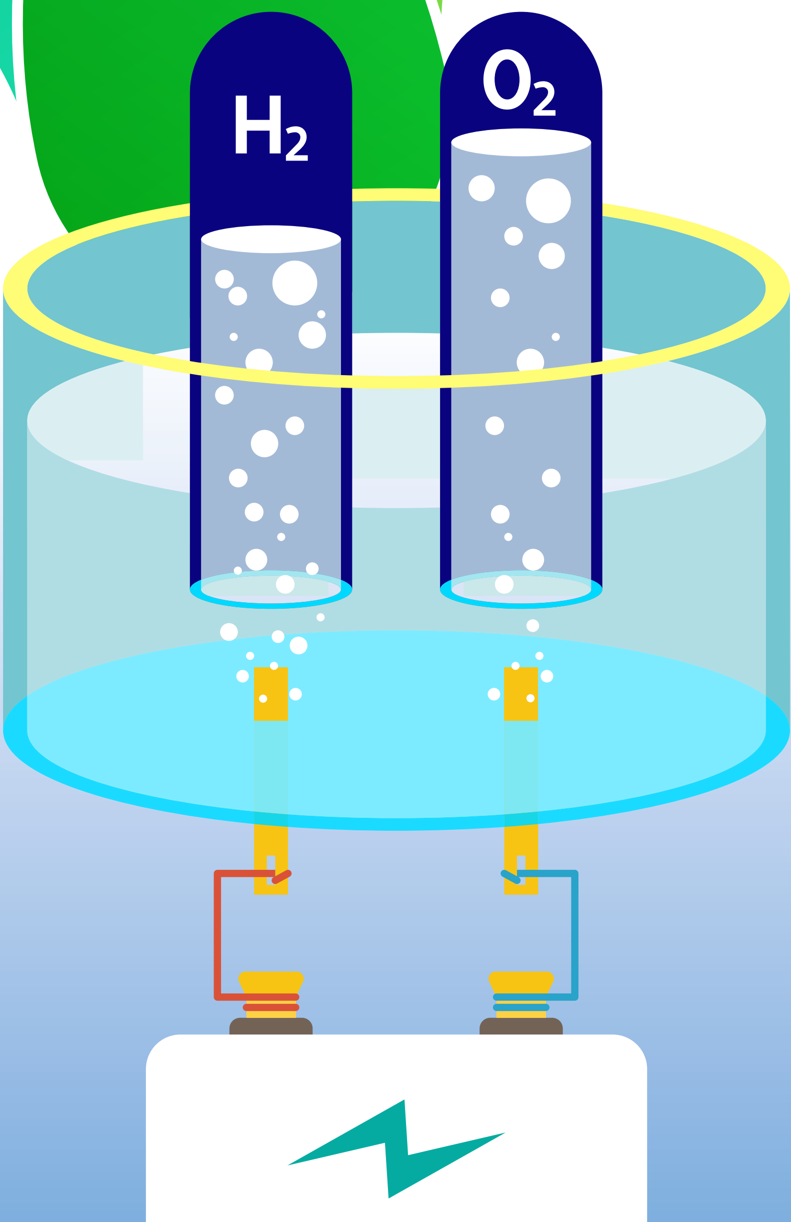
September 2023

Hydrogen UK

Electrolytic Hydrogen Production



Written By
Electrolytic Hydrogen Production Working Group

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Executive Summary

The UK has committed to achieving Net Zero by 2050. In all the major models of possible routes to Net Zero, hydrogen plays a significant role. To deliver the volumes of low carbon hydrogen required, the Government has pledged its support to both CCUS-enabled and electrolytic hydrogen which is produced via the electrolysis of water using electricity. An approach that utilises all hydrogen technologies will reduce the strain on the UK's resources, such as offshore wind, and ensure both dispersed and clustered sites have access to low carbon hydrogen.

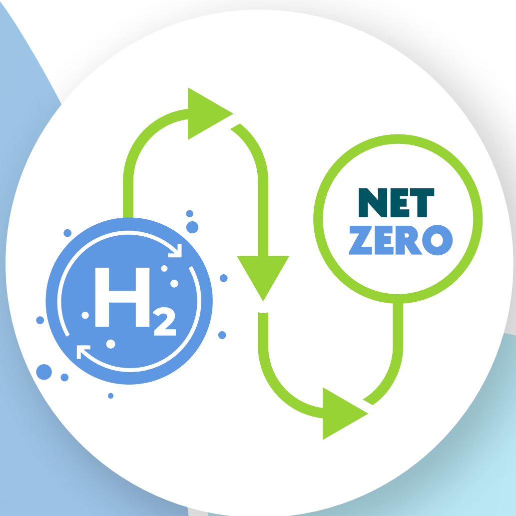
Electrolytic hydrogen has low or zero associated emissions.

The process of electrolysis requires only water and electricity to produce hydrogen and oxygen. Therefore, no carbon emissions are produced directly in the process. The outputted fuel, hydrogen, also releases no carbon emissions when combusted or when used in electrochemical reactions, such as in a fuel cell. Furthermore, when using low carbon sources such as renewables or nuclear for the inputted electricity, electrolytic hydrogen provides an end-to-end low-carbon energy vector, with zero or very low associated carbon emissions at energy source, production and end use.

Harnessing the domestic electrolytic supply chain can deliver economic benefits.

The electrolytic hydrogen supply chain does not start and finish at production. Electrolytic hydrogen offers multiple economic opportunities, such as high values jobs, across the supply chain, from water treatment to the manufacture of electrolyser stacks and their components. In the UK, it is estimated that the electrolytic supply chain could be worth up to £5 billion by 2030 and nearly £30 billion by 2050[74]. Therefore, not only can the UK become a world leader in the production of electrolytic hydrogen, but in the manufacture of key components in the supply chain, supporting a thriving export economy of high value goods such as electrolyser stacks. The economic growth from the domestic supply chain can also support the levelling-up agenda with many of the manufacturing opportunities and the associated decarbonisation opportunities in levelling-up areas.

However, the UK is risking falling behind other countries in its attempts to secure a domestic supply chain, highlighting how rapid support is required to maximise the economic potential of electrolytic hydrogen within the UK.



Electrolytic hydrogen enables the decarbonisation of hard-to-abate sectors across the country.

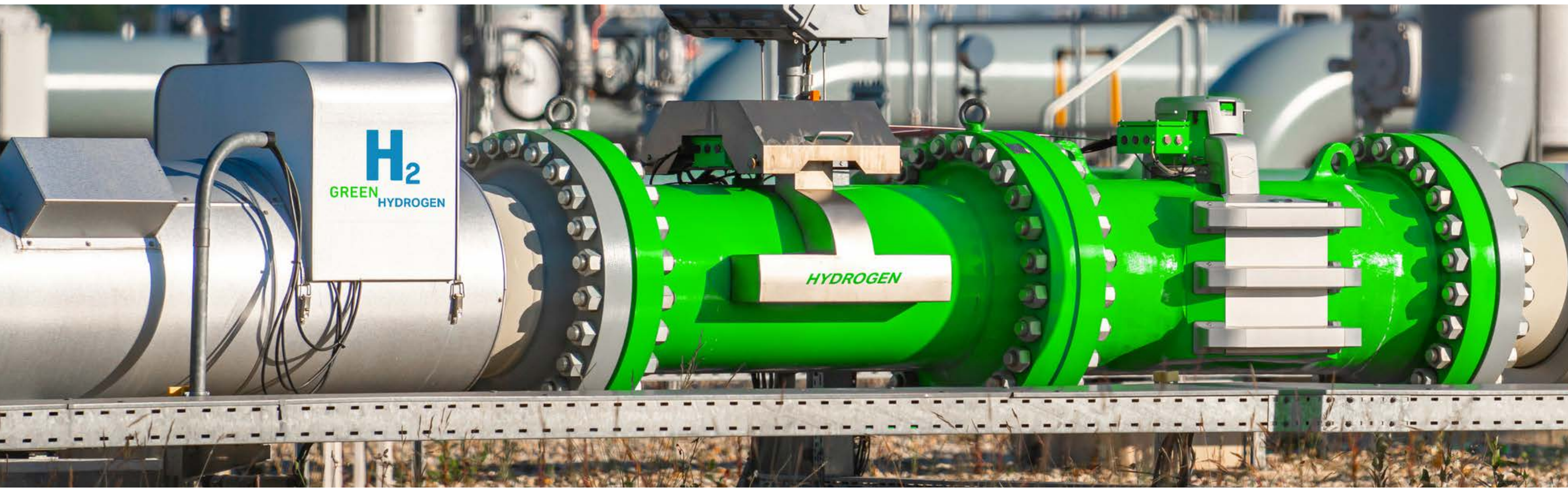
Whilst access to hydrogen transport and storage infrastructure will provide electrolytic hydrogen producers early-stage security of demand, lower production costs and enable the development of a liquid market, these measures are incumbent on the correct policy framework materialising. Electrolytic hydrogen has the potential to deliver a pathway to decarbonisation for dispersed sites irrespective of supportive transport and storage policies, due to only requiring reliable access to water and electricity. Dispersed sites within hard-to-abate sectors such as transport, power, and industry can gain access to low carbon hydrogen, through decentralised electrolytic hydrogen production. Allowing hard-to-reach sites access to low carbon hydrogen, also supports the levelling up agenda, ensuring accessibility to decarbonisation solutions across the country.

The UK is well placed for electrolytic hydrogen.

The UK has a target to deliver up to 10 GW of low carbon hydrogen capacity by 2030 with at least half coming from electrolytic, representing significant growth on current capacities. Reaching this target, therefore, will require cooperation between Government and industry to deliver both private and public investment. Fortunately, the UK is well placed to secure the maximum benefit of electrolytic hydrogen with favourable geography, fantastic centres of innovation, high potential manufacturing hubs, and developed complementary infrastructure combined with strong engineering, wind, and other supporting low-carbon sectors.

Electrolytic hydrogen is more than just a fuel.

Not only will reaching this ambition help to scale up the industry and stimulate demand in other industries, but it will also complement the UK electricity system, with electrolysers operating flexibly to help balance the grid, avoid curtailment costs, and alleviate constraints. Additionally, hydrogen produced using surplus electricity supply can be transported to long duration storage and used in hydrogen-to-power facilities to provide supply side flexibility and back-up capacity to the electricity grid. The Climate Change Committee are confident that hydrogen has a key role in decarbonising the electricity grid by 2035, stressing the necessity of hydrogen transport and infrastructure to enable this. Alongside flexibility benefits and enabling decarbonisation, electrolysers can also maximise their economic benefits and return on capital by operating a dual revenue approach, providing valuable oxygen, which has a global market size of £23.8 billion, as well as hydrogen.



The role of electrolytic hydrogen in Net Zero

Scaling up electrolytic hydrogen production is a fundamental component in reaching the UK 2050 net zero target. The UK Hydrogen Strategy states that by 2050, hydrogen demand will make up 20-35% of the UK's final energy demand (250-460 TWh a year) . When powered through renewables or nuclear, hydrogen may be produced carbon free, most commonly via the process of electrolysis. Hydrogen may then be used to decarbonise emission intensive sectors, especially hard to abate sectors such as heavy transport, heavy industry, and flexible power generation. The use of this electrolytic hydrogen will be essential for the UK to decarbonise in line with mandated targets.

Electrolytic production technologies

Electrolytic hydrogen is produced via the chemical process of electrolysis. This process involves splitting water into hydrogen and oxygen via the use of an electrolyser. An electrolyser consists of a positively charged anode, a negatively charged cathode and an electrolyte in between. To split water and produce hydrogen, electricity must be supplied to the electrolyser. Electrolysers range in size with small, appliance size equipment well suited to small scale distributed hydrogen production and large scale, equipment suited to centralized hydrogen production facilities[5]. There are a variety of electrolyser technologies, each with their own advantages as seen below.

