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Welsh Government

Consultation Document

Hydrogen in Wales

A pathway and next steps for developing the hydrogen energy sector in Wales

Date of issue: 18 January 2021

Action required: Responses by 9 April 2021

Mae'r ddogfen yma hefyd ar gael yn Gymraeg.
This document is also available in Welsh.

Overview	This consultation seeks views on the Welsh Government's commissioned 'Hydrogen in Wales'. This document sets out a proposed pathway and next steps for developing the hydrogen energy sector in Wales.
How to respond	You can respond to this consultation by answering the questions on the form available at www.gov.wales/consultations or through membership of the Welsh Hydrogen Reference Group or HyCymru Hydrogen Trade Association The closing date for the consultation is 9 April 2021. You can reply in any of the following ways: **E-mail:** Please complete the consultation response form and sent it to: decarbonisationmailbox@gov.wales **Post:** Please complete the consultation response form and sent it to the address below: For Attention of Smart Living Climate Change Division Welsh Government Cathays Park Cardiff CF10 3NQ
Further information and related documents	This and the document below is available at www.gov.wales/consultations 'Hydrogen development in Wales' *Baselining report into hydrogen activities and expertise in Wales'* **Large print, Braille and alternative language versions of this document are available on request.**
Contact details	For Attention of Smart Living Climate Change Division Welsh Government Cathays Park Cardiff CF10 3NQ email: decarbonisationmailbox@gov.wales Tel: 03000 251474
Also available in Welsh at:	www.llyw.cymru/ymgyngoriadau

General Data Protection Regulation (GDPR)

The Welsh Government will be data controller for any personal data you provide as part of your response to the consultation. Welsh Ministers have statutory powers they will rely on to process this personal data which will enable them to make informed decisions about how they exercise their public functions. Any response you send us will be seen in full by Welsh Government staff dealing with the issues which this consultation is about or planning future consultations. Where the Welsh Government undertakes further analysis of consultation responses then this work may be commissioned to be carried out by an accredited third party (e.g. a research organisation or a consultancy company). Any such work will only be undertaken under contract. Welsh Government's standard terms and conditions for such contracts set out strict requirements for the processing and safekeeping of personal data.

In order to show that the consultation was carried out properly, the Welsh Government intends to publish a summary of the responses to this document. We may also publish responses in full. Normally, the name and address (or part of the address) of the person or organisation who sent the response are published with the response. If you do not want your name or address published, please tell us this in writing when you send your response. We will then redact them before publishing.

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Hydrogen in Wales

A pathway and next steps for developing the hydrogen energy sector in Wales

December 2020

Prepared by Element Energy for Welsh Government

elementenergy

FOREWORD

The climate emergency demands we use all the tools at our disposal to accelerate progress to a net-zero energy system. We are already actively pursuing greater energy efficiency in our buildings and industries, we have a world-leading approach to recycling and waste management, and last year there was enough electricity generated from renewable sources to meet half Wales' power needs. We are on track to meet our first Carbon Budget but looking ahead, we will need to do even more. Much of this will be set out in the next Low Carbon Delivery Plan, due to be published in November 2021, and I want to include hydrogen as a vital component of our shift towards the goal of net-zero.

Whilst we have effectively banished coal from use for power, we still rely on oil and gas to maintain an affordable and secure energy system. Hydrogen is one of the ways we can shift our reliance away from these fossil fuels and while it is still a developing technology, its unique properties mean it could have a role in Wales' future power, transport, industrial or heating systems, or more likely a combination of these.

Wales needs to be in a position to develop and capture the opportunities offered by hydrogen. For this reason we commissioned Element Energy to baseline where we presently are in Wales with hydrogen-related industries and technologies[1] and to provide a vision of a future Wales, where we can take all the opportunities of a more hydrogen-enabled, lower-carbon energy economy. This document illuminates the latter and sets out a possible prospectus of ten short-term objectives which should, if we can work well together, help accelerate Wales down a hydrogen-enabled path.

We are seeking your constructive thoughts both on the strategic vision and, particularly from those at the sharp end of either energy use or energy technology developments, on the feasibility of this actions-based hydrogen pathway. Our next Low Carbon Delivery Plan for Wales will need everyone to play their part. I am, therefore, particularly interested in responses which explore which actions are needed, and who needs to take them, to help make the most of this promising technology.

Lesley Griffiths AC/AM
Gweinidog yr Amgylchedd, Ynni a Materion Gwledig
Minister for Environment, Energy and Rural Affairs

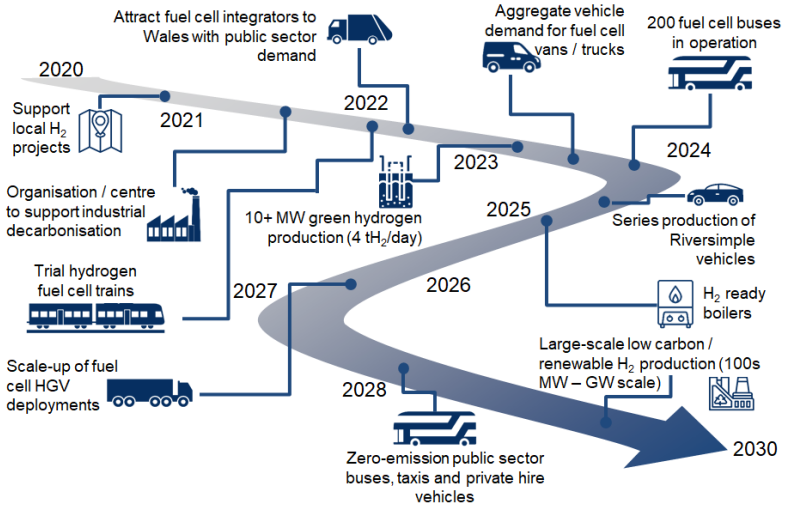
[1] 'Hydrogen Development in Wales' *Baselining report into hydrogen activities and expertise in Wales* December 2020

Executive Summary

Low-carbon hydrogen is increasingly recognised by Governments around the world as having an important role to play in reducing GHG emissions, especially in sectors which are difficult to decarbonise with other solutions. Projections from the Committee on Climate Change and others show a significant increase in low-carbon hydrogen demand by mid-century from existing levels. As part of Covid-19 economic stimulus packages the European Union and several EU Member States have announced significant funding support and ambitious delivery targets for low-carbon hydrogen production.

The UK Government has also announced investment and ambitions for hydrogen to be deployed across a range of sectors including transport, industry, power and heating. For example, in November 2020 the Government outlined a Ten Point Plan for a *Green Industrial Revolution*, which included a target to install 5GW of low carbon hydrogen production capacity in the UK by 2030 and up to £500m of funding to support new production facilities and trials of hydrogen for heat. More details are expected as part of the *UK Hydrogen Strategy*, due to be published in spring 2021. Hydrogen also features as part of the Energy White Paper issued December 2020.

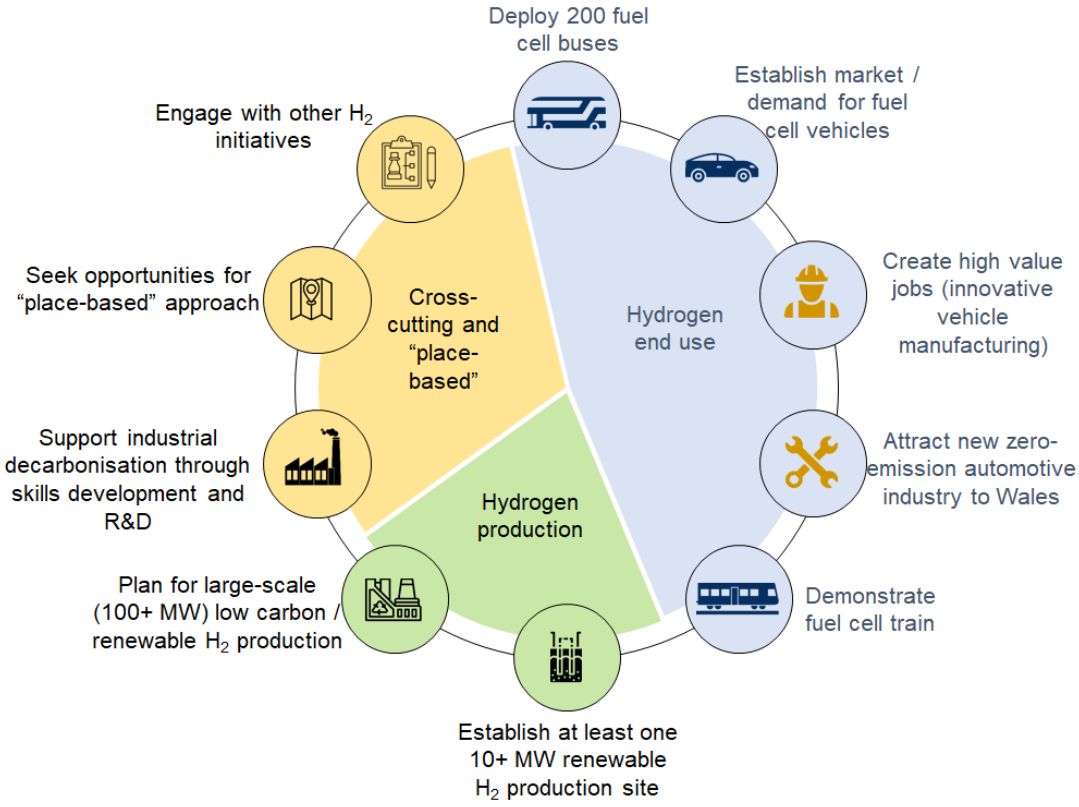
In summer 2020 the Welsh Government commissioned Element Energy to study the opportunities for hydrogen across different sectors in Wales. The hydrogen pathway presented in this report builds on the *Hydrogen Development in Wales: baselining report*, which summarises the current hydrogen initiatives and hydrogen expertise in Wales, aligned with Welsh energy policy ambitions for achieving net zero ambitions.



A key aim of the hydrogen pathway is to inform activities that will take place in the short term (to 2025). At the time of writing (December 2020), the role of hydrogen in the energy sector as a whole is uncertain and will depend on national level policy making (e.g. strategy to decarbonise heat) and international developments (e.g. carbon taxation). Focusing on short term actions, whilst starting to plan for larger-scale projects in the mid- to long-term will ensure Wales is well positioned with respect to hydrogen and fuel cell technologies.

This hydrogen pathway presents ten key objectives, which will help to generate momentum in the Welsh hydrogen sector and lay the foundations for scale-up and commercial deployment from the end of the 2020s.

The objectives cover both hydrogen supply and end use, with a focus on short-term opportunities where the commercial case is more developed.



In no particular order recommended actions include:

1. **Deployment of 200 fuel cell buses in a town / city / region in Wales:** fuel cell buses have been trialled across the UK and the technology is ready for deployment in larger fleets, which benefit from economies of scale. This initiative will create a consistent demand for low-carbon hydrogen and help Wales meet its target for all buses to be zero-emission by 2028.

2. **Establish Wales as an early market for commercial fuel cell vehicles:** fuel cell vans and trucks are at an earlier stage of development than buses. The first commercial fuel cell trucks were delivered to customers in Europe in 2020. To bring these vehicles to Wales in the short-term, a sufficient customer demand is needed. Initiatives to coordinate demand for hydrogen fuel cell vans and trucks are already underway at a UK level. These include plans to develop standard specifications for vehicles which can be purchased at a scale which will attract vehicle manufacturers to bring fuel cell vans and trucks to the UK market. Engaging with these initiatives will help to bring zero-emission vans and trucks to Wales sooner and prepare for large-scale commercial deployments, expected from 2027 onwards.

3. **Consider support for vehicle manufacturers such as Riversimple, a Wales-based designer and manufacturer of fuel cell electric vehicles**: the company is developing a two-seater hydrogen fuel cell car and is looking for sites to manufacture the vehicle from 2022/23. Supporting manufacturers such as Riversimple to establish

manufacturing bases in Wales will promote the fuel cell sector and create additional hydrogen-related jobs.

4. **Attract vehicle integrators to Wales:** there is currently a lack of fuel cell vehicle options offered by vehicle manufacturers. Vehicle integrators can convert existing diesel or battery electric vehicles into hydrogen dual fuel or fuel cell range-extender vehicles, respectively. Coordinating demands for such vehicles, where pure battery electric is not suitable, within the Welsh public sector fleets would send a clear signal to the market of the potential for orders at a sufficient scale to attract vehicle integrators to establish bases in Wales, leading to local job opportunities.

5. **Deploy fuel cell trains in Wales**: Wales has several rural rail lines, by replacing diesel trains hydrogen fuel cell trains provide a decarbonisation solution. There are several fuel cell trains being developed for the UK market and future rolling stock orders should be compatible with the UK Government's target for no diesel-only trains by 2040 and the broader Net Zero 2050 target.

6. **Establish at least one renewable hydrogen production site 10+ MW by 2023 / 24:** the business case for local renewable hydrogen production can be developed if there is sufficient demand for low-carbon hydrogen from the transport sector. This presents an opportunity for one or more hydrogen production sites in Wales, in the order of 10 MW.

