GREEN HYDROGEN: OPTIMISING NET ZERO

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POLICY RECOMMENDATIONS
TO UNLOCK 5GW OF GREEN HYDROGEN

1. **Create a green hydrogen roadmap to deliver the 5GW target**
2. **Define a zero carbon hydrogen standard**
3. **Fully exempt electrolysers from levies to reduce market distortions**
4. **Tailor the Hydrogen Business Model to support green hydrogen production at different scales**
5. **Stimulate demand for hydrogen**
6. **Address planning and permitting barriers to green hydrogen**
7. **Create enduring domestic supply-chains for green hydrogen**
8. **Update regulations to encourage green hydrogen retrofit**
9. **Unlock strategic infrastructure**

INTRODUCTION

Building large volumes of new renewables is a prerequisite for a fully decarbonised, cheap, and secure energy system.

Electrification alone, however, is not enough to unlock a net zero energy system; there is also a need for renewable energy in a form that can be stored and used across wider applications and sectors. The solution is "green" hydrogen – that is, hydrogen produced via electrolysis of water using low-cost renewables.

As a versatile energy vector, green hydrogen can enable deep decarbonisation in sectors ranging from heavy duty road transport to maritime shipping, and as a feedstock for producing essential chemicals, such as fertilisers. Green hydrogen is unique among other types of hydrogen because it also helps solve the challenge of integrating renewables into our energy system through, for example, the provision of system balancing services, seasonal storage and by minimising curtailment of renewables (Figure 1).

A home-grown green hydrogen economy will also create thousands of new high-skilled green jobs in regions outside of just London or the Southeast. In the long-term this provides ample opportunities for the UK to become an exporter of green hydrogen, especially to the EU.

Momentum for green hydrogen is gathering worldwide as an increasing number of stakeholders view it as a critical component of future energy systems. Over 40 countries (including the EU27) have hydrogen strategies, and at least 13 have targets specific to green hydrogen.[1] More recently, the European Commission outlined its plan to achieve EU independence from Russian fossil fuels by quadrupling its 2030 target to 20.6Mt of green hydrogen, which will require well in excess of 100GW of both electrolyser and renewable generation capacity.

Figure 1: Dual Value Proposition of Green Hydrogen

ELECTROLYSER	HYDROGEN
System balancing services	Decarbonises hard-to-electrify sectors
Absorbs excess wind generation at times of oversupply	Reduces greenhouse gas emissions
Alleviates network constraints	Enables seasonal storage of energy
Improves the business case for renewable generators	Potential to be used in existing gas infrastructure

In late 2021, the UK's Business Secretary set a target of 5GW of "low carbon hydrogen" capacity by 2030, underpinned by a Hydrogen Strategy.[2] This target was doubled eight months later to 10GW as part of the Energy Security Strategy, with at least half of this to be met by green hydrogen production (about 1Mt per year).[3]

These developments lay the necessary foundations for a strong UK-based green hydrogen economy, but the ambition shown does not currently line up with the enabling policy and regulatory environment.

We must act now to unlock 5GW of green hydrogen capacity. BEIS indicates that up to £4bn of private investment is ready to be mobilised by 2030, but the hydrogen sector has indicated that this figure could be much greater with the right policy framework in place.[4] RenewableUK therefore urges government and industry to seize this opportunity and put green hydrogen at the heart of the UK's energy system. By laying the necessary groundwork today, the UK can enable a future world leading green hydrogen economy and sustain thousands of jobs.

1. IEA. October 2021. Global Hydrogen Review 2021. https://www.iea.org/reports/global-hydrogen-review-2021, https://www.iea.org/reports/hydrogen; Hydrogen Council. November 2021. Hydrogen for Net Zero: A Critical-competitive Energy Vector. https://hydrogencouncil.com/wp-content/uploads/2021/11/Hydrogen-for-Net-Zero.pdf
2. BEIS. UK Hydrogen Strategy. August 2021. https://www.gov.uk/government/publications/uk-hydrogen-strategy
3. BEIS. British Energy Security Strategy. April 2022. https://www.gov.uk/government/publications/british-energy-security-strategy
4. BEIS. UK Hydrogen Strategy. August 2021. https://www.gov.uk/government/publications/uk-hydrogen-strategy

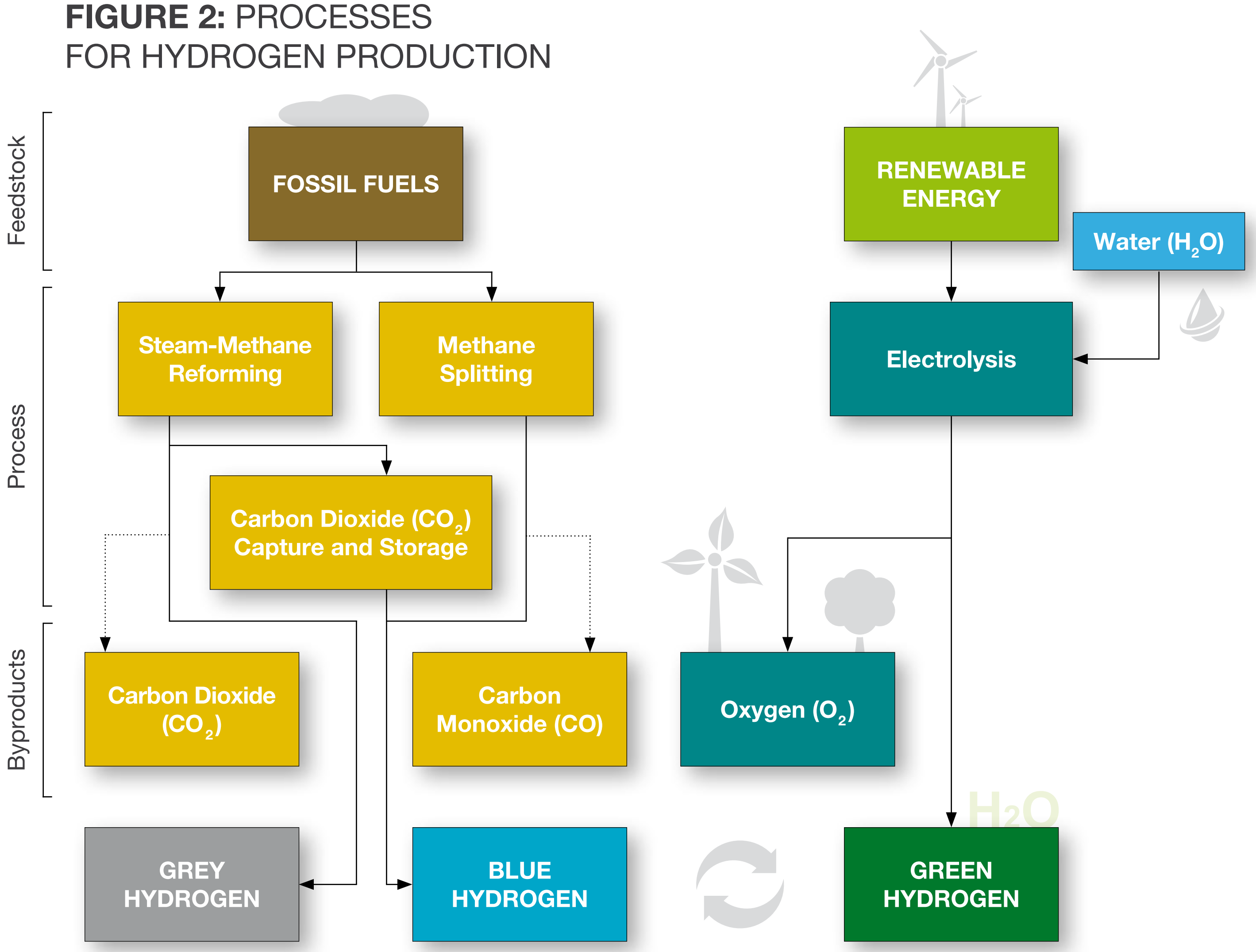
HOW IS HYDROGEN MADE?

Rarely occurring in its natural form, hydrogen must be produced from other materials – and that process requires energy.

Most hydrogen production today is made from methane, through a carbon-intensive process called Steam Methane Reformation (SMR). This produces so-called "grey" hydrogen with an approximate carbon footprint of 10kgCO_2/kgH2.

These emissions, plus the associated upstream methane emissions, can be largely counteracted with carbon capture and sequestration to produce "blue" hydrogen, but not to the extent that the hydrogen is of a zero carbon footprint. Green hydrogen production, on the other hand, never involves processing carbon compounds and is therefore zero carbon.

