Hydrogen Electrolyser Study

Reassessing Approaches to Connecting Large Electrolyser Sites: Work Package 3

National Grid Electricity Distribution

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Gutteridge Haskins & Davey Limited CN 05528602
10 Fetter Lane, Level 6
London, London EC4A 1BR, United Kingdom
T +44 203 077 7900 | **F** +44 203 077 7901 | **E** londonmail@ghd.com | **ghd.com**

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1. Introduction

The role of hydrogen as part of the net-zero challenge is now well established. BEIS predicts that up to 250-460TWh of hydrogen could be required annually by 2050, amounting to about 20-35% of UK's final energy demand (BEIS 2021). The UK government is continuing to build on its comprehensive hydrogen strategy as the national and international energy market conditions evolve, and as new gaps and challenges are identified and addressed. With more stakeholders working on building a national hydrogen supply chain, and with up to 20GW[1] of potential hydrogen projects in the pipeline by 2037 (BEIS 2022a), the UK is well positioned to meet the Government's 10 GW of low-carbon hydrogen production target by 2030, if policy incentives are sustained and further developed. Half of this hydrogen is expected to be produced via electrolysis (HM Government, 2022), which means adding a sizeable amount of demand to electricity networks. Furthermore, there are signs in the marketplace that green (electrolytic) hydrogen will reach cost parity with blue hydrogen produced from natural gas with CCUS by 2030 or earlier given the volatility in gas prices. The case for electrolytic hydrogen production and use (Power-to-X) is even larger today than when the UK hydrogen strategy was first published, suggesting increased demand for grid connections over time.

Given that the UK strategy has a timeline of activities to build out the UK's Hydrogen Supply Chain, much of the focus to date has been on creating a commercially viable Hydrogen Business Model, for early market creation to scale up production and to lower costs. Some of the key projects, policy actions and decision points are highlighted in Figure 1.

While hydrogen is being considered across all energy demand sectors; heat, power, transport, and industry, the trajectory for how the demand for hydrogen will grow across different sectors is somewhat uncertain.

Hydrogen is predominantly considered for hard to abate sectors (such as high grade heat processes, direct reduced iron for steel production, HGVs etc.). In the short term, industrial processes involving natural gas for heat are the most likely to see conversion to hydrogen due to the relative ease of retrofitting. Therefore, a large proportion of the 10GW of hydrogen production targeted by 2030 is expected to be directed to these sectors. For transport applications, the demand is currently less certain. As the energy system is increasingly electrified, even with limited development of a hydrogen gas grid, hard to abate sectors that are difficult to electrify will need hydrogen to decarbonise. National Grid Gas Transmission is planning to link the UK's four industrial clusters, with £1 billion investment to repurpose around 25% of the current gas transmission pipelines under Project Union, and support the establishment of carbon capture, utilisation and storage (CCUS) in four industrial clusters (National Grid 2021).

In terms of the electricity network implications of a growing hydrogen economy, further work is needed to better determine both the impact of hydrogen on electricity networks and the value of hydrogen for enabling energy flexibility in a network that needs to be decarbonised by 2035.

The extent to which hydrogen will be used for long term energy storage is unclear but the government is looking to develop its strategy on this by mid-2020s, followed by the decision on whether hydrogen will be used to heat buildings by 2026. Therefore, the extent to which hydrogen infrastructure develops, particularly pipelines, is currently uncertain. The key indicator for this will be the pathway that is taken for decarbonising residential homes, whether it will be heat pumps or hydrogen boilers, which may be determined on a regional basis. If hydrogen is used for heat in a region, then the existing natural gas network will be converted to hydrogen. Prior to such a decision the Government will be making a decision on hydrogen blending up to 20% by winter of 2023 (ENA 2021), to create demand for producers to scale up production and hence lower costs, and as a step in looking at hydrogen in the grid.

[1] The total project size is based on potential deployment according to planned and developed projects, with many still awaiting final investment decisions or government funding. BEIS notes that 41 Applications were received through NZHF and HPBM plans to make offers Q1 2023 (BEIS 2022a).

This report is the summary of a study assessing the implications of connecting electrolysers to National Grid Electricity Distribution's (NGED's) network to 2030. The study was split into three distinct work packages, with the key objectives of each work package outlined below.

Work Package 1

- An assessment of the potential opportunities enabled by electrolyser deployments on electricity networks, especially grid service provisions, such as grid constraints management and long duration energy storage services, as well as the system level challenges electrolyser connection can present to a DNO.
- An understanding on the status and location of hydrogen production projects in the UK and the implications for connecting electrolysers to electricity networks, with focus on NGED's network, based on the developers needs and challenges, as well as hydrogen policy requirements and mandates from the Government.
- A high-level assessment of network implications of electrolyser connections with key challenges identified

Work Package 2

- A more focussed, regional assessment of implications of electrolyser connection to NGED's network in the South Wales Industrial Cluster (SWIC). This assessment was based on potential demand for hydrogen from key manufacturing industries with high emissions that were most likely to switch to hydrogen. Based on the potential demand and potential substation connection points, we looked at any potential network constraints that can impact developer's decisions to pursue electrolytic hydrogen projects. This work package was initially designed with the objective of obtaining information and data on demand for hydrogen at one or more sites, to present a methodology of assessment that can inform NGED on potential impact of electrolyser connection on the network and hence NGED's strategic plans on network reinforcements. Without key electrolytic hydrogen projects or case studies to use in this work package, we decided to focus on potential demand for hydrogen arising in the South Wales Industrial Cluster as it is the largest industrial hub within NGED's network area, and second most emitting industrial hub in the country, accounting for approximately 15% of emissions in the UK.

The key findings from WP1 and WP2 are summarised in this third work package, with focus on the opportunities enabled by electrolytic hydrogen production (i.e. the key network challenges it can address), with the main gaps in knowledge and projects highlighted. These findings are to help inform any strategic planning work on reinforcements of NGED's network. We conclude with a set of recommendations for key actions and further work needed to fill the gaps to better determine the value of Power-to-X for DNOs, as well key policy actions that can help realise this value, while incentivising grid connection of electrolysers.

For a more detailed assessment of the study undertaken within work package 1 and 2, the reader can look at the relevant reports that can be **accessed here: Add link**.

