How to make Green Hydrogen economic?

Proposals based on Case Studies

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The hydrogen strategies of the German government from June 2020 and the European Commission's hydrogen strategy for a climate-neutral Europe from July 2020 are both based on expectations that hydrogen will be a significant energy carrier. Hydrogen is set to become the basis for future technologies that contribute to a significant reduction in greenhouse gas emissions. The strategies cover a period of 30 years and apply to all sectors of the economy. Under the keyword "sector coupling", hydrogen is the link for electricity generation, industry, heat and mobility, thus enabling the integration of renewable energies in these sectors i.e. integrated energy system transformation. The idea of sector coupling is to identify measures which contribute to CO_2 reduction in different CO_2-emitting sectors at the same time.

So-called green hydrogen is produced by means of electrolysis, with the required electricity coming from wind power and photovoltaic plants. This type of hydrogen production is therefore almost CO_2-free or largely climate-neutral. Today, green hydrogen is expensive compared to grey hydrogen.

The strategies of the German Federal Government and the European Commission are based on expansion targets for hydrogen production until 2030, which Germany is to increase from today's 4 MW_{el} to 5,000 MW_{el}, and Europe-wide up to 40,000 MW_{el}. This means more than a thousand-fold increase in the currently available electrolyser capacities within ten years. This means a steady annual doubling of the capacity over a period of 10 years. This a very challenging, but also importantly is an achievable goal.

Technical progress has already been achieved under the support programmes in recent years. For example, the so-called stacks, which make up an electrolyser and thus the total size in demonstration plants, have been increased tenfold between 2010 and 2015 and again tenfold between 2015 and 2020. Today the first 100 MW electrolysers are under development.

At the same time, government support and the ambitious targets will only lead to the desired CO_2 neutrality if the optimisation of hydrogen technology can be obtained in the long term. This means that electrolyser technologies and transport and logistic facilities must establish themselves on the market even after initial state support, i.e. they must be economically viable, and at best they must entail a large number of other economically interesting investments.

Today, green hydrogen is not yet truly competitive, neither in industry nor in the mobility or heating sector, due to high production costs, lack of infrastructure, restrictive framework conditions and/or high investment costs of e.g. hydrogen-powered cars.[1]

Production costs of green hydrogen in an application example

An economic analysis[2] was conducted looking at the necessary economic hurdles that need to be removed in order to replace grey hydrogen in refineries. Grey hydrogen is produced by steam reforming. In this process, hydrogen is produced from natural gas (methane) and steam, which generates large amounts of CO_2. The cost of grey hydrogen is less than 1.5 €/kg. Substituting grey hydrogen with green hydrogen will eliminate significant CO_2 emissions.

The economic analysis of such a substitution was based on an application with a hydrogen demand of a refinery of 8,850 tonnes per year. This hydrogen demand will be provided on site by an electrolyser of 90 MW_{el}, and the electrolysis is operated with electricity from renewable energy sources, i.e. CO_2-neutral. Renewable electricity will be needed to operate the electrolysis for 6,000 full-load hours per year.

For different scenarios, the generation costs, the "Levelized Cost of Hydrogen" (LCOH), were calculated. The investment costs (capex) consist mainly of the costs for the electrolyser and for the stack renewal after 10 years. Further investment costs are incurred for grid connection, construction costs and buffer storage. However, given these high full-load hours and the current framework conditions, all investment costs account for only about 9 % of the total project costs.

In the case of current framework conditions, all assumptions are based on the electricity price regulations applicable today and the green electricity available via the public grid. The cost components are shown in Figure 1 as "Base Case".

Operating costs account for the largest share of the total costs, in this case 89 % of the costs for green electricity from the grid. The high electricity prices are mainly caused by levies and charges in Germany, such as the EEG levy, KWKG levy, §19StromNEV levy, offshore grid levy, concession levy and levies for cut-off loads.

These high costs for renewable electricity from the grid lead to production costs, i. e. the "Levelized Cost of Hydrogen" (LCOH), of about 11 €/kg-H2 for green hydrogen. The investment for the electrolyser is actually of low importance here.

When the electricity input for an electrolysis plants is not subject to levies and taxes (Figure 1, "Electricity price without levies"), the production costs come down to less than 7 €/kg-H_2.