FIGURE 2: PROCESSES FOR HYDROGEN PRODUCTION



Source: Lazard, RenewableUK

OPPORTUNITIES FOR THE GREEN HYDROGEN ECONOMY

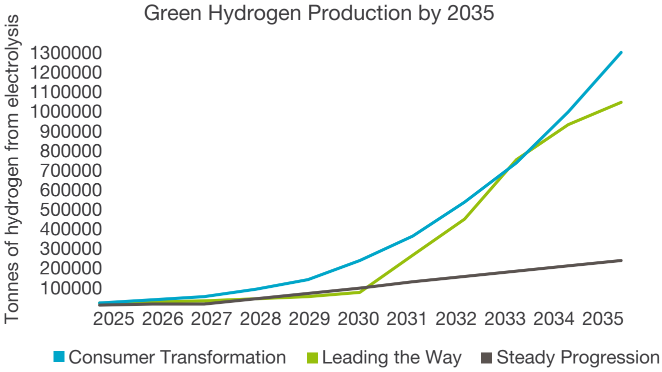
Tackling hard-to-electrify sectors and delivering net zero.

Following the Paris Agreement, the UK set several environmental targets to reduce its greenhouse gas impact and establish itself as an international leader in renewable energy.[5] The UK has already decarbonised its power sector by 68% since 1990, mainly by switching over from coal to gas and renewables.[6] However, to achieve the legally binding target of net zero emissions by 2050, the UK will need to transition its entire economy away from fossil fuels to green solutions.

Direct electrification will achieve the lion's share of decarbonisation, but where it is practical, cost-effective and viable to do so, green hydrogen will play a role in facilitating decarbonisation in a range of sectors. This includes heavy and long-range transport, aviation, maritime shipping, and industrial chemical production.[7] As a result, by 2035 a minimum of almost 1Mt of green hydrogen per year will be required according to National Grid's Consumer Transformation and Leading the Way scenarios (Figure 3).[8]

BEIS's own analysis indicates that the UK will require up to 460TWh of hydrogen in 2050, up from just 27TWh of predominately grey hydrogen (including a very small proportion of green hydrogen) currently used in oil refining, ammonia, and methanol production.[9] To put this into context, the UK currently uses about 1500TWh of fossil fuels, and therefore the increase in hydrogen demand will primarily come from transitioning entire sectors of the economy away from fossil fuel dependence, and towards new hydrogen-based alternatives.[10]

Figure 3: Future Energy Scenarios: Green Hydrogen Production by 2035



Source: National Grid FES

Solving the challenge of integrating renewables and bolstering the UK's energy security

As well as enabling net zero through deep decarbonisation, both the electrolyser and green hydrogen itself have the potential to boost energy security and allow better management of supply and demand of renewables.

At its heart, green hydrogen shifts primary energy demand from fossil fuels to renewable electricity and, in doing so, will require deployment of large volumes of new renewable capacity. Switching domestic homes over to electric heating and electrifying other areas, like transport, will create additional demand for power. Similarly, electrolysers consume electricity to produce hydrogen which can be used to decarbonise sectors where direct electrification is not suitable. Net zero is therefore underpinned by a universal acceptance that the UK will require much more renewable generation; whether it is used for power, or in heat pumps, vehicles, or electrolysers.

5. Climate Change Act 2008. https://www.legislation.gov.uk/ukpga/2008/27/contents
6. The Climate Change Committee. The Sixth Carbon Budget - The UK's path to Net Zero. December 2020. https://www.theccc.org.uk/publication/sixth-carbon-budget/
7. The Climate Change Committee. The Sixth Carbon Budget - The UK's path to Net Zero. December 2020. https://www.theccc.org.uk/publication/sixth-carbon-budget/
8. National Grid ESO, 2021, Future Energy Scenarios, https://www.nationalgrideso.com/future-energy/future-energy-scenarios
9. BEIS. UK Hydrogen Strategy. August 2021. https://www.gov.uk/government/publications/uk-hydrogen-strategy
10. Roser, Max and Hannah Ritchie. Our World in Data. Energy Mix. https://ourworldindata.org/energy-mix

Despite being a relatively small country geographically, the UK is an in an exceptional position because it is naturally endowed with an enormous offshore wind resource, which can support the ramp-up of renewable generation and green hydrogen production. The Offshore Wind Industry Council estimate around 600GW to 1TW of offshore wind generation to be ultimately feasible in the UK, while Imperial College London estimate this at around 1.3TW, although only a fraction of this is likely to be built.[11]

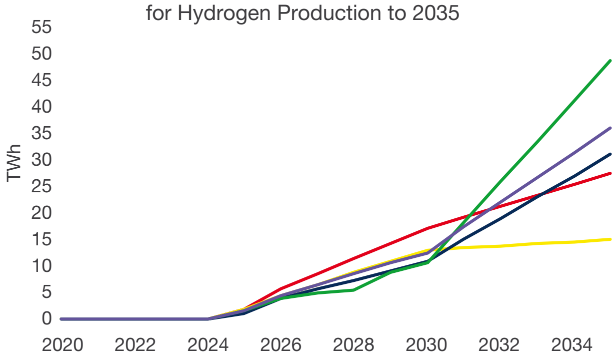
Both these figures are well above the 100GW needed to meet indigenous demand for offshore wind in 2050 and could be used to produce hydrogen. The Energy Network Association (ENA), for example, have estimated that by 2050 the UK will have enough spare capacity between May and October each year to produce about 60GW to 80GW of green hydrogen.[12]

Green hydrogen reduces curtailment of useful energy

Transitioning to higher levels of renewables brings an additional challenge: how to integrate the variable energy output. Renewable generation is dependent on the weather and, as capacity grows, supply will not always match up with the demand. This could mean that at times there will be less output than is needed, and conversely that renewables might have to be turned down when there is excess generation. Generation may also be restricted where there is not enough network capacity to transport renewable energy generated across the cables to demand centres. To manage these challenges in the future, extensive storage and flexibility solutions are required to better balance supply and demand.

Green hydrogen can make a massive contribution to this goal. Electrolysers can soak up excess renewable generation, producing hydrogen that can be stored over the longer term (potentially across seasons) in geological structures, such as salt caverns or depleted oil & gas (O&G) fields, and then be called upon when demand is temporarily greater than generation.[13] For example, the estimated annual wind curtailment of between 3TWh to 11TWh in 2050 could instead be converted and stored as green hydrogen for later use.[14] Taking surplus renewable power and storing it as hydrogen therefore reduces the curtailment of useful energy, and diversifies the UK's energy supply to make it more secure.

Figure 4: Curtailed Electricity Used for Hydrogen Production to 2035



Source: CCC Sixth Carbon Budget

11. Offshore Wind Industry Council. Offshore Wind and Hydrogen: Solving the Integration Challenge. https://www.owic.org.uk/our-work; Bosch, Jonathan et al. August 2018. Temporally Explicit and Spatially Resolved Global Offshore Wind Energy Potentials.
12. Energy Network Association. October 2021, Gas Goes Green. A System for All Seasons: A Holistic Approach to Decarbonisation. https://www.energynetworks.org/newsroom/renewable-hydrogen-offers-best-route-out-of-future-energy-supply-crunches
13. Schenk, Niels J. et al. October 2007. Wind energy, electricity, and hydrogen in the Netherlands https://www.sciencedirect.com/science/article/abs/pii/S0360544207000345
14. Pudjianto, Danny. Et al. Imperial College London. Whole-system Value of Long-duration Energy Storage in a Net-Zero Emission Energy System for Great Britain. https://imperialcollegelondon.app.box.com/s/24b4ynyq49irqxhqf8n8ygpcso0sl1ft; Wallace, Richard. et al, May 2021, Utility-scale subsurface hydrogen storage: UK perspectives and technology, https://www.sciencedirect .com/science/article/abs/pii/S0360319921017481

CASE STUDY
REDEVELOPMENT OF THE ROUGH RESERVOIR AS A HYDROGEN STORAGE FACILITY

Successful redevelopment could offer a phased capacity build up to 10TWh

Depleted gas fields and salt caverns represent primary options for UK hydrogen storage.

Re-purposing Rough, an existing depleted gas field that historically has operated as the UK's largest proven natural gas storage facility and is currently scheduled for closure, is expected to be the most cost-efficient option to meet the long-term need for hydrogen storage.

Rough's unique geological and geographical advantages position it well to support a growing hydrogen economy and has no insurmountable technical barriers to conversion to hydrogen storage. The successful redevelopment could offer a phased capacity build up to 10TWh of storage to UK infrastructure.

