Green hydrogen: overhyped or underestimated?

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Across the globe, governments are betting on hydrogen, especially if it can be produced from wind and solar power as part of the net zero transition. While some developers are racing to announce GW-scale projects that will take decades to come online, others are considering smaller scale, near-term opportunities.

In the UK, it is increasingly challenging to obtain grid connections for wind and solar farms. There is a strong case for using green hydrogen to help integrate more renewables into our energy system and avoid hefty curtailment losses during periods of high wind and low demand.

The appetite for green hydrogen and other so-called 'power-to-x' projects fits in with a broader trend towards co-location of different renewable energy generation technologies, as well as battery storage.

In this article, we explore some of the key questions developers are grappling with. How much green hydrogen can be produced from co-located wind and solar electricity at a specific site? What is the optimal sizing for electrolyser capacity with respect to renewable generation capacity? And, to what extent can electrolysers help to mitigate renewable energy curtailment?

The basics

Electrolyser technology has existed since around 1800. Electricity is used to split water into hydrogen and oxygen gas. While there are different types of electrolysers, the

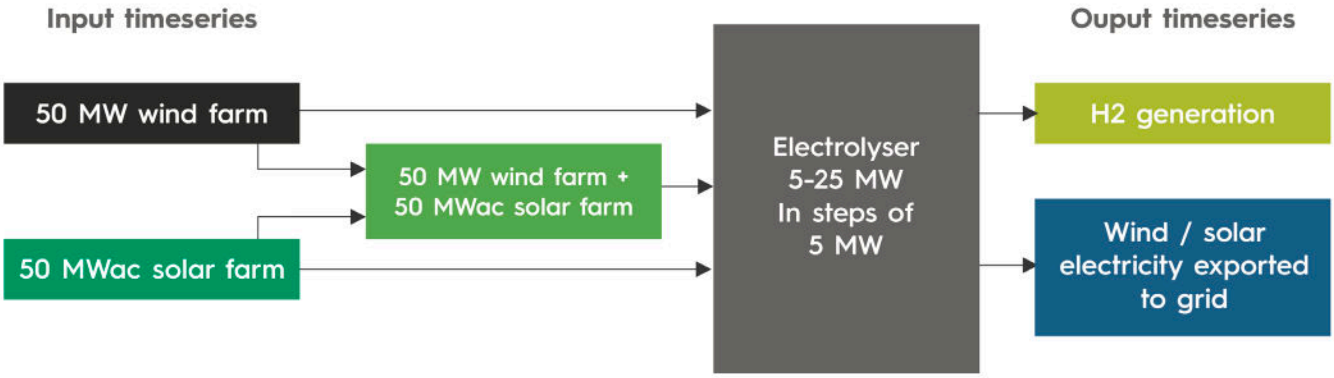


Figure 1: Hybrid time series model

dominant design for co-location with renewables uses so-called PEM, or proton exchange or electrolysis membrane, technology, which is particularly well suited to cope with intermittent input power levels.

Present-day PEM electrolysers are modular devices that can be scaled to meet project requirements. A typical module has a nominal input power rating in the range of 2-5 MW. Taking into account conversion efficiencies, this implies a H_2 production rate of around 400-430 kg/day/MW.

Put simply, a typical 5 MW electrolyser can produce H_2 at a rate of around 0.025kg/s, provided it consistently receives 5 MW of input power.

Of course, wind and solar power are intermittent. Their power output can fluctuate from zero to rated power during short timescales, and also follows time of day and seasonal patterns.

Broadly speaking, a typical UK onshore wind farm has a capacity factor[1] of 30-45%. A typical UK solar farm has a capacity factor of 10-15%. An electrolyser must be run at reasonably high-capacity factor (or utilisation) to be commercially viable - a minimum threshold of 60% is often cited within the industry.

Determining the right combination of each technology therefore requires site-specific analysis.

Sizing optimisation for a wind/solar/H_2 project in Scotland

In this case study, we selected a site in the Scottish borders, which remains one of the most active renewable energy development areas in the UK and can be considered a prime location for green hydrogen co-location due to existing grid constraints.