7. **Scope large-scale hydrogen production sites:** with hydrogen providing a route to decarbonisation for many difficult to decarbonise sectors, the demand for low-carbon hydrogen is set to increase. Given the time required from developing a concept to implementation of hydrogen production at scale, there is a need to begin planning low carbon / renewable hydrogen production and delivery facilities in parallel with the deployment of the initial smaller scale facilities.

8. **Support industrial decarbonisation through skills development and R&D:** further research and development is required for industrial clusters to decarbonise. This sits alongside the need to address the skills gap for industrial fuel switching and the wider scale use of hydrogen as a fuel for industry. There is an opportunity for Wales to develop expertise focused on industrial decarbonisation and export these skills and offer training to other industrial clusters.

9. **Support local projects and place-based approaches:** developing hydrogen projects creates opportunities to engage with the wider community through a place-based approach. Further community engagement should also help to develop public support for these hydrogen projects.

10. **Engage with other hydrogen initiatives:** there is a range of existing hydrogen initiatives which will further develop the hydrogen sector in Wales. While some of these opportunities will need more time to develop, on-going monitoring of wider activities in the sector and stakeholder engagement will support Wales' hydrogen sector and decarbonisation targets.

Next Steps

The proposed objectives from the pathway will be further refined following feedback and developed into projects which can be delivered in Wales. Development and delivery will require collaboration and support from a range of stakeholders, including Governments, public sector, industry, business and academia.

Your views on key strategic questions below will help us with that process. Respondents need not answer all questions, but any views and evidence you can share will be taken into consideration.

Strategic Vision

1 Public and private sector representatives are developing a hydrogen pathway for Wales based on evidence that hydrogen will be required to play a part in the future energy mix if we are to meet our climate change aspirations.
Do you agree this activity is needed to ensure Wales is well positioned to take advantage of potential opportunities arising from use of hydrogen? If not, why? Do you have any evidence to support these views?

2 Why are you supportive/not supportive of Wales pursuing hydrogen opportunities?
If supportive, what actions can you / your organization, take to contribute towards the development of the hydrogen sector in Wales (and under what conditions)?

3 Do you have any evidence on the best sources of energy for low carbon / renewable hydrogen production? Should Wales seek to generate hydrogen within the country or seek import opportunities, or pursue both options?

4 In your view, does the proposed hydrogen pathway complement on-going and planned hydrogen initiatives across the UK? What other actions should be considered in the hydrogen pathway that would further distinguish Wales, or support other UK activities? Do you have any evidence to support these views which you can share?

Hydrogen Pathway Scope

5 Are there other areas where you believe hydrogen and fuel cell technologies have a role to play in Wales in the short term (period to 2025)?

6 Do you believe the pathway strikes the right balance between being ambitious yet proposing actions which can be delivered?

Hydrogen Pathway Delivery

7 In addition to the points set out in the objectives, are there any other “no regrets” actions that you believe Welsh Government / industry should take in the short term to develop the hydrogen sector in Wales? Do you have evidence you can share in support of that view?

8 What are the key barriers, risks and challenges to realise the opportunities described? In your view, what measures would help to overcome these and what are the key enabling factors?

Welsh Language Considerations

9 We would like to know your views on the effects that 'Hydrogen in Wales' and the next steps for developing the hydrogen energy sector in Wales would have on the Welsh language, specifically on opportunities for people to use Welsh and on treating the Welsh language no less favourably than English. What effects do you think there would be? How could positive effects be increased, or negative effects be mitigated?

10 Please also explain how you believe the proposed opportunities could be formulated or changed so as to have positive effects or increased positive effects on opportunities for people to use the Welsh language and on treating the Welsh language no less favourably than the English language, and no adverse effects on opportunities for people to use the Welsh language.

Summary

11 If you have any related comments which we have not specifically addressed in this consultation, please respond under question 11, supported by any relevant evidence.

Contents

Authors

Element Energy is a strategic energy consultancy, specialising in the intelligent analysis of low carbon energy. The team of over 70 specialists provides consultancy services across a wide range of sectors, including the built environment, carbon capture and storage, industrial decarbonisation, smart electricity and gas networks, energy storage, renewable energy systems and low carbon transport.

Element Energy has been supported in this study by Ynni Glân, a clean energy consultancy based in Cardiff which specialises in renewables, fuel cells and hydrogen technologies.

Acknowledgments

This Pathway and Action Plan document has been prepared in consultation with a large number of stakeholders representing the private and public sectors, many of which participate in the *Hydrogen Reference Group*, which comprises representatives of industry and academia that have an interest in the hydrogen sector in Wales. The authors are grateful to all members of this group, and others, such as HyCymru, the hydrogen trade association for Wales and representatives of SWIC who provided input and feedback on the development of the Pathway during summer and autumn 2020.

Acronyms

AMR	Advanced modular reactor (nuclear)
ATR	Autothermal reforming
BEIS	Department for Business, Energy and Industrial Strategy
CCGT	Combined cycle gas turbine
CCS	Carbon capture and storage
CCUS	Carbon capture, utilisation and storage
CHP	Combined heat and power
DfT	Department for Transport
FC	Fuel cell
FCEV	Fuel cell electric vehicle
FCH JU	Fuel Cells and Hydrogen Joint Undertaking
GW	Gigawatt (10^9 Watts)
HFC	Hydrogen and fuel cell
HGV	Heavy goods vehicle
HRS	Hydrogen Refuelling Station
MW	Megawatt (10^6 Watts)
OEM	Original equipment manufacturer
OLEV	Office for low emission vehicles
ROSCO	Rail operating stock company
RFNBO	Renewable Fuels of Non-Biological Origin
RTFO	Renewable Transport Fuel Obligation
TfW	Transport for Wales

Note on terminology

'Blue hydrogen' refers to hydrogen produced from a feedstock of natural gas by steam methane reforming or autothermal reforming (ATR) coupled with carbon capture, and storage (CCS) of the resulting carbon dioxide emissions. **'Green hydrogen'** refers to hydrogen produced through water electrolysis using renewable electricity. **'Low-carbon hydrogen'** refers to both blue and green hydrogen. Whilst there are other forms of colours referenced for hydrogen, the focus for this report is on both blue and green which are the forms likely to contribute to achieving net zero along the 2050 pathway.

'CCS' is preferred to the more general 'CCUS' (i.e. carbon capture, utilisation, and storage), in reading this report, the term CCS should be intended as also referring to forms of CO_2 utilisation that can ensure permanent sequestration.

1 Introduction

1.1 Context

The focus to decarbonise and to take actions to meet the climate change targets set out in the Paris Agreement to limit global warming to well below 2°C, preferably to 1.5°C has been growing, particularly across Europe. At the end of 2019 the UN Environment Programme estimated that global emissions need to reduce by 7.6% each year from 2020 to 2030 to be on track for the 1.5°C temperature target set by the Paris Agreement (1). The European Union has announced the ambition for Europe to become the first climate neutral continent, supported by €1 trillion investment over the next decade through the Green Deal (over half of which is directly funded by the European Union).

The Welsh Government declared a climate emergency on 29 April 2019 and the implications for climate change and Wales has been considered by the UK Committee on Climate Change with further advice provided in December 2020 (2). The Government has also set a number of stretching targets that reflect its ambition to reach its 2050 climate targets. This includes in 2017, the Welsh Government announced a target of meeting the equivalent of 70% of Wales' electricity demand from Welsh renewable electricity sources by 2030 and a target for at least 1 GW of renewable energy capacity to be locally owned by 2030 (3). There is also an expectation for all new energy projects in Wales to have at least an element of local ownership from 2020. To lead the way, the public sector has been set a target of being carbon neutral by 2030.

In December 2020, Ofgem published its Network Price Controls (RIIO-2) Final Determinations for Gas and Electricity Transmission, Gas Distribution, and Electricity System Operator, a five-year spending plan covering the period to 2026. A core aim of RIIO-2 is to allow the regulated network companies to deliver Net Zero at the lowest possible cost to customers. The latest determination provides the conditions for regulated companies to prepare for the scale-up of solutions required for a decarbonised energy system, for example by providing through price controls the ability for Wales & West Utilities to invest in innovative technologies, detailed engineering designs for new infrastructure and to begin building hydrogen pipelines within the next five years

Throughout 2020, the Covid-19 pandemic has engulfed the world, causing severe disruption to public health services and global economies. Political pressure, at least in much of Europe, remains to ensure that investment from the public sector to stimulate the economy post-Covid does not support fossil fuel industries, but rather decarbonisation technologies and low carbon industries. The proposed post-Covid economic stimulus is seen as an opportunity to support the green economy, including the hydrogen energy sector. Within this context opportunities for large-scale production of low-carbon and renewable hydrogen is seen as a particular economic opportunity for Europe. This is highlighted by the ambitious targets set out in the European Hydrogen Strategy, which includes a target for 6 GW and 40 GW of electrolysis to be installed in Europe by 2024 and 2030 respectively (4). Given that the current rate of increase in electrolyser capacity is in the tens of megawatts per year, achieving these targets implies scale up of this sector by several orders of

magnitude. The focus from the European Union and many European member states on green hydrogen production follows growing recognition that despite current high costs of hydrogen generation from renewables, the continuing cost reduction of renewable generation and falling electrolyser capital costs can result in renewable hydrogen becoming commercially viable in a growing number of sectors throughout the next decade. The 40 GW installation target is designed to stimulate the scale-up of electrolyser manufacturing, catalyse development of a robust supply chain in Europe, and achieve economies of scale from electrolysis production.

There is a recognition that the scale of hydrogen demand anticipated in Europe by 2030 will outstrip green hydrogen production capacity, and many European countries, including Germany and the Netherlands have plans to import green and blue hydrogen to meet their growing demands for low-carbon hydrogen.
In November 2020 the UK Government announced support for hydrogen as part of the 10 Point Plan for a Green Industrial Revolution. This includes £500 million of public funding, approximately half of which will be directed towards the production of hydrogen and half for end uses, which includes applications in industry, transport, power and the heating of homes. The UK Government is also currently developing a national hydrogen strategy, which will outline in further detail plans to support the hydrogen sector. This is reported to include support for the production of hydrogen, alongside initiatives to stimulate demand, with an initial focus on industry and depot-based transport. The Hydrogen Advisory Council, established by the UK Government in summer 2020 is currently informing the development of the UK hydrogen strategy, which is expected to be published in spring 2021.

1.2 Project objectives

Element Energy was commissioned to support the Welsh Government to develop a hydrogen pathway for Wales. The aim of this study is to ensure that Wales is well positioned to take advantages of the opportunities (environmental, economic, social, etc.) available from the development of hydrogen energy applications across all sectors. Specific objectives of the study include:

- Collect a comprehensive evidence base of the projects and expertise in Wales relating to hydrogen and fuel cell (HFC) technologies.
- Develop a pathway for implementing hydrogen projects that have the potential to provide benefits to Wales.
- Support and coordinate the implementation of hydrogen initiatives in Wales until at least March 2022.

The hydrogen baselining report identifies existing hydrogen activities and some of the potential opportunities to expand such initiatives across Wales. The baselining report summarises a wide range of hydrogen projects across all regions of Wales, which involve various stakeholders, including universities, large multi-national companies, smaller local businesses and the public sector, including local authorities and Welsh Government departments. The scale and objectives of these hydrogen activities also varies considerably, from large-scale hydrogen deployment proposals for industrial clusters to smaller-scale projects on a local level.

1.3 Purpose of this report

This hydrogen pathway, which builds on the hydrogen baselining report, has been developed in consultation with a wide range of stakeholders, including those within the Hydrogen Reference Group and across different departments within Welsh Government. The purpose of the hydrogen pathway is to identify the most promising opportunities for hydrogen development in Wales, with a focus on supporting Welsh Government's commitment to decarbonisation, whilst unlocking new economic opportunities from the development of Wales' hydrogen sector.

The hydrogen pathway focuses on activities that will help generate momentum in the hydrogen sector in the short term. The role of hydrogen in the energy sector as a whole is currently uncertain and will depend on national-level policy making (e.g. strategy to decarbonise heat) and international developments (e.g. carbon taxation). We therefore recommend focusing on short-term actions designed to ensure Wales is well positioned with respect to hydrogen and fuel cell (HFC) technologies.

This short-term focus does not exclude planning and preparation for larger-scale, mid- to long-term projects. Short-term, smaller-scale projects can help to lay the foundations for scale-up from the mid- to late-2020s. It should also be noted that the proposed initiatives presented here need to be further developed, including discussions and support from relevant stakeholders, assessment of the business case and securing funding or investment before these can be delivered.

There are also areas where Welsh Government policy can be reviewed to support the deployment of low-carbon technologies, including hydrogen. A range of policy levers have been considered and will be further reviewed through consultation with Welsh Government and the wider community.

2 Vision for hydrogen in the Welsh energy system

2.1 Overall role of hydrogen in the energy system

To meet the target set out in the Paris Agreement to limit global warming to well below 2°C, preferably to 1.5°C above pre-industrial levels, it is recognised that global emissions need to reach Net Zero around 2050. In 2019 the UK legislated a Net Zero GHG emissions target by 2050, which strengthened the previous target of an 80% reduction on 1990 levels. Achieving the Net Zero target will require decarbonisation across all areas of the economy, including the difficult-to-decarbonise sectors. Hydrogen has been identified as having a crucial role in decarbonising difficult-to-decarbonise applications such as high temperature heating for industry and heavy-duty transport.

