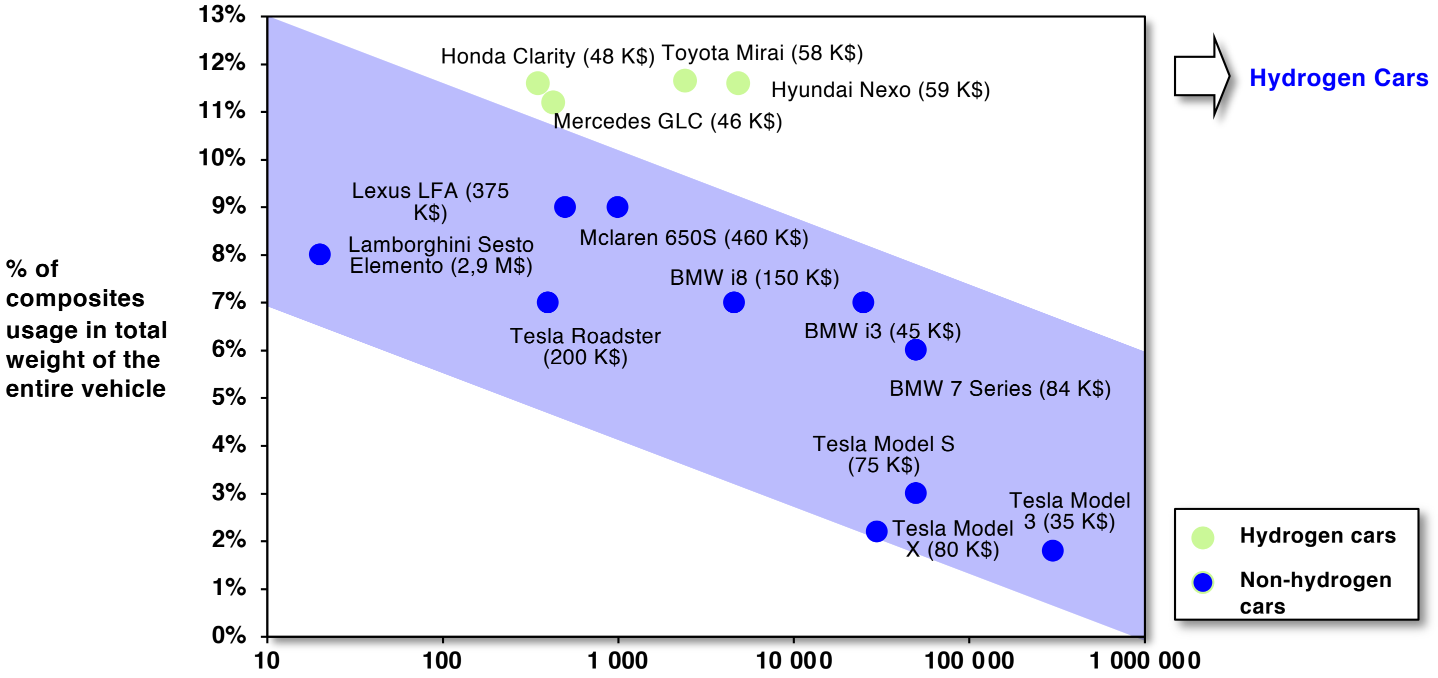
"Decarbonisation" by hydrogen going beyond "clean mobility"

The development of a "low-carbon" source of hydrogen can present significant interest beyond the singular challenge of transport.

- Table 3 -

Hydrogen cars require a higher rate of composites materials due to the need of pressure vessels