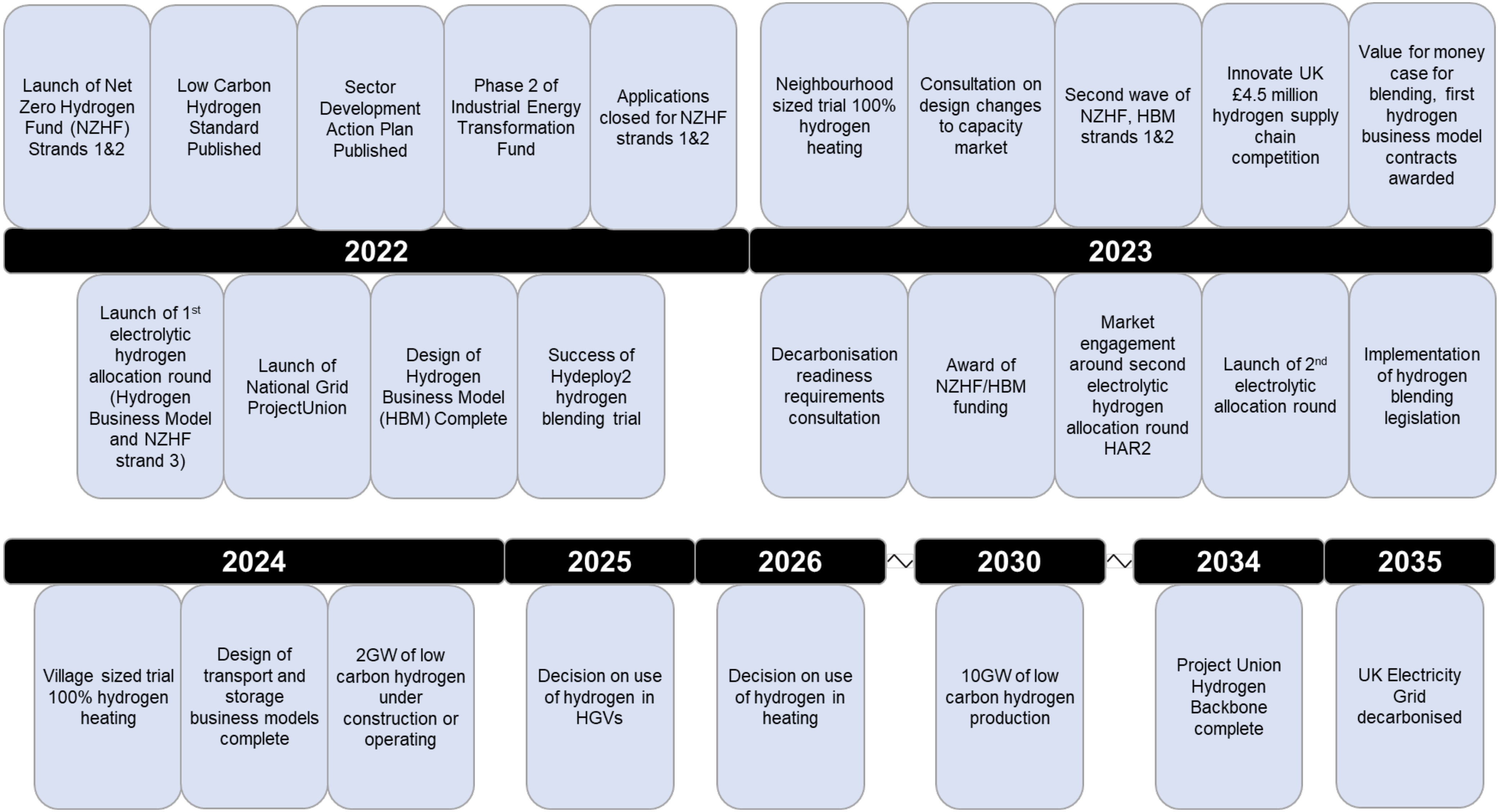

Figure 1: Key UK government initiatives, policy actions and decision points and major projects milestones.

2. Key Network Challenges

There are several challenges the UK's electricity network is experiencing, which will be exacerbated over time with increasing penetration of renewable energy sources (RES) that create an increased need for flexibility due to their intermittency of supply. Some of these key interlinked challenges are:

– **System Integration Challenge of Renewables:** With 24-50GW of onshore wind, 73-100GW of offshore wind and 58-90GW of solar required by 2050 to meet the UK's net-zero target by this time (BEIS 2022b). There will be the increasing challenge of finding grid capacity for connection as well as managing the variability of the supply from these renewables. Hydrogen can be produced from excess electricity supply, stored, and used when and where needed.

– **Electricity Network constraints:** Traditionally the grid has been built with unidirectional energy flow from centralised generators in mind. This conflicts with RES development as RES resources are widely distributed and cannot be concentrated around the existing transmission network meaning existing infrastructure cannot deal with this change in the energy sources and their locations. This results in increased levels of constraint along distribution networks which are now dealing increasingly with bidirectional power flows. This can be managed also via the production of hydrogen in addition to other approaches.

– **Grid Integrity Management:** Many ancillary services traditionally provided by fossil fuel generation such as inertia and black-start capabilities are more difficult to provide via renewables such as wind and solar. Hydrogen is more capable of providing these services as a hydrogen plant would function very similarly to a current gas turbine plant.

– **Balancing Supply and Demand:** The inherent variability of wind and solar power creates a need to balance supply and demand, a challenge that is exacerbated over time with increasing penetration of renewables. Therefore, long duration or seasonal, high-capacity energy storage, enabled by hydrogen, becomes more vital.

– **Decarbonisation of Electricity Grid by 3035:** One of the single largest challenges facing the grid, this encompasses all of the challenges outlined above due to the timeframes in which they have to be addressed, particularly those around the intermittent nature of renewables and long-term energy storage.