For the purpose of this analysis, we focused on a project concept where the renewable generator is physically co-located with the electrolyser facility, and is connected to the electricity grid. This is representative of most projects where we have supported UK developers.

The relative sizing of each technology is key. This determines not only the electrolyser capacity factor, but also the periods when the renewable power output cannot fully be absorbed by the electrolyser and must be fed into the electricity grid, or curtailed.

To assess different sizing configurations and technology combinations, we created a time series model as shown in Figure 1, to assess three scenarios. Scenario 1: Hydrogen created from standalone 50 MW wind farm; scenario 2: Hydrogen created from standalone 50 MWac solar farm; and scenario 3: Hydrogen created from 100 MW wind/solar hybrid farm.

To capture both short-term and long-term patterns in the wind and solar resource, the analysis covered a 20-year period with hourly resolution data.

Headline results

The long-term annual average electrolyser capacity factors are shown for each scenario in Figure 2.

Clearly, the standalone wind farm in scenario 1 can produce more hydrogen than the standalone solar farm in scenario 2, due to wind and solar resource levels in Scotland. In this location, the electrolyser can be sized at up to half of the wind farm's capacity to ensure sufficient utilisation.

Conversely, the standalone solar farm would likely not be a viable option for hydrogen co-location as even a small electrolyser would stand idle for most of the year. Scenario 2 is therefore not considered a priority. However, combining wind and solar generation in scenario 3 allows the electrolyser utilisation to be boosted by around 10% compared to the standalone wind scenario.

In all scenarios, there is a significant proportion of electricity that is not

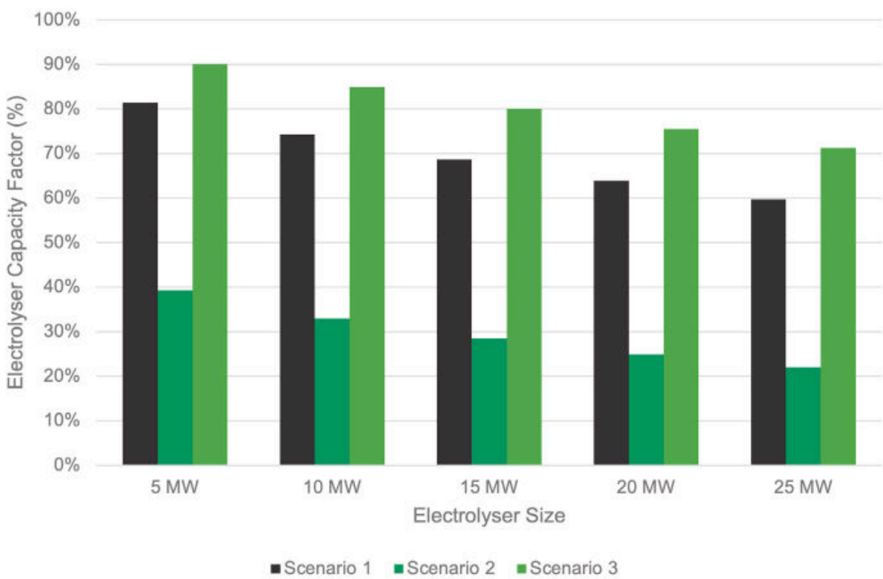


Figure 2: Electrolyser utilisation for different sizing scenarios

1 The term "capacity factor" is defined as follows: Capacity factor = (Actual generation over a year) / (Rated power x 8760h)

converted to green hydrogen, but instead is exported to the grid. It is assumed that the grid connection is sized to match the renewable generator's rated power, i.e. there is no curtailment risk at this stage. The annual percentage of the generation used for hydrogen production and percentage of generation exported to the grid following hydrogen production is displayed in Figure 3, for a 15 MW electrolyser.

