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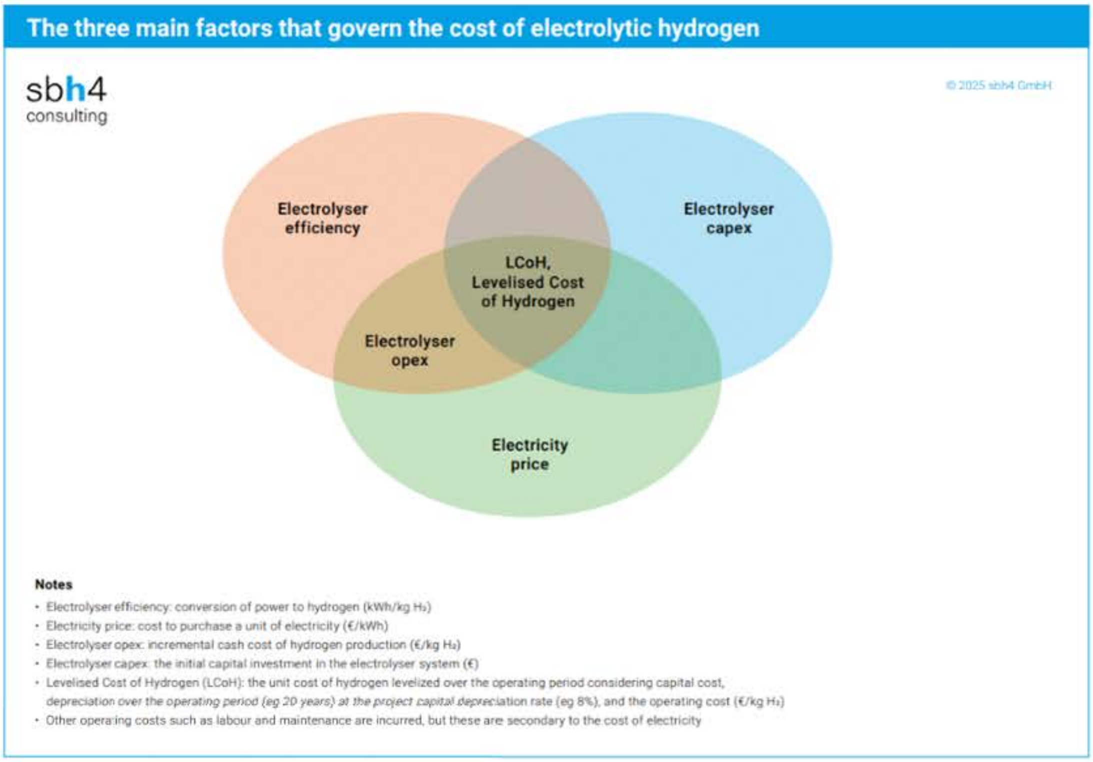
Electrolyser technology selection for intentionally intermittent operation

sbh4 consulting

The main contributors to the levelised cost of green hydrogen (LCoH) are the capital expense of the electrolyser, the purchase price of renewable electricity and the efficiency at which the electrolyser converts electricity to hydrogen. The nature of a green hydrogen scheme will determine which of these three parameters are the most and least important.

Intentionally intermittent electrolyser operation during periods of low, zero and negatively priced renewable power will be an economic way to produce green hydrogen from existing electricity grid systems with a high renewables input. When coupled with high capacity, low-cost hydrogen storage and distribution this combination of technologies could dominate green hydrogen production in Europe.

Executing such an electrolyser operational strategy means understanding the most appropriate technology, regulations and complimentary hydrogen infrastructure.



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Low-cost hydrogen

The cost of renewable electricity, when supplied on a stable basis through a power purchase agreement (PPA) in Europe, is around 50 €/MWh. When purchasing electricity at that price, the theoretical minimum LCoH is €2/kg H2.