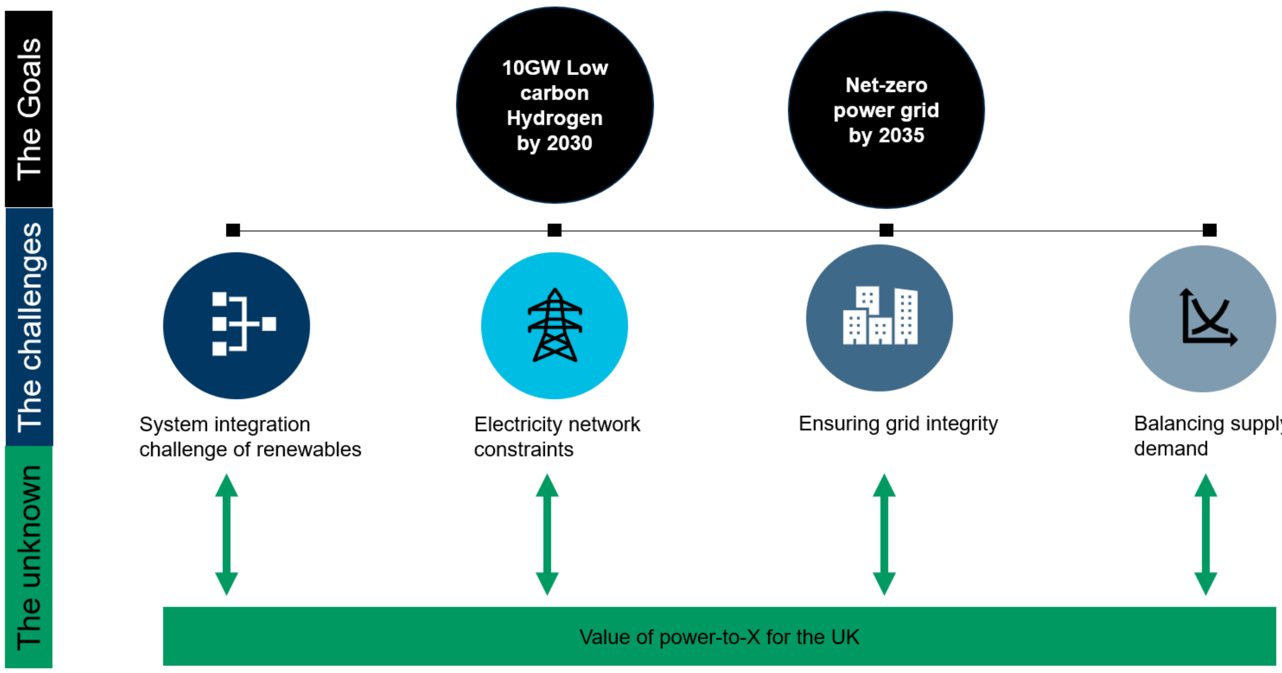

Figure 2 ***Key network challenges***

All these challenges apply across NGED's network, with increasing number of constraints predicted in all Distribution Future Energy Scenarios. NGED's Best View scenario shows that network constraints can increase significantly in all areas between 2025 and 2032 with South Wales being the area with highest increase.

2.1 How can hydrogen help address key network challenges?

Both alkaline and polymer electrolyte membrane (PEM) electrolysers, owing to their operational characteristics, have the capability to provide a variety of balancing and demand side management services.

Through the Power-to-X[2] mechanism, electrolysers can provide grid balancing services including stability, frequency regulation, black start, short term reserve, fast reserve, upgrade deferral, energy arbitrage, capacity firming, seasonal storage, voltage support and islanding. However, currently batteries are predominantly used in most markets for balancing services, especially those with short activation times. Based on their fast response (seconds) and lower cost, the dominance of batteries in the Frequency Containment Reserve (FCR) markets is expected to continue, making it very challenging for electrolysers to compete with batteries in the provision of Frequency Restoration Reserve (FRR).

The major areas in which electrolytic hydrogen production (Power-to-X mechanism) can potentially enable network benefits for NGED are constraint management, seasonal storage and the Flexibility Services which are discussed further in the sections below.

Electrolytic hydrogen production, using surplus renewable energy at times of low demand and high renewable energy supply, can avoid shutting off wind generation (curtailment), which cost the taxpayer £507million in 2021 (Renewables Now, 2022). There is much uncertainty in the level of electricity curtailment expected by 2050 but some estimates showing that wind curtailment alone could cost £1 billion per year by 2025 (Renewable Energy World, 2021) and all FES scenarios show a significant increase by 2030.

2.1.1 Constraint Management

NGED's network is expected to experience an increasing number of constraints in all National Grid ESO Future Energy Scenarios across its network. NGED's Best View scenario shows that network constraints can increase by about 40% in the Southwest, double in East and West Midlands and more than quadruple in South Wales between 2025 and 2032 alone. NGED currently has five different ways to alleviate the projected constraint: Conventional Reinforcement; Strategic Reinforcement; Operational Mitigation; Load Management; and Flexibility Schemes. Electrolytic Hydrogen production can be part of all these schemes and could be used to lower network reinforcement costs in the last three schemes above.

The National Grid ESO (2022) projects the total curtailment in the UK within their four scenarios: 45TWh in the Consumer Transformation scenario, 37TWh in Leading the Way, 21TWh in System Transformation and 4.5TWh in the Falling Short scenarios by 2030.

Hydrogen could potentially help manage constraints via operational mitigation, load management and flexibility schemes particularly where the constraint is with generation headroom. However hydrogen could also contribute to the need for conventional and strategic reinforcement, particularly because the FES scenarios [**2.1.1 WP1**] only consider a limited amount of electrolyser deployments, particularly by 2030, and therefore are not widely accounted for in the constraint estimates.

Understanding the value that electrolysers add to network constraint management and for lowering hydrogen production costs depends largely on the capacity load factors (assuming zero cost of otherwise curtailed electricity) and the Capex and Opex of the electrolyser. Curtailment of renewables due to network constraints

[2] Here X denotes power, such that hydrogen is produced using electricity, stored and reconverted to power when needed through a fuel cell or combustion process (e.g. future combined cycle gas turbines using hydrogen). X can also denote hydrogen gas stored and used in non-power applications (such as fuel for transport and gas for heat).

leads to extended periods of “zero marginal cost electricity”, which in turn could make lower load factors attractive to electrolysers.

2.1.2 Energy Storage & Peak Management

Hydrogen is considered as a competitive solution for long duration energy storage, specifically for seasonal fluctuations in energy supply and demand (for both electricity and gas networks). In the UK electrolytic hydrogen production is increasingly being considered to capture this value stream in the long run, with increasing penetration of renewables and decreasing volume of strategic gas reserves. Companies looking at producing hydrogen at large scale are starting to look at the potential for large scale geological hydrogen storage (salt caverns) in the UK. This could have implications for where electrolysers will be placed in conjunction with renewables unless a hydrogen gas network is built.

Hydrogen can also deliver clean firm power generation and peaking power, which will have increasingly valuable functions within the energy system as we transition to more renewables. The use of hydrogen in gas power plants (Combined Cycle and Open Cycle Gas Turbines) is considered for peaking plants to complement the deployment of renewables. In fact, UK based companies are already making peaking plants that can be converted from using natural gas to hydrogen. Hydrogen is expected to start fulfilling this role between 2030 and 2035. Hydrogen storage from excess renewables and its use in peaking Combined Cycle Gas Turbines (CCGT) to meet peak electricity demand is shown to enable greater cost savings in the transition to a net-zero energy system in the UK (AFRY 2022). The role of hydrogen storage and its use for peaking power is further highlighted with another study showing up to about 80% cost reductions with 10 TWh of hydrogen storage and replacement of gas-fired peaking plants with hydrogen ones, when compared to having only battery storage (Aurora Energy Research 2022).

While battery storage is increasingly being deployed to manage network constraints and to enable electricity flexibility, there is a need to better understand the economic and temporal value of electrolytic hydrogen production (Power-to-X) across different network regions. In this regard, further work is needed to understand the impact of electrolytic hydrogen production not only as part of NGED’s strategic reinforcement assessment and strategy, but for the future electricity system as it is decarbonised to 2030.