The most common technologies used in the UK are:

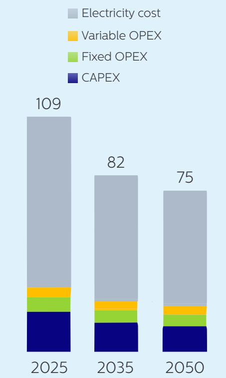
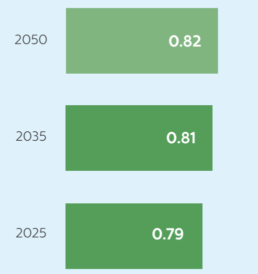
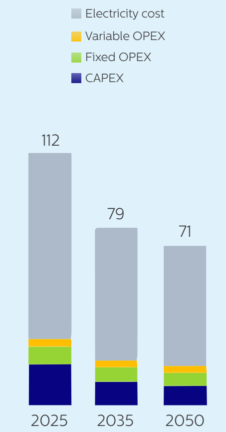
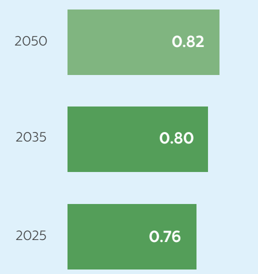
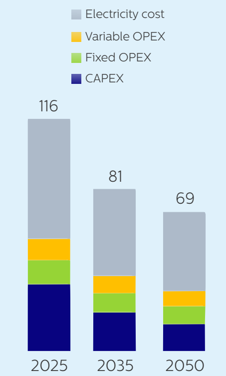
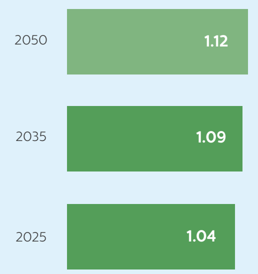
- **Alkaline water electrolysis,**
- **Proton exchange membranes.**

Developing technologies expected to be deployed soon are:

- **Solid oxide electrolysis cells,**
- **Anion exchange membranes.**

These technologies are summarised in **table 1**, using data from the Department of Energy Security and Net Zero Strategy (DESNZ)[10], formerly the Department for Business, Energy, and Industry (BEIS), the United States Department of Energy (DoE), and supplementary information where individually referenced.

Table 1: Summary of electrolyser technologies[7]

Technology	Applications	Degree of Maturity	Cost (£/MWh H_2 (HHV))[8]	Electrical conversion efficiency (kWh H_2 (HHV) / kWh e	Advantages	Disadvantages
Alkaline Water Electrolysis (AWE)	Industrial applications (e.g ammonia, refining, steel, chemicals).	Established technology: commercial technology.			Lowest CAPEX[9], mature technology. Does not require platinum group metal (PGM) catalysts. However, PGM catalysts sometimes used to boost performance[10].	Low current density. Corrosive electrolyte. Less flexible than PEM electrolysers.
Proton Exchange Membrane (PEM)	Diverse use cases, including road transport, refining, ammonia & semi-conductors. Distributed hydrogen production. Grid balancing.	Increasing scale-up; Commercial stage.			Simple cell design and small footprint. High current density Differential pressure operations High dynamic response, suitable for renewables[11].	Scale-up potentially constrained by PGM supply. However, with "thrifting" and closed loop recycling systems, the requirement for catalysts can be reduced four-fold[12]. Less demonstration of long-term durability vs AWE.
Solid Oxide Electrolysis Cell (SOEC)	Low purity industrial use cases. Co-location with high temperature steam.	Laboratory / early commercial stage.			Low electricity demand using steam (high efficiency). Does not always require PGM catalysts. Can use other catalyst types[13].	Heat/steam source required. Limited dynamic response. Durability challenges with high-temperature operations.

Powering electrolysis

The electricity used in electrolytic hydrogen production can come from a range of sources. Electrolytic hydrogen produced using renewable sources such as solar and wind is commonly referred to as green hydrogen. Many of the projects in the immediate pipeline have indicated that they will be using renewables as their source of electricity, as shown by **figure 12**. Projects can access renewable power either through a direct wire connection to the renewable generator or through a power purchase agreement (PPA). PPAs can be structured in many ways but generally, they provide assurance that the electricity consumed by the electrolyser has an agreed share of renewable content.

Electrolytic hydrogen is an effective consumer of renewable power because electrolysers can operate flexibly, especially PEM electrolysers, ramping up and down production in response to external signals. This is useful as renewables produce electricity intermittently, for example, solar power only generates electricity when the sun is shining. Therefore, electrolysers can ramp up production in line with when renewables are generating sufficient electricity. The benefits of flexible production are explored within the next section of this report. Additionally, by using renewable electricity sources, hydrogen can be produced with no associated carbon emissions. Electrolytic hydrogen can also use electricity directly from the grid, however, as shown in **figure 11**, the current carbon intensity of the electricity grid does not allow projects to reach sufficiently high load factors whilst meeting the requirements to be classified as low carbon hydrogen. **Figure 1** shows the split of hydrogen production capacity by technology in National Grid's System Transformation scenario[12].

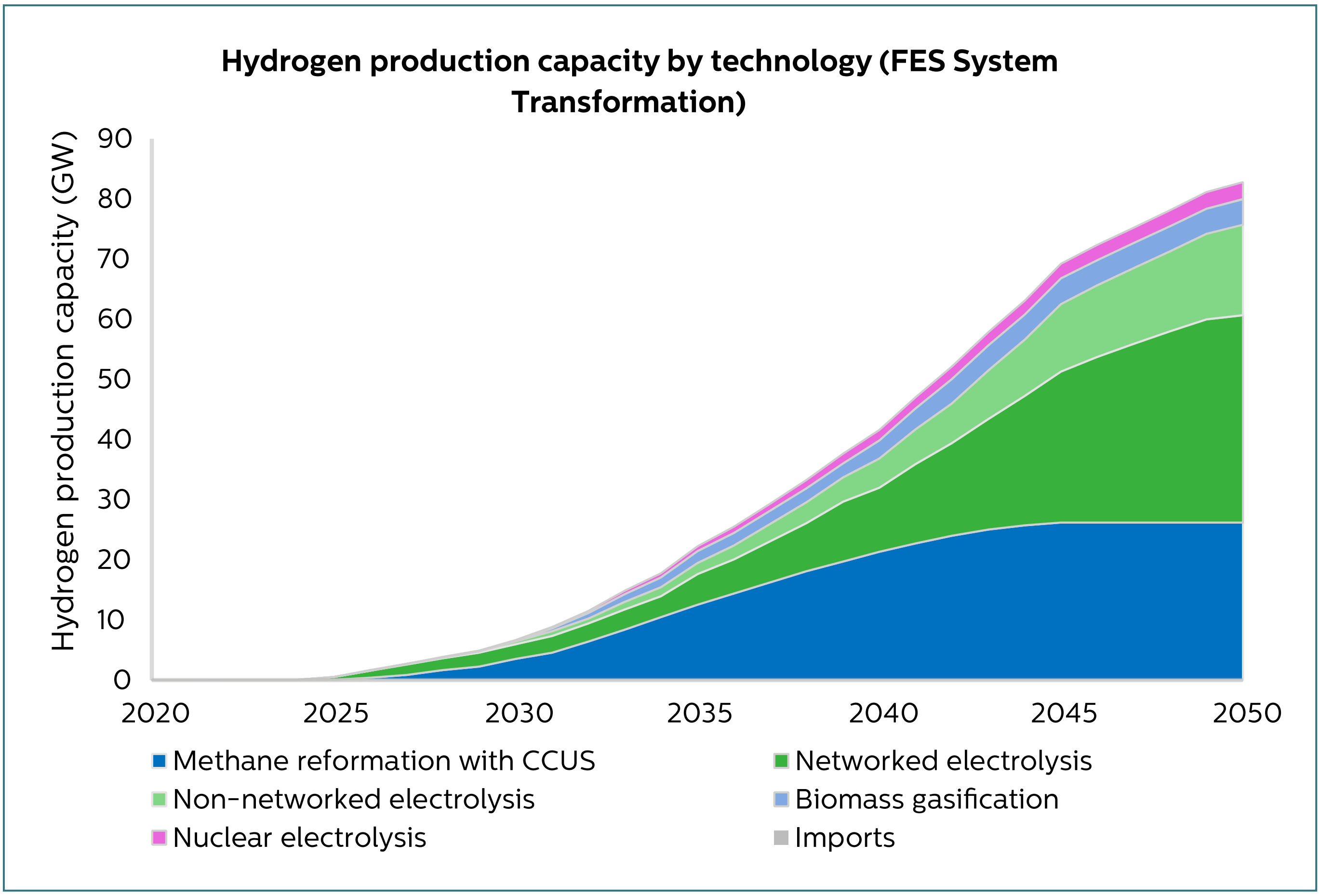


Figure 1: Hydrogen production capacity by technology (FES System Transformation)[12]

However, there is also the potential for low carbon heat, in the form of steam, from nuclear energy to support electrolysis processes. It is worth noting that the National Grid's Future Energy Scenarios include low temperature electrolysis only, hence no thermochemical or steam-driven production is displayed in **figure 1**. The steam from nuclear power can be used in electrolysis at a variety of temperatures. Relatively low temperature steam from existing nuclear reactor designs can be used within currently available solid oxide electrolysers to improve the efficiency of hydrogen production.

In addition to nuclear electrolysis technologies that are currently commercially available, there are also longer-term options which involve new nuclear reactor designs and the use of much higher temperature steam. These technologies have the potential to deliver significantly higher hydrogen production efficiencies, lowering the levelised cost of hydrogen and any potential strain on the electricity grid. These options are detailed below, although, it should be noted that due to the low maturity of these technologies, there is greater uncertainty around the future whole system performances:

1. **High-temperature steam electrolysis** – Heat and electricity from nuclear reactors is used in electrolysis at temperatures up to 1000°C. Heat from nuclear energy used in this process can either be used directly or upgraded using heat exchangers. This process provides higher thermal efficiency and potentially lower production cost than water electrolysis, due to requiring about 35% less electricity, per unit of hydrogen produced, with an overall thermal efficiency of around 50%.

2. **High-temperature thermochemical production** – Nuclear heat, at temperatures up to 1000°C, and a small amount of nuclear electricity is used to produce hydrogen with estimated thermal efficiencies of 40-55%. Several thermochemical processes are currently being considered including sulphur-iodine cycle, hybrid sulphur cycle, and copper chlorine cycle. It is worth noting that this production method is not strictly electrolytic.

The case for electrolytic hydrogen production in the UK

A combination of geographical, infrastructural, and economic factors not only make the UK a favourable place for a comprehensive delivery of electrolytic hydrogen production but show the necessity of the technology in reaching net zero.

Taking advantage of the UK's favourable geography

The UK has access to a large amount of coastline adjacent to shallow seas and high-speed wind, enabling the widespread deployment of offshore wind. **Figure 2** demonstrates this geographical asset with wind speeds in the UK generally being higher than surrounding regions[15]. Wind, as a renewable generating asset, is intermittent meaning that electrical generation occurs in varying periods of high and low output. The UK's electrical demand profile is also intermittent and when the renewable generation exceeds the peak demand, curtailment occurs. Curtailment refers to the process by which renewable operators are paid to turn off their renewable generation assets, which leads to the waste of electricity which could have been productively used.

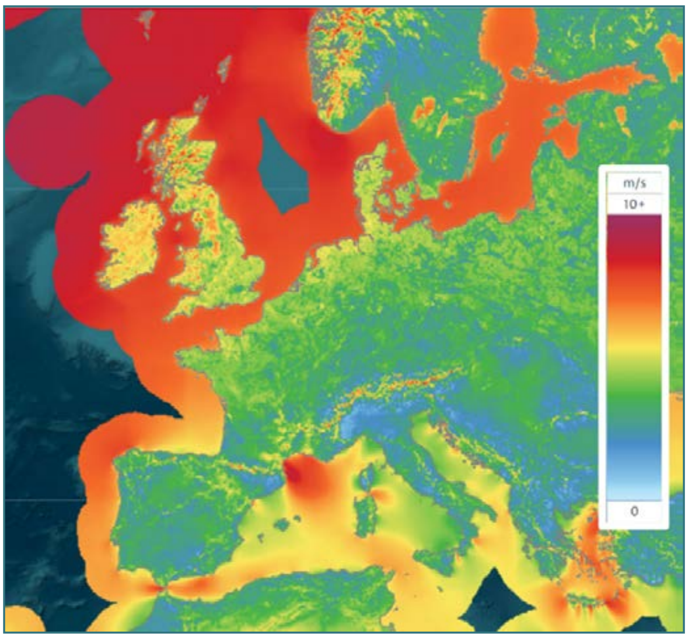


Figure 2: Mean wind speed across the UK and Europe (m/s)

In April 2022, DESNZ published the 'British Energy Security Strategy', which highlighted the plan to increase offshore wind production to 50 GW by 2030[16] . Similarly, in 2020 the Scottish Government also increased their offshore wind ambition to 11GW by 2030[17]. However, more recently, Scottish offshore wind ambition has far surpassed this with around 30 GW of seabed leasing agreements given to offshore wind projects in Scotland through ScotWind[18].