Transportation - Composites penetration in automotive

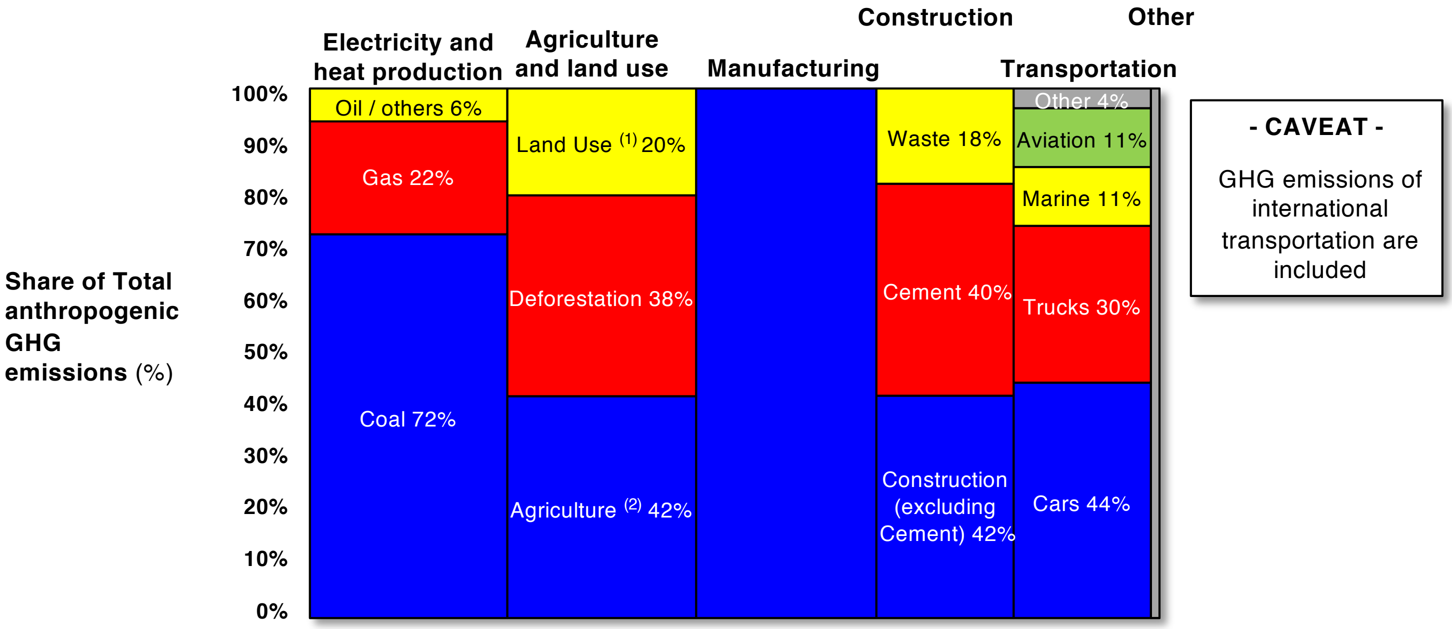


Note: Prices in parentheses, base retail prices in North America; (1) BMW 7 Series, the 6th generation
Sources: JEC Composites, BMW, Tesla, Lexus, Aston Martin, Toyota, Hyundai, Mercedes, Honda, Estin & Co estimates and analyses

- Table 4 -

At global level, CO_2 emissions are generated by electricity and heat production, agriculture, manufacturing, construction, and transportation

Total anthropogenic GHG emissions ($GtCO_2eq/yr$) by economic sectors - 2018



	Electricity and heat production	Agriculture and land use	Manufacturing	Construction	Transportation	Other
Total (Gt CO_2 equivalent)	12	11	11	8	8	1
Total (% of total emissions)	23%	22%	21%	16%	16%	1%

(1) Change in soil organic carbon (SOC), the amount of carbon stored in the soil, mainly due to degraded peatlands and wetlands for agriculture or urbanization ; (2) Crops and livestock, of which : Enteric fermentation of livestock (42%), Manure (24%), Synthetic fertilizers (14%), Paddy rice (10%)
Sources: Climate Watch, World in Data, IEA, Helios, Shift Project, FAO

As a key example, among a few others, we cite the challenge of decarbonization of agricultural fertiliser. In effect the production of "low-carbon" hydrogen can drive the production of "low-carbon" ammonia. Ammonia (NH_3) is a base constituent for agricultural fertilisers, its production to date is strongly dependent on fossil energy (natural gas; see 1st paragraph). So, hydrogen can contribute to the decarbonization of the agricultural sector, currently one of the significant contributors to the emissions of CO_2 at a world level (Table 4.).

The more there are pertinent applications for "low-carbon" hydrogen downstream, the more the source of production upstream will be able to be stabilized by the corresponding scale effects.

What to do?

In concluding the above it is necessary to quantify well and to revisit, so as to challenge or to reinforce, the perceived trends and their implications in good orders of magnitude. It's about sorting between true development and fashionable phenomena.

The sole technological interest of hydrogen will not be sufficient to impose it if the extent and the speed of potential substitution is not met. Even more so if the context of different countries and their energy mixes are contrasted. For investors and companies, the choice between a large-scale or a niche strategy is crucial, with the calibration and "ramp-up" of corresponding investments.

January 2022

Estin & Co is an international strategy consulting firm based in Paris, London, Zurich, New York and Shanghai. The firm assists the management of major European, North American and Asian groups in their long-term growth strategies, as well as private equity funds in the analysis and valuation of their investments.