2.1.3 Flexibility services enabled by hydrogen

Distributed hydrogen electrolysers provide huge potential for demand side grid management. Some of the products in the currently available ‘Flexibility Services’ suite are offered, and some are under trials by the DNOs. The full extent of the role they will be able to play in providing grid services will depend on the policy focus in this area. The government consultation, the Review of Electricity Market Arrangements; results pending early 2023 (REMA 2022), discusses that DNOs could begin assisting the Electricity System Operator in managing grid services. Assuming the market develops as such, electrolysers will be capable of ramping up and down production within certain limits relatively quickly and so would be able to offer frequency control and assist the balancing mechanism from the demand side. If this becomes part of electricity market the improvement in the ability of electrolysers to respond to market price signals and network management instructions would be incentivised further by developers. This would require communication infrastructure to be in place between NGED’s network control centres and a large array of smaller demand and supply side assets as well as hydrogen electrolysers. Such a deployment would put higher peak demand on some of NGED’s substations as these distributed sites would need to build excess capacity to account for running with a lower capacity factor.

The ability for electrolysers to offer flexibility services will also depend on the regional distribution of electrolytic hydrogen projects. As much of the demand for hydrogen in the near term (before 2030) will be from industrial users, which tend to prefer onsite production of hydrogen to avoid additional cost of hydrogen distribution, the ability of electrolysers to offer flexibility services will be somewhat limited, as sites where these are deployed may not necessarily have renewables or associated network constraints. This is assuming that some of the electrolysers producing hydrogen for industrial applications can also be used for grid balancing services under certain contractual agreements. With hydrogen blending or a hydrogen gas network, however, the sites of electrolyser production will be more distributed – enabling greater opportunity for locating electrolysers in regions where constraints can be mitigated.

Table 1 below provides a comparison of different technologies (systems) for the provision of grid services. Electrolysers, through Power-to-X (Ptx), can be used for almost all services, depending on how it is integrated, although the maturity is considered low as such applications of electrolysers are still at demonstration stage.

Flexibility will be of paramount importance to DNOs, and the relevant DSOs (Distribution System Operator). DSOs are involved in the process of maximising the efficiency of the grid and are responsible for distributing and managing energy from the generation sources to the final customer.

One flexibility service which hydrogen electrolysers can provide is Sustain - Peak Management. This flexibility service is delivered at times when demand for electricity is at its highest, which can lead to constraint issues on the network (e.g., overloading a transformer). The relevant DSO will pay the operator of an electrolyser to stop utilising electricity to alleviate the constraint.

Another service which hydrogen producers could partake in is Secure DSO Constraint Management. This occurs when there is an issue with an area in the network, for example a transformer undergoes a fault and therefore the other transformer is at risk of being overloaded. This would involve the hydrogen producer turning off their system to reduce strain on the network.

Hydrogen producers can also partake in the Exceeding Maximum Capacity Import flexibility service, which is a peer-to-peer service provided in agreement with DNOs. This is when the hydrogen producer will reduce its Maximum Import Capacity and sell this to another consumer so they can increase their own import by the same amount in agreement with the DNO. This is currently being investigated by a DNO but doesn’t have widespread commercial implementation.

Offsetting is another flexible service which hydrogen producers can partake in. Offsetting is the principle of flexibility service in a constrained area where there is a limit to the amount or generation or demand in that section of the grid. Matching of local demand with local increase in generation will have zero net impact on the network and yet allowing more generation to be exported at agreed times. Hydrogen electrolysers can increase their demand to match local increase in generation at times when this imbalance is predicted to arise.

Building on NGED’s efforts and initial successes in flexibility services offerings, to allow developers to plan around more easily delivering them more is required to enhance and improve the robustness of existing offerings as currently engagement is predominantly by existing market participants and focuses on procurement of demand reduction. Improvement in this area would reduce the short-term reinforcement needs of the network while still enabling the expansion of electrolytic hydrogen capacity alongside renewables. How this market is potentially shaped will depend on the Review of Electricity Market Arrangements (REMA) results that should be published early 2023.

Grid Service provision	Pumped Hydro Storage	Compressed Air Storage	Liquid Air Storage	Thermal Energy Storage	Flywheel Energy Storage	Li-ion Batteries	Supercapacitors	Redox Flow Batteries	PtX	Reversible Hydrogen Fuel Cells
Stability	✓				✓	✓	✓	✓	✓	✓
Frequency Regulation	✓	✓	✓		✓	✓	✓	✓	✓	✓
Black start	✓	✓	✓			✓		✓	✓	✓
Short term reserve	✓	✓	✓			✓		✓	✓	✓
Fast reserve	✓	✓	✓		✓	✓		✓	✓	✓
Upgrade deferral	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Energy Arbitrage	✓	✓	✓	✓		✓		✓	✓	✓
Capacity firming	✓	✓	✓	✓	✓	✓		✓	✓	✓
Seasonal Storage				✓					✓	✓
Voltage support	✓	✓	✓		✓	✓	✓	✓	✓	✓
Islanding		✓	✓	✓		✓		✓	✓	✓
Uninterruptible power supply					✓	✓	✓	✓		✓
Other considerations										
Maturity	High	High	Med	Low	High	Med	Low	Low	Low	Low
Opportunity to reduce cost	Low	Low	Low	Med	Med	High	High	High	Med	High
Lifetime	Long	Long	Long	Long	Med	Short	Med	Med	Med	Short
Roundtrip efficiency	60-80%	30-60%	55-90%	70-80%	0.9	>95%	>95%	80-90%	35-60%	<30%

Table 1: Electrolyser suitability factors

2.2 Examples of European Projects

The value of Power-to-X grid balancing services needs to be tested and demonstrated on the ground. Many project developers are looking to better understand how electrolytic hydrogen production, as a flexible electricity demand, can bring value to a DNO. While some system level modelling work is done to somewhat determine the value of Power-to-X for grid balancing or ancillary services, such as the examples above, the UK needs more on the ground projects testing the use of electrolysers for such services. Some examples of such projects in Europe are listed below.

Hybalance Denmark 2015-2020 –A 15-million-euro project using the dynamic operation of a 1.2 MW PEM electrolyser powered by wind energy to provide grid balancing services. Green hydrogen generated through the scheme will also be used to balance the grid as well as provide hydrogen to industry and transportation. This scheme was successful in showing the viability and flexibility of PEM electrolysers with the plant able to produce 99.998% purity hydrogen while being a bidder in all Danish electricity markets with a reaction time below 10 seconds (European Commission 2020).

Demo4Grid Austria 2017-2023 – A EU project using a 3.2MW Pressurized Alkaline Electrolyser to provide grid balancing services while producing green hydrogen for decarbonising industrial processes. Aims to be commercially viable producing hydrogen under real operating and market conditions. The electrolyser was successfully installed December 2021. The focus was on establishing a business case with the primary conclusion being that hydrogen electrolysers will often need to combine multiple business cases, such as providing hydrogen for industry, hydrogen for mobility and grid services simultaneously (Stamatakis E, et al 2021).