Lots of potential underground hydrogen storage facilities exist in the UK

There are already sufficient underground storage systems in the UK which can be converted at a relatively low cost to use for hydrogen. This is because they are naturally furnished with the conditions needed to trap the gas, and can store large amounts of energy despite the low volumetric density of hydrogen.[15] These forms of storage have been tested with natural gas since the 1990s, and salt caverns have long been used to store hydrogen, such as in Teesside in the North of England.[16] The ultimate potential for green hydrogen storage under land and sea in UK territory is very large. It has been estimated at over 2600TWh, which is greater than the UK's total annual energy consumption.[17]

Managing supply and demand with green hydrogen storage

Evidence of the need for long-term hydrogen storage is growing. The Climate Change Committee (CCC) found that up to 20TWh of large-scale hydrogen storage is necessary for 2050, while National Grid's Future Energy System 2021 System Transformation Scenario expects 51TWh of hydrogen storage capacity will be needed.[18]

Long-term hydrogen storage is needed because of the seasonal variation in demand and the variability of renewable generation. The associated supply and demand mismatch will be amplified by the electrification of heat for buildings if there is no adequate storage and fast-ramping generation. While battery storage may be used to manage intra-day and inter-day peaks, the long-term storage of green hydrogen can be used by hydrogen-fueled peaking plants to cover periods of supply deficit and alleviate local grid capacity.[19]

Using hydrogen as an energy storage medium is particularly advantageous given volatility in gas prices observed in 2022 which led to a doubling of consumers' energy bills, and was in part due to a shortage of domestic gas storage. Historically, production from the North Sea minimised the need for gas storage but the UK has instead become increasingly reliant on imports.[20]

Green hydrogen is therefore an important means to develop carbon-free long-term energy storage to manage seasonal demands, while diminishing the role of gas in line with net zero targets. This reduces the UK's reliance on gas imports, ensuring the UK is less prone to external market shocks.[21]

15. Elberry, Ahmed M. et al, April 2021, Large-scale compressed hydrogen storage as part of renewable electricity storage systems https://www.sciencedirect.com/science/article/pii/S0360319921005838; A System for All Seasons: A holistic Approach to Decarbonisation. https://www.energynetworks.org/newsroom/renewable-hydrogen-offers-best-route-out-of-future-energy-supply-crunches
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; Wallace, Richard. et al, May 2021, Utility-scale subsurface hydrogen storage: UK perspectives and technology, https://www.sciencedirect.com/science/article/abs/pii/S0360319921017481
17. Mouli-Castillo, Julien. February 2021. Mapping Geological Hydrogen Storage Capacity and Regional Heating Demands: An Applied UK Case Study. https://www.sciencedirect.com/science/article/abs/pii/S030626192031730X?via%3Dihub
18. National Grid ESO, 2021, Future Energy Scenarios, https://www.nationalgrideso.com/future-energy/future-energy-scenarios
19. Auora, February 2022. Long Duration Electricity Storage in GB. https://auroraer.com/insight/long-duration-electricity-storage-in-gb-2/
20. The Oxford Institute for Energy Studies. Sharples. Jack et al. February 2022. The Potential Impact on the UK of a Disruption in Russian Gas Supplies to Europe. https://www.oxfordenergy.org/publications/the-potential-impact-on-the-uk-of-a-disruption-in-russian-gas-supplies-to-europe/
21. Current News. Lempriere, Molly. February 2022. Energy Price Volatility to Last Until 2030 at Least, Warns Cornwall Insight. https://www.current-news.co.uk/news/energy-price-volatility-to-last-till-2030-at-least-warns-cornwall-insight

Electrolysers can provide power system services and alleviate network constraints

Converting electricity into hydrogen can also help alleviate network constraint issues, such as the challenge of connecting 25GW of additional offshore wind capacity that was awarded under the ScotWind leasing round in January 2022. ScotWind lease areas are within a reasonable distance of depleted O&G deposits, which could be connected to the offshore gas transmission network to transfer renewable energy ashore as hydrogen rather than electricity (Figure 5).[22] An enduring regime, as part of the Offshore Transmission Network Review (OTNR), should therefore consider joint use of marine space and consider synergies with existing O&G infrastructure and green hydrogen.

Figure 5: Offshore Gas Pipelines and ScotWind Leasing Areas

Source: OGA, Scottish Crown Estate, RenewableUK

Finally, as the UK transitions away from thermal generation towards renewables that are mostly non-synchronous, there is an increasing need for adequate tools and capabilities to manage aspects such as lower system inertia, frequency deviations and wind curtailment. Electrolysers can help provide these services, as they can respond quickly to frequency deviations by ramping up and down. They can have a positive effect on frequency stability and can provide demand response and voltage support, therefore improving system-wide performance.[23]

Creating jobs and boosting the business case for renewables

Developing and advancing green hydrogen production will contribute to the UK's economy and create thousands of new high-skilled jobs, while utilising many existing engineering and marine skills found within the renewable energy and O&G sectors. Most of these jobs will be found in the manufacturing sector for green hydrogen production and infrastructure technologies; other areas include the automotive sector, industrial centres of hydrogen demand, electricity networks and in the building and operating of the renewable sources used to drive electrolysers. As shown in RenewableUK's EnergyPulse database, these jobs will be spread equally across the country (Figure 6).[24]

Research from various organisations clearly shows that support for a green hydrogen economy also means supporting the creation of thousands of UK-based sustainable jobs and economic growth across the country.

- Analysis from the Fuel Cells and Hydrogen Joint Undertaking indicates that a UK-based green hydrogen economy could be worth £3.3bn by 2030 and create up to 45,000 jobs.
- The Scottish Government has estimated that becoming an exporter of green hydrogen to Europe could create up to £25bn of GVA and over 300,000 jobs in Scotland by 2045.[25]

22. North Sea Transition Authority. Offshore Oil and Gas Activity. https://www.arcgis.com/apps/webappviewer/index.html?id=f4b1ea5802944a55aa4a9df0184205a5
23. IET Renewable Power Generation. Samani, Arash E. et al. April 2022. Grid Balancing with a Large-Scale Electrolyser Providing Primary Reserve. https://ietresearch.onlinelibrary.wiley.com/doi/epdf/10.1049/iet-rpg.2020.0453
24. RenewableUK's EnergyPulse is the industry's go-to market intelligence service, providing comprehensive and accurate energy data, insights, and focussed dashboards for the wind, marine, storage and green hydrogen sectors in the UK and offshore wind globally. https://www.renewableuk.com/general/custom.asp?page=EnergyPulse
25. Wyatt, Steve. Richard Halsey. Gareth Williams. Catapult Network. Accelerating A UK Hydrogen Economy. https://catapult.org.uk/wp-content/uploads/2021/04/9384_Accelerating-a-UK-Hydrogen-Economy-1.pdf ;
Scottish Government. Draft Hydrogen Action Plan. November 2021. https://www.gov.scot/publications/draft-hydrogen-action-plan/documents/

- The Offshore Renewable Energy Catapult estimate that the production and overseas export of electrolysers would produce up to £320bn of GVA and 120,000 jobs by 2050.[26]

As a powerhouse for renewables and manufacturing, the UK is in an excellent position to support the growing global demand for hydrogen which will be worth $2.5trn by 2050.[27] We are already capitalising on this opportunity; ITM Power has established the world's first electrolyser gigafactory in the UK and sold electrolysers to the world's largest hydrogen process plant in Germany, and Ceres has exported fuel cell designs to manufacturing companies.

But this export opportunity is becoming much larger as more countries adopt ambitious targets for green hydrogen. Demand for low carbon hydrogen is expected to reach 614Mt by 2050, with at least two thirds of this being green hydrogen.[28]

The European Commission recently announced REPowerEU, which outlines its plan to reduce the bloc's dependency on Russian fossil fuels following the invasion of Ukraine. A significant part of this includes committing the EU to using a further 15Mt of green hydrogen by 2030, in addition to the 5.6Mt target stated under the Fit For 55 Package. Around 10Mt of this new target will be imported, and therefore as a close neighbour the UK is well positioned geographically to become a major exporter for this large near-term market for green hydrogen. While the hydrogen policy updates announced in April 2022 were a step in the right direction, there is much more that needs to be done to support the development of a healthy UK-based green hydrogen industry that can fully take advantage of this export opportunity.