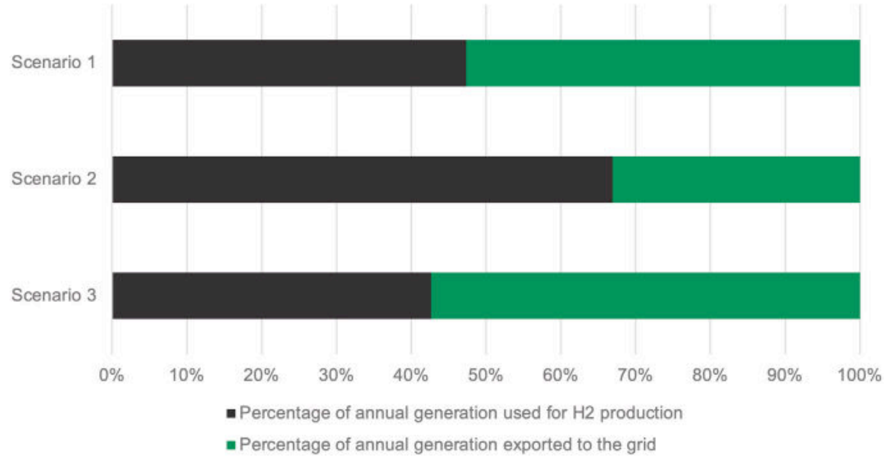


Figure 3: Different uses of generation, 15 MW electrolyser capacity assumed

Benefits of combining wind and solar generation

Co-locating wind and solar can be very beneficial as their respective generations tend to peak at alternative times of day and year. A hybrid facility can achieve a more consistent seasonal generation profile, compared to either of the two technologies in isolation. Wind farms tend to have higher generation during the winter months and night-time hours. In contrast, solar farm generation peaks during the summer months and in day-time hours.

Figure 4 shows how the combination of the wind and solar generation results in a more consistent green hydrogen production profile throughout the year, using a 15 MW electrolyser as a representative example.

Inter-annual variability of hydrogen production

The inter-annual variation (IAV) of the electrolyser capacity factor is important to consider because it represents the typical variability of green hydrogen production from year to year. If a project is committed to delivering a minimum volume of hydrogen to an off-taker each year, the risk of falling short of this threshold must be understood. If the project is unable to import electricity from the grid to power the electrolyser and make up the shortfall, it may need to compensate the off-taker for having to source additional hydrogen from an alternative provider.

Intuitively, the IAV for green hydrogen is primarily driven by the wind and solar resource. Combining the two technologies ensures a more consistent annual production as a poor wind year typically coincides with a strong solar year, and vice versa.

Implications for hydrogen transport and storage requirements

Whether the off-taker is located immediately adjacent to the electrolyser facility or the hydrogen is transported to the off-taker via tanker trucks, there will likely be a requirement to store a certain volume of hydrogen on-site.

Assuming that the generated hydrogen is transported away from site daily, our analysis suggests that a maximum on-site hydrogen storage capacity of around 260 to 270kg would be required in our case study for a 15 MW electrolyser. This falls within the capacity of a typical tube trailer carrying compressed hydrogen gas.

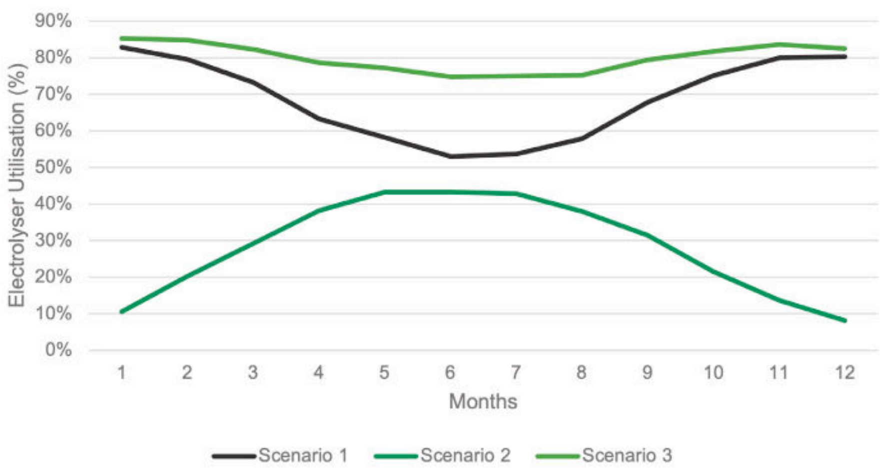


Figure 4: Seasonal electrolyser utilisation (15 MW electrolyser capacity assumed)