To achieve this theoretical minimum, we must assume zero grid transmission fee, no degradation, no maintenance costs, 100% efficiency of the electrolyser, zero capital cost of the electrolyser, and zero financing cost. Clearly, each of these assumptions is wildly unrealistic.

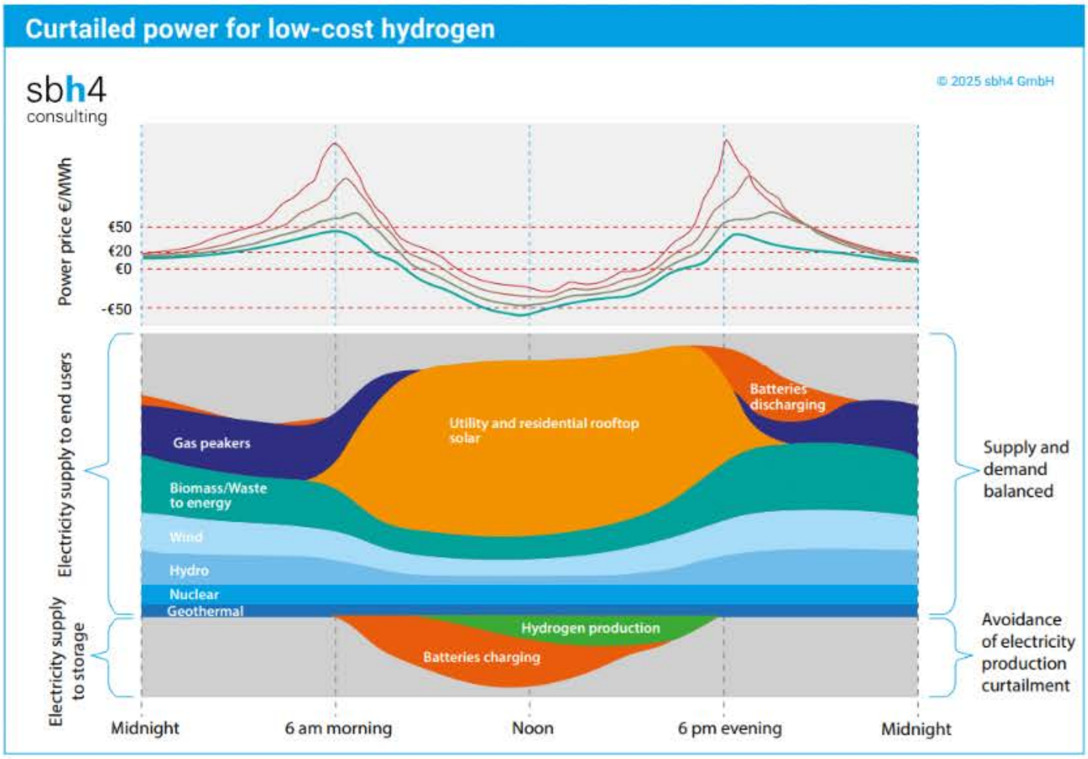
The only way to reduce the LCoH below this theoretical minimum of €2/kg is to reduce the cost of electricity. That means purchasing off-peak electricity during periods when prices are low, zero or negative.

Negative power pricing

As more non-programmable, renewable electricity generation capacity from wind and solar comes onto European grids, the periods where prices fall to zero are becoming longer and more frequent.

During peak solar hours and strong winds renewable power generation exceeds the capacity of the grid to absorb that power. The result is negative pricing to incentivise renewable electricity producers to curtail (AKA downward redispatch) their production.

The ramp up in renewables enables a business model where green hydrogen producers operate only during periods of low, zero and negatively priced power. This serves the dual function of producing renewable hydrogen at the lowest possible cost and balancing supply and demand on the grid.



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RFNBO rules

The EU regulations which define green hydrogen and e-fuels are the RED II/III and its Delegated Regulations (EU) 2023/1184 and (EU) 2023/1185. These refer to green hydrogen as a renewable fuel of non-biogenic origin, or RFNBO.

