WHEC2022
23rd World Hydrogen Energy Conference
26-30 June 2022 - Istanbul

CRITICAL ASSESSMENT OF THE PRODUCTION SCALE REQUIRED FOR FOSSIL PARITY OF GREEN ELECTROLYTIC HYDROGEN

*Joris Proost
Université catholique de Louvain, Division of Materials and Process Engineering, 1348 Louvain-la-Neuve, Belgium

*Corresponding author e-mail: joris.proost@uclouvain.be

ABSTRACT

Hydrogen produced from renewable electricity through Power-to-Hydrogen can facilitate the integration of high levels of variable renewable electricity into the energy system. An electrolyser is a device that splits water into hydrogen and oxygen using electricity. When electricity is produced from renewable energy sources, electrolytic hydrogen can be considered to be green. Key green hydrogen production technologies, mostly PEM and alkaline electrolysers, are still further maturing, both in technical (efficiency), economical (CAPEX) and durability (lifetime) performance. Nonetheless, we will show in this contribution how fossil parity for green hydrogen, i.e. a Total Cost of Ownership (TCO) similar to grey H_2 coming from CO_2 intensive SMR processes, can already be achieved today. Moreover, this can be realised at a scale which corresponds to the basic units of renewable electricity generation, i.e. a few MW.

Keywords: power-to-hydrogen, electrolyser, renewable electricity, fossil parity

INTRODUCTION

Although water electrolysis as such is already a well-established H_2 production technology for almost a century, its large-scale implementation for the production of green H_2 has been hampered mainly by cost issues. In this respect, the current price of fossil SMR-based H_2 provides a very challenging benchmark. According to [1], the global hydrogen feedstock market represented in 2015 a total estimated value of 115 billion $, corresponding to a hydrogen demand of about 56 Mton/yr. From these numbers, the average market price for fossil H_2 can be estimated as 2.0 $/kg. In the current paper, we aim at critically assessing the production scale required to reach such fossil parity for electrolytic hydrogen.

RESULTS

Hydrogen production today

As of today, hydrogen is mainly being used as a specialty chemical in a number of applications. These are generally classified into 4 main categories : (1) the chemical industry, where H_2 is a basic building block for the synthesis of ammonia, methanol and a number of technical polymers; (2) a number of downstream refining processes, like hydro-cracking and hydro-treating; (3) iron, steel and glass manufacturing, where H_2 is the preferred reducing gas during annealing, blanketing and forming processes ; (4) other specialty applications, like the semiconductor industry, the use as a propellant fuel or the cooling of generators. As of today, the great majority of all of the above H_2 is being delivered by a centralised, off-site hydrogen production, dominated by 2 large-scale chemical processes : steam methane reforming (SMR) and coal gasification. Unfortunately, both of these processes are heavily CO_2 intensive, SMR emitting upto 8 tons of CO_2 per ton of H_2 produced. Therefore, with the objective of reaching the CO_2 emission targets also in todays fossil-based H_2 production, the part of green electrolytic hydrogen production from renewable electricity (which represents less than 4% today) can be expected to significantly increase over the coming years. However, in order to meet the current global H_2 demand of around 70 Mton/year, a total of 300 GW installed electrolyser capacity would be needed. As this represents already about 20% of the total installed renewable power capacity today, such massive electrolyser deployment is currently not very realistic. As a result, a selection of technologically feasible market penetrations for electrolytic H_2 needs to be made. Such selection then also implies that todays local H_2 consumers, besides becoming local (on-site) producers of renewable electricity, also need to become local (on-site) producers of electrolytic H_2, at a production scale which still allows to meet the stringent requirement of fossil parity at about 2.0 $/kg.

Green hydrogen production scale-up

Contrary to the intrinsically large-scale SMR, water electrolysis is intrinsically small-scale. Both the geometrical area of the electrodes (a few m^2 at most) and the number of electrodes that can be compiled in series in a single stack is relatively limited. As a result, the unit size of water electrolysers has long been limited to the kW-range, a typical on-site containerized production unit being a few 100 kW at most. However, in order to be able to realize the mandatory coupling to renewables, mainly wind and solar, the power scale of water electrolysers needs to become of the same order of magnitude as the renewable electricity source itself. This requires a major scale-up from the kW-scale, typical for state-of-the art electrolysers about a decade ago, towards the multi-MW scale typical for state-of-the art on-shore wind turbines. Such an electrolyser scale-up is typically being realised by increasing the number of cells per stack. However, from the state-of-the-art data that we recently collected from a number of electrolyser manufacturers [2], such a "keep-on-stacking" approach seems to have an intrinsic limit at around 100 cells/stack. Beyond that number, other balance-of-plant issues come into play, including the risk of electrical shorts and the technological complexity of a safe large-scale gas collection. Therefore, for multi-MW applications, multi-stack electrolyser systems are typically being used.