Using green hydrogen to absorb renewable energy curtailment

Grid-connected wind and solar farms usually have a maximum export capacity (MEC), which defines how much energy can be exported to the grid at any one time. Oversizing the wind or solar farm with respect to the MEC can be attractive if there is sufficient land available to support a large scheme, but grid capacity can only be secured for a fraction of the project's generation potential.

If a project is oversized with respect to the MEC, there will be times when its generation must be curtailed and the associated electricity, and revenues, are lost. This is particularly relevant for wind farms which can experience long periods of operating at rated power.

However, powering an electrolyser purely from curtailed wind power is unlikely to support a business case in isolation. Figure 5 illustrates this challenge. A smaller electrolyser can achieve higher utilisation, but will lead to significant periods where the excess wind generation cannot be fully converted to hydrogen.

In practice, a flexible approach will likely be needed, where wind farm generation is allocated to hydrogen production or export to the grid on an hour-by-hour basis. Battery energy storage could also be used to peak shift renewable generation, thereby ensuring a smoother operating profile for the electrolyser facility, absorbing more curtailment, and ultimately increasing the electrolyser capacity factor.

Conclusion

With a growing number of developers pursuing this type of hybrid project, we have explored various options for combining wind, solar and green hydrogen infrastructure for this article. The main driver for sizing considerations is ensuring a sufficiently high electrolyser utilisation (60%+).