The full role that hydrogen will play in the future energy system is still to be determined, but there is potential for hydrogen to have roles within the industry, transport, heat and power sectors. The Hydrogen Council, a global CEO-level advisory body which focuses on the role of hydrogen in the energy transition, present a vision where hydrogen is widely deployed across the energy sector.

Figure 1 shows the use of power-to-gas technologies to connect variable renewable electricity generation with seasonal storage and use in a wide range of sectors, including transport, industry, heat, power and use as a feedstock.

There is a growing consensus on the need for low-carbon hydrogen, which is widely recognised amongst industry and policy makers in the UK. Forecasts for hydrogen demand in the UK estimate a significant increase in demand from current hydrogen production of 27 TWh/year in the UK (which is currently grey hydrogen). It is worth noting, however, that hydrogen will be one of a suite of technologies to help combat climate change, along with renewable energy technologies, electrification of large part of the heat and transport demands and carbon capture and storage.

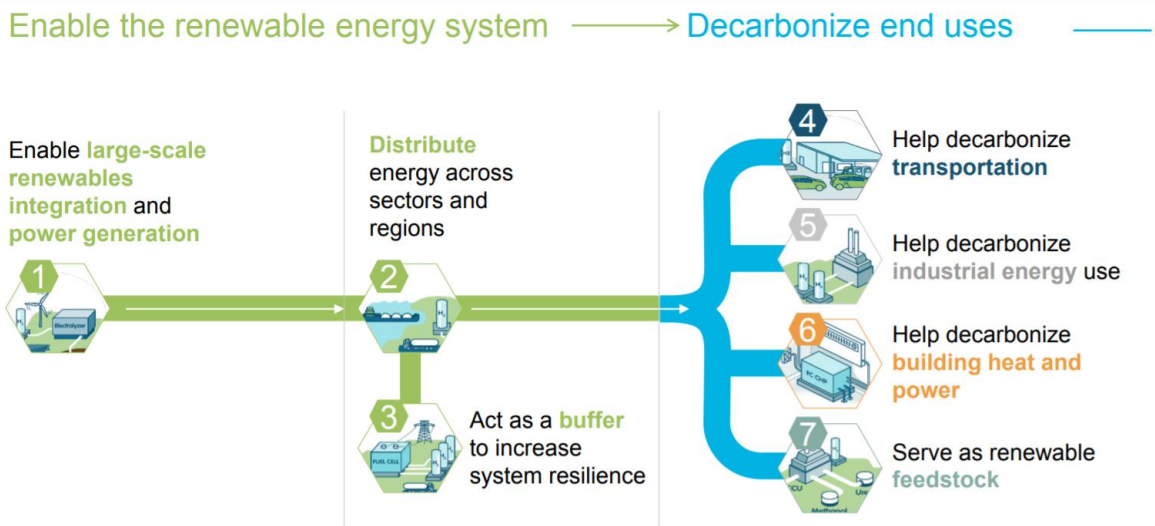
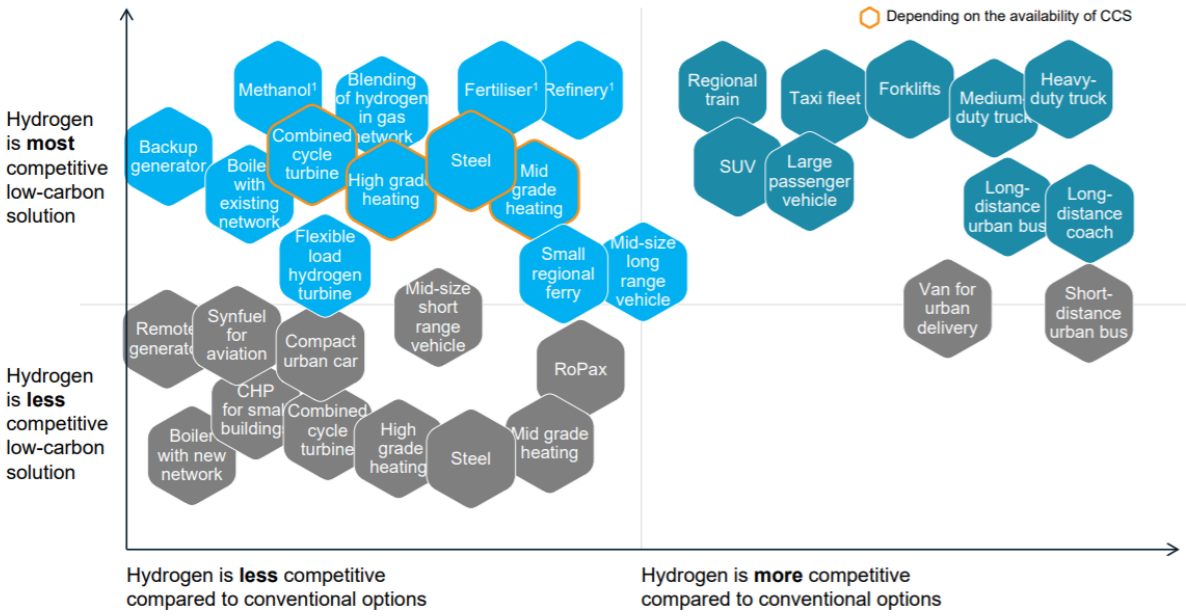


Figure 1: Illustration of the potential role hydrogen can play in the energy sector according to the Hydrogen Council (5)

2.2 Hydrogen's potential to support decarbonisation by sector

Analysis for the global Hydrogen Council, shown in Figure 2, illustrates the sectors where hydrogen is most competitive compared to other low-carbon technologies (e.g. battery electric vehicles, heat pumps) and conventional technologies (i.e. diesel vehicles, natural gas boilers). This analysis is based on total cost of ownership comparison and assumes scale-up in the supply and end use of low carbon hydrogen. This highlights priority sectors for hydrogen, which include heavy-duty transport (heavy duty vehicles, regional trains, buses and coaches) and larger cars, as well as light duty vehicles operating high mileage (taxi fleets).

In a world where low-carbon hydrogen is competing with only other zero-emission technologies, hydrogen is also competitive across industry and heating applications, including steel production, high grade heating and blending hydrogen into existing gas network for domestic heating. It is important to note however that hydrogen is not generally competitive with incumbent technologies in these sectors under current market conditions and the economic case for switching to low-carbon hydrogen will require making exiting options more expensive (e.g. via a carbon tax) and / or subsidising the low-carbon / renewable option.



1. Hydrogen is the only alternative and low-carbon/renewable hydrogen competing with grey (optimal renewable or low-carbon shown)

Figure 2: Comparison of the competitiveness of hydrogen with low-carbon and conventional technologies in different end use sectors from the Hydrogen Council, based on cost assumptions once the hydrogen sector has scaled up (4)

The cost competitive analysis in Figure 2 assumes that the supply and end use applications of hydrogen have been scaled up. The rate of scale-up in the supply of low-carbon hydrogen and development of hydrogen end use technologies will determine when cost parity with other technologies is reached. Figure 3 illustrates estimated timelines when hydrogen applications are expected to reach cost competitiveness with other low-carbon technologies. This is based on the same scale-up assumptions, although illustrates the applications where low-carbon hydrogen is expected to become competitive sooner on a total cost of ownership basis with other low-carbon technologies.

Apart from existing demands for hydrogen feedstock, where hydrogen is the only option, the sectors where hydrogen is competitive earliest include materials handling and transport applications. This includes regional trains, heavy duty trucks, buses and coaches, where hydrogen is forecast to be competitive with other low-carbon technologies, i.e. battery electric vehicles, from the early 2020s. In heavy duty transport applications, which require a long vehicle range, battery electric vehicles are constrained by the battery capacity. Increasing the battery size increases the vehicle range, but also increases the capital cost of the vehicle, charging time, power capacity required at the charge point and reduces the vehicle payload. Increasing the on-board storage of hydrogen on fuel cell vehicles also impacts these factors, although to a lesser extent. Hydrogen fuel cell vehicles can typically offer a closer operational experience to conventional diesel vehicles, without the GHG emissions and other pollutants that contribute to poor air quality.

In the heavy-duty road transport sector hydrogen fuel is competing with the cost of diesel, which includes fuel duty, whereas for rail and off-road applications the lower tax on diesel means that hydrogen needs to be cheaper to achieve fuel price parity with incumbent solutions. It should also be recognised for applications where hydrogen is competing with natural gas as the incumbent fuel, such as industry and heating, the low price of natural gas presents a challenging business case for hydrogen. Widespread use of hydrogen in industry and heating is therefore reliant on subsidy for low-carbon options or carbon tax of sufficient value to promote the low-carbon alternative.

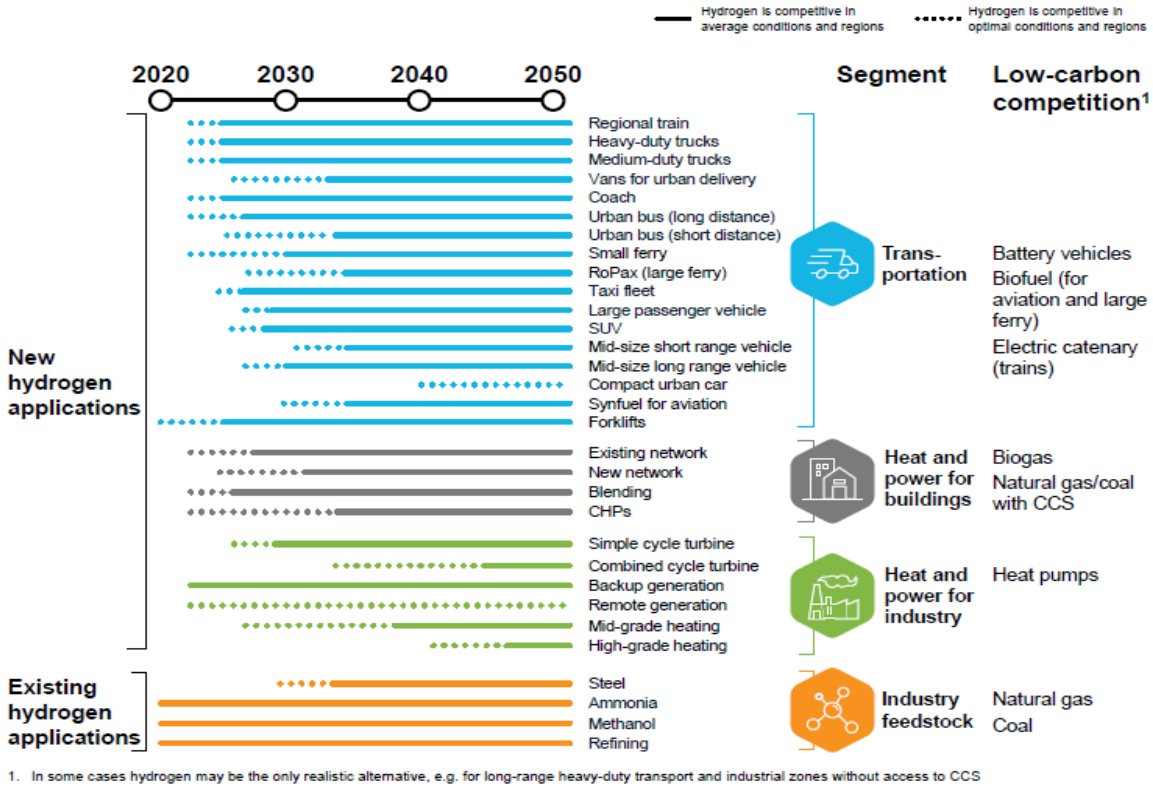


Figure 3: Overview of timelines when low-carbon hydrogen to reach cost parity with other low-carbon technologies according to the Hydrogen Council (assuming scale-up of the hydrogen sector) (6)

The results of analysis shown in Figure 2 and Figure 3 assume scale-up of low-carbon hydrogen production and end use applications, resulting in cost reductions[2]. Similar to the cost of solar, wind and li-ion batteries seen over the last decade, hydrogen cost reductions will be driven by scale-up of electrolysis (manufacturing capacity and installation size). Continuing cost reductions in renewable energy will also reduce cost of green hydrogen, along with economies of scale in hydrogen infrastructure and distribution. Similarly, the increase in manufacturing capacity of fuel cell vehicles and hydrogen appliances will lead to reductions in the capital cost of hydrogen end use technologies[3].

The timing for commercial deployment of hydrogen technologies is also dependent on manufacturers committing to scaling up the number of fuel cell vehicles and hydrogen end use technologies. Based on announcements from vehicle suppliers as well as analysis of the total cost of ownership the estimated timings for commercially competitive hydrogen mobility applications in the UK are shown in Figure 4. Hydrogen fuel cell cars and buses are currently commercially available from vehicle suppliers. Under the right conditions buses are expected to be commercially competitive with other zero emission technologies (i.e. battery electric vehicles) from 2023 / 24, followed by cars and trains after 2025. Vans and trucks are not yet commercially available in the UK, although trials are expected to start in 2021, with commercially competitive products available once the manufacturing has scaled-up sufficiently (estimated to be 2027-28). Industry announcements focus on deploying larger scale cell truck fleets across Europe towards the end of the decade. For example, in November 2020 a coalition of 62 truck manufacturers and hydrogen infrastructure providers signed a statement to deploy 100,000 fuel cell trucks in Europe by 2030 (7). Hydrogen fuelled ferries and boats are also expected to be commercially developed throughout the 2020s. Hydrogen ferry demonstration projects are on-going and industry announcements indicate hydrogen ferries will be commercially available from 2022, becoming commercially competitive with other low-carbon options towards the end of the decade.