Figure 6: Sample of the Green Hydrogen Project Pipeline in the UK

Source: RenewableUK EnergyPulse

26. Fuel Cells and Hydrogen 2 Joint Undertaking. United Kingdom: Opportunities for Hydrogen Energy Technologies Considering the National Energy & Climate Plans. https://www.fch.europa.eu/publications/opportunities-hydrogen-energy-technologies-considering-national-energy-climate-plans
27. All Party Parliamentary Group on Hydrogen. January 2021. All Party Parliamentary Group on Hydrogen, Non-Verbatim Minutes – Global Export. https://connectpa.co.uk/appg-hydrogen/
28. IRENA. World Energy Transitions Outlook: 1.5°C Pathway. March 2022. https://www.irena.org/publications/2022/Mar/World-Energy-Transitions-Outlook-2022

CASE STUDY
GIGASTACK HYDROGEN PROJECT

> **Gigastack is a flagship project within the UK's decarbonisation portfolio**

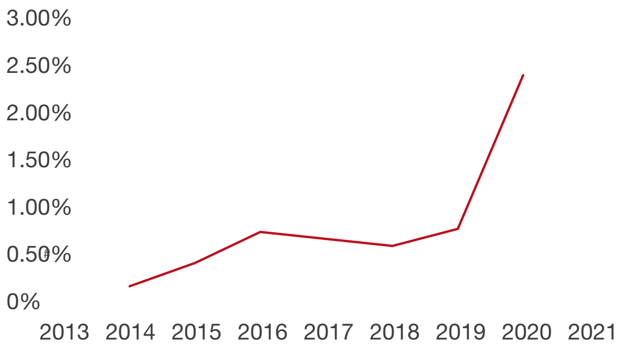
The Gigastack project is led by a consortium comprising ITM Power, Ørsted, Phillips 66 Limited and Element Energy.

Gigastack is a flagship project within the UK's decarbonisation portfolio since it is the most technically advanced large-scale renewable hydrogen project. Funded to date by BEIS' Low Carbon Hydrogen Supply Competition, Gigastack is a multi-phase programme which aims to take feasibility stage concepts through to a preliminary design for a 100MWe -scale electrolyser system, using renewable power. Gigastack has achieved these goals by bringing together an ambitious consortium to provide economically viable renewable hydrogen at scale

Green hydrogen improves the business case of renewable projects.

In a generation portfolio increasingly dominated by renewables, the cost of producing an additional unit of power is almost zero, as the energy provided by the wind and the sun is free. As more renewables connect to the grid, this has led to a negative side-effect in the phenomenon called "price cannibalisation".[29] The presence of price cannibalisation in the market makes investment harder without a subsidy or diversified revenue streams.
Green hydrogen can help mitigate the price-cannibalisation effect by absorbing surplus power from the grid and storing it, thereby stabilising the market price generators receive. Higher levels of low-cost renewable power strengthen the case for investment in electrolysers, which produce hydrogen when wholesale prices are low, in turn creating additional electricity demand and stabilising the market value of renewables.[30]

Figure 7: Percentage of Settlement Periods with a Negative System Price Since 2014



Source: Elexon

Furthermore, Government has already put in place regulatory incentives for renewable generators to find innovative solutions to manage periods of low system prices. As an example, changes made to the Contracts for Difference (CfD) scheme (the primary support scheme for renewable generation) include not offering subsidies when power prices are negative. Incorporating an electrolyser to produce green hydrogen when power prices are low or negative is exactly what this policy change incentivises; it enables developers to diversify revenues and not rely primarily on power markets for incomes.

29. Price cannibalisation is a result of the increasing penetration of renewable energy generation into the wholesale electricity market which applies downward pressure on electricity prices due to their low short run marginal cost. This is particularly prominent in settlement periods with high levels of renewable energy penetration, windy and/or sunny days. The absence of fuel costs means renewable energy generators squeeze out higher cost capacity from the price stack resulting in more volatile, sometimes negative, wholesale pricing. The greater the percentage of renewable energy generation at any given time, the greater this effect becomes, meaning the price captured by wind and solar projects is eroded over time.
30. Ruhnau, Oliver. February 2022. Applied Energy. Vol 307. How Flexible Electricity Demand Stabilizes Wind and Solar Market Values: The case of hydrogen Electrolyzers. https://www.sciencedirect.com/science/article/pii/S0306261921014641

CASE STUDY
BPP RENEWABLES

> **Producing green hydrogen offshore using floating wind farms offers a commercial solution**

BPP Renewables together with key technology providers is investigating the design feasibility and the economics of a net zero hydrogen solution. This involves large-scale production of green hydrogen from floating wind farms.

Producing green hydrogen offshore using floating wind farms offers a commercial solution to store and deliver energy onshore. However, while the system components (e.g. electrolysers, wind turbines and platforms) are commercially available at a high technology readiness level (TRL 9), the overall system design and integration is much lower (TRL 3-4).

BPP is working to develop the required engineering tools to simulate and design the dynamic behaviour of the different components comprising the green hydrogen system, when powered by fluctuating wind power. This will contribute to reliable and safe integration of the different technologies at TRL 9.

MISSING THE OPPORTUNITY

Green hydrogen helps solve the challenge of integrating renewables, improves energy security and decarbonises sectors that are hard to electrify. To date, however, only a few demonstration projects have used green hydrogen, mainly in transport. Bringing these opportunities to fruition requires effective and targeted policy that enables rapid deployment to drive down the cost of green hydrogen and build out domestic supply-chains.

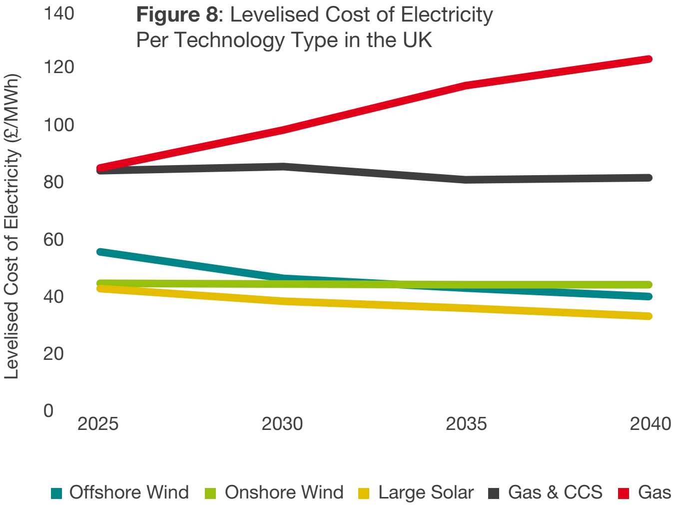
The cost question

Past studies indicate that the cost of green hydrogen is around £2.30-6.10/kg and would take close to a decade to reach parity with grey and blue (£0.45-2.30/kg). Given the current fossil fuel crisis and very high gas prices, however, green hydrogen is beginning to reach cost parity with grey and blue hydrogen at a much faster pace than anticipated. While blue and grey hydrogen may become relatively cheaper should natural gas prices subside in the coming years, the price of green hydrogen will also drop due to economies of scale and technology gains, and as power prices become less dependent on gas in a world with more renewable generation.

The cost of green hydrogen is predicated on the cost of electricity because renewable energy generation is needed as an input to drive electrolysis. In other words, cheap renewables translate into more affordable green hydrogen.[31]

Rapid investment in renewable energy, in part due to support mechanisms, saw the UK meet over a third of its demand from renewables in 2020.[32] This deployment has afforded huge cost reductions, with prices for offshore wind plummeting by 65% between 2015 and 2019, and solar PV seeing capex reductions of 20% for each doubling of capacity. Globally, this means green hydrogen could reach around £1.50/kg in most areas and even lower where renewable energy sources are favourable.[33] However, the caveat is that these cost reductions will be difficult to realise in green hydrogen production without immediate reform to the grid levies paid on top of the electricity prices paid by electrolysers, as detailed below.

Figure 8: Levelised Cost of Electricity Per Technology Type in the UK



Source: BEIS, Carbon Brief

31. Caspersen, Dr. Michael. KPMG. Hydrogen is Already a Well Established Market, but Currently Based on Fossil Feedstock. https://home.kpmg/xx/en/home/insights/2020/11/the-hydrogen-trajectory.html#:~:text=Cost%20of%20green%20hydrogen%20from,is%20cost%2Dcompetitive%20with%20blue
32. Drax. Drax Electric Insights. https://electricinsights.co.uk/#/dashboard?period=1-year&start=2020-01-01&&_k=pmxsu9
33. Energy Transition Commission. April 2021. Making the Hydrogen Economy Possible: Accelerating Clean Hydrogen in an Electrified Economy. https://www.energy-transitions.org/clean-electrification-and-hydrogen-can-deliver-net-zero/

The prices of blue and grey hydrogen, on the other hand, are predicated on the assumption that natural gas markets will remain cheap and stable. Recent hikes in gas prices however mean that the cost advantage of low carbon blue hydrogen is lost.[34] For example, in October 2021 grey hydrogen was £6/kg, while the price of green hydrogen remained a constant £3.39/kg.[35]

Blue hydrogen was even more expensive than grey hydrogen because of the additional cost of carbon capture, which adds around 10% for fuel costs and a doubling of operational costs for the transport and storage of carbon.[36] Following Russia's invasion of Ukraine, European green hydrogen prices reached cost parity with grey hydrogen without a carbon price.[37]

Capital expenditure is also a considerable cost component of green hydrogen, albeit a much smaller one than the power price. Estimates reveal that the cost of electrolysers are expected to drop in price as more are deployed due to economies of scale.

