

## Hourly matching, additionality, and the case for flexible electrolysis

sbh4 consulting's Stephen B. Harrison explores how Europe's green hydrogen projects could tap into low-cost power to deliver cheap molecules and balance electric grids

Electrolyser capital costs, renewable electricity prices, and system efficiency are the three main contributors to the levelised cost of green hydrogen (LCOH). But which is the most important will depend on individual projects.

Intentionally intermittent electrolyser operation during periods of low, zero, and negatively priced renewable power is the only viable way to produce green hydrogen for less than €5 (\$5.83) per kilogramme in most European countries. Executing such a strategy means understanding regulations and complementary hydrogen infrastructure.

Over the next 10 years, intentionally intermittent operation is likely to be the main, or perhaps the only, way that green hydrogen will be produced with unsubsidised business cases in most of Europe.

### Lowest LCOH

The cost of renewable electricity, when supplied on a stable basis through a power purchase agreement (PPA) in Europe, is around €50/MWh (\$58.31). When purchasing electricity at that price, the theoretical minimum LCOH is €2/kg H<sub>2</sub> (\$2.33).

However, achieving this would

mean zero grid fees, a zero-cost electrolyser with no degradation and no maintenance costs that is 100% efficient, and zero financing costs. 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.

Crucially, these same low, zero and negative pricing periods also underpin the only scalable pathway to comply with post-2030 RFNBO additionality and hourly matching requirements.

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 (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.

### Frequency management

The electricity grid in Europe is designed to operate with alternating current at a frequency of 50Hz. Furthermore, motors and other electrical appliances are built to consume electricity at this frequency.

When there is an imbalance between electricity supply and demand, the frequency changes. Too much demand reduces the frequency; too much supply pushes it up. One of the key roles of the grid operator is to maintain the frequency within extremely tight limits around the 50Hz target.

However, electricity generation and consumption are not always within the scope of the grid operator. They must perform their task in collaboration with producers and consumers. When the grid frequency drops, additional power generation capacity is brought online. This may be from gas peakers or battery energy storage schemes (BESS). When the frequency increases, generators are requested to turn down their supply.

Demand side frequency regulation

is also important. The grid operator makes an agreement with large electricity consumers that they will either ramp up or ramp down their electricity consumption when requested. With such an agreement, the grid operator pays a fee to have the capacity adjustment reserved. Additionally, a fee is paid when the capacity adjustment is implemented at the request of the grid operator.

For a multi-megawatt electrolyser scheme with intentionally intermittent operation, the revenues associated with this capacity reservation for frequency regulation support can improve the overall economic viability of the project. These schemes can complement gas-fired peakers and BESS in the broad mix of grid management tools.

Electrolysers can participate in frequency containment and restoration markets as controllable demand, receiving capacity payments for reserving upward or downward flexibility, and an activation payment when instructed to change load.

In several European markets, multi-megawatt electrolysers can generate revenues comparable to battery systems on a €/MW-year basis, while simultaneously reducing their average electricity purchase price.

### RFNBO-compliant

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 (RFNBO).

These regulations state that from 1 January 2030, strict additionality and hourly matching 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 less than €20/MWh (\$23.32), 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. It is the silver lining around the dark regulatory cloud which currently hangs over the European green hydrogen sector. >>



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### >> Electrolyser capital cost and efficiency trade-offs

However, this method doesn't come without its 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 megawatt hour 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,