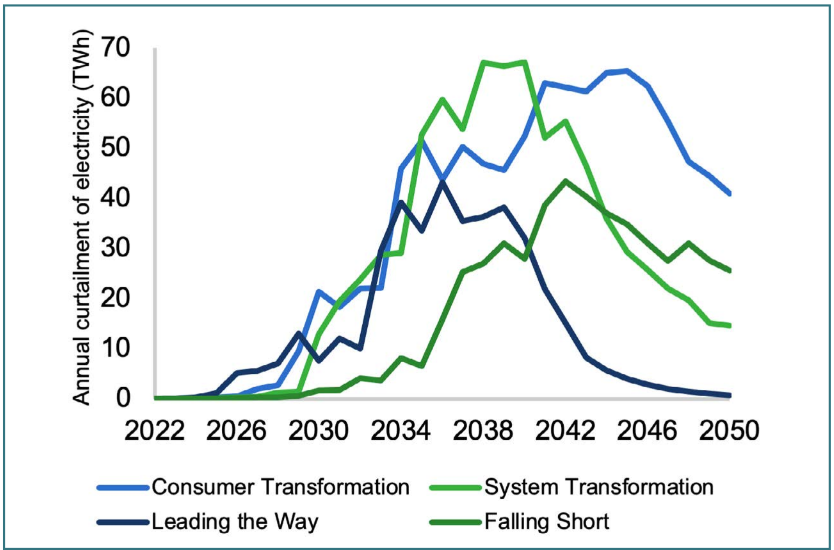


Figure 3: Predicted Annual Curtailment of Electricity

In 2021, 2.3 TWh of power from wind farms was curtailed, resulting in curtailment costs of £200 million in November alone[19]. With increased deployment of intermittent, renewable power, more demand side response will be required to avoid curtailment costs and balance the grid. According to National Grid's System Transformation (ST) scenario, in 2035 there could be 53TWh of curtailed electricity, equivalent to 14% of total wind and solar generation[20]. This is shown in **Figure 3**.

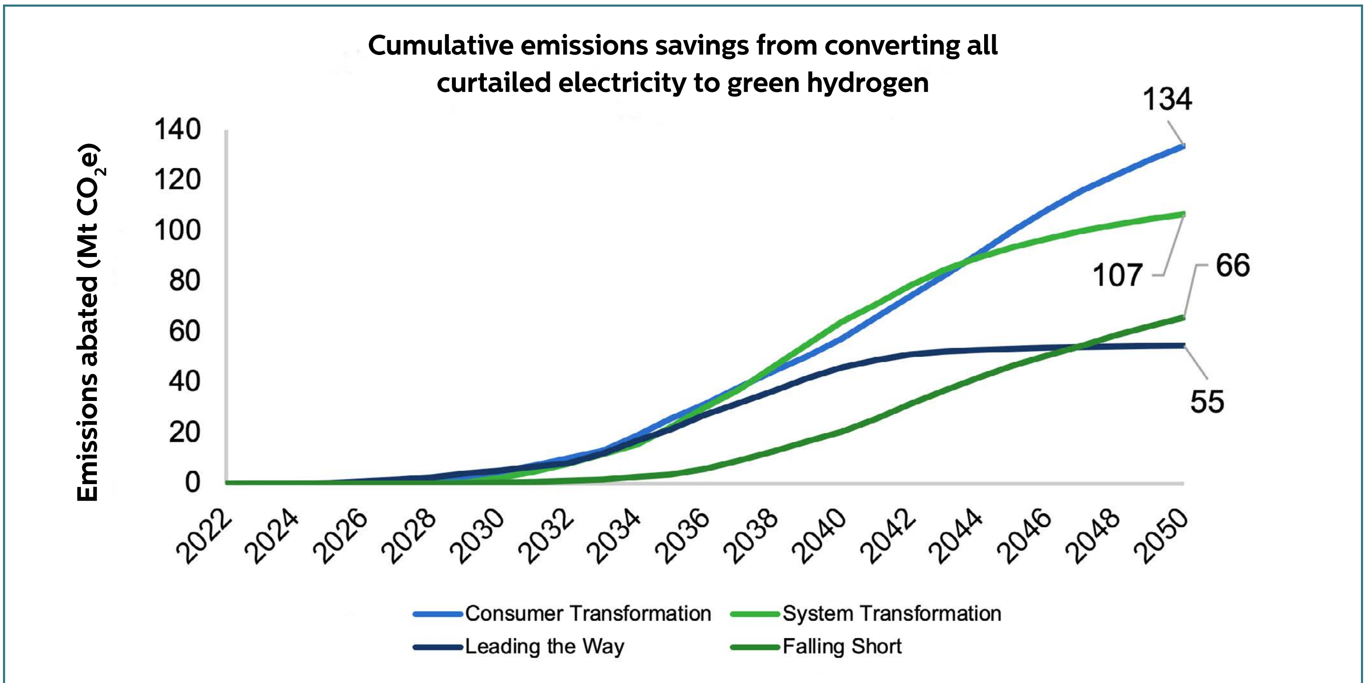


Figure 4: Cumulative emissions savings from converting all curtailed electricity to green hydrogen[21]

Producing electrolytic hydrogen can help alleviate the need for curtailment due to the ability of electrolysers to ramp production up and down quickly. The ability of different technologies to operate flexibly varies, with technologies such as PEM electrolysers especially effective in ramping production up and down. This means they can be placed in areas of potential constraints to soak up excess generation, avoiding lost power and curtailment costs whilst producing a versatile and low-carbon fuel suitable for long duration storage. Curtailed electricity and low-cost dedicated renewable energy will allow the production of low-cost, zero carbon hydrogen. **Figure 4** demonstrates the cumulative emission saved from converting all curtailed electricity to electrolytic hydrogen.

Assuming all curtailed electricity in National Grid's Consumer Transformation scenario is instead used to make green hydrogen to displace natural gas, by 2050, 134 $MtCO_2e$ in cumulative emissions could be abated. That's nearly as high as the annual emissions released in the Netherlands and more than the annual emissions released in Nigeria[22]. Under the System Transformation scenario, nearly 9 Mt CO_2e could be avoided in 2040 alone, the equivalent of taking nearly 5.3 million cars off the road[23].

The UK's favourable geography also includes hydrogen storage assets. The UK has a relative abundance of salt caverns, suitable for the development of large-scale hydrogen storage facilities, with up to 9TWh of potential hydrogen storage capacity in them[24]. Offshore gas fields and salt basins can also be used to store large amounts of hydrogen over long durations. **Figure 5** shows potential offshore hydrogen storage locations in the UK, showing the abundance of storage potential, especially near the Humber and North West industrial clusters[25]. There is also potential for storing hydrogen onshore, both in natural below ground sites and small-scale above ground storage.

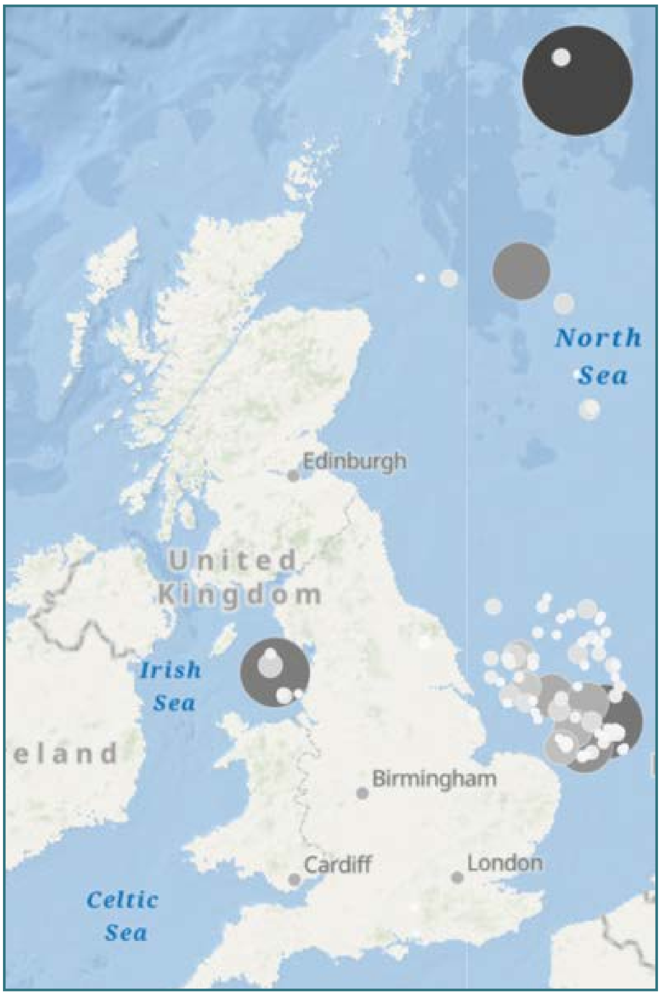


Figure 5: Location of potential offshore hydrogen storage sites sized by potential by capacity[24]

Hydrogen storage is a key enabler for electrolytic hydrogen as it can smooth the output of electrolysers operating with variable renewable electricity supply. Instead of curtailing electricity, we could turn it into low-cost hydrogen, store it and use it to help meet electricity demand during times of low wind output, alongside decarbonising industry, and heavy transport. According to DESNZ levelised cost of hydrogen estimates, by 2025, hydrogen produced using curtailed electricity with a PEM electrolyser will be 67% lower cost than hydrogen produced using grid electricity and 30% lower cost than hydrogen produced using dedicated offshore wind[26]

The intermittent supply of curtailed electricity could also be smoothed through the use of co-located batteries, maximising the load factor an electrolyser can operate at whilst consuming curtailed electricity. Although electrolysers can operate flexibly, smoothing the electricity supply can avoid oversizing of the plant so that the load factor and return on investment is maximised. It should also be noted that after considering engineering challenges of ramping up and down production to match curtailment, different electrolyser types may be more suited to providing grid flexibility benefits.

Electrolytic hydrogen is the perfect technology to complement the increased deployment of renewables. The development of hydrogen transport and storage infrastructure can enable surplus renewable energy to be used to produce hydrogen which can be stored and then used in hydrogen-to-power facilities when the wind is not blowing, and the sun is not shining. Flexible hydrogen from storage will enable important dispatchable power production, a key requirement for decarbonising the electricity grid by 2035.

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Matching supply and demand outside clusters

The UK is home to industrial cluster sites, or 'clusters' defined as areas of intensive industrial activity. CCUS-enabled hydrogen production will play a critical role in helping decarbonise these areas by providing a low carbon feedstock and fuel. 53% of the UK's industrial emissions emanate from six coastal industrial clusters, meaning that 47% are emitted outside of these defined locations[27]. As transport and storage infrastructure, needed to distribute this CCUS-enabled produced hydrogen to outside the cluster sites, is unlikely to be available before 2030, decentralised hydrogen production will be needed to provide a pathway for these dispersed sites outside of clusters to decarbonise.

Electrolytic hydrogen production will provide a route to decarbonisation for these dispersed industrial activities, resulting in greater decarbonisation of industry at an earlier date. **Figure 6** displays the diverse spread of electrolytic projects within the UK. As shown in **figure 7**, a recent survey of industrial sites showed that hydrogen is seen as the most cost-effective decarbonisation solution within many industries, demonstrating the importance of allowing all industrial users access to low-carbon hydrogen.

Figure 6: Electrolytic Projects within the UK (Hydrogen UK)

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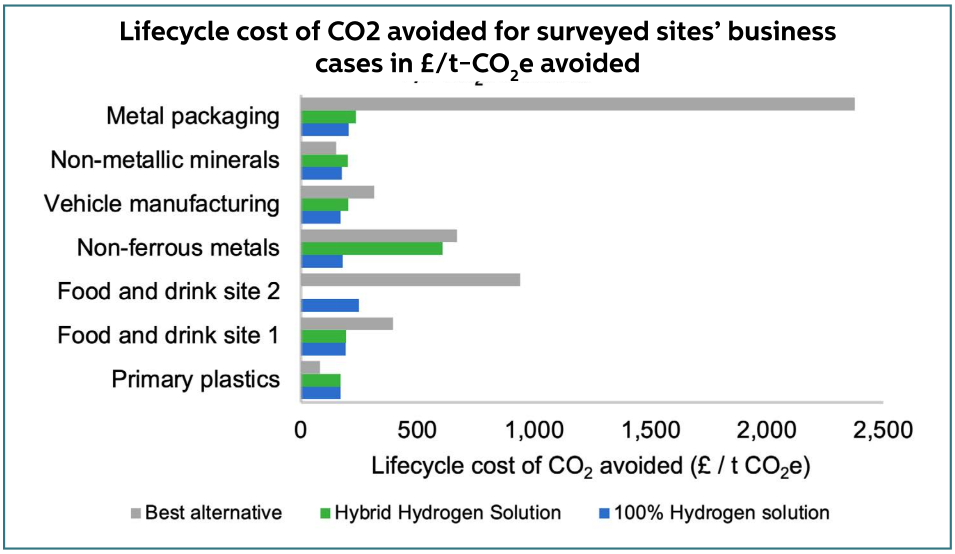

Figure 7: Lifecycle cost of CO_2 avoided for surveyed sites' business cases in £/t-CO_2e avoided[28]

Although, electrolytic hydrogen is suitable for small and large offtakers, the hydrogen production capacities of electrolysers can especially suit the demand for certain end use applications. Appropriate sizing and location of electrolytic projects can ensure a hydrogen supply that meets the demand profile of the offtaker, lowering the risk profile of the site. For example, the various hydrogen demands for Hydrogen Refuelling Stations (HRS) are well matched to production capacities of electrolysers – both currently available and available in the next few years. Using the Tyseley hydrogen refuelling station as an example; a 3MW PEM electrolyser produces enough fuel to fill up 40 buses a day[29]. Whilst the transportation of CCUS-enabled hydrogen from cluster sites will play an essential role in certain decarbonisation applications, there are others which are better suited to the supply capacities of electrolysers, which therefore does not require the extensive pipeline network to be constructed.