Proton Exchange Membrane electrolysers, for example, were 1100-1800$/kW in 2019 and are expected by ITM Power to fall to 400-500$/kW by 2030.[38] Unlike fossil-fuel-derived hydrogen (which is a relatively mature technology and therefore unlikely to result in a significant reduction in costs), up-scaling green hydrogen production is expected to lead to big drops in capex as the emerging technology matures.[39]

Driving down cost with policy

While the horizon for cost reductions in green hydrogen looks promising, establishing a hydrogen economy in the UK will only be met through targeted policy. Effective policy can guide and stimulate initial deployment to achieve scale and enable huge reductions in cost, and develop local supply chains, as we have seen in offshore wind.

It is encouraging to see a 5GW target for green hydrogen by 2030, with an interim target of 1GW by 2025. However, now this ambition must be met with an enabling policy and regulatory environment. To date, government have been slow to announce key policy decisions which are needed to give certainty and unlock future pipelines of green hydrogen projects, such as the revenue support that would create bankable projects that can attract investment and enable rapid deployment.

Failing to enact the necessary policy changes for green hydrogen in the 2020s could result in the UK losing out on this opportunity to countries with robust electrolyser-specific strategies, as it did with onshore wind in the 1980s. In the 1980s the UK was well placed to lead global development of wind turbine manufacturing. However, policy failed to provide a framework for investment, and resulted in wind turbine manufacturing moving abroad to countries like Denmark (who saw wind power as an alternative to fossil fuels following the energy crisis of the 1970s).[40] During this period, Denmark seized the opportunity by setting up the conditions that allowed small wind turbines to succeed in the market (that otherwise would not have been economically viable), thereby giving it the necessary boost to kickstart the wind turbine industry. Establishing the right conditions is therefore a prerequisite for any economy and the Danish example shows that supply-chains are developed around these first movers.

To stop history from repeating itself, RenewableUK has highlighted several enabling actions to drive the green hydrogen revolution. Despite the welcome updates announced in the Energy Security Strategy, industry still wants government to go further and faster, and to put green hydrogen at the heart of its strategy. Laying the necessary foundations today could enable the cost of green hydrogen to fall to £2/kg by 2030, and less than £1.50/kg by 2050.

34. UK wholesale natural gas price moved from 50p per therm April 2021 to 450 pence per therm in December. ICE. UK Natural Gas Futures. https://www.theice.com/products/910/UK-Natural-Gas-Futures/data?marketId=5253318
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ENABLING ACTIONS TO UNLOCK THE GREEN HYDROGEN REVOLUTION

1

Create a green hydrogen roadmap to deliver the 5GW target.

Long-term commitments to renewable technologies can encourage long-term confidence needed to drive down costs, attract private capital and accelerate the pace of deployment. This is demonstrated in the offshore wind sector whereby a 40GW (now 50GW) target by 2030 has successfully delivered £1bn of investment in 2021 alone.[41] This is why the 5GW target for green hydrogen production announced in April 2022 as part of the Energy Security Strategy is a welcome and much needed development.

Despite this, there is a noticeable absence of detail for how the 5GW green hydrogen target will be met. The Hydrogen Strategy published late 2020 is now out of date, and there is a far more robust roadmap for blue hydrogen than there is for green hydrogen.[42] Government must renovate its strategy to ensure its enhanced ambition lines up with the enabling environment and set out a green hydrogen specific roadmap for how the UK will achieve up to 5GW of green hydrogen.

SOLUTION

- **Design a joined-up strategy** which sets out how the UK will stimulate up to 5GW of green hydrogen by 2030. This should be equivalent to the cluster sequencing strategy designed for blue hydrogen production.
    - Include how electrolysers interface with renewables, such as offshore wind.
    - Onshore wind can enable the production of low-cost green hydrogen given the technologies' wide geographical distribution and high load factors. Set a target of 30GW of onshore wind by 2030, including a supportive planning regime for co-located electrolysers.

41. Norris, Rob. RenewableUK. December 2021. Latest Announcement Takes Investment in New UK Offshore Wind to Factories to New Annual £1bn Record. https://www.renewableuk.com/news/news.asp?id=588906#:~:text=03%20December%202021&text=SSE%20Renewables%20has%20announced%20that,1%20billion%20%E2%80%93%20a%20new%20record.
42. BEIS has set out cluster sequencing for CCUS deployment; CCS Infrastructure Fund; Transport & Storage Business Models; and Industrial; Power CCUS Business Models; and a roadmap for CCUS supply chains. £171mn was awarded under the Industrial Strategy Challenge Fund to nine CCS and blue hydrogen projects.

2

Define a zero carbon hydrogen standard.

BEIS has published its response to its consultation on the design of the Low Carbon Hydrogen Standard (LCHS), which defines the conditions by which hydrogen will be considered low carbon. Notably, any hydrogen production technology that meets the threshold of 20gCO_2/MJ is treated as "low carbon" irrespective of whether it has zero associated emissions or negative emissions.

BEIS's decision to use a single "low carbon" hydrogen label for all certified hydrogen production obscures the premium that many customers associate with green hydrogen as a zero carbon fuel. Using a single label means consumers may not otherwise know the input energy source of the hydrogen, which makes it difficult to link it to quota targets or deliver on ESG strategies.[43]

SOLUTION

- **Differentiate between "zero carbon" and "low carbon" hydrogen in the LCHS.**
    - Include an incentive for green hydrogen producers that not only meet the LCHS, but track downwards toward zero carbon across the life of the plant.
    - Include incentives for flexible electrolysers that operate mainly on renewables and only use grid electricity during periods of below-average grid carbon intensity.
- **Ensure the LCHS's definition** of the role of renewables in electrolytic hydrogen is pragmatic and applied consistently across all government policy and departments.
    - For example, ensure the Department for Transport is aligned with the definitions included in the LCHS to ensure support for a full range of hydrogen in transport use cases.

43. IRENA. December 2020. Green Hydrogen Cost Reduction: Scaling Up Electrolysers to Meet the 1.5°C Climate Goal. https://www.irena.org/publications/2020/Dec/Green-hydrogen-cost-reduction#:~:text=Scaling%20up%20electrolysers%20to%20meet%20the%201.5oC%20climate%20goal&text=Green%20hydrogen%20can%20help%20to,haul%20transport%2C%20shipping%20and%20aviation.
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3

Fully exempt electrolysers from levies to reduce market distortions.

Grid-connected electrolysis can help displace fossil fuels and will become cleaner and cleaner as the power grid reaches zero carbon by 2035. A connection to the grid is essential for early sector growth, as it increases utilisation of the electrolyser, ensures a baseload supply of hydrogen can be met, and improves the business case of green hydrogen production by driving down costs.

The cost of electricity is the most significant cost component of green hydrogen. Grid-connected electrolysers, however, pay environmental levies on top of the wholesale price of electricity which increases the levelised cost of green hydrogen. Under the Energy Intensive Industries exemption scheme, qualifying businesses can claim an exemption of up to 85% of these levies. The government has also indicated that it "intends" to boost this up to 100% in the Energy Security Strategy, although it is yet to deliver this.