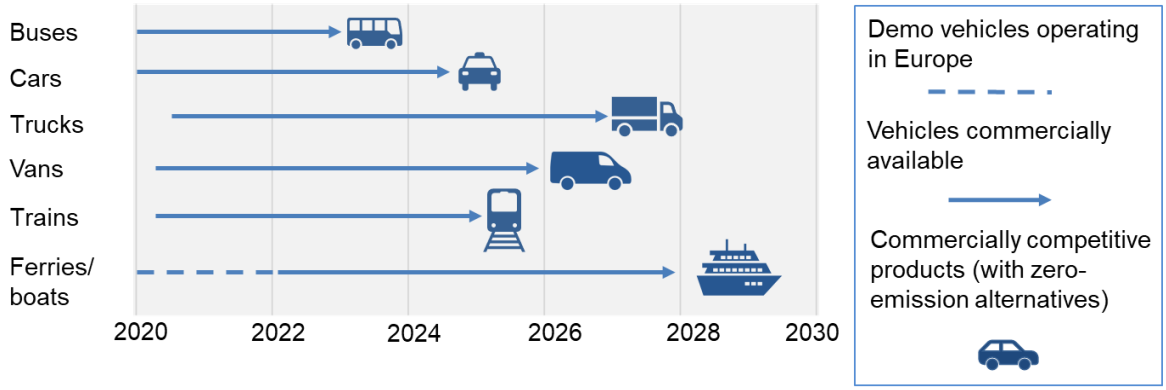


Figure 4: Indicative timelines for commercial deployment of hydrogen fuel cell vehicles in the UK. Commercially competitive products refers to hydrogen transport modes which are competitive with other forms of low / zero emission transport

[2] This is in the order of a hydrogen cost reduction for fuel cell trucks from $8-10/kg H_2 at the pump in 2020 to $4–5/kg H_2 by 2030.
[3] Estimated fuel cell truck capital costs from x3 the cost of a diesel in 2020 to x1.2 the cost in 2030, based on a manufacturing scale-up to 150,000 fuel cell trucks/year.

The results of a comprehensive study into the costs of hydrogen technologies and alternatives summarised above show that heavy-duty, or high-mileage road transport applications currently present the most promising business cases for hydrogen. There are certain conditions that would further improve the business case of early-stage hydrogen projects. All sizes of hydrogen vehicle fleets require a minimum amount of refuelling infrastructure and a supply of low-carbon hydrogen. The costs of this infrastructure do not scale-up linearly, larger vehicle fleets will spread the capital cost of refuelling infrastructure across a larger number of vehicles. Deploying infrastructure to produce and distribute hydrogen to the end users will also benefit from economies of scale, with lower unit costs in hydrogen when the capital cost is spread across a larger demand for hydrogen.

2.3 Renewable hydrogen scale-up plans in Europe as of 2020

The year 2020 saw a range of announcements for large-scale (100+ MW) low-carbon hydrogen production projects in Europe. Figure 5 shows a selection of large-scale green hydrogen projects that have been announced in Europe and reflects the plans from megawatt to gigawatt-scale electrolysis. As of December 2020, none of these projects have been delivered. At the time of writing all are under development and as such there are risks some of these projects may be delayed or not delivered. These announcements, however, reflect the increasing ambition and willingness from the public and private sector to invest in low-carbon hydrogen.

Many of the large-scale hydrogen production projects also include a large-scale hydrogen end user, such as an oil refinery to act as the anchor demand for the hydrogen. These end users typically have an existing large-scale demand for hydrogen, which is currently met from methane reformation (grey hydrogen). Some of these large-scale projects are also looking to supply hydrogen directly to fuel cell vehicles, the higher value of hydrogen as a transport fuel strengthens the business case and allows the hydrogen supply to scale with demand when larger fleets of fuel cell vehicles are delivered.

There is also an increasing focus on using low-carbon hydrogen for synthetic fuel production, which is driven by the Renewable Energy Directive II (RED II). RED II sets targets for renewable transport fuels to be used in the EU from 2021-30 and applies to fuel suppliers. RED II has introduced targets for advanced fuels, which includes renewable fuels of non-biological origin (RFNBO). Hydrogen produced from electrolysis and other e-fuels, using green hydrogen are considered within RFNBO. Synthetic fuel production, supported through RED II, provides a basis for some of these green hydrogen projects across Europe, as can be seen below.

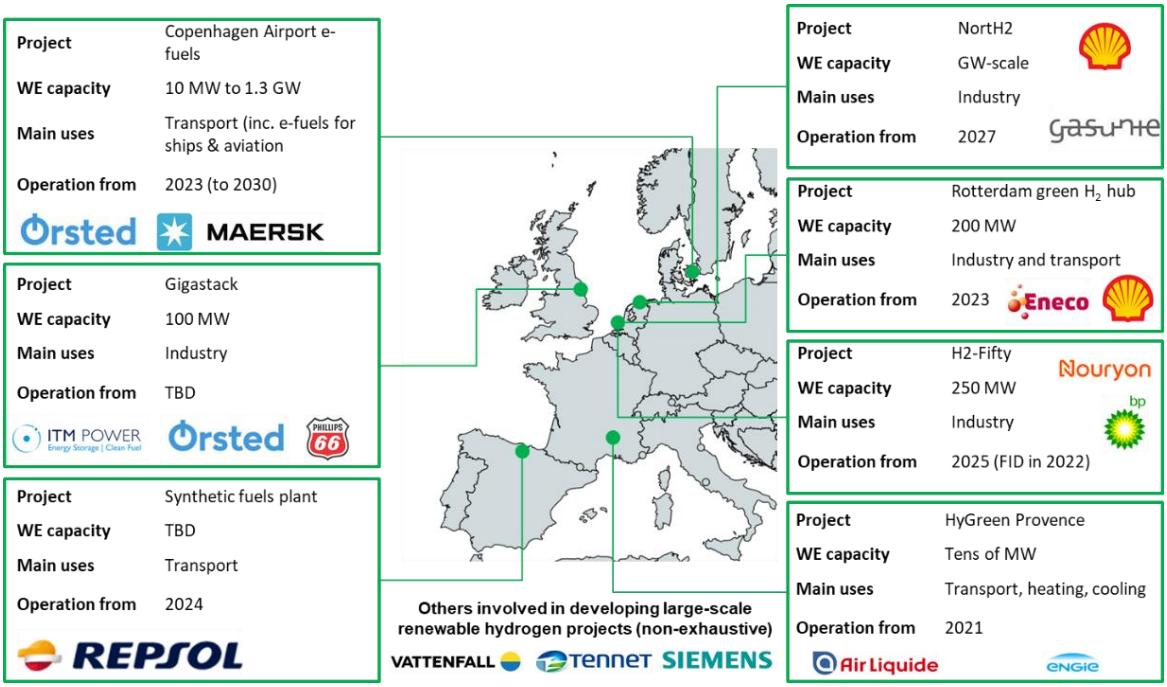


Figure 5: Selection of some of the large-scale green hydrogen projects announced in Europe to be deployed in the early 2020s

Plans for large-scale electrolysers are not restricted to Europe. There have been similar announcements around the world, particularly in locations with very low cost renewable energy, including Saudi Arabia and Australia, where falling costs of renewables can unlock new business models based on using hydrogen (or hydrogen-derived fuels) as a bulk energy carrier. For example, the NEOM project in Saudi Arabia is planning to deploy 4 GW of renewables and electrolysis to produce 650 tonnes green hydrogen per day, which will be transported in the form of ammonia to markets around the world (8). The NEOM project is expected to start production in 2025, with Europe and the UK likely markets. For hydrogen end use there will need to be an ammonia cracking process to convert ammonia back into hydrogen and nitrogen.

Along with ammonia, there are also options to transport hydrogen in ships as liquid hydrogen and via liquid organic hydrogen carriers (LOHC). Figure 6 illustrates the estimated cost of producing hydrogen from very low-cost renewables in the Middle East and shipping it to the UK in different forms. Regions which have very low-cost renewable electricity are estimated to be able to produce and ship hydrogen at a competitive cost to the UK. The production of low-carbon hydrogen in the UK will, therefore, also have to compete with the cost of hydrogen imports from regions with abundant, low-cost renewable energy and low-cost natural gas and CCS.

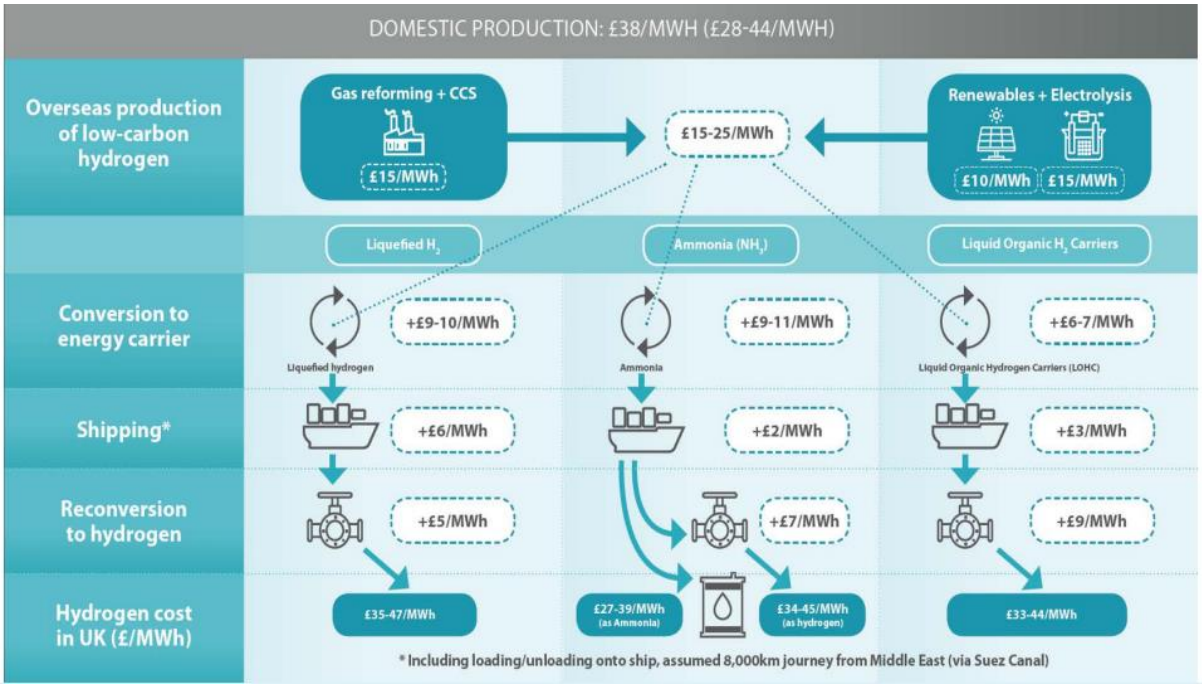


Figure 6: Comparison of the estimated cost of low-carbon hydrogen produced in the Middle East and imported to the UK from the CCC (9)

2.4 Potential demands for hydrogen in energy applications in the UK

As discussed above there is a range of potential uses for low-carbon hydrogen to decarbonise the industry, transport, heating and power sectors. Although hydrogen is very likely to play a part in the technology mix that will support decarbonisation, the extent to which hydrogen will be used is still to be determined. However, there is widespread acknowledgement that low-carbon hydrogen demands will increase as the UK looks to decarbonise.

Figure 7 compares estimates for the UK's low-carbon hydrogen demand in 2050 from several sources. All of these scenarios show a significant increase in hydrogen consumption to reach Net Zero from the current production scale of 27 TWh/year, with the largest showing a hydrogen demand > 700 TWh/year. It is clear that demands for low-carbon hydrogen are set to increase to enable the UK to achieve Net Zero GHG emissions.

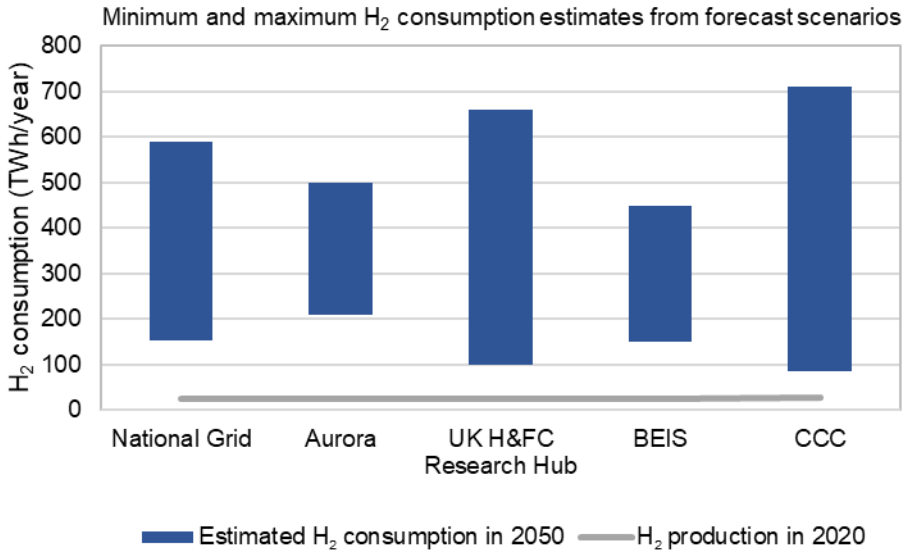


Figure 7: Selection of hydrogen consumption estimates in the UK by 2050 compared to current UK grey hydrogen production of 27 TWh/year; National Grid (36), Aurora (37), UK H&FC Research Hub (38), BEIS (39), CCC (40)

2.5 Long-term role of hydrogen in the Welsh energy system

As of December 2020, there is uncertainty regarding the exact role hydrogen will have in supporting decarbonisation in Wales. A full analysis of the level of penetration that hydrogen could have across the transport, industry, heat and power sectors is beyond the scope of the current work. However, it is clear that to achieve decarbonisation there will be an increasing demand for low-carbon hydrogen across Wales.