These regulations state that from 1st Jan 2030 strict additionality and an hourly matching temporal correlation will become effective. These are in addition to the requirement for proximity, meaning power for electrolysis must be drawn from the same bidding zone, or an adjacent one if the grid is not congested. When combined, these regulatory restrictions are likely to make high-utilisation green hydrogen schemes uneconomic in most European countries.

However, there are two hugely important exceptions to these regulations that soften their impact dramatically. Firstly, electricity will be regarded as renewable and additional if it is from renewable power generation (of any age) drawn during an imbalance period and avoids downward redispatch of the renewable power. Furthermore, if the electricity for the electrolysis is purchased at a low price (<€20 / MWh) the temporal correlation is assumed to be met.

The assumption in the above cases is that this electricity may otherwise have been curtailed or is being generated at a period of very low demand from other users. The implications for intentionally intermittent operation are overwhelmingly positive. Intentionally intermittent operation is the silver lining around the dark regulatory cloud which currently hangs over the European green hydrogen sector.

Capex and Opex trade offs

When operating an electrolyser continuously at full load efficiency is of primary importance for technology selection. A small improvement in the amount of hydrogen produced per MWh of electricity consumed will comfortably pay for the additional capital cost of a more efficient electrolyser. In these high utilisation green hydrogen schemes, solid oxide electrolysers or advanced alkaline electrolysers may be favoured.

On the other hand, intentionally intermittent operation of an electrolyser drives down utilisation because it is idle for a portion of the time. Low utilisation puts pressure on minimising capital. Also, since the electrolyser is not operating for so many hours, its efficiency plays a smaller role in the economic viability of such a scheme. With intermittent operation, low electrolyser capex becomes more important than high-efficiency when considering technology selection.

In many green hydrogen schemes, pressurised alkaline electrolysers are selected due to their availability, technical maturity and low capital cost. A limitation of these electrolysers is that hydrogen begins to cross over the membrane to the oxygen side at low loads.

This generally limits their safe operating range from 30% to 100% of nominal power consumption. However, at 30% power consumption, their hydrogen production efficiency can be cut in half. In the ideal case, pressurised alkaline electrolysers like to be turned on, ramped up and left alone.