H2 Future Austria 2017-2022 – A flagship European project for generating green hydrogen from renewable energy. Being coordinated by the utility VERBUND, steel manufacturer Voestalpine and Siemens Energy with the intent to use a 6 MW PEM electrolysis system to generate hydrogen for the Linz steel plant and provide ancillary services to the transmission system operator (TSO) Austrian Power Grid. If demonstration is successful at the plant faces challenges with upscaling to the requirements of the steel plant, which could use up to approximately 340,000 tonnes of hydrogen a year (European Commission 2022a).

REFHYNE Germany 2018-2024 – A 20-million-euro project to install and operate a 10MW electrolyser at a large refinery in the Rhineland, one of Germany’s key industrial hubs. This electrolyser will provide hydrogen feedstock to refinery processes to replace existing methane reformers while running reactively to balance the refinery’s internal electricity grid and selling primary control reserve services to the German TSO. Final outcomes of the project have yet to be seen but seem promising enough to have led to REFHYNE 2 (EU Commission 2022b).

REFHYNE 2 Germany 2021-2026 – Aiming to build upon REFYHNE by building a 100MW PEM electrolyser site powered by a mixture of dedicated renewables and grid electricity. With an estimated budget of 149 million euros the hydrogen will be as with REFHYNE 1, primarily supplying the refinery (REFHYNE 2022).

2.3 Network assessment of selected sites in South Wales

To help identify the most optimal site or substation(s) for connecting electrolysers, a methodology was developed in work package 1 based on a set of requirements provided by a project developer. This methodology was intended to help review different substations with a set of specifications collected from the electrolyser project developers upon application for connection. Each site for a given substation gets assessed against a set of criteria using a scoring system, with both network and non-network factors assessed. The objective of this methodology is to streamline the site identification process for project developers and NGED, by providing NGED a better understanding of the factors that are important for electrolytic hydrogen project developers. It is of most value when there is some flexibility on the network connection site.

The criteria scoring and weighting according to their importance to the developers was based on a survey conducted online. The participation was low mainly due to the length of time required to engage many developers and sensitivity around their projects. Therefore, to test and validate this methodology we intended to use it for the network assessment in work package 2 for selected projects. We wished to work with developers to use a real project as a case study for this methodology but could not get consent from those we had worked with during the survey phase. Due to the time constraints wider engagement with the industry to find case studies was not possible. This methodology however has a high potential for aiding the connection design process but needs validation and further refinement before it can be implemented as business as usual. For example, currently it does not include the cost element for the electrolyser site locations such as the cost of connecting infrastructure.

As a result of these challenges, we pivoted towards an assessment of the South Wales Industrial Cluster (SWIC). This cluster will be a key area for hydrogen developments in NGED’s network area, as it is one of the five industrial clusters identified in the UK’s 10-Point-Plan as regions of focus for decarbonisation and economic growth, e.g. job creation. We performed a high-level analysis for a selection of industries to estimate their potential impact on NGED’s network, assuming they converted their processes to electrolytic hydrogen and needed partial grid connection to ensure continues supply of hydrogen. As we were not able to obtain data on the type and amount of fuel uses for the industries in the SWIC we identified three high emitters and used their CO_2eq emissions from estimated natural gas consumption to calculate their potential energy and hence hydrogen demand. The industrial corridor from Pembroke Docks to Port Talbot in the East was specifically chosen for identification of the industries to focus on as shown in Figure 2. With the industries analysed: Solutia UK and Liberty Steel (Newport), Rockwool and Tata Steel (Port Talbot).

Our investigation showed that there is a high variance in potential demand for electricity for hydrogen from industry to industry. This is because of the high variety of processes used even between two locations in the same sector. This makes it difficult to generalise the impact of industries converting to hydrogen on NGEDs network using this method. Due to this variance reducing the communication friction between industries hydrogen developers and DNOs will be key to enabling effective widespread assessments of the future impact of hydrogen electrolysis.

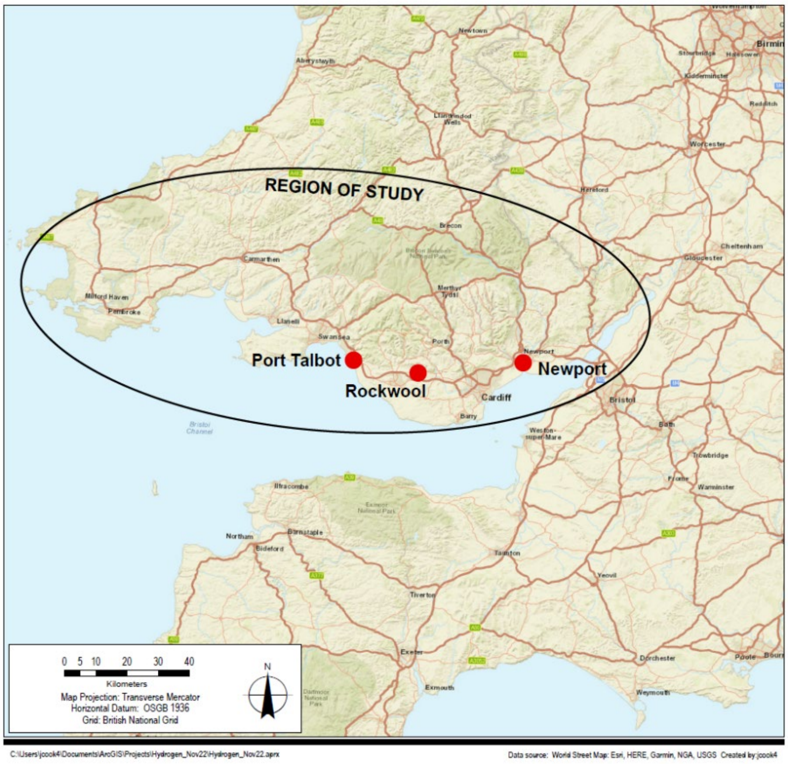

Figure 3 Depiction of area of study and key locations

This investigation highlighted the current difficulty with acquiring data from stakeholders on the network. NGED is in a strong position with its membership within SWIC to facilitate the creation of a platform to improve communication and reduce the friction between industries, developers, and the network operator. This would have the objectives of enabling the collection and sharing of anonymised data enabling more efficient decarbonisation pathways for industries and network reinforcement plans for NGED by allowing greater cooperation between existing industries, outside developers and NGED. This would particularly help NGED mitigate the uncertainty caused by not knowing the preferred decarbonisation pathways of industries currently connected to the grid.

2.4 Key challenges relating to grid connected electrolytic hydrogen production

While hydrogen presents opportunities for network operators, many challenges abound. These challenges, as identified in WP1 and WP2, act as barriers to grid connection of electrolysers, dissuading project developers from investing in such projects and preventing their uses for DNOs to be potentially realised. We have identified some common themes, categorised below as *Regulatory, Technical & Economic, and Project Siting and Network Planning Challenges*

2.4.1 Technical & Economic Challenges

Developers have reported having issues securing connections and challenges in identifying grid capacity to access. Many of the available load demand sites on the network are being taken by battery energy storage projects, and some cases EV charging or heat pump connections. Any synergies with electrolyser and battery co-location needs to be further investigated. Most battery storage operators prefer to have flexible contracts that do not constrain their level of operation.