Utilising the UK's existing infrastructure

Security of demand is an increasingly prevalent challenge for early-stage electrolytic hydrogen producers. Although electrolytic hydrogen has the potential to reach dispersed sites without the need for large scale transport infrastructure, to further develop a resilient supply of hydrogen, access to large-scale storage and a 100% hydrogen network will be required. Often, the best place to produce electrolytic hydrogen is where there is access to lower cost renewable power. Commonly, these areas do not coincide with areas of high industrial output and so hydrogen transport infrastructure allows for supply to reach demand whilst maximising the use of curtailed renewables.

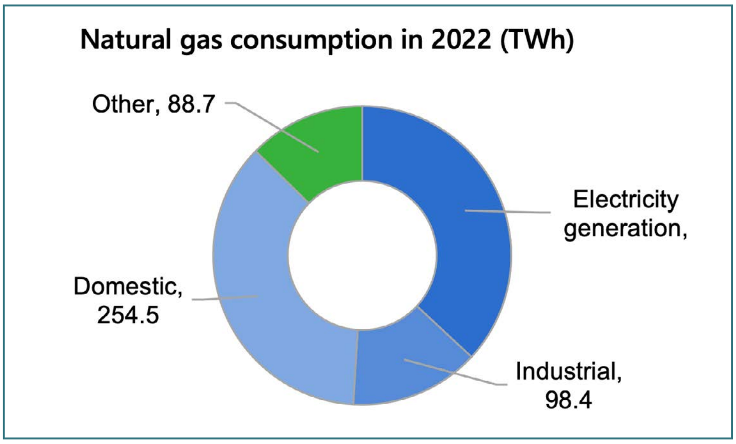

Figure 8: Natural gas consumption in 2022 (TWh)

The UK gas grid also carries the potential to provide secure hydrogen demand via hydrogen blending, and therefore could provide confidence that produced hydrogen will be bought. This would enable developers to over size capacity ahead of additional hydrogen demand coming online. 284,000 km of gas network infrastructure[30] delivering 900TWh of energy every year[31] makes up Great Britain's world leading gas network. Extensively connected, with over 85% of homes connected, domestic demand accounts for just over a third of total gas demand, with industry and power generation accounting for the other two thirds, as shown by **figure 8**[32] . Pilot projects within the UK such as HyDeploy have provided firm evidence that a hydrogen blend of up to 20% by volume can be used in existing pipelines and appliances with little disruption.

Blending will most likely be used as an offtake of last resort, thus not be utilised to the 20% blend. Hydrogen could be blended into the gas network at a lower percentage providing a buffer for excess hydrogen to be supplied to the existing gas grid in the surplus supply. Additionally, as well as insuring investors against demand side risk, blending would reduce the emissions intensity of gas in existing networks.

Further benefits include providing confidence to producers that if offtakers could no longer accept hydrogen in unique circumstances, there would still be a reserve offtaker for their hydrogen – this could be caused by the switching of equipment or unplanned maintenance. Hydrogen blending would also further enable the flexible production of hydrogen to benefit the grid. Electrolysers could ramp up production to alleviate grid constraints and utilise curtailed electricity whilst having confidence in demand for any intermittently produced hydrogen. Blending hydrogen into the gas distribution network at a low percentage also increases the investment case and reduce costs of early production projects, especially before large-scale storage is available. Increasing production and availability is also likely to reduce the levelised cost of hydrogen within the UK, increasing overall investment potential and increase the number of interested offtakers. National Gas recently included a 5% blend at their FutureGrid project site demonstrating appetite for this solution.

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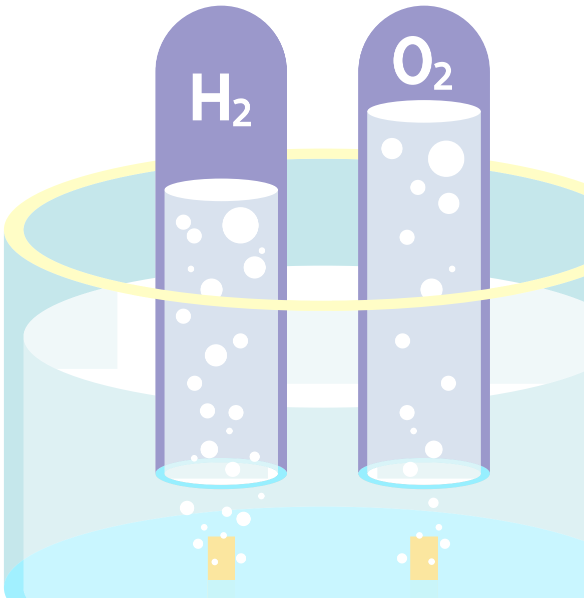
Complementing the UK's nuclear ambition

Nuclear enabled hydrogen production offers a range of benefits and could play an integral role in the future hydrogen system. As expected, operational dates for advanced nuclear enabled electrolytic production are later than for conventional renewable derived hydrogen, although low temperature electrolysis, or production of traditional electrolytic hydrogen, using existing nuclear power is also currently a commercially available production route. Therefore, the government must start planning for past the 2030s to ensure the potential of nuclear enabled hydrogen is realised and the roll out of production is not constrained. Nuclear technology provides 24/7 heat and power whilst also providing the potential for high efficiency hydrogen production, with the option for the development of future technologies in a very small land area, harnessing the high power density nuclear provides. Technologies using nuclear power and heat are available now using current reactors, however, there are also advanced nuclear electrolytic production methods which will utilise future reactors and rely on developing technologies.

The nuclear sector carries cross party support with strong nuclear ambitions written in top level policy. The Nuclear Industry Association's (NIA) Hydrogen Roadmap states that 12-13 GW of dedicated nuclear capacity could produce 75 TWh of hydrogen per year by 2050, a third of the lower bound 2050 aim[33]. This generation could complement intermittent renewables, providing baseload capacity at low operating costs which are relatively stable compared to those of fossil fuel generation sources. This would help insulate UK energy prices from international market fluctuations, which as demonstrated by recent wholesale gas price volatility, is crucial to the UK's energy security. In the British Energy Security Strategy, DESNZ increased the UK's nuclear production ambition to 24 GW by 2050, 3 times our current capacity[34]. It should be noted that this 24 GW aim is an electrical capacity ambition only, indicating the need for a set nuclear capacity ambition dedicated to hydrogen production alone. As with renewables, nuclear capacity could also be used for hydrogen production in times of excess generation on the electricity grid. The government have committed to investing over £2 billion and ensuring one final investment decision (FID) on new nuclear projects this Parliament and 2 FIDs in the next parliament.

The integration of nuclear enabled hydrogen production will complement renewable roll out, ensuring a resilient whole system model. The 24/7 supply profile of nuclear provides certainty of output and revenue, alleviating pressure on storage and thus providing net energy system benefits. The combination of hydrogen and nuclear can add flexibility to the future GB energy system, with more nuclear energy being used to support hydrogen production at times of high renewables output and nuclear output switching to meet core national electricity demand at times of lower renewables output. Whereas hydrogen produced via electrolysis of offshore wind power may be suitable for many locations, inland production of electrolytic hydrogen may suit nuclear power. Overall, there is potential that a tandem nuclear and hydrogen approach could improve grid stability and reduce overall system costs whilst providing a diverse suite of generative technologies consistent with the push for energy security.



UK production outlook

Policy and funding landscape

The UK has created a strong framework for private investment to match the ambitions of government. Enshrining Net Zero in law, committing to decarbonise the electricity system by 2035, publishing the Hydrogen Strategy and then increasing the ambition for low carbon hydrogen production to up to 10 GW by 2030, with at least half coming from electrolytic, alongside funding support mechanisms released by the government, all provide strong signals for developers to invest in hydrogen in the UK.

Hydrogen Production Business Model (HPBM) and Net Zero Hydrogen Fund (NZHF)

The Hydrogen Production Business Model (HPBM) is a contractual business model offering ongoing revenue support for hydrogen producers whilst the Net Zero Hydrogen Fund (NZHF) will deliver up to £240 million of grant funding, available until 2025, to assist with upfront costs of developing low-carbon hydrogen production projects[35]. The government's Contracts for Difference (CfD) scheme for low-carbon electricity generation is widely regarded as a success story, demonstrating the ability for new technologies to reduce their costs significantly with the right market framework. The price of offshore wind has reduced drastically since the first auction, and producers are now agreeing to contracts setting the price at £47/MWh, a 67% decrease compared to 2017[36]. However, the UK risks repeating the same mistakes demonstrated through the renewable CfD scheme, where high value industries within the wind and solar supply chains concentrated sourcing of components outside of the UK, due to inadequate, initial support into facilitating domestic supply chains. If the UK government focus efforts solely on bolstering domestic hydrogen production and not fostering key parts of the supply chain, such as electrolyser manufacture, a similar missed opportunity could occur. Learning from the shortfalls of comparable sectors, it's worth noting that a more balanced approach may stimulate greater domestic economic benefits and ultimately, lower production costs in the medium term. The consequence of a lack of proactive measures to develop a domestic supply chain was recently demonstrated in the offshore wind industry, where supply chain pressures combined with high inflation and interest rates resulted in zero bids from offshore wind projects in the fifth CfD auction round.

The proposed support for electrolytic hydrogen via the HPBM is expected to realise similar cost reductions to those witnessed in the offshore wind sector, especially when combined with access to low-cost renewable electricity which forms the largest contribution to the levelised cost of production. DESNZ estimates suggest that 73% of the levelised cost of hydrogen produced via a PEM electrolyser with dedicated offshore wind supply will be from electricity costs[37].

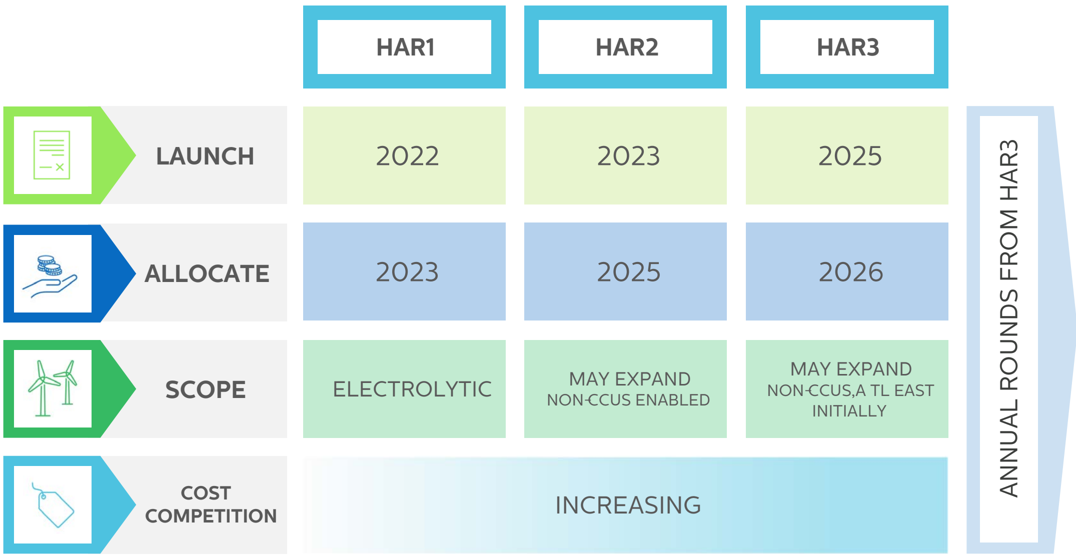


Figure 10: A potential evolution from HAR1[42]

In March 2023, 20 projects were shortlisted to receive funding through the HPBM/NZHF under the first Hydrogen Allocation Round. These 20 projects had a combined capacity of 408 MW[38]. In August 2023 however, three projects pulled out of negotiation leaving the remaining projects at 17, with a combined capacity of 262 MW. In the same month, Government published the Low Carbon Hydrogen Agreement, laying out the groundwork for contractual agreements to be made with electrolytic projects receiving funding under the Hydrogen Production Business Models[40]. The second Hydrogen Allocation Round is expected to be launched in the fourth quarter of 2023, intending to award contracts to 750 MW of electrolytic projects by the first quarter of 2025, bringing the total capacity of funded projects to 1GW. After the second allocation round, Government intends to move to a price based competitive allocation mechanism for funding electrolytic projects, whereby projects compete solely or primarily on price in annual allocation rounds [41]. This model will be similar to the current scheme used for offshore wind, with the future intention that competition in the market can drive down production costs.

