# Green $H_2$ accelerating the energy transition



In a recent statement, Fatih Birol, head of the International Energy Agency, affirmed his belief that in order to achieve the targets of the Paris Climate Agreement, global low carbon hydrogen production must reach 40 million tons annually by 2030, requiring an almost one hundredfold increase from today's levels. The European Commission just announced its hydrogen strategy, which includes the ambitious goal of reaching an annual production capacity of one million tons of renewable hydrogen by 2024, and ten million tons by 2030. A new wind and hydrogen project in the Danish North Sea aims to become one of the world's largest renewable hydrogen plants, featuring a standalone 1 GW of electrolyser capacity that will use electricity from wind turbines to produce hydrogen, with dedicated pipelines connecting it to industrial demand in Belgium and the Netherlands. Germany followed suit with plans to build up to 5 GW of electrolysis capacity. Several other solar-to-hydrogen demonstration projects are also underway.

These examples make it clear that hydrogen dominates public discourse and cutting-edge projects as the potential technology of the future. It promises to bridge the intermittency gaps of renewable energy generation and provide a clean and transportable energy carrier that can replace fossil fuels in combustion applications. Propelled by policymakers and industry alike, this promising solution to a techno-economic problem has given rise to an entirely new energy economy subsector bearing its name: the hydrogen economy.

The operational principle of the hydrogen economy is this: at times when production exceeds demand, surplus energy is converted into hydrogen sourced from water through electrolysis, which can then either be used on the spot to generate electrical power or be transported over long distances to demand centres, without a loss of energy content. The benefits are many: a versatile energy carrier, hydrogen is carbon-free when burnt and emits only water vapour. It does not require a particular geographic contour to function, as pumped storage dammed hydroelectricity does. It can be stored over long periods and transported over long distances, unlike large battery storage. It can be used to produce other gases such as methane or ammonia, as well as liquid fuels. It has a higher energy density on a volumetric basis as compared to batteries, making it suitable as a transport fuel.

Currently, hydrogen is produced on an industrial scale mainly through natural gas, with the output referred to as grey hydrogen. Though carbon-free when burnt, this is merely a case of transferring carbon emissions from the place of consumption to the place of production. Where carbon emissions from hydrogen production are captured and stored, the assigned color-coding changes to blue, marking a more environmentally friendly version. A turquoise designation has been assigned to the products of pyrolysis where instead of $CO_2$ the carbon residues are collected in solid form. If gained through nuclear-powered production, the output is interchangeably


termed red, pink or purple. Hydrogen gained through renewables-powered production has, fittingly, been categorized as green. This article aims to critically examine the feasibility of precisely that.

To fully comprehend the impact this bridge technology promises to bring to the electricity industry, it is necessary to contemplate the inherent needs of electrical energy systems.

A key problem with electricity is that the sources and uses of power on a grid must be balanced at all times. Generated power must be tweaked continuously to equal grid losses and load demand at every instant, which means that more power must be available to come online at a moment's notice and be technically and economically able to be dispatched on demand at times when load demand tends to exceed power supply. In the reverse case, supply of electrical power must be able to be curtailed at times when demand starts to drop below supply levels. This balanced relationship is monitored in real-time by controlling upwards or downwards power frequency deviations from the regulated levels of 50 Hz, applicable to most countries, or 60 Hz (in the USA and a few other places).

A difficulty faced specifically by renewable energy sources compared to other electricity-generating technologies is their inability to be dispatched on demand, as they are dependent on the availability of the respective resource, namely wind in the case of wind farms or sun in the case of solar facilities. An electrical system that relies heavily on wind infrastructure will invariably find itself in situations where more wind power is available for harvesting than is required on the grid – for instance, during night hours when aggregate energy demand is typically low. Similarly, there will be times when prevailing winds lead to low output levels and the system will require additional supply sources to meet load demand.