1 See: Grothey, Tim; Wiechert, Sebastian. (2020). Die Auswirkungen des CO2-Preises auf die Wirtschaftlichkeit von Wasserstoff als Kraftstoff im Verkehr in Deutschland. In Witte, Frank (Hrsg.): 8. Sammelband Nachhaltigkeitsmanagement: Ökonomische Aspekte des nachhaltigen Wirtschaftens. Reihe Nachhaltigkeits-Management - Studien zur nachhaltigen Unternehmensführung, Hamburg: Kovac Verlag.

2 See: Snoppek, Marlene (2020). Aktuelle Entwicklungen zur Wirtschaftlichkeit von Power-to-Gas-Projekten. Masterarbeit. Beuth Hochschule für Technik Berlin und Hochschule für Wirtschaft und Recht Berlin

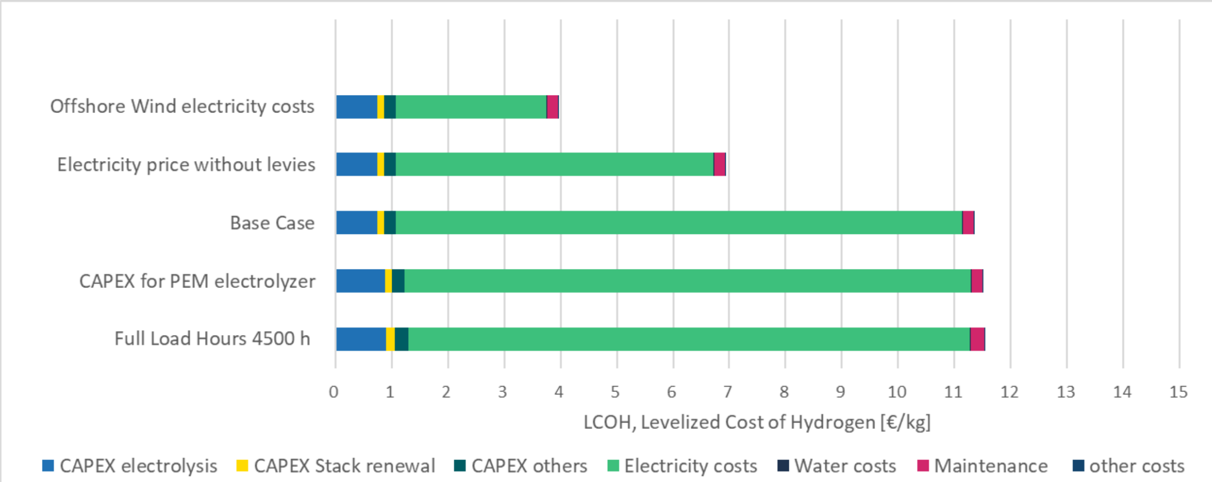

Figure 1: Components of the Levelized Cost of Hydrogen (LCOH) and sensitivity analyses[3]

Finally, the case "Offshore Wind electricity cost" will result in even cheaper green hydrogen: In this case, only direct offshore wind power is used for the electrolysis, which does not have to be transported via the public grid; at expected electricity costs of approx. 45 €/MWh. Two other factors need to be considered; first is lower annual full-load hours of 4,500 h, because the wind does not blow continuously even at sea. This leads to slightly higher production costs. Second, the investment costs are slightly higher for a PEM[4] electrolyser, which is suitable for alternating and partial load instead of an alkaline electrolyser. Still, this case results in total hydrogen production costs of less than 4 €/kg-H_2, as shown in Figure 1. This is a production cost level which, with further future savings in purchase and operating costs, already comes very close to the production costs of grey hydrogen.

CO_2 Abatement Costs of Green Hydrogen

The central objective of hydrogen strategies is to reduce emissions in the various sectors of the economy, including transport, heavy industry, and heating. Since the production cost of green hydrogen are higher than grey hydrogen, the substitution involves costs that are to be attributed to the avoidance of CO_2 emissions. The "CO_2 abatement costs" indicate the cost-effectiveness of decarbonisation, showing that the costs for each tonne of CO_2 has been avoided by the application of the technology.

Looking at possible applications for green hydrogen, such as transport fuels, already today certain proportions of biodiesel are blended into individual refinery end products, such as "E10" to reduce emissions. The corresponding CO_2 avoidance costs for biodiesel today are around 100 €/tCO_2.