A potential large-scale demand for hydrogen would be to partly replace natural gas currently used in the gas network for cooking and heating. Conversion to a hydrogen gas network is being reviewed by gas utilities, including Wales & West Utilities (10), alongside other technologies such as electric heat pumps and other low carbon gases to decarbonise Wales' heating demand. It should be recognised that some of the decisions that will impact the deployment of hydrogen in Wales will be determined on a national level by the UK Government, including the decarbonisation of heat.

Another significant energy demand and source of GHG emissions in Wales is from industry, and industrial hubs in Wales are preparing decarbonisation plans. These plans include the use of hydrogen, as well as carbon capture, utilisation and storage (CCUS) and electrification wherever possible. International initiatives, such as carbon taxation will also have a large impact on the decarbonisation of industry and the future deployment of hydrogen technologies in Wales.

Despite these external influences, there is still an urgent need to take the first steps to develop the skills, expertise and supply chain for hydrogen scale-up in Wales. This will prepare for the commercial scale-up of hydrogen end uses in the future. Based on industry announcements, some of these sectors, including heavy duty vehicles will be developing commercially towards the end of the decade. The

hydrogen pathway presented in the following section looks to build on Wales' existing strengths from industry and academia to prepare Wales for emerging opportunities in the hydrogen sector. This looks at the steps which will set Wales on track to deliver the infrastructure needed for hydrogen and to support green growth by creating commercial opportunities and jobs in the hydrogen sector in Wales.

3 Hydrogen pathway for the 2020s

3.1 Overview

The hydrogen pathway presented below focuses on actions, which can build momentum in the hydrogen energy sector in Wales throughout the 2020s. With growing interest globally in hydrogen as a clean energy vector, the recommended set of next steps are designed to ensure that Wales is well placed to take advantage of the environmental and economic benefits that further development and commercialisation of the sector offers. The baselining report produced as part of this study shows a significant amount of activity in terms of research, feasibility studies, and interest in hydrogen and fuel cell (HFC) technologies across Wales but very few examples of the technology being deployed in the country. The hydrogen pathway, which has been developed in consultation with a wide range of public and private sector stakeholders, focuses on a targeted set of initiatives designed to (a) realise some meaningful deployment of HFC technologies in Wales in the early 2020s and (b) prepare for the further roll-out and up-scaling from the mid to late 2020s, which is expected to be required for Wales to achieve its decarbonisation targets. The potential actions that form the basis of the pathway for hydrogen development in Wales can be classified into the following broad categories:

- End use (creating demands for hydrogen as a fuel)
- Hydrogen production (including distribution and delivery to customers)
- Cross-cutting and “place-based”[4]

In terms of generating demand, there is a focus on the transport sector as this is amongst the most technically mature uses of hydrogen in energy applications and an area closest to commercial viability (partly due to the relatively high value of fuel against taxed petrol / diesel). Some of the key actions proposed in the pathway are highlighted in Figure 8 below.

[4] “Place based approach” refers to a Local Authority area community-centred, bottom-up approach, which takes into consideration the unique aspects of local environment and community.

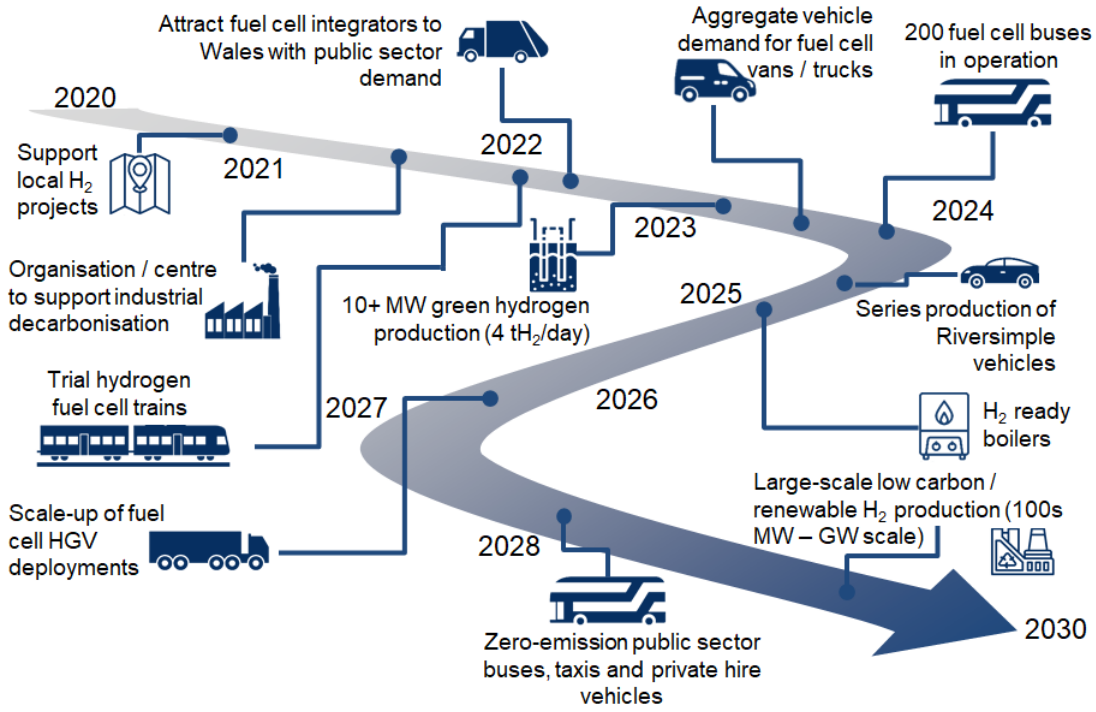


Figure 8: Illustration of hydrogen pathway to 2030, highlighting some of the key actions

While hydrogen is likely to have a role in other areas (e.g. decarbonising industry / heat / power), and is anticipated to be required in multiple sectors for the UK to achieve Net Zero, the commercial case for such applications relies on wider developments (e.g. a UK-wide heat decarbonisation strategy, a sufficiently high carbon price for low carbon / renewable hydrogen in industry, etc.). These areas are seen to be more suited to deployment in the mid-term, requiring further research and development and testing in the short term.

Objectives for short-term activities (i.e. to 2025) relating to hydrogen use in energy applications in Wales that forms the basis of the Pathway are summarised in Figure 9 below. These are focused on developing opportunities for hydrogen in Wales to lay the foundations for larger scale projects from 2025 onwards, which will help decarbonise the wider transport, heating, industry and power sectors. The objectives are outlined, in no particular in order in the following sub-sections of this document, with further explanation of the rationale for each discussion of the benefits realising these objectives would bring to Wales.

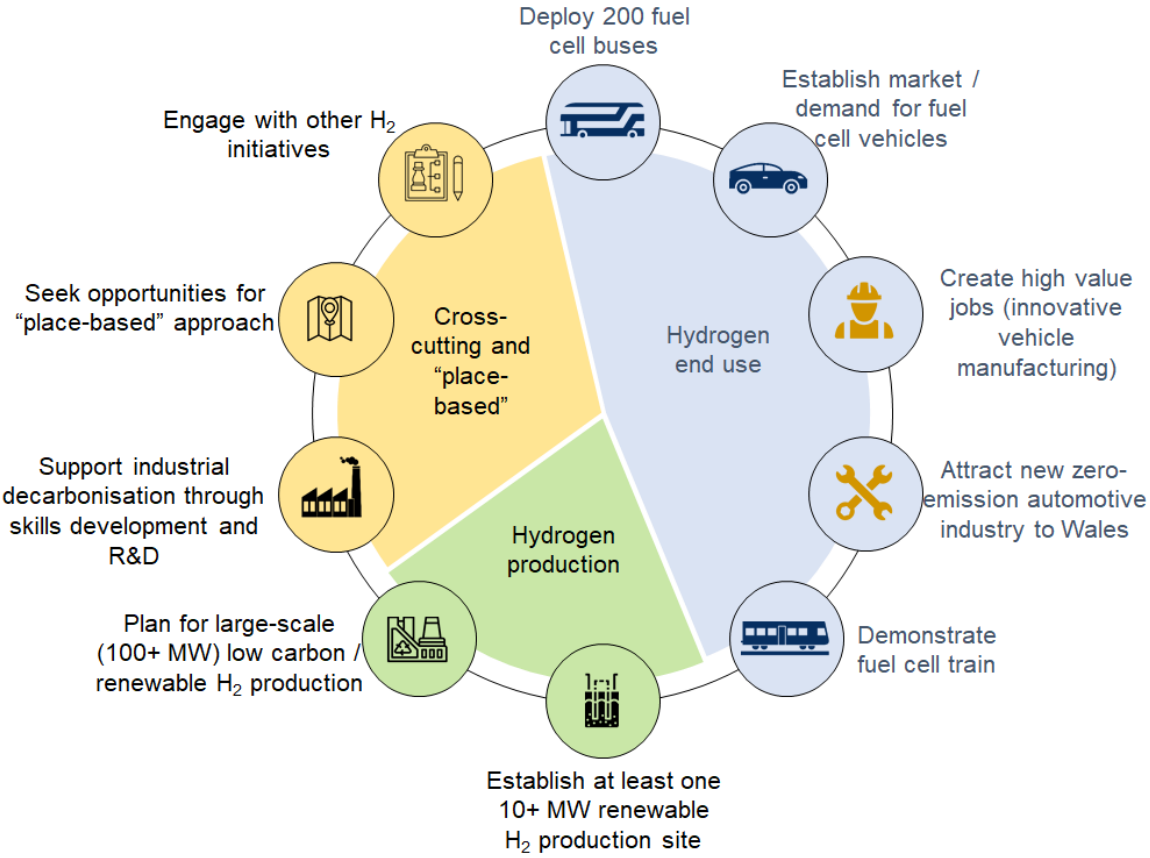


Figure 9: Proposed near-term objectives to develop the hydrogen sector in Wales

3.2 Deploy 200 fuel cell buses in a hydrogen bus town / city / region

Context

The Welsh Government has set a target for all buses in Wales to be zero emission by 2028, alongside taxi and private hire vehicles (11). The UK Government has commitment to deploy 4,000 zero emission buses across England and Wales by 2025 as part of their £5 billion investment in bus services and cycle routes (12). The ambitious target from Welsh Government to roll out zero emission buses across Wales, supported by the commitment from the UK Government to invest in zero emission buses presents an opportunity to commence deployment of hydrogen fuel cell buses in Wales.

Figure 10: Hydrogen fuel cell bus in service in London from 2010–2020 (30)

Activity

The objective proposed here is focused on an initial deployment of a fleet of 200 hydrogen fuel cell buses in a town / city / region in Wales by 2024. This will establish Wales as a leading country for hydrogen mobility deployment in Europe and demonstrate how a bus fleet can transition to hydrogen, which will be an important step towards Wales' 2028 zero-emission bus target.

Fuel cell buses have been developed and demonstrated in numerous projects over the past two decades, many supported by European funding. In terms of UK activity, experience is focused in London and Aberdeen, where fleets of fuel cell buses were first deployed in fare-paying passenger service in 2010 and 2015 respectively. These early demonstration activities helped the technology achieve a level of technical readiness that allowed larger scale deployment to be planned, and Aberdeen and London, along with other UK cities (e.g. Birmingham) and bus operators (Brighton and Hove Buses), are amongst the consortium of organisations committing to deploying fleets of tens of fuel cell buses under the FCH JU-funded[5] *JIVE* and *JIVE 2* projects). Some bus manufacturers and hydrogen suppliers are also planning larger scale deployment of fuel cell buses on a commercial basis (the *H2Bus Europe* consortium is one example) and such initiatives will see hundreds of fuel cell buses deployed across the UK over the coming years. Fuel cell bus technology has been well demonstrated, the deployment of a large fleet of fuel cell buses would benefit from economies of scale and provide an innovative solution in terms of the scale of the fleet and demonstrate the conversion of a whole bus fleet to zero-emission buses.

Benefits

There are currently three UK-based bus manufacturers, all of whom are developing or offering hydrogen fuel cell buses. Local manufacturing in the UK will ensure there is local support with the maintenance of buses, and they would also be well placed

[5] FCH JU: Fuel Cells and Hydrogen Joint Undertaking is a public private partnership supported by the European Commission, Hydrogen Europe and Hydrogen Europe Research.

to train local staff at the bus depots in Wales to support refuelling and routine maintenance activities on the buses.