DISCUSSION

The cost of electrolytic hydrogen

While it is technically feasible to produce green electrolytic hydrogen with such multi-stack systems at the multi-MW scale (even > 100MW), the critical question still remains at what price/cost. In this respect, the 3 major parameters affecting the electrolytic H_2 production cost are the operational time of the electrolyser, the cost of renewable electricity, and the electrolyser CAPEX [3]. Hence, before becoming a realistic alternative production technology, there is a need for cheap(er) renewable electricity (well below 70 Euro/MWh), the investment cost of electrolysers needs to be brought down (well below 1000 Euro/kWh), and there should also be a clear industrial commitment to CO_2 reduction. Luckily, with respect to these parameters, significant progress has been made over the past years. First of all, a significant price reduction for renewable electricity has already been realised for both solar PV and on-shore wind, with prices on the order of 30-40 $/MWh becoming realistic by 2025. Moreover, for alkaline systems, a CAPEX of 750 Euro/kW is already realistic today for a single stack 2 MW system. Moreover, as seen in Fig. 1, a significant further reduction in CAPEX as low as 450 Euro/kW is currently being projected for multi-stack systems when scaling up to 50-100 MW. Also note from Fig. 1 that single stack electrolysers are much more susceptible to CAPEX reduction than multi-stack systems.

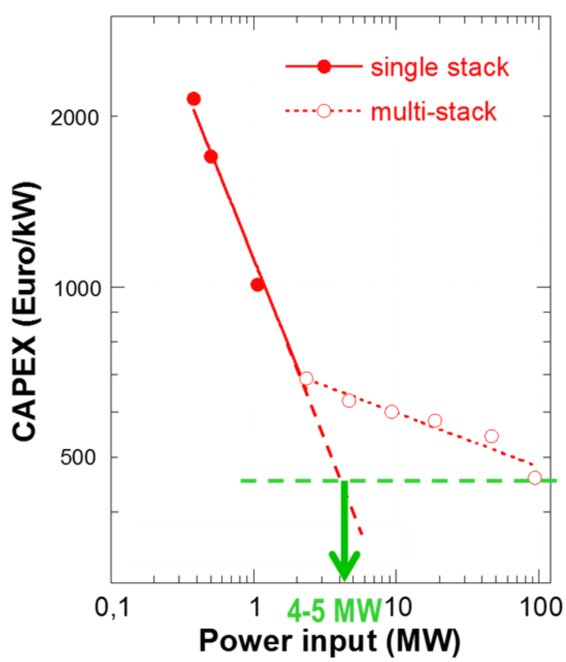

Fig. 1. State-of-the-art CAPEX data for alkaline electrolysers as a function of power input. The change in slope for alkaline electrolysers corresponds to the use of multi-stack systems.

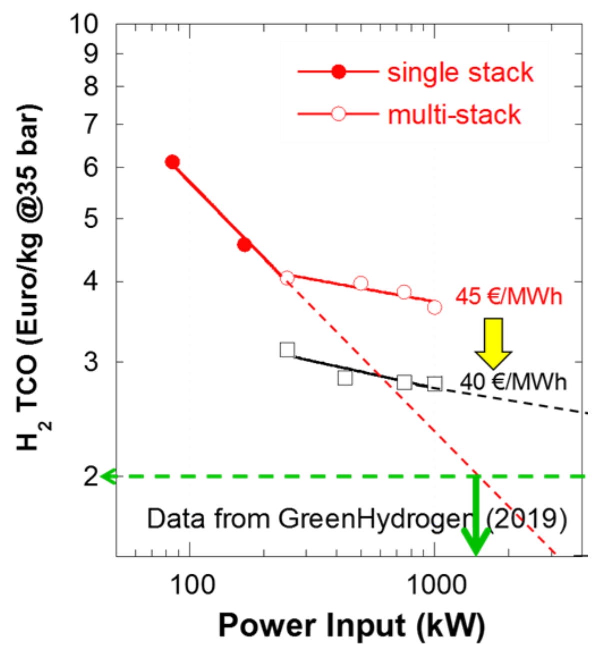

Fig. 2. Total Cost of Ownership (TCO) of electrolytic H_2, delivered at 35 bar, as a function of power input. OPEX includes the use of electricity, water and nitrogen (for purge), assuming a renewable electricity price of 40 and 45 €/MWh, respectively.