The Renewable Transport Fuel Obligation (RTFO)

The RTFO encourages the use of renewable fuels by placing an obligation on suppliers of relevant fuels to be able to show that a percentage of the fuel that they supply comes from renewable or sustainable sources[43]. Electrolytic hydrogen meets the criteria to be an eligible fuel under the RTFO and therefore, fuel suppliers can meet their obligation by purchasing hydrogen produced via electrolysis[44]. Producers can also access support through both the RTFO and the HPBM if the produced hydrogen is going to a transport offtaker, however, they cannot claim support for the same volumes of hydrogen under both schemes. Despite this, volumes of hydrogen claimed through the RTFO have been very low with 163 MWh claimed in 2022, although, this is a large increase on 2021, where only 14 MWh were claimed[45]. Under the current drafting of the Energy Security Bill, it is proposed that nuclear derived fuels also be made eligible for support under the RTFO. This is a positive step as this will increase the incentive to produce electrolytic hydrogen using nuclear power, and potentially nuclear heat, encouraging future nuclear capacity[46].

Low Carbon Hydrogen Standard (LCHS)

The Low Carbon Hydrogen Standard (LCHS), released in April this year with a version 3 update expected this summer, is a standard that sets out in detail the methodology for determining the emissions associated with hydrogen production, and the maximum allowed intensity which will allow access to government support schemes. These mechanisms put in place within the UK have and will result in quality hydrogen being produced, which is monitored, regulated, and trusted, fostering long term resilience in the UK electrolytic hydrogen production market.

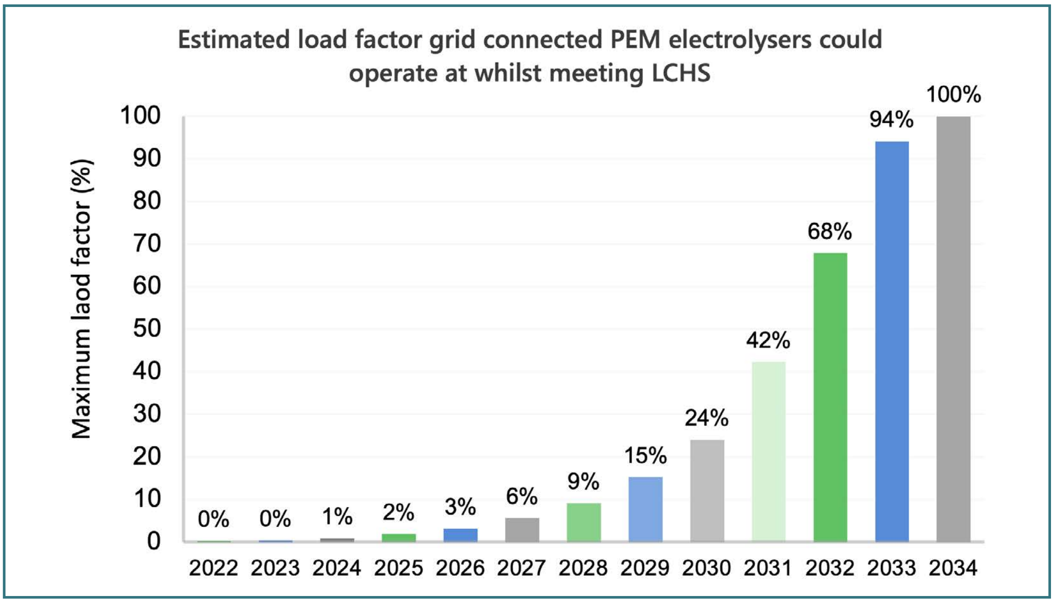


Figure 11: Estimated load factor grid connected electrolysers could operate at whilst meeting LCHS[47].

The emissions standards laid in the LCHS mean that, in the short term, for electrolytic projects to operate at profitable load factors, they will have to procure electricity from dedicated renewables or nuclear power, via a PPA, or provide evidence that they are using electricity that would have otherwise been curtailed. Hydrogen UK analysis shows that only by 2034, electrolysers could operate at a load factor of 100% whilst using electricity straight from the grid and still meeting the LCHS **(figure 11)**. However, it is also worth noting that although this would be possible on a carbon intensity basis, commercially speaking, electrolysers will likely operate at lower load factors, using electricity when prices are lower, and the electricity is not produced via heat-to-power.

Energy Bill

However, the rate at which investment is made, and the supply chains develop, hinges on the swift passage of the Energy Bill. Investor confidence is crucial, and the certainty afforded by the long-term commitment to the HPBM is needed to ensure that capital is invested in the UK and not in other regions that are attempting to overtake the UK's lead in creating the right market conditions for electrolytic hydrogen to flourish.

Supply side policies

The success of the electrolytic sector is evidently reliant on ensuring reliable access to low-cost, low-carbon electricity supply for electrolytic projects. Therefore, policy that influences the future of low carbon electricity generation will indirectly influence the rollout of electrolytic hydrogen. As discussed in the "Complementing the UK's nuclear ambition" section, nuclear enabled hydrogen offers a secure and promising route of producing hydrogen and therefore, investment into new nuclear assets will help support electrolytic hydrogen.

The ongoing Review of Electricity Market Arrangements (REMA)[48] is also likely to impact the investment case for electrolytic projects. The review is focused on improving price signalling in the energy market to encourage flexibility, decarbonisation, and energy security. Under one of the possible changes, transitioning to nodal or zonal pricing could lead to lower cost wholesale electricity prices in areas of surplus electricity supply, incentivising electrolytic projects to situate in areas of constraints and therefore offering grid balancing and flexibility benefits. However, pricing in this manner would have to be considered alongside other impacts on the electricity system and generation investment as well as the need to protect consumers from unfair exposure to higher-cost energy. Other proposed changes to support grid balancing, promote auxiliary system benefits, support mass rollout of low carbon generation, and pay-as-you-bid wholesale markets could also influence the way electrolytic projects interact with the electricity grid as well as the availability and cost of low carbon generation.

The Capacity Market is a government support mechanism, set up with the aim of supporting active demand management and ensuring the system has reliable generating capacity[49]. Reforms to the Capacity Market[50] could set carbon-based conditions on access to the Capacity Market, helping the grid to decarbonise and displacing unabated gas and coal generation. A lower electricity grid carbon intensity will allow grid connected electrolytic projects to be deployed on mass.

Changes to the CfD scheme for renewable energy will also influence electrolytic projects[51]. A range of options for reform of support for low carbon generation are under consideration, including potential changes to the CfD or moves to a revenue cap and floor mechanism. Government has also been considering the addition of non-price factors into the CfD evaluation criteria. Changes to these mechanisms could impact on electrolyser location and economics in a variety of ways, including the extent to which electrolytic projects may be incentivised to locate in new areas or co-locate with new wind and solar capacity.

The buildout of renewables has the potential to lower the cost of electricity, especially to electricity consumers that are able to operate flexibly to benefit the grid, such as electrolysers. Therefore, it is evident that the generation mix of the future will be a key enabler in driving down the levelised cost of hydrogen and driving scale. According to Hydrogen UK's project database, 82% of electrolytic projects in the current pipeline will rely on either wind, solar or both for their electricity supply, as shown in **figure 12**.

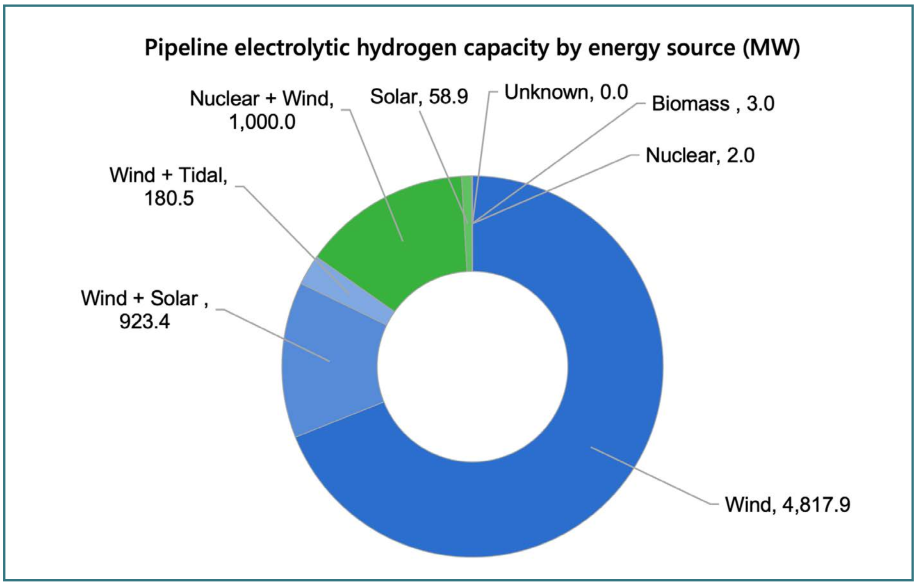


Figure 12: Pipeline electrolytic hydrogen capacity by energy source (MW) (Hydrogen UK project database)

Demand side policies

Whereas there are established supply side policies to enable the production of hydrogen, demand side policy is a less developed area. Demand side policy for hydrogen is currently aimed at incentivising decarbonisation via carbon taxing and regulation, and subsidising production such that hydrogen can be delivered to the consumer at a price near to that of the clearest counterfactual fuel, natural gas. Generally, however, this strategy for supporting demand does not go far enough and may not encourage offtakers to take on the potentially risky and costly process of fuel switching.

In the power sector, demand for electrolytic-produced hydrogen could be supported through the previously discussed Capacity Market. Additionally, under the options presented in the Review of Electricity Market Arrangements, the Capacity Market could give stronger support for low carbon capacity, either through separate clearing prices or separate auctions. This could also raise demand for low carbon hydrogen. Hydrogen power facilities could also be funded via a separate hydrogen-to-power business model. Hydrogen-to-power facilities could offer vital peaking electricity capacity in a decarbonised grid and therefore, placing emissions regulations on generators in the capacity market could encourage the construction of new hydrogen-to-power facilities or the conversion of gas CCGT sites to using hydrogen as a fuel, incentivising demand for hydrogen.

Currently, the main demand side policy for hydrogen in industrial and power applications is the UK Emissions Trading System (ETS). The ETS works on the "cap and trade" principle, with a cap placed on the total amount of emissions that can be emitted by scheme participants and participants able to trade credits to offset any emissions produced over their allowance.

As adopting low-carbon hydrogen would lower the emissions of an industrial site, there is incentive to adopt hydrogen as a fuel as it would allow industrial operators to either sell excess emissions credits or to not be forced to purchase credits. However, it is widely thought that ETS prices are too low and too volatile, as shown by **Figure 13**, to give sufficient incentive for industrial operators to switch fuels – a process which can involve significant capital expenditure and lost revenue from downtime. The UK ETS price has also fallen substantially over the past year, substantially reducing the incentive on operators to reduce carbon emissions. Reforms to the UK ETS, or linkage with the EU ETS, are required to deliver a stronger carbon price which is properly reflective of the costs of carbon emissions. A carbon CfD could also be considered, whereby Government subsidises the carbon price received by industrial operators up to a strike price which is seen as sufficient to incentivise decarbonisation efforts. It is also worth noting that electricity generators are also subject to the UK ETS, providing additional incentive for power facilities to switch to hydrogen as a fuel.