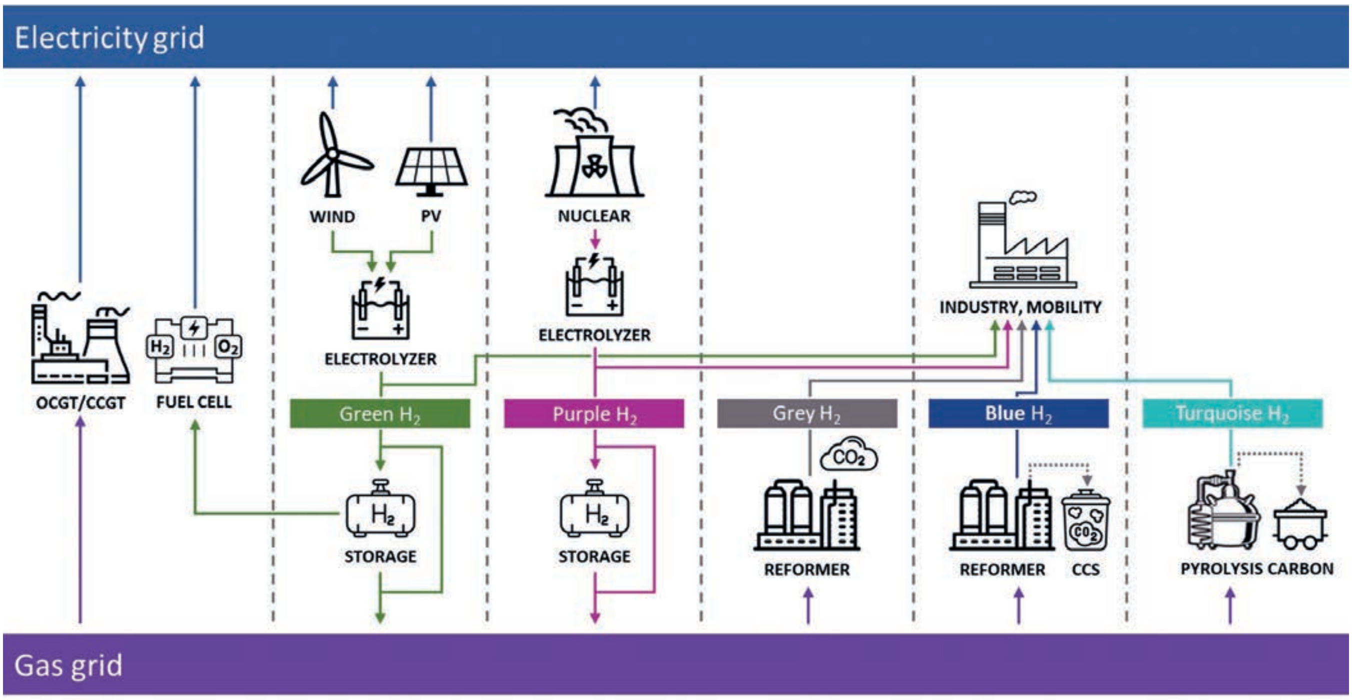
In a recent example, significant price hikes were experienced by consumers during the February 2021 power outages in Texas, USA. Due to an unusual cold spell, entire blocks of conventional and renewable generation infrastructure went offline and left power utilities with few and expensive options to continue to supply the grid. The crisis resulted in millions of homes being left without power, billions of dollars in damages and over 100 deaths. An effective arsenal of energy storage technologies that can be dispatched on demand is therefore essential to the stability and to the secure economic operation of energy systems.

Hydrogen as a means of energy storage precisely addresses the problem of intermittency and the inherent need for curtailments and balancing of energy systems, enabling a wider reliance on renewable energy sources. The EU Commission's strategy on the subject recognises that an integrated energy system that utilises existing gas infrastructure is more cost-effective than one relying on maximum electrification. For the same reason, the Commission's climate target plan foresees an extensive reliance on hydrogen, by as much as 9% of the EU's energy demand in 2050 compared to less than 2% today.