Other countries have explored options for exempting electrolysers to make their green hydrogen industries more competitive. Germany made amendments to the Renewable Energy Act which proposes to exempt the power used to produce green hydrogen from environmental levies. This one exemption drops the price of green hydrogen from$7/kg down to $2.5/kg.[44] In the UK, removing final consumption levies completely would reduce energy charges from £55MWh to nearly £16MWh, according to Gigastack.[45]

In principle, electrolysers are not genuine forms of final energy demand; they simply convert one form of energy to another, enabling the end-use to take place. Therefore, they should not pay final consumption levies. This would overcome the risk of double charging whereby if the hydrogen were converted back into electricity, then the genuine end-use would pay final consumption levies on that same energy for a second time. Licensed storage facilities are excluded from final consumption levies on a similar basis, as their primary function is to "consume" electricity in order to store it and then export it back to end-users.[46]

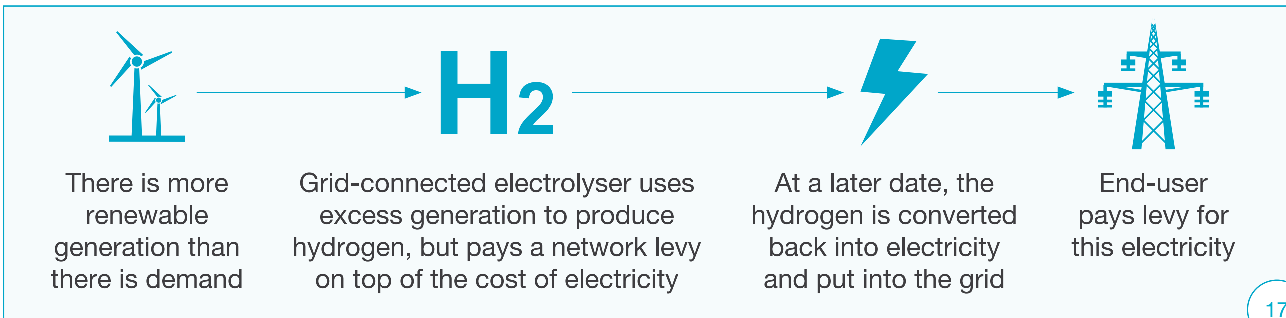
SOLUTION

- **Fully exempt electrolysers** from Final Consumption Levies as an Energy Intensive Industry.
- **Explore options for exempting electrolysers** from other network charges and fees on a logical basis. For example, through locational signals or where it is contracted with a network to provide grid services.

Furthermore, if there is an incentive in the Hydrogen Business Model for electrolysers with a hybrid operating regime to prove "additional" renewable power, it seems counterproductive to then charge developers network fees on top of this for this additional power.

In general, the UK has high levies on the use of electricity, despite electricity moving towards becoming zero carbon due to the greater integration of renewables. At the same time, the UK does not apply any significant levies to the use of natural gas from the gas grid which has no existing solution or near-term plan to become zero carbon. This disparity needs to be redressed, because it inhibits the economic production of green hydrogen which clearly is a form of zero-carbon gas.

Additionally, electrolysers have potential to take renewable power at times of network constraints. This can help alleviate challenges faced by the System Operator that might otherwise only be solved through expensive network reinforcements. To ensure an optimal approach to network investments that delivers value to consumers, it is important to have a cross-sector strategy which ensures, among other things, that green hydrogen production is considered in future network planning.



CASE STUDY
HYDROGEN POWERED VEHICLE

> **By utilising fuel cell technology, the vessel is “zero-emission”**

Longitude was contracted by Caledonian Maritime Assets Limited to undertake the design for a hydrogen fuel cell powered vehicle and passenger ferry, to be the first sea going hydrogen fuel cell ferry in Europe. The vessel is of a Ro-Ro design to maximise overall efficiency.

By utilising fuel cell technology, the vessel is “zero-emission” and will utilise the local supply of green hydrogen. Consideration is also given within the design to minimise emissions and waste during the build and disposal of the vessel. Propulsion options include the Voith eVSP unit with integrated electric motor, again enhancing efficiency.

As the first of its type in the UK, Longitude is working closely with both Class and the UK Flag authority to agree the design philosophy for the novel aspects of the design and ensure the highest levels of safety and reliability for the vessel.

The vessel is being custom-designed around the client’s specific requirements for capacity, crewing, bunkering and maintenance.

4

Tailor the Hydrogen Business Model to support green hydrogen production at different scales.

Green hydrogen projects require financial support in order to reach financial investment decision and begin construction, which would allow scaling up to the levels required to drive down costs of the entire industry. This process can be seen through the success of the CfD scheme, which has led to significant price reductions in the offshore wind sector. BEIS is yet to reach a decision on the final design of the Hydrogen Business Model that will provide this support, but should ensure that:

- Once designed, contracts need to be allocated as quickly as possible, as delaying this would be to the detriment of projects that need support today and the long-term health of the industry.
- BEIS should ensure it does not adopt a one size fits all approach to the design of the business model, but instead be cognizant that there are multiple different hydrogen production archetypes, all with different characteristics and requirements.
- Ensure support is accessible to small-scale electrolytic projects, which are necessary due to the speed at which they can be deployed, and to drive efficiency gains which can be replicated to reduce costs down the line. Evidence from the wind sector shows that simpler schemes, such as the Feed-in-Tariff (FiT), have worked well in the past.

SOLUTION

- **Reflect the different characteristics and requirements** of multiple types of green hydrogen projects in the final design of the Hydrogen Business Model. Avoid a one-size-fits-all approach.
  - Large-scale projects take 3 years between FID and operation, meaning they would be unable to meet a 2025 operational date if contracts are allocated in 2023. To ensure these projects are not implicitly excluded from the scheme, BEIS should develop alternative pathways for projects over a certain size.
- **Ensure small-scale projects can access support** under the Hydrogen Business Model to help facilitate rapid deployment, learnings, and enhanced innovation that further de-risks and reduces the cost of future larger scale developments.
  - Include a 5MW threshold for eligibility (rather than the considered 10MW threshold) because this would result in more eligible projects entering the scheme which will foster more competition between projects.
  - To further facilitate competition, explore options to allow aggregation of joint bids from sub-5MW green hydrogen projects for future rounds.
  - Include an optional stripped-down (i.e. minimal negation) pathway for producers with limited resources applying to the Hydrogen Business Model. This will ensure the mechanism is accessible to projects and organisation of all sizes.

5 **Stimulate demand for hydrogen.**

The "chicken and egg" problem is often cited as one of the major challenges to the development of the green hydrogen sector: that is, how can production be ramped up if there is no demand, and how will demand come forward if there is not a reliable and affordable supply.

Unfortunately, the Hydrogen Strategy places a lot of emphasis on supply but remains relatively quiet on demand-side policy. An effective strategy must have clarity on both demand and supply, and therefore Government must revisit its Hydrogen Strategy to consider a credible suite of demand-side policies to give confidence to investors that there will be off-taker demand.

SOLUTION

- **Actively promote a level playing field** for hydrogen to compete with counterfactual fuels across strategic demand sectors and remove barriers to fuel-switching.

- **Accelerate hydrogen uptake within industry:**

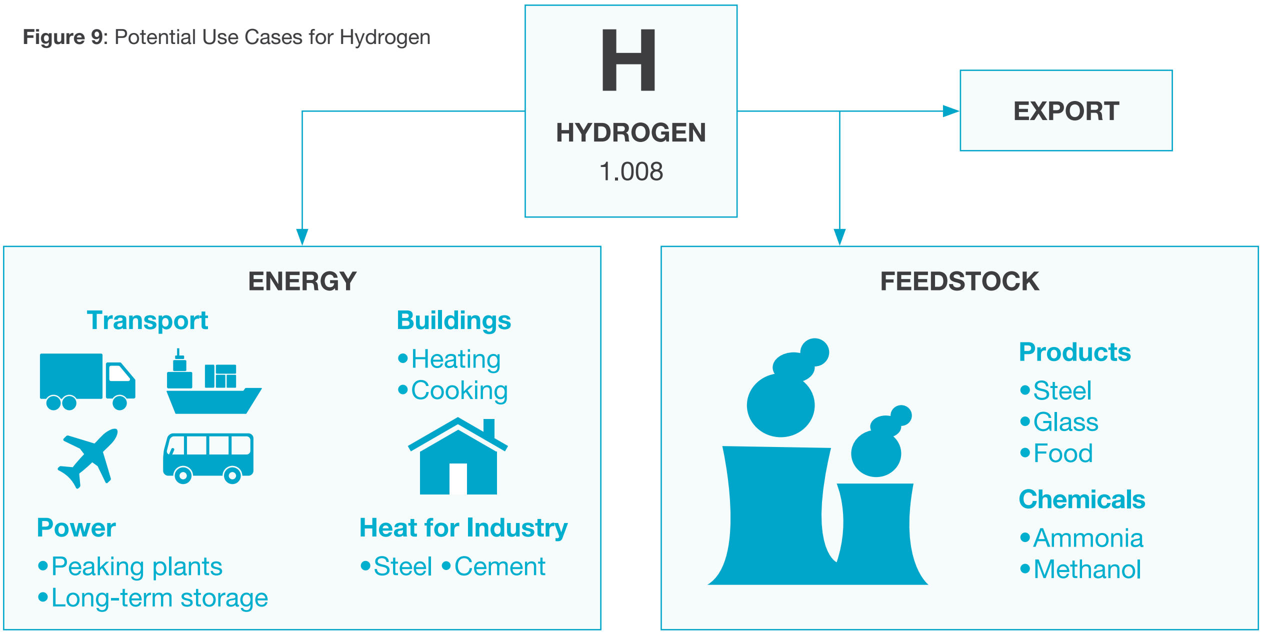
  - Phase out grey hydrogen production facilities from 2027 onwards.