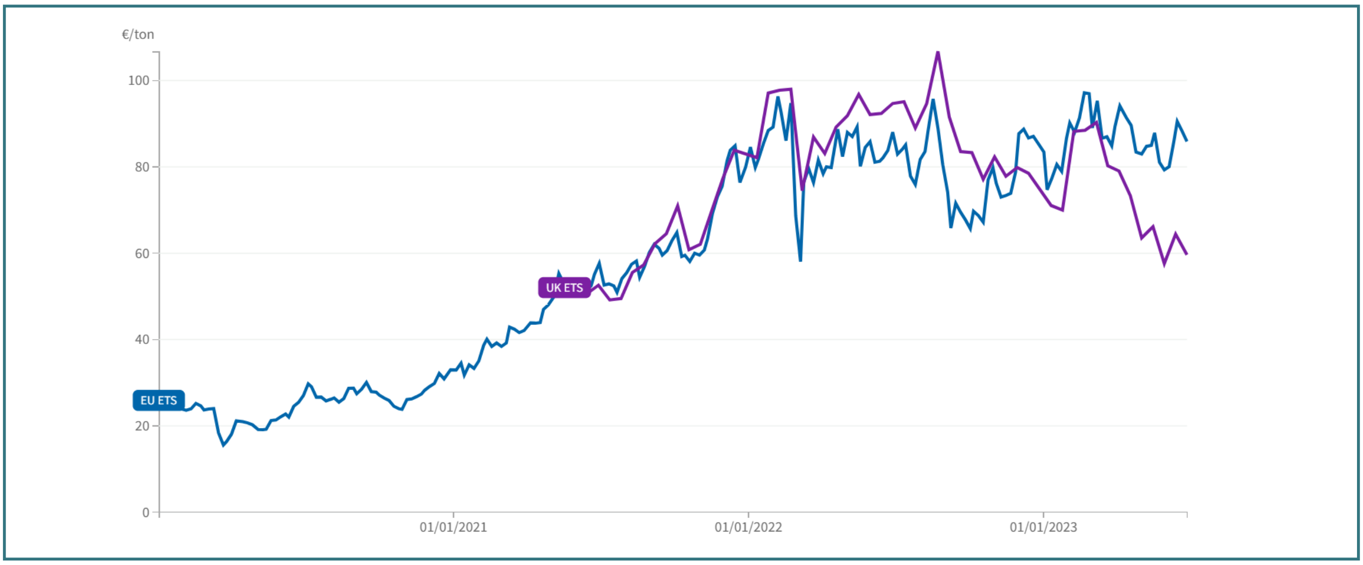


Figure 13: Price of emissions allowances under the UK and EU ETS (€/tonne CO_2e)[52]

Within the transport sector, externally to the Renewable Transport Fuel Obligation, Government is considering a mandate on the use of sustainable aviation fuels (SAF)[53]. Sustainable aviation fuel can be produced from a range of sustainable feedstocks, including biomass, waste, and low-carbon hydrogen. Due to potential constraints in the supply of biogenic waste and other biogenic feedstocks, hydrogen has a huge potential role in meeting the demand for sustainable aviation fuels. Processes such as hydrosaturation and hydrocracking can be used to produce hydrogen derived aviation fuels, such as renewable ammonia. Under the SAF mandate, aviation fuel suppliers will need to ensure that a certain share of the fuels they supply are sustainable, increasing demand for low carbon hydrogen as a means to meet this obligation.

The UK in the global hydrogen market

The policies discussed above are a starting point for kickstarting the UK electrolytic economy. There is no denying that the UK has made significant movements towards developing a market for electrolytic hydrogen in the last five years, however, the rest of the world too, has become evidently aware of the energy transition as a new economic reality. The race, therefore, is on, and ensuring that private investment is made in the UK will require action to make the UK a competitive and attractive market for electrolytic projects.

In the United States, the Inflation Reduction Act (IRA) has provided a compelling draw for substantial investment into low carbon technologies. The Inflation Reduction Act will use tax credits to subsidise electrolytic producers with increased support for projects with lower carbon intensities. Projects can either receive subsidies towards a share of capital expenditure or per unit of hydrogen produced. For example, a project producing hydrogen at 2 kg CO_2e/kg H_2 could receive 6% of their capital expenses as a tax credit or $0.60 /kg H_2[54]. In total, the Inflation Reduction Act provides $370 billion in climate funding and also includes funding for hydrogen fuel cell vehicles as well as other parts of the hydrogen supply chain[55].

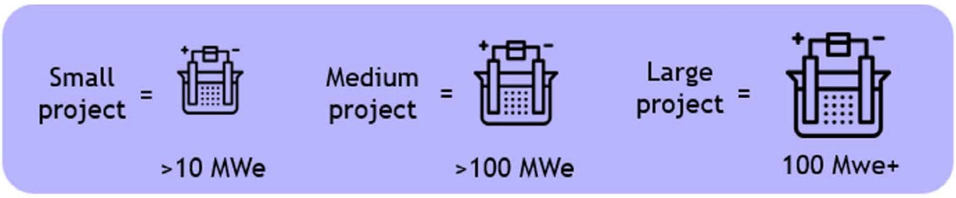
This is an excellent development for the global hydrogen industry, however, there is concern amongst the UK electrolytic hydrogen industry that in comparison, the UK is now a much less competitive market for electrolytic producers. In the upcoming autumn statement, the UK must provide a robust response to ensure that private investment potential does not leave the UK for more profitable markets. Similar investment into the electrolytic supply chain now can realise long-term economic growth as well as help the UK meet its climate targets.

Pipeline analysis

Hydrogen UK's Project Database is composed of 146 projects totalling 24.8 GW of capacity with data sourced on publicly announced hydrogen projects based within the UK. Of these, 104 are electrolytic production projects which combined result in a total pipeline capacity of 12.4 GW.

Comparing the years that projects become operational gives an indication of total capacity and average project size across the next decade. This analysis assumes that all proposed pipeline projects meet their stated capacity figures at their stated operational dates, meaning the following analysis is for indicative purposes rather than actual capacity projections. **Figure 14** demonstrates how the average capacity of projects operational in 2022 was 2.20 MW, however, by 2030, the average capacity of electrolytic projects in the current pipelines is nearly 40 times higher at 84.86 MW. This figure could well be higher due to certain projects not detailing intended dates of operation. The total pipeline average is 134.27 MW.

Figure 15 displays how the cumulative capacity changes from 2022 to 2035 and the total pipeline capacity. Hydrogen UK have assumed a small project is < 10MW, a medium project is < 100MW and a large project is ≥ 100MW, to give an indication of the spread of the scale of operational electrolytic projects. If projects did not detail an operational date, they were included in the pipeline category.



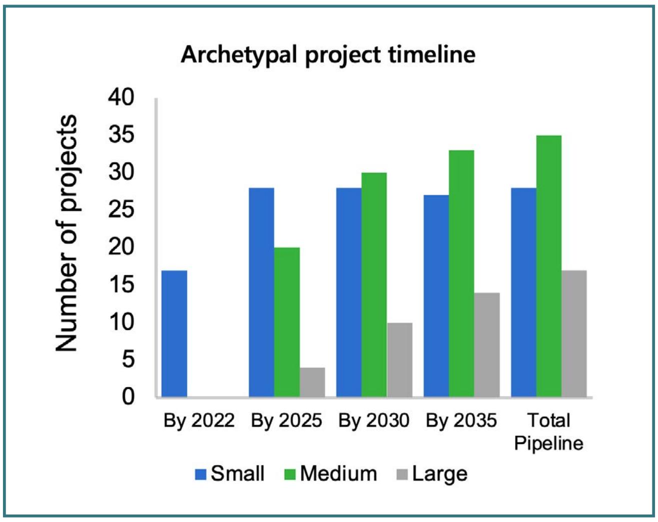


Figure 14: Archetypal project timeline

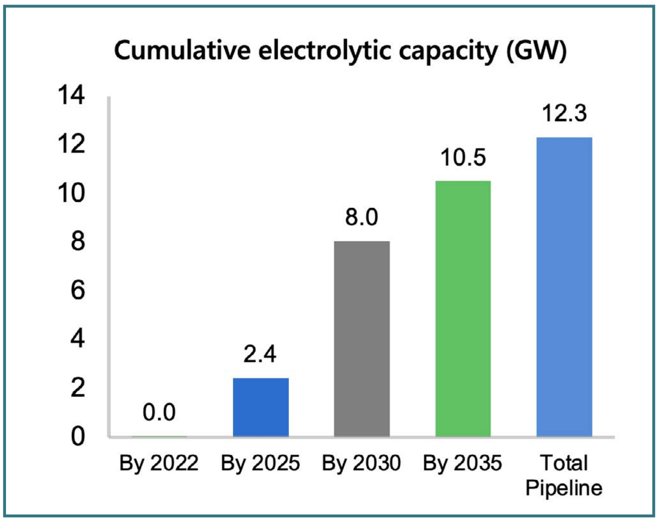


Figure 15: Cumulative electrolytic capacity (GW)

Projects that were shortlisted for the first Hydrogen Allocation Round[56] through the Hydrogen Production Business Model and are still in the negotiation stage give strong evidence on the current credible pipeline. This analysis only includes projects that are still in the negotiation stage as of August 2023[38]. These projects were characterised by two main archetypes. The first major archetype was large electrolytic plants which are located near industrial clusters and indicated power or industry as preferred offtakers. The second archetype was smaller projects which often indicated transport as a preferred offtaker and are situated away from clusters.

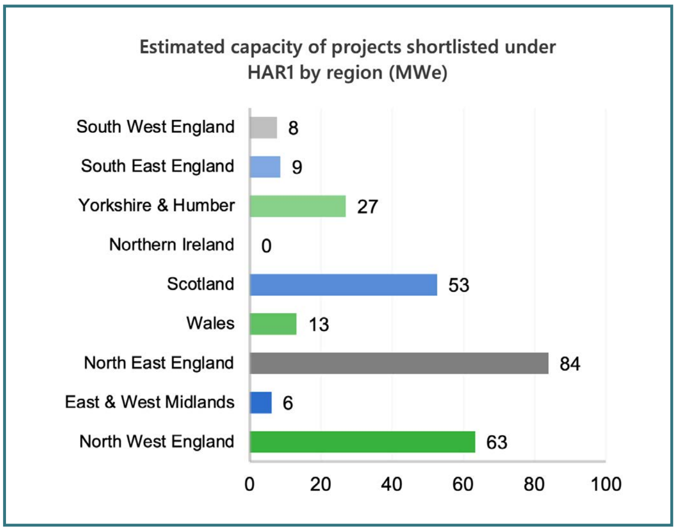


Figure 16: Capacity of projects shortlisted under HAR1 by region (Hydrogen UK Project Database)

There were only 2 shortlisted projects in the North East of England with an average capacity of 42 MWe, meaning the region had the most capacity in the UK. It is worth noting that Government targets are in terms of hydrogen output and not electricity input, as many of these figures are given in. These large-scale projects are situated nearby to the Teesside cluster showing the role of high-capacity projects in supplying low carbon hydrogen to large industrial offtakers. The prevalence of capacity situated near to demand also shows the behaviour of projects before the introduction of a developed hydrogen network, with projects required to locate near to demand rather than surplus supply of electricity. On the contrary, the region with the most projects was Scotland, where 4 projects were shortlisted, with an average capacity of 13 MWe, showing the role of smaller-scale projects in reaching dispersed sites.

Larger projects tended to indicate either industry or power as preferred offtaker, whereas smaller projects tended to indicate transport as preferred offtaker. Only 4 of the 17 projects indicated power as preferred offtaker, however, these were the larger shortlisted projects with an average capacity of 31 MWe. As shown by **figure 17**, the offtaker type with the most potential capacity was industry with up to 230 MWe electrolytic capacity. However, it must be noted that many projects indicated multiple types of preferred offtaker, so this is an upper estimate. The specific industrial offtakers mentioned ranged from paper manufacturers in industrial clusters to dispersed distilleries. Many smaller projects indicated transport as a preferred offtaker with 9 projects in total with an average capacity of 18 MWe. This demonstrates the suitability of the demand volumes of transport applications in matching the supply of electrolytic projects, especially in dispersed areas.

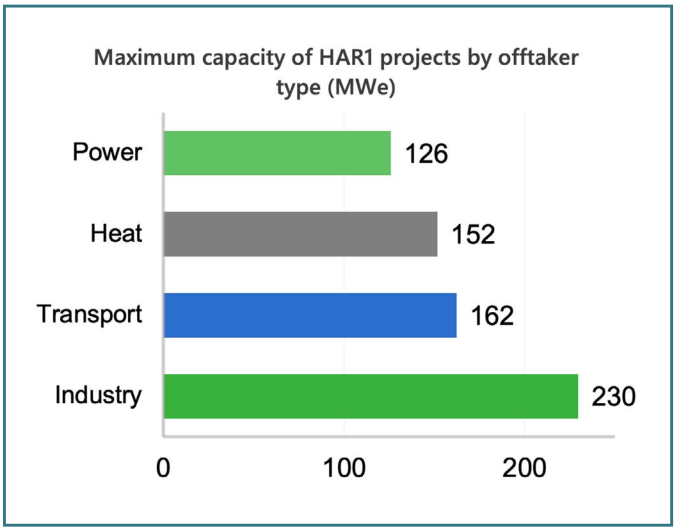


Figure 17: Maximum capacity of HAR1 projects by offtaker type (MWe)

Demand within UK

IRENA's World Energy Transitions Outlook sees hydrogen covering 12% of global energy demand and cutting 10 % of CO_2 emissions by 2050[57]. DESNZ' own estimates for hydrogen demand in the UK in 2050 range from 250 – 460 TWh per annum[58]. This represents a significant opportunity for the UK to develop a supply chain for domestic consumption and export to the rest of the world.

The four main sectors where hydrogen is expected to play a significant role in decarbonisation are: industry, power, transport, and heat. Estimated demand splits between these sectors, according to National Grid's System Transformation scenario, are shown in **figure 18**[59].

