EFFICIENCY WILL MAKE ITS POINT
SOME CONSIDERATIONS ABOUT HYDROGEN FUTURE

Viktor Wesselak

Institute for Renewable Energy Technologies, University of Applied Sciences Nordhausen
Weinberghof 4, 99734 Nordhausen (Germany)
wesselak@hs-nordhausen.de

Abstract

The current discussion about the future role of hydrogen in our energy system underestimates the limitations that conversion efficiencies and the growth of renewable power generation capacities have on this energy carrier. This leads to misconceptions about the economic and social sectors that need to be electrified.

Keywords: hydrogen, power-to-gas, power-to-liquid, decarbonisation, energy system

1. Introduction

The actual global conflicts changed paradigms in how a cost-effective and climate-responsible transformation of our energy system can succeed. Europe in particular has strongly favoured natural gas as a transitional energy source, as it is cheap and multi-purpose with comparatively low CO_2 emissions. Natural gas will no longer play this role in the foreseeable future. Instead, Europe is now focusing on an accelerated substitution of natural gas by hydrogen and of liquid fuels by hydrogen-based fuels [1,2]. In Germany, there is currently a discussion about "technology-open" solutions, which means that investments in fossil technologies are still possible, provided they can be switched to hydrogen [3]. The following theses try to capture the current hydrogen euphoria from an efficiency point of view.

2. A hydrogen future?

The hydrogen future should be examined using the example of Germany, a highly industrialised economy. For this purpose, a number of current scientific studies [5-8] are evaluated which have a great influence on the energy policy discussion in Germany. The following table 1 shows the development of final energy consumption and the shares of electricity, hydrogen and hydrogen-based fuels.

Table 1: Comparison of the role of hydrogen and hydrogen-based fuels in 2045 in different energy scenarios for Germany

	dena [5]	Ariadne[3] [6]	Fh-ISE[4] [7]	Prognos [8]
Final energy consumption [TWh]	1477	1667	1902	1665
- thereof electricity	724	1103	1407	1017
- thereof hydrogen	226	150	331	85
- - thereof imported	90 %	100 %	30 %	65 %
- thereof hydrogen-based fuels	271	150	250	55
- - thereof imported	90 %	100 %	100 %	100 %

[3] Scenario „Technologie-Mix“
[4] Scenario „Referenz“

It can be seen that Germany's final energy consumption of currently about 2500 TWh will decrease by 25-40 % until 2045. At the same time, the share of electricity in final energy consumption will increase from currently about 20 % to 50-70 %. Hydrogen and hydrogen-based fuels each contribute about 10-15 % of final energy consumption. It is expected that the majority of this will be imported. In all scenarios, an additional amount of hydrogen of the same amount is assumed which will be used for electricity production - partly in combined heat and power generation. The use of hydrogen and synthetic energy carriers is mainly for the supply of industrial heat or in heavy-duty transport. A decentralised use of hydrogen for the purpose of space heat is not considered.

Overall, it can be seen that in the scenarios considered, hydrogen and hydrogen-based fuels do not play a central role in Germany's future energy system, but nevertheless account for 20-30 % of final energy consumption. This will be discussed in the following section on the basis of a few theses.

3. The Theses

Hydrogen will remain a limited energy carrier

The production of hydrogen as an energy carrier requires about 1.5 times the amount of electricity, the production of hydrogen-based fuels about 2.5 times [4,7]. The necessary capacities from renewable energies would have to be created in addition, i.e. on top of the generation capacities needed to decarbonise electricity generation. For example, the EU's target of additional green hydrogen production of 10 million tonnes per year by 2030 [1] would require more than 500 TWh of electricity - one-sixth of the current electricity production of the EU-28. If this amount of electricity is to be generated by photovoltaics, for example, a quarter of the current global production would be needed until 2030 - per year.

Such an additional build-up of renewable power generation capacities is unlikely at present. In fact, current trends show that the existing expansion targets will probably be missed by a significant margin [9].

If we take a look at the situation in Germany, we see that the additional electricity demand for the production of hydrogen or hydrogen-based fuels is on average in the order of magnitude of the total electricity demand within final energy consumption (see table 2). These electric power generation capacities may be located outside Germany or Europe, but must nevertheless be built.

Table 2: Additional electricity demand in 2045 for the production of hydrogen and hydrogen-based fuels in different energy scenarios for Germany

	dena [5]	Ariadne [6]	Fh-ISE [7]	Prognos [8]
Final energy consumption [TWh]	1477	1667	1902	1665
- thereof electricity	724	1103	1407	1017
Additional electricity demand	1016	600	1122	265

Hydrogen will remain an expensive energy source

The use of electricity in the ratio mentioned in the above section also defines the relation between electricity and hydrogen costs. If one further assumes that the energy sources are imported, transport costs must also be taken into account. In [4] and [7], the costs for imported fuels listed in table 3 are given for the year 2050 and 2045, respectively. This includes both the production and transport costs of the fuels.