How does this work technically? The basic setup in offshore projects comprises a desalination unit where a moderate throughput of sea water is used, approximately equal to a quarter of a cubic meter of $H_2O$ per stored MWh. This stage may be skipped in onshore projects where network water is accessible. The next stage in the train is an electrolyser, which separates water molecules into $O_2$ and $H_2$. The resulting hydrogen is then either injected into a gas distribution grid or stored for use at a later stage. Local storage can be configured at low pressure conditions to minimise safety risks, thereby protecting asset integrity and keeping insurance costs in check. The final stage comprises fuel cells, where the stored hydrogen is converted back to electricity and which can be dispatched on demand. The current end-to-end efficiency of the full train approaches 50%.

There are several possible practical applications of this storage: firstly, the straightforward conversion of electrical power to hydrogen for injection into gas grids, which is also the solution that maximises systems integration in line with the EU's strategic thinking.

Pipeline grids in Europe are already aligning their systems proactively to enable the co-mingling of hydrogen into the gas mix and in some cases developing the potential to transition to pure-hydrogen operations. The volumetric energy content of hydrogen is lower than that of all fossil fuels, making logistics operations costlier. This is offset by other factors, such as rising $CO_2$ emission prices, driving an increase in demand in large markets like maritime and mobility, with indications of valid business cases. Given the uncertainty around market prices for hydrogen, some reliance on regulation and potentially subsidies is required for the sector to take off. This can be expected to spark a virtuous circle of reinvestments and R&D, leading to further cost and efficiency optimisations in the industry. Factoring in




the effect of carbon taxes, hydrogen may be able to become an economic substitute to natural gas by its own merit.

Secondly, this technology can be applied in cases of small, isolated micro-grids, where there is already abundant choice of modular power-to-hydrogen-to-power solutions that can complement generating infrastructure, be it wind or solar, to achieve self-balancing. The cost of running such facilities can be significant, with an end-to-end levelised cost of electricity (LCoE), excluding the input cost of electricity, still ranging above 100 EUR/MWh. Despite the high LCoE, this can still be competitive given the cost – and in some cases the environmental impact – of the next best storage or balancing alternatives.

Thirdly, hydrogen storage systems alongside interconnected wind farm infrastructure can serve a wide range of functions: they can be used to store energy at times of grid-imposed curtailments and of low or negative grid electricity prices. These applications can be cost-competitive to a varying degree depending on the differential between peak and low electricity prices, with the main question here being the correct dimensioning of the capacity of the power-to-hydrogen-to-power facility to maximise usage over its lifetime.

Importantly, wind farm hydrogen storage can also cover the self-consumption electricity needs of generating facilities. These applications become cost-competitive where industrial consumer prices of electricity are high. In offshore wind farms, hydrogen production can be sized appropriately to also cover the fuel needs of crew transport vessels (CTVs). One added complication is the significant increase in space needs and design structural tolerance at the offshore substation or at the individual tower bottom platforms, with the alternative being to place the hydrogen facility at or near the export cable landfall location.

A basic SWOT analysis of this technology should highlight:

- Strengths: versatile, carbon-free energy storage carrier that can be stored over long periods and transported over long distances.
- Weaknesses: LCoE ranges at high levels; end-to-end solution requires complex storage and transportation infrastructure when hydrogen is produced in remote plants; limited direct use in hydrogen-powered applications; reliance on policy or subsidies.
- Opportunities: hydrogen is a key component of the energy transition, and strongly supported by policymakers; $CO_2$ prices ranging at present at all-time highs offer additional support to carbon-free solutions; smart networks expected to enable further optimisation potential across integrated energy systems.
- Threats: other technical developments that may offer higher efficiency or lower LCoE.

In conclusion, the cost of clean hydrogen is underpinned by the capital cost and efficiency of such systems, which are expected to continue on their downward trend. Public policy is essential in order to create regulatory clarity, incentivise a critical mass of demonstration projects and create demand through production subsidies.

Even though power-to-hydrogen-to-power systems still face a few hurdles to cross, the balance appears to be in their favour. They have an important role to play in the energy transition, alongside wind farms and other renewable energy systems. Whether in micro-grids or in interconnected grids, they offer an accessible solution to bridging production intermittency and balancing grids.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**Energy Infrastructure Partners AG**

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