Industry

The main use cases in industry are to displace 'grey' hydrogen, which has an emissions intensity of 10 kg CO_2/kg H_2[60] , as a feedstock in industry, and heat for industrial processes. High heat industrial processes lend themselves to hydrogen as a route for decarbonisation due to unsuitability for electrification. The HyNet low-carbon cluster has already achieved a world first, with trials started in Liverpool to produce float (sheet) glass using hydrogen. Pilkington Ltd have used low-carbon, clean-burning hydrogen in a furnace to produce architectural glass at temperatures as high as 1,600 degrees centigrade[61]. Further afield, in Sweden, HyBrit have started producing steel using electrolytic hydrogen with virtually no emissions. Renewable sources are used to power water electrolysis which in turn is used in the direct reduction of iron. Evidence shows that the produced steel is superior compared to its high carbon alternative[62]. In Germany, the REFHYNE project will use a 10MW ITM electrolyser to produce green hydrogen in order to help decarbonise an oil refinery at the Shell Rhineland Energy and Chemicals Park in Wesseling[63].

The opportunity exists for green hydrogen to be used to decarbonise food, drink, glass, chemicals, and many other industrial processes. Furthermore, the Green Hydrogen Alliance, recently founded and consisting of major multinationals such as Airbus, Tata Steel and Air Products, has sent a letter to the then Secretary of State, Grant Shapps, calling for a UK green hydrogen strategy. The group explains how this would allow for the delivery of significant investment and highly skilled jobs to regions that need it most[64].

Power

Power-to-hydrogen and hydrogen-to-power represents a key opportunity to help the UK achieve its goal to decarbonise the electricity grid by 2035, providing flexibility and increasing system resilience. In combination with hydrogen transport and infrastructure, electrolytic hydrogen can be used for large scale centralised power generation, through converted or new-build gas-fired turbines, and decentralised power generation from combined heat and power (CHP) units and stationary fuel cells for industrial customers, construction sites, data centres, and other dispersed electricity consumers.

Transport

Hydrogen is widely regarded as being well suited to decarbonising heavy surface transport, maritime and aviation. While battery electric has become established in the passenger vehicle market, around 30% of the population do not have access to home charging[65], and supply chain constraints may also provide an opportunity for hydrogen fuel cell vehicles to offer an alternative solution to consumers.

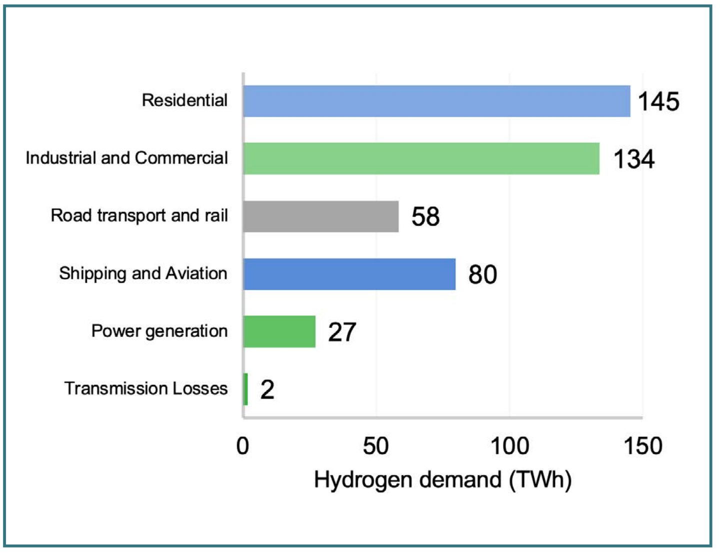


Figure 18: Low carbon hydrogen demand in 2050 (FES System Transformation)

Fuel Cell Electric Vehicles (FCEVs) are also more suited to high utilisation, long range, heavy payloads with faster refuelling times and no loss of performance in cold conditions. For example, a long-haul heavy goods vehicle (HGV), due to its high utilisation rate, would require nearly a month per year of charging with the highest capacity electric chargers currently available, 350 kW. Alternatively, a fuel cell HGV would only require around a day per year for refuelling, allowing the operator to maximise utilisation rates and productivity. The UK established a world-leading program of zero emissions bus deployment through the ZEBRA scheme, with domestic original equipment manufacturer (OEM) Wrightbus producing the world's first hydrogen double decker bus.

The Tees Valley Hydrogen Transport Hub, a £20 million project funded by the Department for Transport, aims to create a long-term sustainable demand for hydrogen and to de-risk hydrogen's adoption for transport owners and operators[66]. Rail is also seen as a potential user of green hydrogen, with approximately 10% of the current unelectrified network more suited to hydrogen than electrification[67].

Maritime and aviation are the sectors with the largest potential demand for hydrogen. The IEA notes that there are more than 100 pilot and demonstration projects for using hydrogen and its derivatives, such as renewable ammonia, in shipping, and major companies are already signing strategic partnerships to secure the supply of these fuels[68]. Similarly, in the aviation sector, hydrogen derived synthetic jet fuels are likely to supplement sustainable aviation fuels produced using constrained biogenic feedstocks to help fuel suppliers meet the conditions under the Sustainable Aviation Fuel Mandate[53]. The transformation of hydrogen into hydrogen derivatives such as ammonia and renewable methanol not only presents an opportunity to decarbonise hard-to-treat heavy transport sectors but could pave the way for a thriving hydrogen export economy.

Heat

Space heating in residential and commercial buildings is another significant opportunity for green hydrogen, however it is recognised that this depends on a positive decision by government in 2026. Hydrogen provides an alternative heating solution to buildings where electrification is not possible or economically viable and represents a familiar solution to consumers who would prefer to keep using a boiler after the gas grid is decarbonised. In these properties substituting hydrogen for natural gas may entail less upfront cost and disruption when compared to conversion to electric heating technologies.

Other revenue streams

Alternative revenue streams, beyond the direct sale of produced hydrogen, exist for electrolytic hydrogen producers.

Flexibility services in the form of demand side response and grid balancing as well as ancillary services enable electrolytic hydrogen producers to benefit from market mechanisms in certain grid-related circumstances. For example, electrolytic producers with access to storage may be sold cheap electricity in times of high renewable generation to reduce curtailment payments, benefitting both the electricity grid and the producer. Electrolytic projects can also be mobile, especially floating offshore projects, meaning they can be used to relieve temporary constraints, reducing the risk of grid connection delays for individual projects. This opportunity is likely to increase as the penetration of intermittent renewables continues to grow. As shown by **figure 19**, the share of Great Britain's electricity coming from solar and wind has increased from 1.3% in 2009 to 32% in 2022. By 2040, National Grid estimate that between 6-12 GW of demand side response potential will be required to effectively balance the grid[69].

Figure 19: Share of GB generation mix over time

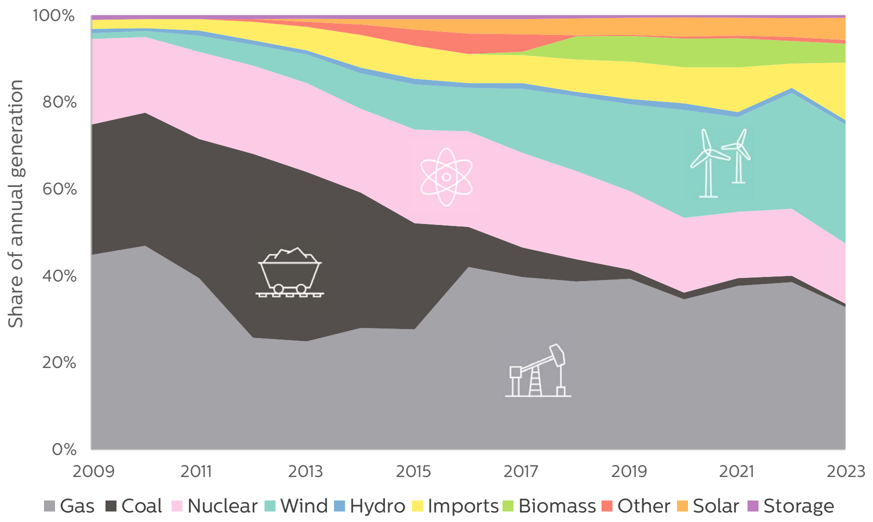


Figure 19: Share of GB generation mix over time[70]

Hydrogen UK

Alternatively, if the frequency of the grid was straying from the stable operating limits, an electrolytic producer may be compensated to stop producing and help the electricity grid return to the acceptable operating bounds. This illustrates the benefit that certain electrolysers carry, varying between electrolyser type, in being able to turn on and off almost instantly. PEM electrolysers especially have been shown to be effective at operating flexibly. Furthermore, the use of this demand side response enables a greater proportion of electricity to be used to meet electricity demand directly and increased interconnection means surplus generation can be exported to other markets, rather than needing to meet demand in the UK[71]. Relieving constraints through demand side response can help to avoid curtailment payments and excessive grid reinforcement requirements, lowering whole system costs with the benefits passed on to consumers, electricity generators and electrolytic producers.

A by-product of the electrolysis process is oxygen and in terms of mass, nearly eight times as much oxygen is produced as hydrogen during electrolysis. Oxygen plays an essential role in several industries. For example, a key stage of the glass manufacturing process is supplementing or replacing air-fuel combustion applications to melt, soften and treat glass more efficiently. Adding relatively pure oxygen to increase the oxygen concentration of combustion air, can result in increased flame temperature, improved heat transfer rates and overall combustion efficiency[72]. In the ceramic manufacturing industry, 40% of emissions come from fuel combustion in pyro processing. During this process, oxygen can be used to reduce energy losses in exhaust gases and therefore increase fuel combustion efficiency. Furthermore, by increasing oxygen content in air, the relative nitrogen content is limited meaning less nitrogen oxides are released in exhaust gases. There are many more examples of use-cases for oxygen including the medical and aviation sector.

The global market for oxygen is expected to grow from £23.8 billion in 2021 to £45.2 billion by 2026, at a compound annual growth rate of 13.5%[3]. For prospective electrolytic hydrogen producers, the ability to sell oxygen to a growing market will increase investment appetite. This dual revenue approach for electrolytic producers is especially attractive at sites where there is demand for both hydrogen and oxygen, such as water treatment sites, hospitals, and the heavy industrial applications described including glass and ceramics.

Domestic Supply Chains

Electrolytic hydrogen production based within the UK will create strong domestic supply chains, a plethora of skilled jobs and export opportunities. DESNZ commissioned a study by Wood and Optimat[74] which found that the UK hydrogen equipment supply chain could create annual GVA of £0.6-0.7 billion pounds by 2030 and £0.9-2.9 billion by 2050. Additionally, 6100-7100 jobs could be supported by 2030 and 9000-27500 jobs by 2050 with exports having the potential to reach £0.8-2.2 billion by 2030.

Because electrolytic production projects will be geographically dispersed, the benefit of this value chain is more likely to be felt across the country, helping contribute to the 'levelling up' of the nation. Cluster sites will experience significant economic benefit, yet they are confined to discrete areas. Dispersed electrolytic hydrogen production will enable the economic and social benefits, both short term (construction) and long term (operation and maintenance), to be felt by industries outside of the clusters.

Within the hydrogen sector, there is a desire that the economic and social benefits offered by electrolytic hydrogen are maximised within the UK. There is an invaluable opportunity here to capitalise on the strengths that UK based world leading companies, such as ITM Power, hold within the electrolytic hydrogen production sector by retaining as much of their business as possible, instead of it shifting overseas. Hydrogen UK firmly believes that the setting of voluntary targets is not the best approach and is looking forward to working with industry and the Department for Energy Security and Net Zero to set clear actions for maximising the benefits of a strong domestic supply chain.

Table 2 shows supply chain opportunities for the electrolytic hydrogen production sector based on the Wood and Optimat study for DESNZ, demonstrating the market opportunity for the sector. The findings show that the electrolytic production sector is overall, an attractive market opportunity with only electrolysis package manufacture a current supply chain gap.

	MARKET OPPORTUNITY	SUPPLYC HAIN GAP
ELECTROLYTIC PACKAGE MANUFACTURE	X	X
ELECTRICAL EQUIPMENTA ND MATERIALS	X	
CIVILA ND STRUCTURAL MATERIALS	X	
COOLINGW ATER PACKAGE MANUFACTURE	X	

Table 2: UK Electrolytic Production Supply Chain Analysis

It is estimated that through key strategies such as improved electrolyser design and construction, economies of scale, replacing scarce materials with abundant metals, increasing efficiency and flexibility of operations, and learning rates with high technology deployment, investment costs for electrolyser plants can be reduced by 40% in the short term and 80% in the long term[75]. However, only with investment into both the production of electrolytic hydrogen and the manufacture of electrolysers can this be realised in the UK and the domestic supply chain benefits maximised. Current evidence, however, suggests that support for electrolyser manufacture is far greater in surrounding nations than in the UK.