Based on the above updated numbers, a recent study from the International Energy Agency [4], allows to anticipate a significant reduction in the electrolytic H_2 production cost as a function of the available renewable electricity price, assuming the most favorable (but still realistic) CAPEX value of 450 Euro/kW. It shows that for a combination of high load factors and a non-zero but relatively low electricity cost, on the order of 30 $/MWh, the electrolytic H_2 production costs can be competitive with SMR.

The scale of fossil parity for green hydrogen

A final issue then relates to the production scale required for obtaining such fossil parity with electrolytic H_2. Indeed, from Fig. 1, one could wrongly conclude that reaching the required reduction in electrolyser CAPEX down to 450 Euro/kW would require very large-scale electrolytic H_2 production units, on the order of 50-100 MW. However, Figure 1 also suggests that there might still be a much smaller production scale for reaching such low CAPEX values. Indeed based on an extrapolation of the currently available CAPEX data for single-stack alkaline electrolysers in Fig. 1, the level of 450 Euro/kW (dashed horizontal green line) can already be reached around 4-5 MW. Such a significant reduction in the scale required for fossil parity is directly related to the much steeper reduction in CAPEX that can be realised for single-stack as compared to multi-stack electrolyser systems.

Even more direct corroborating evidence for this relatively small scale fossil parity for green electrolytic H_2 is given in Figure 2. The latter represents state-of-the-art industrial data for the Total Cost of Ownership (TCO) of electrolytic H_2 as a function of power input. Values are based on a 10 years operation, including a 10 years' service & maintenance agreement, for a complete turnkey, containerized alkaline electrolyzer unit (including inverter and water treatment), delivered and installed in Europe. The electrolyser efficiency is guaranteed at 46.7 kW/kg at 100% load, and delivers H_2 at 35 bar. Until now, it was commonly agreed that the only option to decrease the electrolytic H_2 production cost towards fossil parity was to increase the capacity of the (multi-stack) system upto 50-100 MW, as already discussed in Fig. 1. However, as suggested by the dashed red line in Fig. 2 through the TCO data for single stack systems, there is yet another technological alternative. It consist in extending the power input that can be taken up by a single-stack electrolyser upto a few MW (2-4 MW, the exact number depending on the electrolyser technical characteristics like electrode size). This then also corresponds to the scale of the basic units of renewable electricity generation. The (only) remaining technological challenge on the electrolyser level would then be to try to increase the number of cells/stack for such a single stack system, or to increase the specific area of each individual electrode (e.g. by replacing classical 2-D plates by 3-D electrodes [5]).

CONCLUSIONS

In this paper, we have addressed the question what would be an economically viable (minimum) production scale for green hydrogen, produced from water electrolysis using renewable electricity. A realistic benchmark to do so is to take the current price of grey hydrogen (the so-called fossil parity), currently estimated at 2.0 $/kg and produced by fossil-based and thus CO_2 intensive processes. Using the most recent TCO values for electrolytic hydrogen, it was concluded that fossil parity could already be reached at a production scale on the order of a few MW. Although this might still require a further intensification of the water electrolysis process, e.g. by extending the power range of a single-stack electrolyser, such small-scale fossil parity provides an important paradigm shift. Indeed, with respect to the current, large-scale unit size fossil fuels (SMR) based centralised hydrogen production, it has the important advantage of allowing a decentralised local H_2 production. Renewables can then be harvested anywhere, and used directly for the local production and consumption of green electrolytic hydrogen, fully in line with the small-scale local H_2 demand.

ACKNOWLEDGEMENTS

We cordially thank Eric Dabe from NEL and Henrik Steen Pedersen from GreenHydrogen for providing their state-of-the-art CAPEX and TCO data on electrolytic hydrogen. This paper also benefited from a number of insightful discussions at the International Energy Agency with Uwe Remme and Cédric Philibert, respectively at the IEA's Energy Technology Policy Division and the Renewable Energy Division. Finally, financial support from the Public Service of Wallonia – Dept. of Energy and Sustainable Building is gratefully acknowledged as well for allowing these fruitful interactions with the IEA.

REFERENCES

[1] IRENA report 2018 : *Hydrogen from Renewable Power : Technology Outlook for the Energy Transition*

[2] J. Proost, International Journal of Hydrogen Energy, 44, 4406-4413 (2019)

[3] J. Proost, International Journal of Hydrogen Energy, 45, 17067-17075 (2020)

[4] C. Philibert, *Renewable Energy for Industry : from green energy to green materials and fuels*, IEA Insight Series 2017, p. 28

[5] Q. de Radiguès, G. Thunis and J. Proost, International Journal of Hydrogen Energy 44, 29432-29440 (2019)