Fuel cell buses are one of the most commercially developed fuel cell mobility applications. The cost of fuel cell buses has reduced drastically over the last ten years, largely as a result of the projects described above, which have streamlined the manufacturing of fuel cell buses. A large-scale deployment of 200 fuel cell buses will further establish the UK supply chain. There are also economies of scale savings from the operation and maintenance of larger fuel cell bus fleets, with fixed costs spread over a larger number of buses and higher hydrogen demand helping to reduce the unit cost for the production and distribution of hydrogen. The commitment from the UK Government to support the deployment of 4,000 zero emission buses across England and Wales along with the announced financial support provides an opportunity to secure subsidy for the investment in new fuel cell buses and hydrogen refuelling infrastructure.

The fuel consumption of a fuel cell bus is dependent on the bus route, climatic conditions and the speed at which the bus travels. An approximate hydrogen design requirement is 15 – 20 kg H_2/day for a fuel cell bus. A fleet of 200 buses will therefore require approximately 3,000 – 4,000 kg H_2/day. This scale of hydrogen demand is unlikely to merit blue hydrogen production (which includes infrastructure for carbon capture and becomes cost effective at larger scales), however this hydrogen can be supplied by a 10+ MW electrolyser. Operating at full load, a 10 MW electrolyser produces c.4,000 kg H_2/day, however lower load factors (which would be the case for electrolysers connected directly to renewable generators) will require a larger electrolyser capacity to produce this quantity of fuel.

The deployment of a large number of fuel cell buses increases demand for low carbon hydrogen for the transport sector and the deployment of hydrogen production and refuelling infrastructure. This will have a range of wider benefits as other vehicle sectors can benefit from the infrastructure (as an example the hydrogen bus project in Aberdeen also includes a hydrogen dispenser at 700 bar to refuel fuel cell light duty vehicles).

It is important that the deployment of this initial large-scale fuel cell bus and hydrogen depot in Wales is replicated with subsequent projects to meet the target for a zero-emission bus fleet by 2028. This initial deployment will act as a template for other bus fleets and although initially focused on larger, urban bus fleets, can then be applied to more rural bus fleets from 2025 onwards. By this time the cost of fuel cell buses are expected to have further reduced and low-cost, green hydrogen to refuel the buses will be more readily available.

Summary

Activity / objective	Scale	Timescales	Role of public sector
Deploy a fleet of 200 fuel cell buses in a Welsh town / city / region (1–2 depots) by 2024 in preparation for thousands in operation by 2028.	200 buses will create demand for hydrogen of the order 3 – 4 tonnes H_2/day, sufficient for an anchor demand for a 10+ MW electrolyser.	Deployment by 2024 implies project development work needs to start in 2020/21. Lead time for a wind-to-hydrogen system expected to be at least 24 months from investment decision.	Help secure funding for a fuel cell bus roll-out project at scale in Wales. Consider options for financial support to bridge any cost gap relative to incumbent solutions, including engagement with DfT / OLEV.

3.3 Establish Wales as an early market for fuel cell vehicles

Context

There is currently a limited selection of hydrogen fuel cell vehicles offered by vehicle original equipment manufacturers (OEMs). As of 2020, the lack of availability of fuel cell vans and trucks is a major barrier to deployment of hydrogen for heavy duty transport. Vehicle OEMs active in developing fuel cell powertrains for light duty vehicles have recently started diversifying fuel cell vehicle options to include heavy duty vehicles.

The move to heavy duty vehicles has partly been driven by customer demand, as highlighted by the case with the planned deployment of 1,600 Hyundai XCIENT fuel cell trucks in Switzerland by 2025 (13). In this case a commitment from a consortium of HGV customers has provided certainty to Hyundai, the fuel cell vehicle manufacturer, to invest in manufacturing a heavy-duty fuel cell vehicle option. This commitment from the end user also provides more certainty to the hydrogen supplier and refuelling infrastructure provider for the demand of hydrogen. Without the demand and commitment from customers the business case for investment is too risky for hydrogen suppliers and vehicle manufacturers. The deployment of fuel cell vehicles has been limited because of the lack of refuelling infrastructure, and the refuelling infrastructure has been limited because of the lack of vehicles. The business case for each relies on the deployment at scale of the other. A commitment of sufficient scale from the customer to provide a business case to the vehicle manufacturer and hydrogen supplier reduces this risk, with these three components required to support the business case, as illustrated in Figure 11.

Activity

To support the business case for vehicle OEMs developing fuel cell vehicles and operators of hydrogen refuelling infrastructure a sufficient demand from customers is required. An early commitment to this demand will help unlock investment from vehicle OEMs and refuelling infrastructure providers. By coordinating customer demand from Welsh Government, local authorities and the public sector organisations across Wales an initial demand for hydrogen vehicles can be identified. Commitment from the public sector will provide more reassurance and further reduce the risk to vehicle manufacturers and hydrogen suppliers. This can then be expanded to include demand from private organisations in Wales. In a similar vein to the Swiss Hyundai fuel cell truck project, with plans to also replicate a similar scheme in Norway (14), there are existing programmes looking to develop an aggregated customer demand for hydrogen fuel cell vehicles in the UK. Operators of large fleets

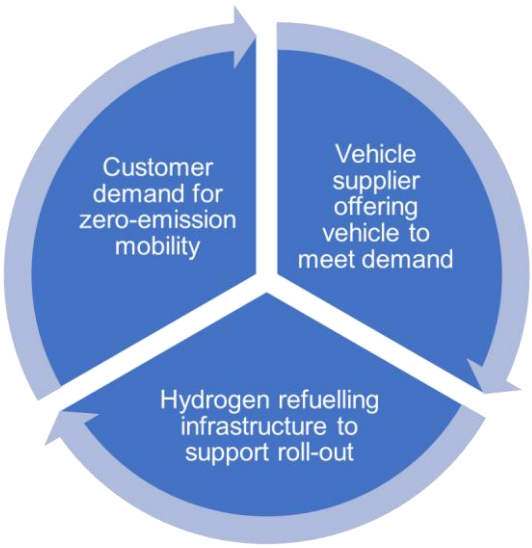


Figure 11: Illustration of need for commitment from the customer to commit to demand for fuel cell vehicles and hydrogen refuelling infrastructure

of vehicles in Wales should engage with such demand aggregation initiatives to ensure that Wales is an early market for deployment of heavy-duty fuel cell vehicles.

To demonstrate a viable business case for the hydrogen supplier and vehicle manufacturer a sufficient demand from the customer is required. This is where the benefit of engaging with other UK-wide plans for aggregated vehicle demand will help. Through combining with wider plans, the roll-out of a fleet of vehicles in the order of 300 fuel cell vans or 150 fuel cell trucks in Wales will be possible (when combined with similar demands for vehicles from regions and organisations across the UK). The plan would then be for this consortium to lead discussions with different hydrogen vehicle manufacturers on their options for delivering fuel cell vehicles to the UK market. As these vehicles are not currently being manufactured by most existing vehicle manufacturers the timescales for deployment are not be expected until at least 2023/24.

Figure 12: The first delivery of the Hyundai XCIENT fuel cell trucks to customers in Switzerland (31)

Benefits

The UK has a smaller manufacturing base for vans and trucks than it does for buses, however there will be opportunities for maintenance and manufacturing of the electrolysis and hydrogen refuelling equipment, which will create jobs in Wales.

Establishing Wales as an early deployment region for heavy duty hydrogen vehicles will build demand and unlock opportunities for further hydrogen production sites as well as locations for hydrogen refuelling stations.

At the scale of 300 fuel cell vans or 150 fuel cell trucks the hydrogen demand is expected to be lower than the demand of 200 fuel cell buses discussed in objective one. However, this would still require an electrolyser in the order of 8+ MW.

The requirement for hydrogen refuelling stations from this initial deployment also helps to prepare for the wider scale rollout of commercial heavy-duty hydrogen vehicles, which are expected from 2027 / 28. This presents an opportunity to develop a skeleton hydrogen refuelling infrastructure in Wales, potentially along or near strategic transport corridors (e.g. M4, A55). When larger volumes of commercial hydrogen fuel cell vehicles become available from the late 2020s Wales will have an initial infrastructure, and low-cost green hydrogen, ready for further expansion throughout the 2020s to support the commercial roll-out of zero-emission heavy duty vehicles.

Summary

Activity / objective	Scale	Timescales	Role of public sector
Secure early production volume from OEMs offering fuel cell vans / HGVs via involvement of Welsh fleet operators in aggregation / joint procurement initiatives.	First deployment of the order 300 fuel cell vans / 150 fuel cell trucks, with a view to deploying thousands of vehicles in the second half of the decade.	Procurement from 2021. First vehicles (prototypes) not expected before 2023/24.	Coordinate national-level involvement of public sector fleets with various initiatives ongoing across the UK trying to aggregate demand for fuel cell van / HGV deployment.

3.4 Create high value jobs via an innovative vehicle manufacturer and associated supply chain with new FCEV production plants in Wales

Context

Wales' benefits from the presence of Riversimple, a manufacturer of zero-emission fuel cell vehicles with a research and development base in Llandrindod Wells. Riversimple is currently producing prototype vehicles for customer trials, which will take place throughout 2021. This is alongside an investment round to finance manufacturing facilities, with target delivery of the Riversimple Rasa to customers from 2023. The Welsh Government and local authorities in Wales have been supportive of Riversimple and are potential customers, as well as partners to support the development of a manufacturing base in Wales. There are clear benefits for job creation if Riversimple established a manufacturing base in Wales, which will also help to establish a wider supply chain. The next few years will be critical for Riversimple as they look to scale-up from the current demonstration of vehicles to a commercial offering.

Activity

There are various actions that Welsh Government can take to build on the success enjoyed to date by Riversimple and establish local manufacturing of fuel cell vehicles in Wales, including:

- **Review and encourage opportunities to deploy hydrogen vehicles in public sector vehicle fleets such as the Riversimple Rasa:** as a small two-seater vehicle the Rasa is only suited to certain duty cycles, however the Rasa and other hydrogen vehicles should be considered in public sector vehicle fleet reviews as it supports zero-emission transport within Welsh Government, local authorities and the public sector.

- **Consider options to support investment in manufacturing**: this includes; direct investment, support to secure third party investment or other measures, such as low interest loans. As with any investment or financial support, the necessary due diligence and fair competition rules need to be followed. Support from Welsh Government will help attract investment in manufacturing by investors through helping reduce the risk of investment. Given the innovative nature of Riversimple's Rasa vehicle and proposed future vehicles and potential other innovative manufacturers, there could also be opportunities for innovation funding to support vehicle development in Wales.

Figure 13: Riversimple Rasa refuelling at the temporary Abergavenny hydrogen refuelling station (32)

- **Support activity to identify sites for manufacturing facilities and refuelling infrastructure**: Suitable sites for manufacturing facilities need to be identified, along with multiple sites for refuelling infrastructure in locations where demand will initially be deployed. Synergies with all activities should be considered such as opportunities for sharing refuelling infrastructure with other light-duty vehicles or taking advantage of renewable hydrogen supply systems established for fleets of heavy-duty vehicles.
- **Consider options to encourage the uptake of zero-emission vehicles:** This is not specific to Riversimple, or even fuel cell vehicles, however there are actions that Welsh Government and local authorities should consider to encourage zero emission vehicle uptake. At a local authority level this could include; bus lanes being accessible to zero-emission vehicles, free parking in town centres etc.

Benefits

Establishing manufacturing such as a fuel cell vehicle manufacturing base in Wales will have significant economic benefits by creating high value R&D, engineering and manufacturing jobs in Wales. There is potential to also attract component suppliers to Wales and establish a wider supply chain with further job creation and economic benefits.

As an example, as a zero-emission vehicle, the Rasa will help to reduce GHG emissions and improve air quality across towns and cities in Wales. The vehicle itself is most suited to driving shorter distances, this presents opportunities to establish early hubs where the Rasa can be deployed in regions or towns and cities supported by localised refuelling infrastructure. Riversimple plan to deploy the vehicle through a monthly lease, which includes maintenance and fuel. The low fuel consumption of the vehicle is also a benefit, as the cost of operating the Rasa is less sensitive to the cost of hydrogen fuel. Throughout 2021 Riversimple is planning to trial vehicles with customers, which will provide feedback on the vehicle operation and highlight any technical issues. Alongside this Riversimple has been gauging customer interest, including memorandum of understanding (MoUs) with local authorities to evidence the potential demand for the vehicle.

Manufacturing requires scale for demand and production and in the case of Riversimple its business model will depend on achieving this balance. Potential investors will assess this as part of due diligence activities prior to support.

Summary

Activity / objective	Scale	Timescales	Role of public sector
Establish manufacturing opportunities in Wales, including production of Riversimple FCEVs in Wales by 2024/25	Investment case requires critical level of demand	Covid-19 has impacted on manufacturing developments and proposed start of production may be affected.	Facilitate opportunities for manufacturing development in Wales. Support companies such as Riversimple to help establish manufacturing operations. Clearly, any further financial support is subject to checks of the business case, evidence of demand, etc.