In the EU, revenue from the EU Emissions Trading System is being invested back into industry through innovation projects that will strengthen domestic supply chains, creating strong investment cases for industrial decarbonisation and stimulating export markets. In July 2023, 11 clean tech manufacturing projects were allocated €800 million in grant funding under the EU Innovation Fund, four of these projects being electrolyser or fuel cell projects[76]. Further funding is available for hydrogen producers and electrolyser manufacturers via the IPCEI funding programme for companies based in the EU[77]. In total, electrolyser manufacture in countries such as France, Germany, and Belgium have received far more public investment than in the UK, with an estimated £0.5 billion committed in public funding to electrolyser manufacturers in Germany.

Investment into manufacturing capacity within the electrolyser supply chain is extremely minimal in the UK with only small-scale investment such as the £800 thousand in grants given to electrolyser manufacturer Oort Energy[78]. This level of investment falls far behind the marker that has been set in the EU and a clean tech manufacturing investment package of £127 million would be required in the UK for support relative to the EU Innovation Fund[79]. Not only is the UK at risk of being outcompeted by its European neighbours in capturing its share of the electrolytic hydrogen supply chain, but by other nations too with 55% of the world's current electrolyser manufacturing capacity in China, as shown by **figure 20**.

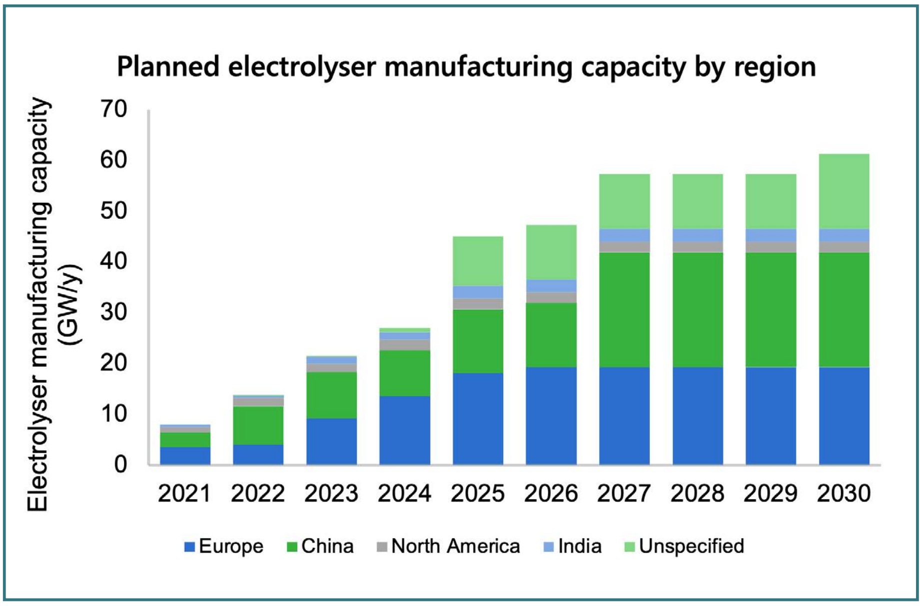


Figure 20: Planned electrolyser manufacturing capacity by region[80]

Case Studies

Lhyfe

Lhyfe design, install and operate three types of green hydrogen production units specific to end use applications, all proven and tested in real world applications. Onshore production units harness local renewables to fill containers with hydrogen for transportation or industry uses. Lhyfe have operated a production unit of 300 to 1000 kg of hydrogen a day in Vendée, France since 2021[81]. On-site production units are similar yet use pipelines to transport the produced green hydrogen directly to the end use, located on the same site as the production unit. Lhyfe will operate an onsite production unit in Denmark in 2024 producing between 5,500 and 12,000 kg of hydrogen a day[82]. Lhyfe also offer offshore production units and are developing the first offshore hydrogen production in the world off the coast of Le Croisic, at Centrale Nantes' offshore pilot site. The site will initially produce 440 kg of hydrogen per day[83].

Recently, Lyhfe signed a Memorandum of Understanding (MoU) with Centrica to jointly develop offshore renewable green in hydrogen in the Southern North Sea[84].

Carlton Power

Formed in 1995, Carlton Power is an independent, UK based energy development company developing a portfolio of green hydrogen production hubs across the UK[85]. Carlton Power has 3 projects successfully shortlisted by DESNZ in HAR1[86].

Trafford Green Hydrogen will produce green hydrogen at Trafford Low Carbon Energy Park in Greater Manchester[87]. Planning permission has been granted for the project which will initially operate a 20 MW electrolytic plant reducing carbon dioxide emissions in Manchester by over 20,000 tonnes per year.

Langage Green Hydrogen is a separate project, delivering green hydrogen to Langage Energy Park in the South West of England[88]. The hydrogen will be produced through an electrolyser with an initial capacity of 10 MW, and decarbonise industry, with the future ambition of transport and heating sectors as well. A planning application was submitted in May 2022.

The largest of Carlton Power's green hydrogen projects is the Barrow Green Hydrogen Project[89], with an initial electrolyser capacity of 35 MW, and the potential to be scaled to several hundred megawatts. The hydrogen will be used to decarbonise several industrial sites in the area of Barrow-in-Furness.

Figure 21: Barrow Green Hydrogen

ITM Gigafactory

ITM's Gigafactory at Bessemer Park is a semi-automated PEM electrolyser manufacturing plant with significant production capacity. This blueprint is designed for easy duplication, facilitating the swift setup of local facilities to meet substantial demand surges. As a manufacturing factory, Gigafactory could manufacture 1 GW of electrolysers a year and findings from a business case for Gigastack suggest the project could reduce the levelised cost of hydrogen by 47% by 2030[90].

Bay Hydrogen Hub Project

EDF is leading the Bay Hydrogen Hub project, an innovative R&D project in Lancashire to demonstrate solid oxide electrolysis using nuclear heat and electricity. Using low carbon heat from nuclear stations has the potential to significantly improve the efficiency of hydrogen production and this project would be one of the first demonstrations worldwide illustrating how nuclear energy can support hydrogen production in this way. Working with Hanson UK, the low carbon hydrogen produced will be transported via novel, next generation composite storage tankers and used at nearby Hanson sites to decarbonise asphalt and cement production[91]. In September 2023, Government announced funding for the next phase of the project, which hopes to boost hydrogen production efficiencies using solid oxide electrolysers and help deliver 3,300 tonnes of CO_2 savings for industry in the region[92].

Figure 22: Bay Hydrogen Hub Project

Recommendations

The UK is in a strong position to capture the full potential of electrolytic hydrogen; however, work is required to realise this. A strong offshore wind sector, favourable geography, developed engineering culture and availability of complementing infrastructure mean that electrolytic projects in the UK should have a comparative advantage to those in other parts of the world. We believe that the following recommendations will help the UK maximise the domestic decarbonisation and growth potential of electrolytic hydrogen whilst also paving the way for a thriving export economy:

1. Support a strong domestic electrolytic supply chain.

The electrolytic hydrogen supply chain is made up of many components, and capturing as much of this supply chain domestically will provide local economic growth and opportunities for electrolytic efficiency improvements through agglomeration effects, innovation, and domestic skills. Investment into the production of hydrogen is only half the story and this approach runs the risk of neglecting other valuable upstream supply chain components.

The EU have laid down the gauntlet for investing into clean tech manufacturing, using revenues collected from industry through their Emissions Trading System as well as supporting manufacturing through the Important Projects of Common European Interest scheme. Hydrogen UK would like to see similar efforts made to invest into the manufacturer of electrolyser stacks within the UK as this will lower the levelised cost of hydrogen domestically and create high value jobs, often in levelling up areas. The UK has shown its potential for manufacturing electrolysers, with companies such as ITM power, however, without short term action could lose out to demand for electrolysers from abroad and simultaneously rely on imported electrolyser stacks. Consideration should also be given to electrolyser technologies that are less mature, such as solid oxide electrolyser and other heat-assisted electrolysers, as these technologies could offer significant efficiency improvements and diversity to the electrolytic use cases within the UK.

Government must also track the development of other parts of the supply chain and look to intervene where supply chain imbalances may appear. Water treatment, electricity infrastructure and pre-FEED water infrastructure are all required for electrolyser plants, and for many sites small-scale above ground storage, battery energy storage, and renewable energy infrastructure for feeding power in will also be vital for the success of the project. Ensuring a healthy economy for all components of the supply chain will ensure that the benefits of electrolytic hydrogen stay in the UK.

2. Streamlining planning

The planning system in the UK is not consistent with the boom in electricity generators and offtakers that is required to transition to Net Zero. There is currently a race for businesses to connect to the grid, however, this race has hit significant congestion with 176 GW of new generation and interconnector schemes currently in the queue for a connection to the electricity transmission system in England and Wales[93]. The story is the same for those wishing to receive DNO approval, with projects looking to source a supply of electricity often having to wait a considerable amount of time to do so. Similarly, planning authorities in the UK are currently under-resourced and not equipped for the Net Zero transition, meaning that receiving planning consent can often be burdensome and take too long. This is a significant barrier to the deployment of electrolytic hydrogen and causes significant investment uncertainty.

Government must make efforts to ensure that planning authorities are appropriately resourced and remove needless planning barriers to fast-track the deployment of new electrolytic projects.

Similarly, Hydrogen UK are encouraged by the proposed introduction of a Future System Operator under the Energy Bill[94]. The Future System Operator will act as a fully independent operator of the entire energy system to help build a smart, efficient, and flexible system. If set up effectively, the Future System Operator could help ensure a low carbon and low-cost system, reducing energy costs faced by households and businesses, such as electrolyser plants. A whole system approach to strategic planning will help to enable suppliers and offtakers to be deployed optimally. Government must take a coordinated approach and work with industry to ensure that the Future System Operator is set up efficiently and in time to support the Net Zero transition in the short term.

3. Delivering electrolytic hydrogen capacity targets

In the British Energy Security Strategy[95], the UK government set out its doubled ambition to deliver up to 10 GW of hydrogen production capacity by 2030, with at least half of this coming from electrolytic hydrogen[96]. As an interim point, a target of 1 GW of electrolytic capacity, under construction or in operation by 2025, has also been made. Hydrogen UK welcomes the ambition laid out in these targets and urges the Government to ensure that this ambition becomes reality.

To achieve this, Government must provide a well thought out and transparent roadmap for capacity to be funded under each allocation round. This must be considered in conjunction with the proposal to provide flexibility to developers in the delivery year of their project. The recent market engagement on the second allocation round[97] and call for evidence on the move to price based competitive allocation[98] go part of the way in achieving this, but further clarity on the objectives and evaluation criteria will enable project developers to strategically plan projects in line with the requirements of Government. Only through an effective allocation mechanism that evolves in line with the technical development within the industry, can the UK achieve 5 GW of electrolysis by 2030.

In combination with supply side policy, efforts must also be made to encourage demand for electrolytic hydrogen. Within transport, definitions of low carbon hydrogen under the RTFO and HPBM should be aligned, and new mechanisms are required to encourage low carbon options within heavy road transport, maritime, and aviation. Within industry, reforms to the ETS market to make the industry cap net zero consistent are welcomed[99], as are moves to prevent industry from carbon leakage[100], however, more incentive is required to encourage industrial fuel switching. This could be achieved through a carbon contract for difference (CCfD) mechanism.

4. Securing the future of hydrogen

For the electrolytic hydrogen market to grow, the UK must secure an appropriate funding route in the short term to realise medium- to long-term economic gains. It is clear there are concerns with the Hydrogen Levy, as currently included in the Energy Bill. It is important that the energy transition is delivered in a way that is fair on consumers, and there is little political support for the approach currently taken by the Bill on these grounds.

However, the removal of a funding mechanism for Hydrogen Business Models in the Bill risks leaving the UK without a mechanism to get the hydrogen projects we need to deliver on our targets off the ground – along with the associated jobs and GVA. Government must work with industry to develop an alternative funding approach that satisfies all relevant parties and protects consumers, especially those most vulnerable to energy prices. Through a suite of funding measures, the UK hydrogen industry can be supported through its nascency, bringing the UK economy, households and businesses with it.

5. Developing enabling infrastructure

Electrolytic projects have the potential to reach dispersed sites without the need for an extensive hydrogen network, allowing decarbonisation of some dispersed sites in the short term. However, for a liquid market for electrolytic hydrogen to emerge, and the whole system benefits to be maximised, hydrogen transport and storage infrastructure is required.

Repurposing the current natural gas grid, as well as developing new pipeline infrastructure, will enable projects to locate in areas which are optimal for producing low-cost hydrogen, such as in areas of surplus electricity supply, and transport the hydrogen to areas of high demand, such as industrial clusters. Hydrogen storage will allow electrolytic projects to ramp up production during times of surplus electricity generation, alleviating constraints, with the produced hydrogen stored so that it can be used in hydrogen-to-power facilities during times of low renewable output. Additionally, utilising the current gas grid, hydrogen can be blended, de-risking electrolytic projects, enabling flexible production and reducing the carbon intensity of the gas grid. Government must make a clear pathway for the development of hydrogen transport and storage infrastructure, including an interim business model, and make a positive decision on blending in 2023.

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