Table 3: Future costs of imported fuels in €/MWh

	dena [4]	Fh-ISE [7]
PtG-H_2	81[3]	145
PtG-CH_4	101	224
PtL	121	271

[3] only production costs

Even though a clear spread can still be seen in Table 3, these energy costs run against mean electricity costs of 55 €/MWh in 2045 [8].

Hydrogen will remain an inefficient energy source

Green hydrogen is based on electricity and therefore always has to be compared with an electricity-based application in regard to its operating costs, where this is possible. This results in a cost difference that, conservatively calculated, equals a factor of 5 or more. This will be shown by considering two examples:

(1) When using hydrogen in fuel cell vehicles (FCEVs), at least the efficiencies of electrolysis (65%), compression (95%) and the vehicle itself (48%) must be taken into account [7]. This leads to a well-to-wheel efficiency of less than 30%. In contrast, the corresponding efficiency of battery-powered electromobility (BEVs) is 68% [7]. The difference is even clearer with combustion engines (ICEs) that are powered by synthetic fuels. Here, the fuel production (46.6%) and the efficiency of the vehicle (21.5%) [7] result in a well-to-wheel efficiency of 10%.

(2) When considering natural gas-powered heating systems, a substitution of the natural gas by hydrogen is discussed. With an efficiency of the electrolysis (65%) and the boiler (98%), the power-to-heat efficiency is 64%. In contrast, an average COP of 300% is realistic when using an electricity-fed heat pump.

In the context of the first thesis, the efficiency in the mobility and heat sectors, which is worse by a factor of 5, means that in a hydrogen-based solution, five times more electricity generation capacity must be built up from renewable energies. Both examples demonstrate why hydrogen is not considered to have a future in either passenger transport or decentralised space heating.

The low efficiency of hydrogen-based applications makes them vulnerable to technological developments in the electricity sector. One example is the decarbonisation of railway transport on non-electrified lines. Only a few years ago, fuel cell trains were seen as the ideal technology. However, as non-electrified railway lines are predominantly found in the local passenger transport sector with short distances, the fuel cell train is already being replaced by battery-electric trains [10].

4. Conclusions

Hydrogen will neither be able to establish itself as a substitute for natural gas nor in refined form as a synthetic fuel if all-electric solutions are available as an alternative. Hydrogen can neither be offered at competitive costs, nor are corresponding capacities from regenerative power generation in sight. Insofar as there are no massive subsidies for hydrogen and synthetic fuels - corresponding considerations are certainly being made [11] - this will lead to a massive electrification of all areas of the economy and society that have so far been dominated by chemical energy sources.

Hydrogen will therefore play a much smaller role in a future energy system than the political discussions currently make it appear. There will not be a hydrogen grid that transports a clean and cheap energy carrier to every household. It is certain that hydrogen will be used in some industrial processes - such as in the steel industry. It is also certain that hydrogen-based fuels will have to be used for shipping and aviation. To what extent hydrogen or hydrogen-based fuels will actually be used in heavy goods transport on land is an open question at the moment. The necessary infrastructure for transporting hydrogen or synthetic energy sources over long distances is also an open question. These questions will be answered by the technological development in the coming years, guess efficiency will make its point.

5. References

[1] European Commission: REPowerEU Plan. Document 52022DC0230, Brussels 18.05.2022

[2] German National Hydrogen Council: Key issues paper on revisions to the National Hydrogen Strategy. Berlin 2022

[3] Bundesministerium für Wirtschaft und Klimaschutz: Novelle des Gebäudeenergiegesetzes, Berlin 2023

[4] German Energy Agency (dena): Dena Study Integrated Energy Transition. Berlin 2018

[5] German Energy Agency (dena): Dena-Leitstudie – Aufbruch Klimaneutralität. Berlin 2021

[6] Potsdam Institut für Klimafolgenforschung (Hg.): Ariadne-Report Deutschland auf dem Weg zur Klimaneutralität 2045. Potsdam 2021

[7] Fraunhofer ISE: Paths to a Climate-Neutral Energy System - The German Energy Transition in its Social Context. Freiburg 2021

[8] Prognos, Öko-Institut, Wuppertal-Institut: Klimaneutrales Deutschland 2045. Wie Deutschland seine Klimaziele schon vor 2050 erreichen kann. Berlin 2021

[9] IEA, IRENA, UNSD, World Bank, WHO. 2022. Tracking SDG 7: The Energy Progress Report. World Bank, Washington DC 2022

[10] VDE (Ed.): Alternativen zu Dieseltriebzügen im Schienenpersonennahverkehr. Frankfurt 2019

[11] European Commission: Boosting Hydrogen through a European Hydrogen Bank. Luxembourg 2023