Developers foresee increasing challenge in finding capacity and connection limitations, with high cost and competition for sites. The forthcoming implementation of Access and Forward-Looking Charges Significant Code

Review (Access SCR) could have favourable implications for the developers in terms of reinforcement costs and alleviate some of the economic challenges.

2.4.2 Regulatory Challenges

Low Carbon Hydrogen Standard

The Government's Low Carbon Hydrogen Standard (LCHS): 20g CO_2 equivalent per MJ LHV Hydrogen or less, is potentially a barrier for grid connection of electrolysers today. Those projects seeking government funding and development support need to adhere to this standard. Given most of the major projects will be seeking government support and will depend on government funding to go ahead, the CO_2 intensity of the network electricity will be an important factor for those looking at network connection. Currently the future projections for the carbon intensity for medium and long term are not available. This data is critical in the assessment of the economic case for projects and therefore this is an area for future development. Also, forecasts for more localised areas geographically would be greater value to the project developers.

Today, electricity from the grid would not meet the threshold of this standard in most regions on most days in the UK. It is projected that by 2030 the CO_2 equivalent emission intensity would be around 90gCO_2e/KWh (324 gCO_2e/MJ) (BEIS, 2019). Therefore, developers would not be able to access government funds under the Hydrogen Business Model, if they were exclusively connected to the grid, in many areas of the UK (including NGED's network region). This means many projects will need to have agreements to use low carbon energy sources (i.e. renewables or nuclear) to ensure the hydrogen produced has a CO_2 intensity below the threshold set out in this standard. In fact, any project that applies for these funds is subject to an additionality requirement, which is a criterion put in place to uphold the principles of the LCHS. This additionality criterion requires the electricity used for hydrogen production is from new low carbon electricity generation, such that low carbon electricity is not diverted from other users, avoiding negative impacts on wider decarbonation" (BEIS, 2022). Under this additionality criterion, projects are assessed against preferred sources of energy (BEIS, 2022): new purpose-built, curtailment of existing assets, extension of the life of existing assets and recommissioned assets.

For grid connection to be feasible under the additionality requirement, there will need to be Power Purchase Agreements (PPAs) between renewable energy source project owners and electrolyser project owners. The additionality criterion insists that new renewables are used due to demand for PPA-based power supply is currently being significantly higher than supply, therefore, green hydrogen producers will be competing in an already congested market. Power purchase agreements for 24/7 clean energy are one way in which this challenge can potentially addressed, but these are still extremely rare making it difficult for green hydrogen producers to compete.

Lack of comprehensive and joined-up network-infrastructure building programmes

With the lack of adequate hydrogen storage and transport infrastructure currently, the production of hydrogen needs to be closer to the off-takers and therefore developers have very limited flexibility in the choice of locations for siting electrolyser plants. The prevailing network capacity shortage issues and the high costs of network reinforcements and long lead times pose significant issues for the developers.

Currently there isn't a clear picture of demand and supply constraints and how this is likely to change over time. In areas such as South Wales, where the government is looking to decarbonise large industrial clusters, there needs to be a more comprehensive infrastructure building programme to address constraints and support development of green hydrogen projects. Therefore, BEIS needs to be more joined up with NGED and other DNOs to ensure there are no barriers for the UK to meet its electrolytic hydrogen production target of 1GW by 2025 and 5GW by 2030. In the long term to ensure security of supply for industrial users, grid connection will be required. While off takers are linked to hydrogen production projects to qualify them for BEIS funding, further policy drivers are needed to scale up demand and hence all supply chain elements.

2.4.3 Project Siting and Network Planning Challenges

Addressing the grid connection needs of hydrogen prosumers (producers that also consume the energy)

Many project developers have highlighted that it is a slow process to identify sites that are feasible to connect to on the network, and costs are very high. Many developers are looking to have access to information, targeted for the needs of project developers, on where the best electrolyser connection sites are. Such site selection or optimisation criteria will benefit developers if made accessible online with NGEDs other network datasets and tools.

The siting of electrolysers needs to consider a range of factors to maximise value to the energy system and the hydrogen producers and prosumers (those producing and using the hydrogen). Today, the optimal sites for locating electrolysers from the network connection perspective is still highly uncertain for electrolytic hydrogen production projects and project developers.

Given the various needs of project developers and the network constraints, undertaking a site optimisation assessment (based on a set of considerations) when determining a connection site will help streamline the process for DNOs and project developers.

Many of these different considerations for electrolytic hydrogen projects are listed in Figure 4, which shows the considerations for DNOs and developers in a Venn diagram. While most of these considerations are specific to project developers, there are a number of considerations common to both DNOs and developers, these are: access to curtailed electricity, renewables co-location, flexibility provisions and connection costs. All these factors will impact costs for the DNOs and electrolytic hydrogen producers.

A set of site optimisation criteria, based on these factors, with assigned weightings and scoring system, was developed as part of this study for NGED to better understand the needs and priorities of electrolytic hydrogen producers in the process of identifying the most optimal sites, while streamlining the process and enabling benefits both parties. A more detailed description of this criteria can be found in section 4.3 of Work Package 1. Application of these criteria rely on access to data both from industries, the distribution network, and developers, attempts to gather this data were made to enable these criteria to be used in WP2 but concerns around data anonymity and limited engagement from stakeholders prevented this. This leads into one of the key high-level recommendations we outline below about building robust communication channels and data sharing platforms to better enable this type of research.