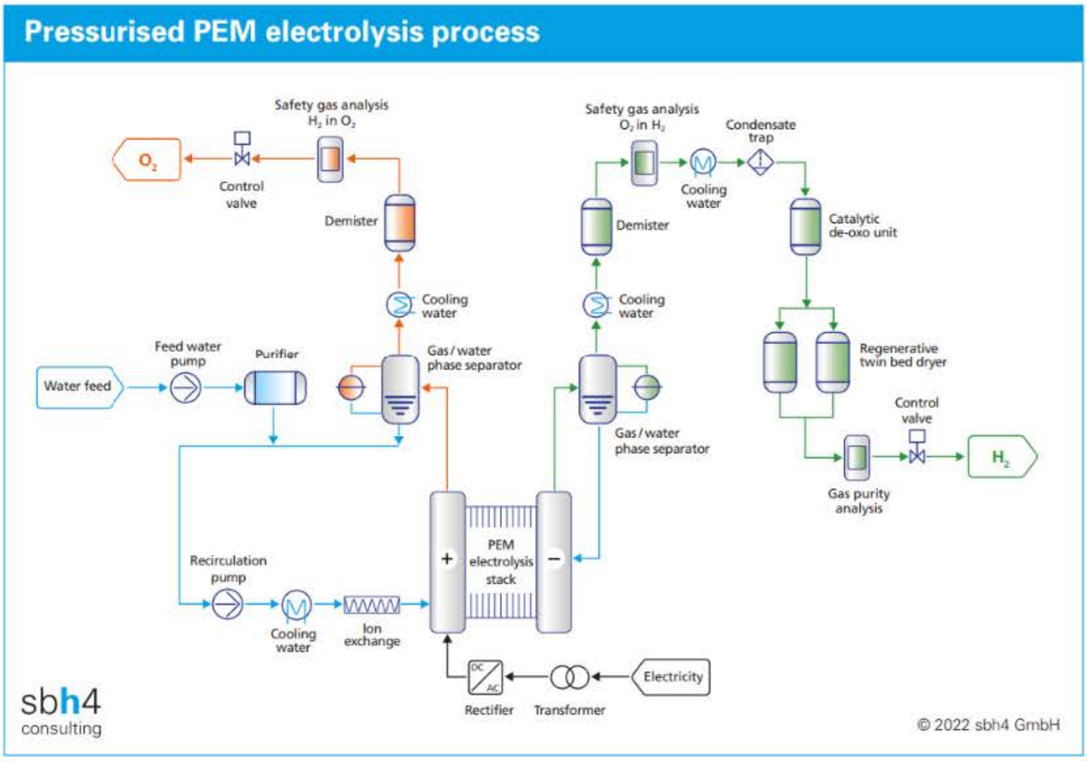
Electrolyser technology selection

The key attribute of an electrolyser to exploit the concept of intentionally intermittent operation is hyper-flexibility. Hyper-flexibility means that an electrolyser can turn on and off rapidly, and can turn down to consume almost zero power.

In the future anion exchange membrane (AEM) electrolysers may be appropriate for intermittent operation. The decoupled water electrolysis technology in development by H2Pro and Hysata's bubble-free electrolyser may also be well placed. However, none of these options is currently 'bankable' for a large-scale green hydrogen project.

Proton exchange membrane (PEM) electrolysers are the best-fit for intentionally intermittent operation today. PEM electrolysers can be more tolerant of rapid ramping and daily idle periods associated with intentionally intermittent operation.

The capital cost of a PEM electrolyser stack can be up to twice that of a pressurised alkaline electrolyser stack sourced from China. However, this cost differential is progressively being eroded as PEM technologies mature and manufacturing scales up. Furthermore, when considering the balance of stack and the total project costs, the difference in cost between PEM and pressurised alkaline stacks becomes less significant.



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High capacity hydrogen storage

Balancing intermittent hydrogen production with the demand profile of end users requires hydrogen storage. The build out of hydrogen pipelines with integrated underground storage capacity will serve the dual purpose of connecting suppliers with offtakers and be a hydrogen storage buffer.

The European Hydrogen Backbone concept includes pipelines to transport hydrogen in addition to high capacity underground storage. In northern Germany and the Netherlands, salt cavern storage is proposed. Where the geological conditions make this possible, it offers the lowest levelised cost of storage (LCoS).

In Southern Europe and the Nordics the option to use salt cavern storage does not exist. Here, lined rock caverns are likely to be the most cost-effective high capacity hydrogen storage mechanism.

Aligning with downstream processes

The main capital cost of a green hydrogen scheme will be the electrolyser itself. When producing hydrogen derivatives such as ammonia, e-methanol, or e-SAF the capital cost of the project also includes downstream synthesis equipment.

With more capital invested, the need for high utilisation increases. Additionally, the chemical synthesis units prefer stable operation close to their nominal design point to maintain product purity and optimise process efficiency. Balancing intermittent hydrogen production with hydrogen derivatives production can be achieved using high capacity hydrogen storage. However, this further increases the capital commitment of the scheme.

It is most likely that intentionally intermittent green hydrogen projects will not include downstream production of hydrogen derivatives on site. However, when their green hydrogen is fed to a pipeline with integrated hydrogen storage, the economics of producing hydrogen derivatives can be favourable.

When multiple green hydrogen production schemes feed into a pipeline to which a very large ammonia or e-fuels plant can be connected, there can be significant economies of scale.

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