3.5 Attract vehicle integrators to Wales

Context

Objective four looks to further develop the hydrogen vehicle manufacturing base in Wales by supporting hydrogen vehicle integrators. Where alternatives, such as pure battery electric, are unsuitable this objective focuses on addressing the lack of availability and choice of fuel cell vehicles offered by vehicle OEMs. Vehicle integrators offer a platform to convert existing vehicles and modify the powertrain to convert this to either hydrogen dual-fuel (where hydrogen is combusted in a diesel engine) or hydrogen fuel cell range-extender (from a battery electric vehicle) (15) (16) (17).

Figure 14: ULEMCo hydrogen-diesel dual fuel conversion of Yorkshire Ambulance vehicles (33)

The cost of the modified vehicle is therefore always at a premium to the base vehicle purchased from the OEM. Adapting existing vehicles allows zero emission options for vehicle segments to be developed where there are currently non available on the market, and extend the vehicle range/ allow quick refuelling for converted battery electric vehicles to suit a duty cycle where their operation is compromised. Examples include the conversion of diesel ambulances to hydrogen-diesel dual fuel vehicles (shown in Figure 14).

Activity

Given the current lack of selection and choice of zero-emission vehicle options, an initial assessment of the public sector vehicle fleet to identify vehicles most suitable for conversion will quantify the demand for retrofit vehicles. There are several vehicle integrators based in the UK, including Arcola Energy, Hypermotive and ULEMCo. Discussions with these vehicle integrators will establish vehicle options they are able to provide, as well as the cost to retrofit existing vehicles and options to develop a manufacturing and maintenance facility in Wales. There are previous examples of vehicle integrators establishing a maintenance/ vehicle retrofitting base near vehicle deployments, with Arcola Energy setting up facilities alongside vehicle deployments in Dundee and Liverpool.

Welsh Government and local authorities can also have a role in locating suitable sites for vehicle integrators to establish a base for vehicle retrofitting, support the site selection for hydrogen refuelling stations and look at options to encourage further demand for retrofitted zero emission vehicles in private sector fleets, such as promoting clean air policies and supporting ultra-low transition towards retrofitting heavy duty vehicles.

Benefits

Retro-fitting vehicles to enable zero-emission operation, or extending the range of existing battery electric vehicles enables the Welsh public sector vehicle fleet to decarbonise earlier than waiting for commercial offerings from vehicle OEMs. This does, however, include a cost premium as the retrofitting requires additional components and labour on top of the price of a conventional vehicle.

Supporting a vehicle integrator to establish a base in Wales will create further high value jobs and there are also potential synergies with a Riversimple manufacturing base. This will further strengthen the offering to attract component suppliers and support a supply chain in Wales.

The integration of fuel cell or dual-fuel powertrains into new vehicle categories is innovative and this work would have opportunities for innovative research and development funding. There are also opportunities for research collaborations and vehicle testing with academic research partners in Wales, as well as with vehicle OEMs. An example is the partnership in France between Renault and vehicle integrator Symbio FCell. After Symbio FCell developed the range-extender Renault Kangoo van, Renault has since take the development of fuel cell vans in-house and is offering a fuel cell van based on the vehicle integration by Symbio (18).

Summary

Activity / objective	Scale	Timescales	Role of public sector
Establish new automotive activity in Wales (e.g. vehicle integrators) via a project to develop, trial, and then deploy at scale speciality FCEVs used in public sector fleets (e.g. fire engines, ambulances, municipal vehicles).	Fleets of at least 10 prototype vehicles for trials, with a view to expanding to small series production.	Prototype design, build, and testing likely to take several years. Series production post-2025.	Provide / help source RD&D funding for this type of activity. Create demand for trial vehicles and signal the existence of the market for zero emission solutions.

3.6 Attract fuel cell train demonstration and testing activities to Wales while providing increasing anchor demands for hydrogen in transport

Context

To reduce GHG emissions from the rail network the DfT has set a target to phase out diesel-only trains by 2040 (19). With only a small section of Wales' rail network electrified, east of Cardiff, the rail network currently relies heavily on diesel trains. There is an on-going campaign to electrify the mainline network in Wales, including the South Wales (Cardiff – Milford Haven) and North Wales (Crewe – Holyhead) routes. If these lines are electrified, then electric trains will provide a low carbon and efficient rail network. However, there are several lines that are used less frequently where there will not be a viable business case for electrification, this includes rural lines across Wales. In these instances, hydrogen fuel cell trains offer a credible option to decarbonise the rail network. These routes include the Cambrian line from Shrewsbury to Aberystwyth and Pwllheli, the Conwy Valley Line from Llandudno to Blaenau Ffestiniog and the Heart of Wales line between Shrewsbury and Swansea (see Figure 15).

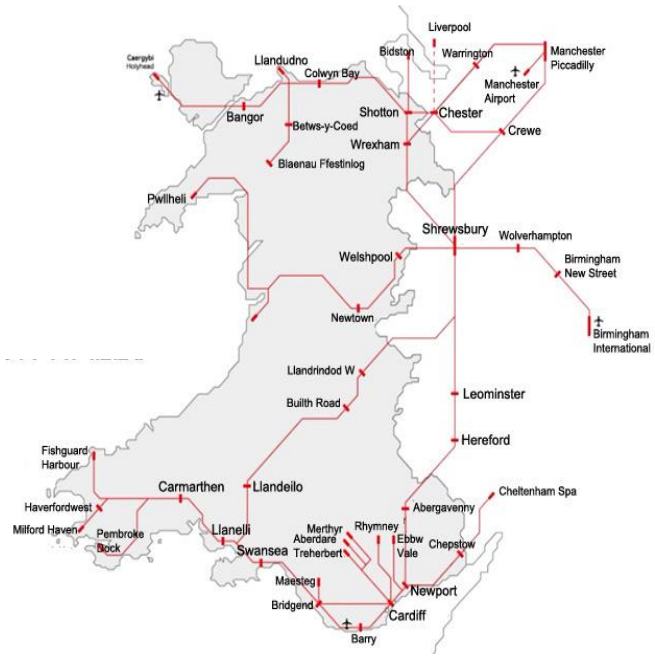


Figure 15: Transport for Wales rail network map (34)

Passenger rolling stock manufacturers and rolling stock operating companies (ROSCOs) are currently developing hydrogen fuel cell trains for the UK market. Examples of these are shown in Table 1. For the European market Alstom has developed a fuel cell train which is operating passenger services in Germany and Austria and has completed over 180,000 km. Alstom is currently developing a hydrogen fuel cell train for the UK market with ROSCO, Eversholt, which uses converted Class 321 units (20). The ROSCO, Porterbrook and the University of Birmingham are also developing a fuel cell train from a converted Class 319, which is currently undergoing mainline testing. Vivarail, is also developing a fuel cell train offering, using Class 230 units previously used on the London underground.

Table 1: Summary of hydrogen fuel cell trains being developed for the UK market

Companies involved	Details	
Alstom – Eversholt		The 'Breeze' converted Class 321 with hydrogen fuel cell and hydrogen tanks in carriage with 1,000 km range and 140 km/hour top speed. Planned for operation from 2022.
Porterbrook – University of Birmingham		The 'HydroFlex' converted Class 319 is being tested on the UK mainline and will include a 100 kW fuel cell and 20 kg H_2 per unit.
Vivarail – Arcola Energy		Vivarail have also announced trials for hydrogen fuel cell trains in converted Class 230. These units will contain hydrogen tanks below the carriages with an estimated >1,000 km range

In England, rail operators have been in discussions with the Department for Transport to deploy hydrogen fuel cell trains on suitable routes (21). In Scotland, Scottish Enterprise and Transport Scotland recently issued a tender notice for the conversion of a Class 314 train to run on hydrogen for a demonstration ahead of COP26 (22).

Activity

Under the Transport for Wales (TfW) rail and metro franchise, which was awarded to KeolisAmey and will be operated by Transport for Wales from February 2021, a range of new rolling stock vehicles have been ordered. This includes diesel units, and overhead electric-diesel-battery tri-mode trains, as well as battery-hybrid (diesel gen-set) Class 230 units from Vivarail[6].

Given these new rail vehicles are already committed to, it is unlikely there will be opportunities for fuel cell train deployments within Wales for the next 15 years. However, the contract does allow some flexibility for introducing new technology if found to be operational and commercially viable, but it should be recognised that since passenger rail rolling stock has a typical service life >30 years (23) new rolling stock orders from 2020 will likely be operating beyond the 2040 target to ban diesel-only trains and beyond the UK Net Zero target for 2050.

[6] Clearly, the deployment of new fleets of diesel-fuelled trains restricts the short to medium-term opportunities for zero emission alternatives. In addition to the choice of drivetrain, a further barrier in some cases is the fact that some trains have specific signaling systems (e.g. the signaling system on the Cambrian route which was installed as part of a Network Rail trial is specific to the CAF trains operating on the route).

A detailed assessment of the potential role of hydrogen fuel cell trains in Wales as part of the overall transport decarbonisation strategy will identify routes that should be converted to hydrogen, specifications of the trains and refuelling infrastructure options. From 2030 it will be worth assessing options to convert remaining diesel only trains on the network to hydrogen. By this time the costs of hydrogen fuel cell trains are expected to be commercially competitive with diesel units and the use of hydrogen as a transport fuel will be more widespread across Wales and the rest of the UK.

There are several hydrogen trains being developed for the UK market, none of which has yet been deployed in passenger service, as of December 2020, there is still a need to demonstrate and trial the technology before mainstream roll-out. Despite commercial roll-out of fuel cell trains unlikely in Wales before 2035, there is still an opportunity to support small-scale technology trials. This will increase the awareness and understanding of operating a hydrogen fuel cell train, and prepare for larger orders for hydrogen fuel cell trains from 2035.

Benefits

Hydrogen fuel cell trains provide the most viable option to decarbonise the rural rail network. Fuel cell trains will increase the demand for low-carbon hydrogen, creating hydrogen supply chain jobs from installing and operating hydrogen production and supply infrastructure.

There are also opportunities for hydrogen fuel cell train testing and wider research and development through the proposed Global Centre of Rail Excellence which is under development in the Neath / Port Talbot area. This R&D work would be applicable for innovation funding. Options to establish fuel cell train manufacturing at existing rolling stock manufacturing facilities in Newport, where diesel multiple units for TfW are currently being manufactured should also be explored in the future.

Summary

Activity / objective	Scale	Timescales	Role of public sector
Encourage fuel cell train pilot trial to demonstrate fuel cell technology and conduct detailed review of potential for hydrogen trains in Wales	Encourage pilot trial with one train	Piloting activities in the early to mid-2020s alongside studies into the potential long-term role of fuel cell trains in Wales	Commit to reviewing fleet(s) and decarbonisation options, including fuel cell trains subject to piloting / testing and research proving operational capability for contract delivery.

3.7 Establish at least one renewable hydrogen production facility at 10+ MW scale by 2023/24

Context

A 10 MW electrolyser operating at full load produces around 4 tonnes H_2/day, this is at a scale that is generally too small for blue hydrogen[7] production to be viable (with the associated costs of carbon capture and storage). Electrolyser suppliers are starting to offer larger scale electrolyser modules in sizes from 5 – 20 MW, which can be combined in a modular system to scale-up the size of the electrolyser installation. There has been a series of announcements in recent months of large-scale electrolyser deployments across Europe (see section 2.3). Many of these projects are yet to be built, however there is a clear trend of increasing scale of electrolyser installations and numerous suppliers have announced plans to invest in increased electrolyser manufacturing capacity. Both the scale-up of the installed electrolyser size and the electrolyser manufacturing capacity helps to reduce the capital cost of electrolysers. An electrolyser capacity of the order of 10 MW would be comprised of one or two of these larger electrolyser modules.

Activity

The objective is to install at least one 10+ MW electrolyser by 2023 / 24 which will benefit from cost reductions in electrolyser capital cost from current electrolyser installations. The viability of the business case for an electrolyser operator producing green hydrogen, however, is reliant on both the local hydrogen demand and input cost and load factor of renewable electricity. The objectives above will generate sufficient hydrogen demand, including fuel cell buses, vans or trucks discussed previously. If the hydrogen is used as a road transport fuel, it could also be eligible under the Renewable Transport Fuel Obligation (RTFO) scheme[8]. The RTFO supports the business case for hydrogen produced from electrolysis, although this needs to meet certain criteria, including the requirement for the electrolyser to be connected to a new build renewable asset.

Similar sized electrolysis projects have recently been announced in Scotland, with a 9 MW and 10 MW installation both announced recently (24) (25). Both of these projects are planned to connect to onshore renewables and provide hydrogen to local road transport demands. There are also electrolysis projects planned in England with connections to offshore wind farms for road transport (26) and industrial uses (27).

Establishing hydrogen production will require initial feasibility assessment on the site location, co-locating the electrolyser with the renewable generation asset, electrolyser size and the logistics of delivering hydrogen to the demand centre(s) as required. Other important considerations include the load factor from the renewable

[7] Blue hydrogen refers to hydrogen produced from a feedstock of natural gas by steam methane reforming (SMR) or autothermal reforming (ATR) coupled with carbon capture, and storage (CCS) of the resulting carbon dioxide emissions.
[8] The RTFO is a Department for Transport scheme to reduce GHG emissions from the road transport and implements the EU's Renewable Energy Directive (RED) policy

generator and the impact this has on hydrogen production (a lower load factor from the renewable generator will require a larger electrolyser to produce the same quantity of hydrogen). Qualification for the RTFO scheme will also need to be considered, as this will have a large impact on the business case of green hydrogen production for use as a transport fuel. There are also opportunities to support local ownership for hydrogen projects (following the support for local ownership of renewable projects).