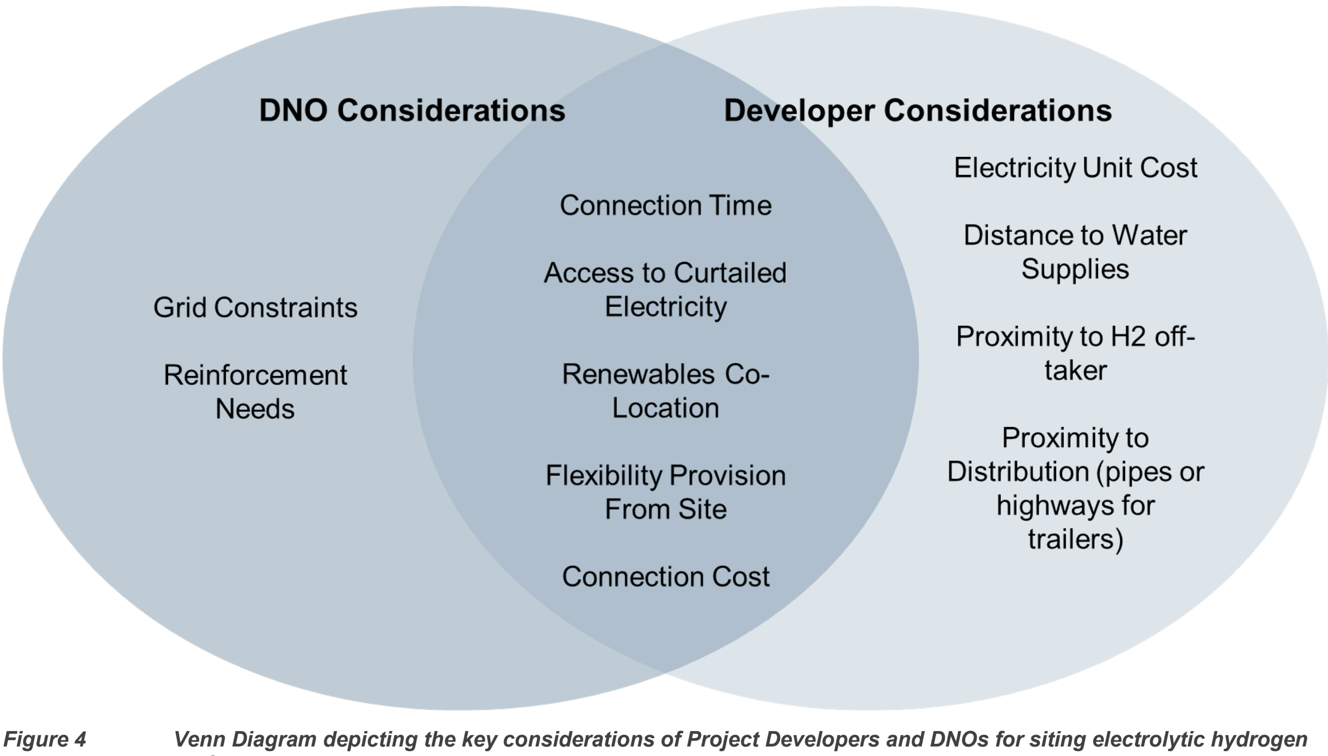

Figure 4 ***Venn Diagram depicting the key considerations of Project Developers and DNOs for siting electrolytic hydrogen projects.***

It should be noted that in the case of industrial hydrogen users, early hydrogen project developments will be severely limited on location choice due to high costs associated with transporting hydrogen in the absence of a hydrogen grid and the need for nearby or co-located renewables to enable generated hydrogen to meet the low carbon hydrogen standard (LCHS). This facilitates the need for developers to locate early hydrogen electrolysis on site with or very close to a hydrogen off takers to be viable. This means it will be difficult to encourage hydrogen project developments to show up at areas with excess grid capacity if there are no off takers in that area. This could lead to additional reinforcement requirements around existing industry.

Uncertainty on how grid power demand for electrolytic hydrogen projects will grow

One of the challenges faced by NGED in highly industrial regions will be dealing with the diversity of industrial sites and their changing needs for power through their decarbonisation journeys. Unlike residential customers, who will have a similar decarbonisation pathway at a regional level, industrial users will have differing processes, requiring case-by-case assessments for demand growth and network planning. Moreover, many of the smaller industrial users that are more likely to connect to a DNO’s network (as opposed to TSOs network) have limited information available publicly regarding their processes, energy use and decarbonisation plans. This limits the ability for accurate estimates to be made without the time-consuming process of consulting directly with each industrial customer. Often even larger firms that own multiple sites perform different processes across their sites, and data on these processes are not publicly available.

Additionally, higher levels of distributed connection of electrolysers will invariably result in an increase in the number of ‘active’ network boundaries in which the electrolysers in combination with renewable generation and battery storage solutions will seek to offer grid balancing and flexibility services. This could increase the number of constraint management zones. This presents integration challenges and management responsibilities requiring policy initiatives and technical infrastructure by the DNO to be implemented.

These challenges are compounded by the uncertainty surrounding hydrogen more generally, specifically the development of a hydrogen gas network, and if it is to develop, the shape the market will take for supplying hydrogen to the grid during the interim years where it is a blended with natural gas. The impact of hydrogen on NGEDs grid currently has a very wide degree of uncertainty and that uncertainty will continue until the deployment, and method of deployment of hydrogen via the existing natural gas pipelines is confirmed, beyond the existing plans for hydrogen blending. Many industries are likely to delay their decisions on switching to hydrogen until there is more certainty around hydrogen’s future. This will be the key factor in defining whether the hydrogen sector is dominated by a few large, centralised producers of hydrogen or many distributed producers and users.

Process Challenges

Currently acquiring a connection to the network can take up to 5 years. This process needs to be streamlined to provide developers with more certainty and reduce the risks associated with a project. This could be accomplished via early engagement with the hydrogen community and project developers so challenges can be addressed before they manifest. Open engagement also increases the chances of DNOs being able to benefit from the hydrogen electrolyser for grid services as this can be more easily worked into a developer’s plans. This type of engagement would help incentivise grid connected electrolysers by reducing project risk and benefit both the DNO and developer by providing more time to discuss and negotiate possibilities such as the use of mechanisms including time of use tariffs, real-time pricing, or demand-side-response payments all of which could make a scheme more viable.

Data Availability

The lack of data on the potential electricity demand arising from hydrogen being used as a low carbon alternative in the processes of many industrial users has emerged as a key issue to be addressed.

With regards to outside communication, developers expressed difficulty with easily accessing data, particularly around current and future grid capacity. Currently although capacity information is available, it is down to developers to process this to identify network areas where they could connect. Additionally, developers lack the complete picture available to DNOs, for example data regarding cable or overhead line capacities which may be important if a site would be well positioned for a T-in connection. Developers have expressed a desire in **[WP1**

Appendix C] for DNOs to communicate areas in the grid that would suit electrolysers in terms of managing power flows and integrating renewables. Additionally, data that is currently public lacks the information developers need to make informed decisions around the potential for dynamic connections or regarding curtailment that would enable them to cut costs.

3. Key Recommendations and Future Work

We also speculate that going forward, hydrogen developers will desire to use more grid electricity for production rather than continuing to rely on co-located renewables. This will become increasingly possible as the grid decarbonises but will require more granular, accurate and reliable carbon intensity data for business modelling. This would enable developers to produce more reliable business cases and improve the certainty of future developments. In the future as an international market develops accurate carbon intensity data will likely be required for export. This may also enable more flexible placement of hydrogen electrolysers benefiting DNOs who will be more able to take advantage of the flexibility services provided.

As discussed above there are many gaps and challenges that need to be addressed to both incentivise and enable grid connection of electrolysers as well as to facilitate the easier, more refined, impact assessment of hydrogen growth on distribution networks.