  - Obligate industrial users of hydrogen to ratchet up demand over time to encourage fuel-switching.

- Sunset clause on new non-hydrogen compatible equipment in industry from 2030. **Create a level playing field for hydrogen in transport:**

  - Change the VAT classification for hydrogen as an industrial gas and create a category for hydrogen as a fuel source. Tie the rate of VAT on hydrogen in transport to red diesel.
  - Create a roadmap of strategic locations for hydrogen refuelling infrastructure and introduce options which support the switchover of heavy goods vehicles to fuel cell technologies.
  - Continue development of large-scale hydrogen use in maritime demonstration projects to build confidence in the sector and encourage private investment.
  - Explore options that create a level playing field for renewables to displace fossil fuels. For example, a sunset clause requiring vessels to phase-out fossil fuels by a specified date.

Figure 9: Potential Use Cases for Hydrogen



6

Address planning and permitting barriers to green hydrogen.

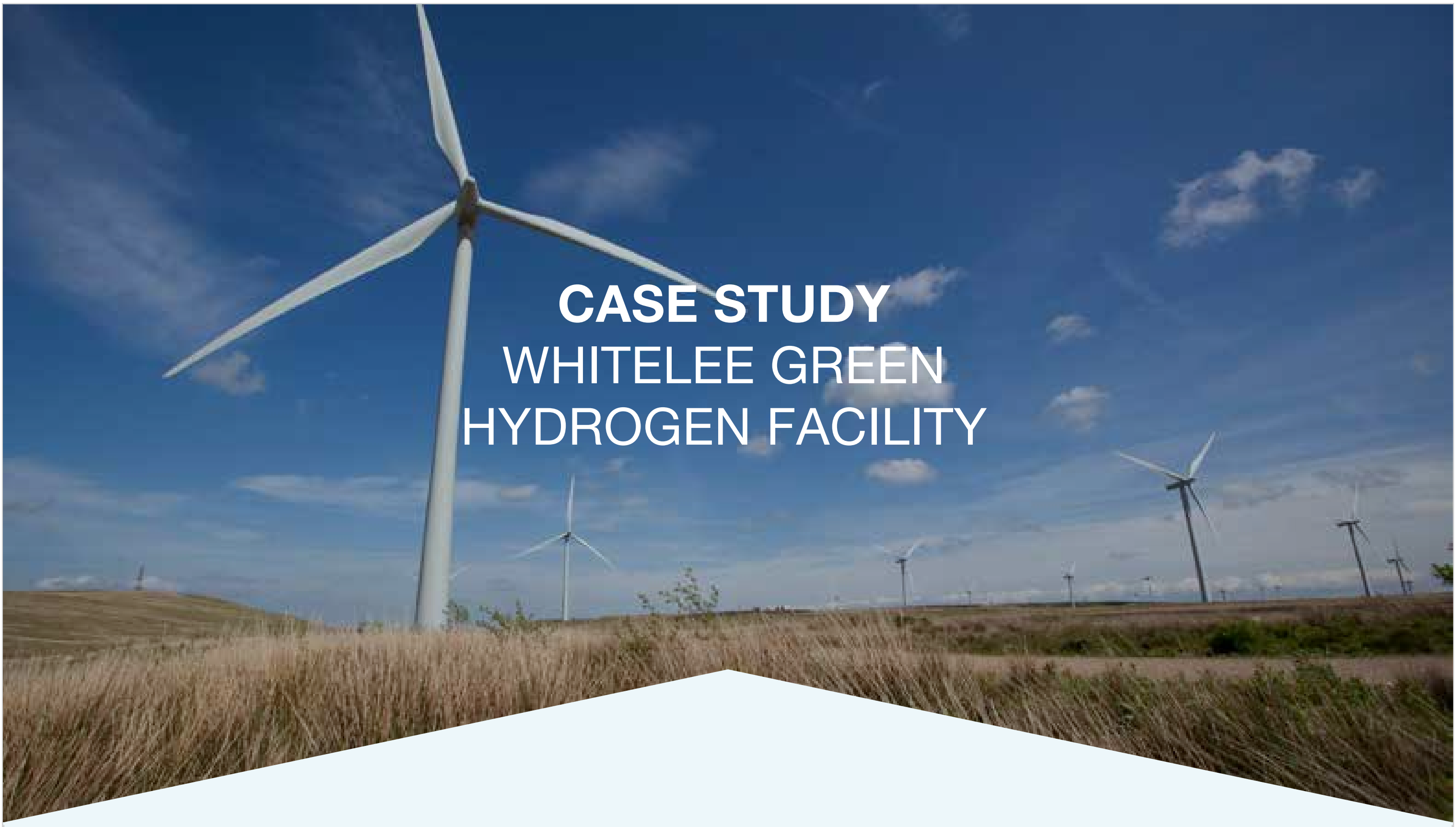
To accelerate the deployment of multiple green hydrogen projects, a simpler and faster national permitting procedure is required across the entire UK. Clear guidance is required on how individual electrolytic projects are consented through the planning system, including how hydrogen infrastructure will be treated in the planning and permitting regime, and how electrolysers interface with a renewables-dominated power grid.

Most hydrogen projects will likely involve technologies which require interaction with several planning bodies and different support regimes. However, these bodies are not able to deal with electrolytic projects in a timely manner to enable 5GW of green hydrogen. There needs to be substantial funding increases for current planning and environmental bodies, including local planning departments, DEFRA, Marine Management Organisation, Natural Resource Wales, Natural England and Health and Safety Executive (HSE).

Organisations responsible for skills and knowledge, such as the HSE, are not being proactive enough in establishing new skills and deployment frameworks, which are required to ensure workers are ready to safely operate future clean technologies. Adding net zero to the remit of these organisations could benefit the pace of development and innovation.

SOLUTION

- **Allocate more resources** to the regulatory bodies (HSE, NRW, DEFRA) responsible for processing environmental permits and planning applications.
- **Add net zero** to the remit to environmental regulators and planning bodies.
- **Provide clear guidelines** on how electrolysers interface with a renewables-based power grid in a way that ensures all devolved governments align their respective planning regimes.



CASE STUDY
WHITELEE GREEN HYDROGEN FACILITY

ScottishPower are expecting to receive planning consent in Q2 2022

ScottishPower's Whitelee green hydrogen project will be one of the UK's largest electrolysers, located at ScottishPower Renewables' Whitelee windfarm south of Glasgow.

The 20MW electrolyser will be part of a green hydrogen production facility able to produce up to 8 tonnes of green hydrogen per day – ready to power industrial uses and heavy transport around the wider Glasgow region. As well as electricity from the existing 539MW windfarm, the project will make use of solar energy from a new solar PV array (up to 40MW) as well as stored renewable energy from a new 50MWh battery.

At the end of the 2021, the project secured £9.4 million of funding through the Storage at Scale competition run by BEIS. ScottishPower are expecting to receive planning consent in Q2 2022 and aim to be supplying green hydrogen by the end of 2023.

7

Create enduring domestic supply-chains for green hydrogen.

History has shown that supply-chains are established around first movers. By not seizing the opportunity for onshore wind, manufacturing was lost to Europe which has meant that the UK has since had to develop systems around local content to boost domestic manufacturing ex post facto, as we are seeing in the offshore wind CfD requirements. We urge government not to repeat this mistake by developing supply-chain plans for green hydrogen to maximise the local content opportunity in the UK.

Supply-chain bottlenecks delay green hydrogen projects from becoming operational and prevent the establishment of a pipeline of projects needed to boost production and encourage end-users to switch. As of April 2022, for example, there are just two electrolyser factories in the entire UK, which are both located in England.

To avert supply-chain bottle necks and rapidly scale up the green hydrogen industry, greater manufacturing capacity of mains equipment (e.g. electrolysers, compressors) is required across all parts of the UK and Governments should work together to spread the benefits of the hydrogen economy across the whole of the UK.