In the present example's "Base Case", the avoidance costs with green hydrogen in the refinery are, by comparison, 900-1,000 €/tCO_2, which is far higher than the CO_2 avoidance costs caused

3 See: Snoppek, Marlene (2020). Aktuelle Entwicklungen zur Wirtschaftlichkeit von Power-to-Gas-Projekten. Masterarbeit. Beuth Hochschule für Technik Berlin und Hochschule für Wirtschaft und Recht Berlin

4 Proton exchange membrane (PEM) electrolysis is the electrolysis of water in a cell equipped with a solid polymer electrolyte (SPE) that is responsible for the conduction of protons, separation of product gases, and electrical insulation of the electrodes.

by biodiesel. In the case of "Offshore production costs", i. e. with electricity costs from offshore wind farms, the CO_2 avoidance costs are still higher at 347 €/tCO_2. However, this is already below today's RED fine of 470 €/tCO_2 when not meeting refinery emission reduction targets.

CO_2 pricing, including the EU emission allowance trading scheme (ETS), was meant to stimulate this substitution effect and investments in greenhouse gas-reducing technologies. However, the current CO_2 prices from the ETS and even the planned future prices from the new Fuel Emission Trading Act in Germany are much lower than the CO_2 abatement costs of green hydrogen. Consequently, the CO_2 price is at present not expected to provide any incentive for green hydrogen in industry. Also, in regard to the passenger car transport sector, the German CO_2 price will not create increased market opportunities for hydrogen.[5]

The Ideal Hydrogen Production

However, the "Base Case” at current framework conditions and the case "Offshore electrolysis" show that economically feasible projects can only be found when location, sufficient quantities of renewable electricity available for a sufficiently long period of time, regulatory framework conditions, logistics and total costs match.

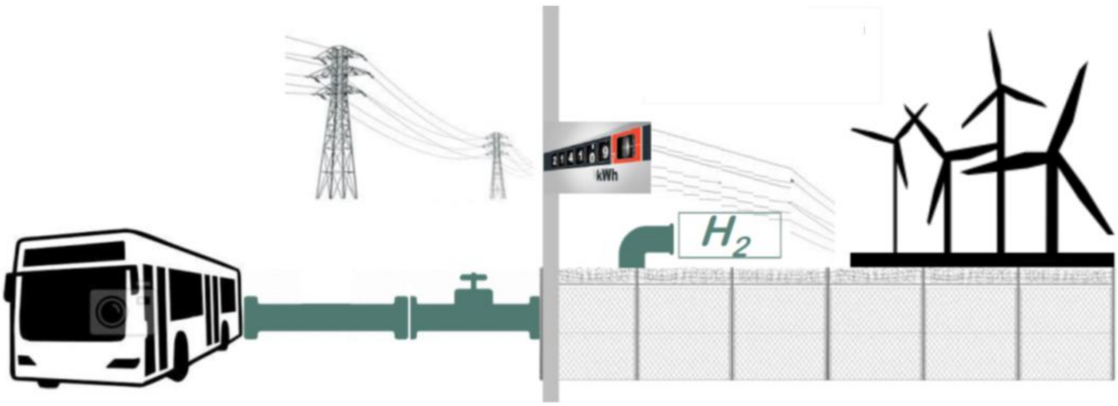

Figure 2: The "ideal project" in regard to hydrogen production cost

The "ideal project" from the point of view of hydrogen costs is the use of electricity directly from wind power plants without feeding it into the grid. But, clusters have to be found in which sufficient quantities of electricity can be generated over a longer period of time so that a downstream electrolyser can produce enough hydrogen for a sufficient number of hours per year. Today, there are not yet enough suitable clusters for the implementation of domestic hydrogen production on a large scale. In practice, the task will be to find locations, such as those shown in Figure 2, where sufficient wind power is available and where it is technically and logistically possible to ensure reliable offtake, so that the cost advantage is not offset by transport and storage.

5 See: Grothey, Tim; Wiechert, Sebastian. (2020). Die Auswirkungen des CO2-Preises auf die Wirtschaftlichkeit von Wasserstoff als Kraftstoff im Verkehr in Deutschland. In Witte, Frank (Hrsg.): 8. Sammelband Nachhaltigkeitsmanagement: Ökonomische Aspekte des nachhaltigen Wirtschaftens. Reihe Nachhaltigkeits-Management - Studien zur nachhaltigen Unternehmensführung, Hamburg: Kovac Verlag.