The value of electrolytic hydrogen production and use (Power-to-X) needs to be better determined

Demonstration projects in the UK are needed to further test and evidence the potential of electrolytic hydrogen production (Power-to-X) for provision of flexibility services to electricity networks. This can be done in the near term by NGED actively engaging with developers to identify planned projects that can also conduct such tests while providing hydrogen for the intended end uses. In the medium term more demonstration projects can be designed for such purposes based on initial sets of results. There are a number of European Commission funded projects that have been designed to do this. Engagements with these project developers on early findings and results can help transfer learning to projects in the UK.

Prior to these demonstration projects, more regional level modelling work needs to be completed to get a better understanding of the economic and temporal value of Power-to-X across different network regions, including NGED’s network region. This can be done by a consortia effort by bringing together the most relevant stakeholders.

To accelerate decision making and address systemic challenges better communication channels need to be established between DNOs and hydrogen stakeholders

One of the key findings of Work Package 1 and Work Package 2 has been that there needs to be increased levels of communication at the strategic level between NGED and electrolytic hydrogen producers and other hydrogen stakeholders. Currently applications for connections are done on a case-by-case basis, and the process for securing sites can be very slow and could take as long as five years on a distribution network if reinforcements are needed at a site. While NGED has communication channels open for developers, this needs to be done at a strategic level with multiple gaps and challenges identified and addressed through planning and policy work.

To accelerate strategic planning and decision-making hydrogen stakeholders have been advocating for the creation of an independent body that brings together different energy system stakeholders that are looking at hydrogen. This has been re-iterated and emerged as one of the key conclusions of a recent National Grid ESO workshop looking at ‘Bridging the Gap 22/23’, in which GHD has participated. NGED needs to be involved in such discussions and be part of such an entity, if created. Such an entity can ensure the role of hydrogen is realised at the system level (e.g. to help address grid constraints along with batteries) and to ensure there are no electricity network barriers in meeting the Government’s electrolytic hydrogen targets.

Another problem that can be addressed through such high-level strategic coordination is the discrepancy between BEIS/DfT hydrogen project requirements, such as project deployment dates (which is mandated as around 2025 by most government funds in 2022) and the timelines for getting grid connection, which can be up to five years as mentioned above.

NGED should not wait for such an entity to be established. In the meantime, NGED can engage with the UK Hydrogen Champion; Jane Toogood, to address the issues above at the strategic level. It should also look at how to set up a mechanism to enable data sharing in an anonymised system, so that the potential for hydrogen demand and production growth can better forecasted, especially in industrial sites such as that in South Wales.

Policy incentives, with suitable contracts or provisions are required to enable grid connection of electrolysers

Given that there are major challenges associated with the difficulty and cost of connection of electrolysers. In addition to government mandates that can be barriers to connection, such as the Low Carbon Hydrogen Standard and the Additionality Criterion. Policy incentives: with suitable contracts or provisions, are required to enable grid connection of electrolysers**.**

The potential options need to be identified at the strategic level. Some options are PPAs, co-location with renewables and/or use of otherwise curtailed electricity from renewables to enable projects to meet the low carbon hydrogen standard. The contractual mechanism to use include such mechanisms including Time of Use Tariffs, Real-Time Pricing, or Payments for entering a Demand-Side-Response or Active Network Management Schemes. Variable and interruptible tariffs would also make grid connections more feasible. The DNOs advising a suitable operating regime and demand side response schemes would also help.

While such mechanisms will make projects more feasible, creating these mechanisms will require further evidence on the benefits of electrolysers for grid service provisions.

Next Steps for NGED

- Appointment of a Hydrogen ambassador: Currently NGEDs systems are not setup to coordinate hydrogen developments making it difficult for information to be accessed and used. While these systems are refined NGED should appoint to hydrogen ambassador with the task of keeping up to date both with key hydrogen industry events such as those outlined on our timeline and being the first point of contact within NGED for Hydrogen queries. This individual would also pay a key role in the development of NGEDs Hydrogen strategy and coordinating the engagement with various hydrogen stakeholders.
- Improvement of internal tracking for hydrogen connections. Currently it will be difficult to identify hydrogen trends within NGEDs network due to the categorisation currently used for electrolysers being “other”. Due to the unique opportunities offered by hydrogen electrolysers such as demand side flexibility NGED should strive to categorise them separately as soon as possible to enable more informed network management decisions as electrolyser counts increase.
- NGED should begin the development of a hydrogen strategy, similar to its existing Low Carbon Heating Strategy and EV strategy. Like the two existing strategies this would act both as a repository of key information relating to hydrogen, able to quickly get individuals within the company up to speed with expectations and challenges. While also outlining the actions NGED need to take to meet the challenges that are relevant to NGED.
- Further development of the criteria-based connection location optimisation methodology so that it can be used in the connection design process. Wider engagement with the industry will be required to refine criteria scoring and validation by testing with real projects.
- Currently the carbon intensity data available is minimal and does not provide projections over longer term to assist the investors in building hydrogen electrolyser business models accurately and reliably. NGED should engage the DNOs and the ESO in developing a solution for improved data provision.
- Additionally, DNOs and developers need work together to
    - test flexible operation of electrolysers to meet the needs of end-users while providing flexibility services.
    - accelerate decision making and set direction by setting up an independent body to make decisions and coordinate.
    - Industry needs a flexibility roadmap, outlining in more detail what is likely to be needed in 2035, so that investment decisions can be made
    - Urgent consideration needs to be given to finalise the commercial frameworks that will enable business models to develop and improve the ability to make investment decisions, based on the full value of hydrogen to the energy system.

4. Conclusion

As has been seen throughout work packages 1, 2 and 3, electrolytic hydrogen is in its infancy as a market and due to this many unknowns remain as to how the market will develop particularly around the size and distribution of electrolyser deployments the distribution infrastructure for hydrogen and the use cases for hydrogen in industrial processes, power generation, transport, and heat. Despite the outcomes of all these elements impacting the extent to which NGED will see hydrogen electrolysers deployed on its network it is certain hydrogen will become a key vector in the energy system and NGED should prepare accordingly. Flexibility should be built into any future hydrogen strategy so that developments in these spaces can accounted for as they happen.

Hydrogen electrolysers provide significant opportunity to NGED going forwards if utilised effectively to provide flexibility particularly demand side flexibility as constraints from renewable generation increases. The ability of electrolysers to ramp up and down should be taken advantage of by network planners to reduce unnecessary reinforcement. Moving forward electrolysers will increasingly be coupled with electricity generation and will be able to provide long term storage on the network as well as supply side flexibility as it starts taking on the role of peaking.

To address the large variance both in the challenges posed by hydrogen electrolysis and the opportunities it is vital that NGED opens more effective lines of communication or platforms that enable easier exchange of information between industries, developers, and network operators. This project has highlighted the current challenges that exist with acquiring real world data from stakeholders further limiting the impact analysis that can be performed beyond that caused by market uncertainty.

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