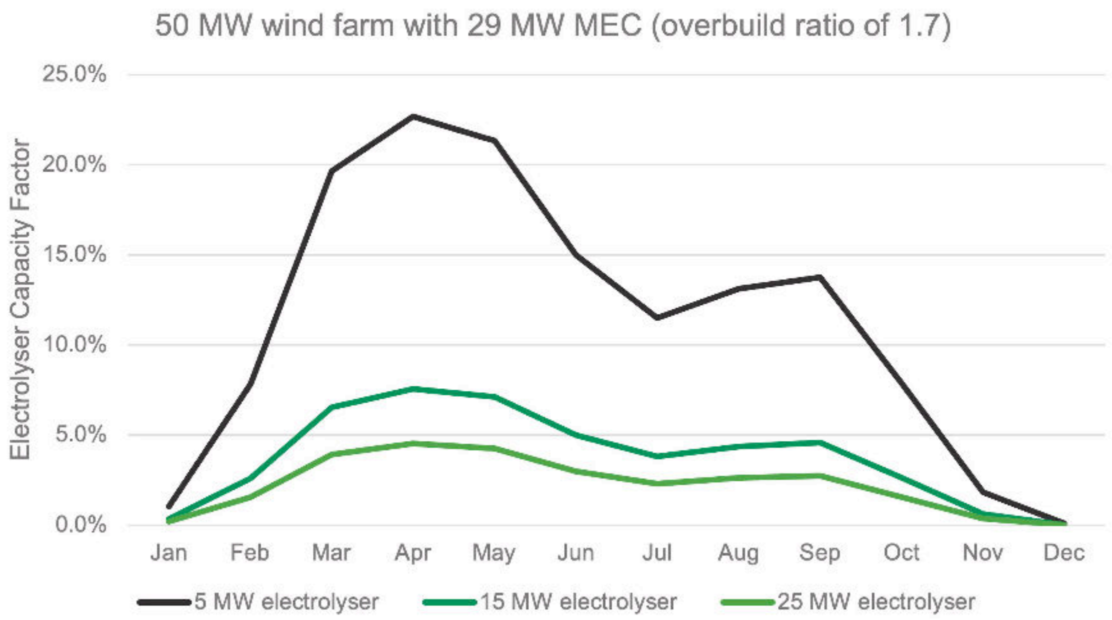
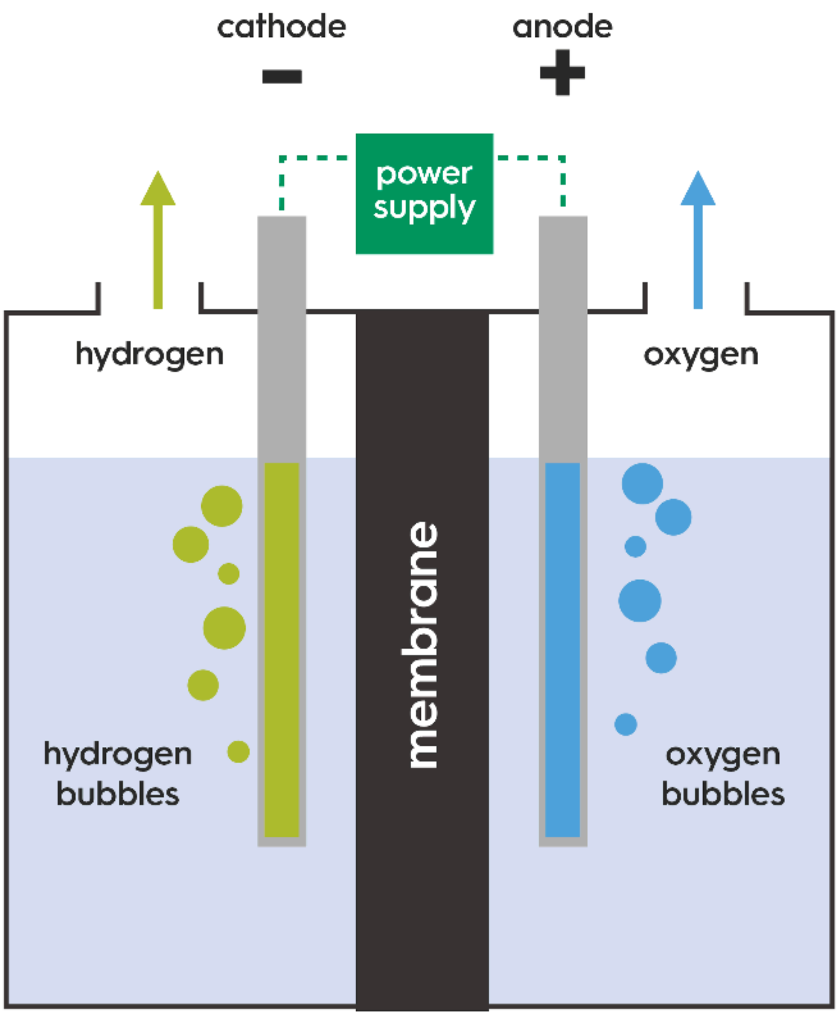


Figure 5: Seasonal electrolyser utilisation from curtailed generation only

In markets like the UK, wind and hydrogen are better suited to co-location than solar and hydrogen. However, the highest electrolyser utilisation is achieved by combining wind and solar generation, due to the complimentary resource profile.



While electrolysers can help to absorb curtailment losses in a scenario where the renewable generator is oversized with respect to its grid connection, this is unlikely to support a viable business case in isolation. Adding BESS could help to achieve a smoother hydrogen production profile and higher electrolyser utilisation. Understanding inter-annual variation as well as the average and maximum daily hydrogen production profile is key to hydrogen storage and offtake considerations.

Our advice to developers is this: hydrogen is not a silver bullet, and any co-location with wind and/or solar PV will need to be carefully considered. But one thing is clear, with the continued advancement of both fresh thinking and new technology, we're leading the way for the expansion of hybrid sites which will be critical to achieving our net zero energy targets.

About Natural Power

Natural Power is an independent consultancy and service provider that supports a global client base in the effective delivery of a wide range of renewable projects including onshore wind, solar, renewable heat, energy storage and offshore technologies.

It has a global reach, employing more than 450 staff across 14 international offices. Its experience extends across all phases of the project lifecycle from initial feasibility, through construction to operations and throughout all stages of the transaction cycle.

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