Required Changes in the Framework Conditions and Measures

Today, the development of green hydrogen production with renewable electricity from the grid would fail economically due to the regulatory framework for electricity and is not competitive, at least in Germany at present, due to the high levies and charges. In order to achieve the objectives of the hydrogen strategies with partial domestic production in Germany, it will therefore be crucial to remove regulatory barriers and create incentives. This would allow competitive operating costs to be achieved, which in turn would promote investment in green hydrogen. Only by removing regulatory barriers will it be possible to find sufficient investment projects that will be economically interesting even later on without subsidies and by further cost reductions due to economies of scale.

In the short term, the reduction of the electricity supply cost for electrolysis is key for an economically viable green hydrogen production. In essence, this means largely exempting electrolysis electricity from the electricity price levies. Once the levy exemption is granted for a hopefully then higher and higher production level of hydrogen, the remaining costs and levies will then have to be distributed amongst all the other electricity end users and will need to be increased or will need to be financed from the federal budget. As a consequence, the system of current electricity pricing itself with apportionments and cost distribution has to be reconsidered.

A recent study from the German Energy Agency calls for cutting the EEG levy down to zero. This would significantly promote investment in technologies such as electrolysis and accelerate the energy turnaround in the short term. The study also has comprehensively analysed the effects of this measure on bureaucracy and on the federal budget. Above all, the area of sector coupling, hence the "integrated energy system transformation" would benefit greatly from a significant reduction in the EEG levy.[6]

Another structural disadvantage for hydrogen production is that electrolysers or power-to-gas plants are legally considered as electrical end users. However, from the point of view of sector coupling this is not the case: renewable electrical energy is merely transferred to another energy carrier in order to be used elsewhere as final energy. If these plants were not be declared as end consumers, further taxes and levies could be dropped. A much greater use of renewable energy in other sectors would also become economically feasible.

A further challenge is the problem of passing on the "green property" of renewable electricity to the green hydrogen produced with it. It is currently difficult to certify the green part of the grid electricity as green. This means that the gases produced are not automatically considered renewable and emission-reducing credits are not possible. Green PPAs[7] represent an additional possibility to make hydrogen more economical, at least, for a certain period of time.

6 Vgl. dena (2020): Vorschlag für die Senkung der EEG-Umlage auf null. Berlin: Deutsche Energie Agentur, abgerufen am 09. August 2020 von https://www.dena.de/fileadmin/dena/Publikationen/PDFs/2020/KURZSTUDIE_Vorschlag_fuer_die_Senkung_der_EEG-Umlage_auf_null.pdf

7 A PPA or Power Purchase Agreement is a bilateral contract between the one which generates electricity (the seller) and the one which is looking to purchase electricity (the buyer). The PPA defines all commercial terms for the sale of electricity directly between the two parties. A Green PPA refers to green electricity from wind or solar plants.

Conclusion

In summary, the German and European hydrogen strategies set high and ambitious targets which in principle are achievable. However, the realisation of the high levels of required investments depend strongly on the legal framework conditions and the site conditions of such plants. An integrated approach for plant planning is required where the temporal and spatial supply of electricity and the use of hydrogen are considered from the beginning. The resulting cost savings have the potential to make hydrogen competitive with grey hydrogen, which is currently very cheap for industry. From the point of view of CO_2 abatement costs, hydrogen can currently not compete with biodiesel, for example. But hydrogen offers more extensive applications in the future and therefore could become established as the most cost-effective climate protection measure for all sectors of the economy.

In addition, in order to achieve these goals, it is imperative that the obstacles mentioned in this paper be removed by means of a restructured legal framework. Above all, a fundamental reform of ancillary electricity costs is urgently needed. This opens up extensive potentials for competitive hydrogen production. Moreover, for a truly integrated energy system transformation, power-to-gas must be defined as a connection technology rather than as a final consumer. Further levers include the use of Green PPAs and the recognition of the emission reduction effect of green hydrogen in the context of the greenhouse gas quota obligations.

Hydrogen imports, for example from sunny and windy regions outside Europe will be economically attractive despite the required transport. This is because there, renewable electricity generation costs of 20 €/MWh are already achievable. Hence, in the long term, imports will represent a significant share of the hydrogen supply and consequently of a future hydrogen economy. In order to ensure a long-term secure and sustainable international supply, first, the local energy supply situation of a country and the avoidance of competition between hydrogen electrolysis and local electricity supply must be considered from the very beginning in any hydrogen partnership. Secondly, a high dependency from single countries and their political risks, as is the case with today's oil procurement, must be avoided.

The current promotion of domestic hydrogen production is nevertheless appropriate and important, because it stimulates technical development and the reduction of international supply risks and dependencies.

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