SOLUTION

- **Develop supply-chain** plan for green hydrogen to maximise local content opportunity for the wider UK and to deliver on levelling up agenda, focusing on:
  - Explore ways to scale up local manufacturing of main equipment (i.e. electrolysers, compressors) equally across the UK. This would reduce reliance on overseas markets and build UK-based jobs.
  - Continue support for research & development of green hydrogen systems and equipment to drive efficiency improvements.

8

Update regulations to encourage green hydrogen retrofit.

The current regulatory landscape for gas was designed for a system based on fossil fuels. As a result, there are multiple legacy regulatory barriers that hinder the deployment of hydrogen projects and its uptake in end-use sectors. Not addressing these legacy barriers may perversely incentivise consumers to use fossil fuels rather than green hydrogen.

Green hydrogen and electrolysers can provide a range of services to the electricity system, as noted above. But the regulatory framework relating to co-location of generation with demand or storage, interaction of different support regimes and the interface for electrolysers with the wider electricity system, is not fit for purpose.

Government should ensure the current regulatory framework facilitates a level playing field for the mobilisation of green hydrogen deployment by addressing some of the barriers identified by RenewableUK.

SOLUTION

- **Introduce a process** allowing Ofgem (and LCCC) to provide a conditional approval on ROC (and CfD) accredited site when it is being altered (with an electrolyser and other flexible technologies) to avoid risks faced by developers wishing to add green hydrogen and avert capex write off.
- **Build on the existing co-location guidance** for ROC, CfD and FiT projects to include guidance for retrofitted electrolysers, including how multiple subsidy regimes interact (i.e. projects with both a power CfD and Hydrogen Business Model).
- **Work with DEFRA** to create an easier route to market for renewable hydrogen via the Medium Combustion Plant Directive (e.g. include blending within a variable band so a site can use between 0-20% on an alternating basis without needing a new permit).

9

Unlock strategic infrastructure.

Long-term storage

The UK's existing gas storage capacity remains relatively low at 16TWh. This predominately due to the closure of Centrica's Rough gas storage facility that used to hold over 70% of the UK's gas reserves.

With natural gas prices soaring and supplies dwindling, it is becoming increasingly clear that the UK needs to wean itself off from natural gas, diversify its energy supply and have reserves at the ready. Large-scale hydrogen storage and interconnection with the European hydrogen backbone could fulfil this role.[47]

This sentiment is captured in BEIS's recent announcement that it intends to design a business model for hydrogen storage and transport infrastructure by 2025. However, its strategy for hydrogen storage remains undeveloped. Significant time and capital will be required to develop and commission long-term storage, so there is no time for delay to have projects online by 2030.

Hydrogen blending and 100% hydrogen backbone

As stated in the government's response to the Hydrogen Business Model consultation, blending is needed as demand-sink for producers that face volume risk. To ensure this role is fulfiled, government must make a decision on permitting a 20% blend of hydrogen into distribution networks by 2023 at the latest. Blending hydrogen into the gas grid with existing natural gas can is a relatively quick win to help mitigate demand risk while the number of available end-users grow.

Energy systems tend to adapt over time as the market evolves, and therefore blending is synergetic with a 100% hydrogen backbone – this refers to a dedicated hydrogen pipeline connecting electrolytic production with clusters of industrial demand and hydrogen storage locations.[48] Hydrogen will initially be pumped into the gas network as a blend, and over time it can be injected into the backbone.

Dedicated hydrogen infrastructure can integrate large volumes of renewables, create cross-border markets for hydrogen and decarbonise large clusters of industry. Our view is that support should be provided to facilitate the deployment of a UK-based 100% green Hydrogen Backbone by the late 2020s.

SOLUTION

- **Create a robust strategy** for large scale storage, including a consideration of hydrogen storage and its interaction with renewable energy sources and pipelines.
- **Accelerate removal of barriers** to gas network access through:
  - Promoting blending of 20% of hydrogen into the distribution gas network to act as a demand backstop.
  - Ensure that blended volumes of hydrogen that are injected into the gas distribution network can receive support under future Hydrogen Business Model allocation rounds.
  - Government support, acceleration of timeframe and no regrets funding for 100% hydrogen backbone to ensure delivery in late 2020s.

47. Several gas infrastructure companies in Europe have set out a vision for a dedicated hydrogen backbone spanning across ten European countries via a 39,700km network by 2040.
48. National Grid's Project Union, for example, would repurpose up to 85% of current gas transmission pipelines to create a 2,000km hydrogen backbone by 2030. Connecting industry from Grangemouth to Southampton and Milford Haven to Bacton.

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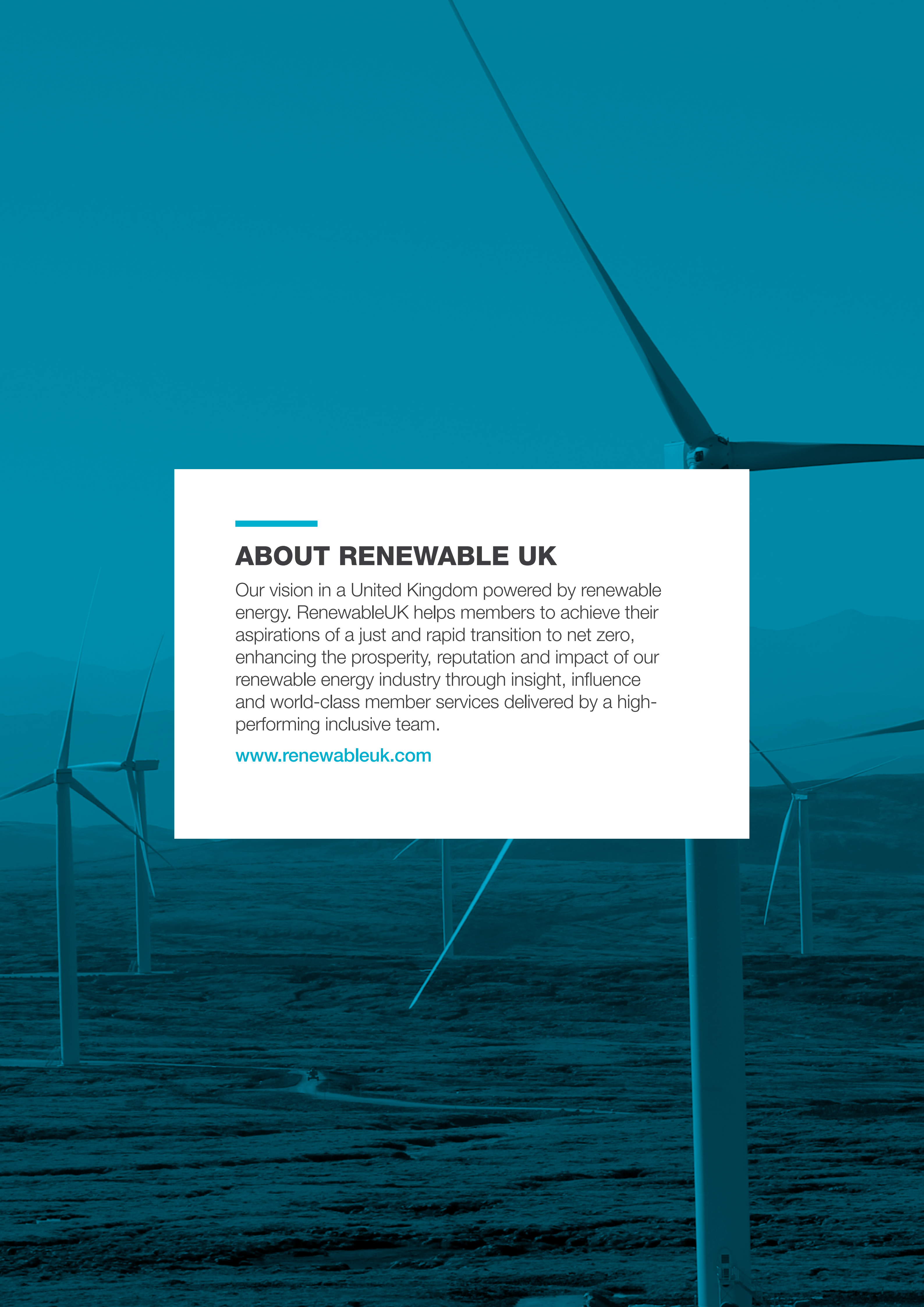

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Our vision in a United Kingdom powered by renewable energy. RenewableUK helps members to achieve their aspirations of a just and rapid transition to net zero, enhancing the prosperity, reputation and impact of our renewable energy industry through insight, influence and world-class member services delivered by a high-performing inclusive team.

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