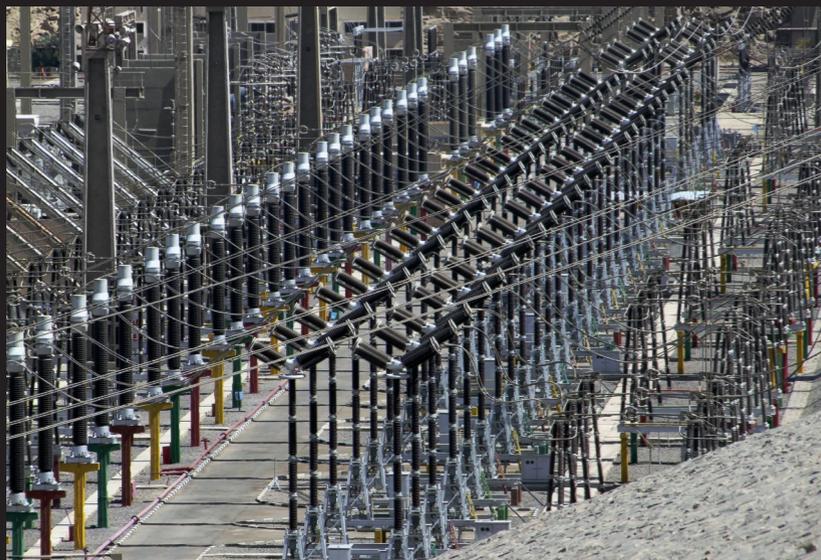
their hydrogen production efficiency can be cut in half. In the ideal case, pressurised alkaline electrolysers like to be turned on, ramped up and left alone.

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 electrolysers may be ideal 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 considered to be 'bankable' for a large-scale green hydrogen project.

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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### Balancing hydrogen supply and demand

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.

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.

### Enabling hydrogen derivatives

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 must include the downstream chemical synthesis and processing equipment.

With more capital invested, the pressure to achieve high utilisation increases. Additionally, the chemical synthesis units prefer stable operation close to their nominal design point to maintain product purity and process efficiency. Balancing intermittent

hydrogen production with continuous downstream operation can be achieved using hydrogen storage. However, this further increases the capital commitment of the scheme.

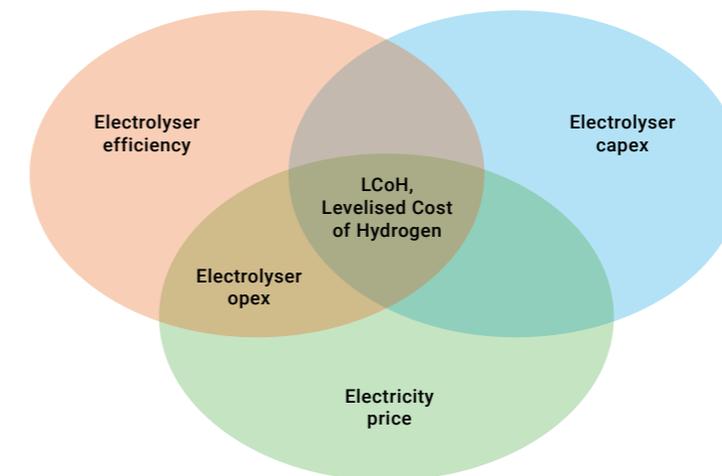
It is most likely that intentionally intermittent green hydrogen production of hydrogen derivatives on-site. However, when their green hydrogen is fed to a pipeline with integrated hydrogen storage, the economics of producing hydrogen derivatives from the stable pipeline hydrogen supply are highly favourable.

This is especially beneficial when multiple green hydrogen production schemes feed into a pipeline where a very large ammonia or e-fuels plant can be connected, thereby benefiting from economies of scale. 

### The three main factors that govern the cost of electrolytic hydrogen

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#### Notes

- Electrolyser efficiency: conversion of power to hydrogen (kWh/kg H<sub>2</sub>)
- Electricity price: cost to purchase a unit of electricity (€/kWh)
- Electrolyser opex: incremental cash cost of hydrogen production (€/kg H<sub>2</sub>)
- Electrolyser capex: the initial capital investment in the electrolyser system (€)
- Levelised Cost of Hydrogen (LCoH): the unit cost of hydrogen levelized over the operating period considering capital cost, depreciation over the operating period (eg 20 years) at the project capital depreciation rate (eg 8%), and the operating cost (€/kg H<sub>2</sub>)
- Other operating costs such as labour and maintenance are incurred, but these are secondary to the cost of electricity