This proposal will require planning consent, which cannot be guaranteed and therefore carries a risk. This needs to be taken into account when considering selecting a suitable site, ensuring appropriate national and local policies provide the relevant framework for the development and the project plan takes account of the need to work through these issues to ensure any barriers, including consents, form part of the project scheduling and risk analysis.

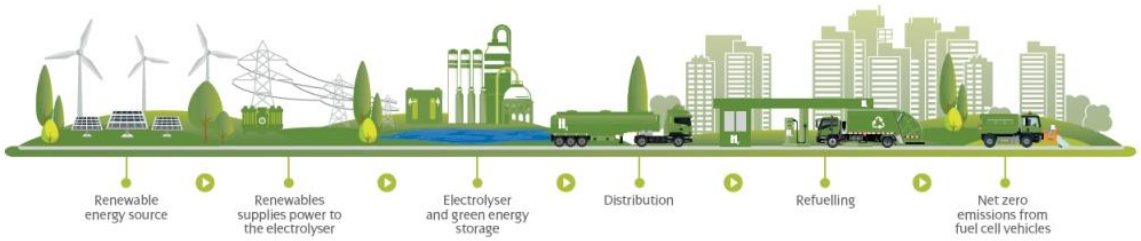


Figure 16: ITM Power, BOC and Scottish Power project to install a 10 MW electrolyser and produce green hydrogen for road transport uses in Glasgow (23)

Benefits

Establishing green hydrogen production in Wales will prepare the way for larger scale projects as demand for low-carbon hydrogen is forecast to increase. This approach will help start developing the skills and local experience required to operate electrolysers co-located with renewables and the logistics of transporting hydrogen to refuelling infrastructure demand. Local hydrogen production will support investment into Wales, with transport fuel derived from Welsh renewable resources, rather than imported fuel. There are also wider opportunities for hydrogen to unlock renewable energy projects that are limited by costly grid upgrades or electricity grid constraints.

The 10 MW scheme has been approximated based on the demand from 200 – 250 fuel cell buses. Consideration for expansion should be included in this design, as hydrogen demand is aimed to grow, with the target to expand on initial hydrogen demand projects described above. There could also be emerging hydrogen demands from other sectors within this timeframe.

These projects should be planned alongside the scale-up for larger green hydrogen production, which will be needed as more hydrogen applications reach commercial competitiveness. For instance, fuel cell trucks and vans are expected to be commercially available towards the end of the decade, which will lead to significant demands for low-carbon hydrogen. Planning for large-scale hydrogen production is considered in objective seven.

Summary

Activity / objective	Scale	Timescales	Role of public sector
Establish at least one renewable hydrogen production facility in Wales with an electrolysis system 10+ MW by 2023/24 (e.g. a wind-to-hydrogen system).	10 MW of electrolysis provides a capacity of >4 tonnes hydrogen per day (e.g. sufficient to fuel c.200 – 250 buses).	Lead time for such a facility expected to be at least 24 months.	Support demand creation activities (see above), which will allow the private sector to deliver.

3.8 Plan large-scale low carbon / renewable hydrogen production in Wales

Context

Today there are several barriers preventing further penetration of hydrogen in the transport sector, principally availability of vehicles in certain segments (e.g. vans, trucks), and challenging economics. However, there is a focus on bringing new products to market and scaling up production of FCEVs to reduce costs through the 2020s. If FCEVs achieve even a modest share of the heavy-duty transport market, there will be a need for much larger scale hydrogen fuel production and delivery systems. For example, a fleet of 1,000 fuel cell trucks will lead to fuel demands of the order of 30 tonnes H_2/day, requiring c.75 MW electrolysis (operating at full load). There will also be demands for low-carbon hydrogen from industry and heating, which will potentially be much larger than the demand from transport. To meet these demands large quantities of low-carbon hydrogen are required, which will need large-scale hydrogen production facilities.

As discussed in section 2.3 there are a growing number of large scale (hundreds of MW+) electrolysers and blue hydrogen projects being planned in Europe and beyond. There are opportunities to develop large-scale hydrogen production in Wales. Although the hydrogen demand and business case might not yet be fully developed, conducting scoping and feasibility studies to outline the concept will provide the first step to make this happen and could attract interest from potential partners and investment. As part of scoping and feasibility work, it will be important to ensure considerations of potential issues such as timing, planning and financing are taken into account and any issues arising can then be addressed earlier in the process.

Activity

The scoping of larger hydrogen production opportunities should be conducted alongside early deployment activities, where the smaller demands are easier to develop business cases. This scoping work should explore what large-scale hydrogen production in Wales will look like, considering:

- different sources of energy (e.g. offshore wind, small modular reactors, natural gas with CCUS)
- different hydrogen production technologies (electrolysis, methane reformation, by-product hydrogen, thermochemical processes)
- customers for the hydrogen (road, rail, maritime transport, industrial feedstock, hydrogen for heating)
- hydrogen distribution options (compressed or liquefied road transport, pipeline)
- pre-conditions for a commercial case for actors across the supply chain (input energy cost, carbon price)
- Ensure account is taken of planning considerations and potential issues so the following risks can be minimised during the planning process - potential sites, land requirements, etc. (offshore renewable energy landing points and onshore sites)

Table 2: Summary of different energy sources for hydrogen production

Energy source	Description
Renewable energy	Electrolysers powered by renewable electricity produce 'green' hydrogen. This could be an electrolyser directly coupled to a renewable generator (e.g. through a private wire), in this case the electrolyser load factor would be dependent on the load factor of the renewable generator. Alternatively, a grid connection and power purchase agreement with a renewable generator can produce green hydrogen.
Natural gas	The vast majority of hydrogen currently produced in Europe is from natural gas. This is currently produced from the steam methane reformation process, producing grey hydrogen. CCS can be applied to steam methane reformed hydrogen as well as advanced thermal reformation (ATR) to capture CO_2 emissions from the hydrogen production process to produce blue hydrogen (ATR with CCS is estimated to capture 95% of CO_2 emissions and steam methane reformation with CCS is estimated to capture 90%).
Nuclear energy	Production of hydrogen alongside nuclear electricity and heat has yet to be commercially demonstrated, however trials are planned by EDF for the proposed Sizewell C nuclear reactor in Suffolk (28). There are similar opportunities for Wales to develop the decommissioned Wylfa and Trawsfynydd sites. There are several options to produce hydrogen from nuclear electricity and heat including: • Electrolysis powered using low-carbon electricity from nuclear power stations • Electrolysis powered from low-carbon electricity and heat from nuclear for high temperature / steam electrolysis (e.g. solid oxide electrolysis) • Thermochemical production of hydrogen from waste heat and electricity from nuclear (e.g. sulphur-iodine, hybrid sulphur or copper chlorine cycle) • Utilisation of waste heat to assist reforming natural gas / gasification of biomass
Biomass	Biomass gasification is still at an early stage of development and operates at high temperatures (500–1,400ºC) and pressures (up to 33 bar) to thermally decompose biomass into hydrocarbons, which is then converted into syngas through a gasification step. The output composition of syngas is dependent on the biomass feedstock, the biomass to steam ratio, gasification temperature and specific gasification technology used. The syngas can then be converted to bio-SNG

(through methanation), liquid biofuels (through Fischer Tropsch) or hydrogen.
There is also on-going research to produce hydrogen from anaerobic acidification, this is at an early stage of research, mainly at the laboratory scale, which produces an output gas mixture of hydrogen and carbon dioxide.

Benefits

In addition to the hydrogen supply side, understanding (large-scale) demands for hydrogen will be critical. The scoping work should be carried out in consultation with large-scale end users (e.g. industrial sites and gas networks for blending hydrogen into the gas network to decarbonise heat), building on existing work in this area (e.g. those part of the South Wales Industrial Cluster roadmap / deployment projects and under HyNet). A key output should be the clear articulation of the conditions under which large (potential) hydrogen customers can commit to being off-takers for the output from 100+ MW / GW-scale production facilities.

Preparing for large-scale hydrogen production in Wales will identify the most promising opportunities for sites to produce hydrogen, large-scale hydrogen demands as well as potential partners for these projects. Repurposing or utilisation of existing infrastructure, such as the natural gas transmission grid from Milford Haven should also be considered in opportunities for large-scale hydrogen supply, with potential to export hydrogen to the rest of the UK or even further afield.

Summary

Activity / objective	Scale	Timescales	Role of public sector
Scope large-scale hydrogen production facilities in parallel to deployment of systems at the low tens of MW scale.	Scoping activities for low carbon / renewable hydrogen production in Wales at 100+ MW and GW scale.	Scoping can be carried out in the short term, although delivery likely from the late 2020s.	Fund and / or feed into scoping activities for large-scale production and use of hydrogen in energy applications.

3.9 Support industrial decarbonisation through skills development and R&D

Context

Converting existing industrial processes to hydrogen (from conventional fuels) is complex. Most plants are different, which suggests that bespoke solutions will be required. There are also multiple issues to understand and resolve in terms of the practicalities of fuel switching. Furthermore, there is currently a significant skills gap in the use of hydrogen as a fuel in industry.

Activity

The objective of this activity is to support industrial decarbonisation in Wales through developing the required skills, training and facilitating research and development for hydrogen fuel switching of industrial appliances. An initial review and engagement with industry will identify the key challenges of industrial decarbonisation, including the skills gap, technical challenges with hydrogen supply and end use, conversion of utility supplies and requirement for hydrogen infrastructure.

There are a variety of forms this support could take, including a facility to provide tailored support to sites undertaking hydrogen fuel switching, development and testing of hydrogen industrial appliances, training and R&D facilities. This should link in with existing industrial expertise in hydrogen use and academic research Wales has established in the hydrogen sector, including the combustion of hydrogen and ammonia in gas turbines. There would be opportunities to extend this support to cover CCS, CO_2 shipping and hydrogen production, with the potential to link with the Nuclear Futures Institute at Bangor University and the options for coupled hydrogen production from nuclear electricity and heat.

Benefits

Developing a centre of excellence, or similar grouping, on industrial decarbonisation and hydrogen fuel switching will help prepare Wales' industrial organisations for decarbonisation. This will also build and strengthen existing partnerships and collaborations between industry in Wales, and research expertise in hydrogen combustion. Establishing Wales at the forefront of industrial decarbonisation knowledge and learning will help to attract further private investment into research and development in the hydrogen sector, as well as opportunities to apply for wider UK research and innovation funding. The focus of the industrial decarbonisation support is expected to be on Wales / the UK initially, but the services offered would be relevant to other industrial clusters around the world, leading to new export opportunities.

Summary

Activity / objective	Scale	Timescales	Role of public sector
Scoping work into the opportunities to build further expertise in industrial fuel switching to support industries with understanding transition to low / zero carbon operations.	Focus on solutions for industry in Wales, elsewhere in the UK and Europe.	Review industry needs and develop plans / remit and funding requirement in 2020/21. Proceed with solution from 2022/23.	Support and feed into a review of options. Source funding for development and deployment from private sector, academia and Government.

3.10 Seek opportunities for a "place-based" approach when developing hydrogen projects in Wales

Context

There are multiple local hydrogen initiatives currently on-going in Wales, including Milford Haven Energy Kingdom, Holyhead hydrogen hub, Bridgend, Monmouthshire and Flintshire amongst others. Many of these projects are early stage developments and may require further support to proceed to a delivery / expansion phase.

The outcomes from these projects, including those focused on whole system developments and the integration of hydrogen into existing energy systems, will help inform the direction of the hydrogen sector in Wales. A place-based approach should take a holistic view on the wider system, this reflects the wider impact that developing the hydrogen sector can have on the community including the provision of energy, transport services, waste services, water supply and treatment, jobs and industry, education and training.

Activity

It is proposed to engage with and, where appropriate, support on-going hydrogen projects in Wales. Welsh Government and local authorities can support the wider engagement these projects have with the local community. A place-based approach will take into consideration local aspects and engage with the wider community. This requires communication and dissemination at different levels. Many of the projects discussed above are focused on industrial or academic stakeholders, the place-based approach requires wider outreach to the general public through stakeholder engagement and supporting policy frameworks for place-based hydrogen facilities.

Benefits

There are a wide range of benefits developing the hydrogen sector will have on local communities, including decarbonisation, improvement in air quality, job creation and encouraging investment in local areas. These messages should be communicated through Welsh Government and other relevant key stakeholder channels. This will help gain public acceptance and support for hydrogen projects, which is important for developing and expanding the pipeline of hydrogen initiatives in Wales.

Summary

Activity / objective	Scale	Timescales	Role of public sector
Support local 'place-based' projects and engage with project outputs	This will focus on regional projects, the scale of each will be dependent on the project.	Dependent on the individual project timescales.	Dependent on the local project, from supporting hydrogen demand and providing / supporting

and development plans.	applications for funding where appropriate.

3.11 Engage with other hydrogen initiatives

This study identified a range of other initiatives and opportunities that could further establish the hydrogen sector in Wales. Some of these require third party decisions, such as policy changes from UK Government (e.g. UK heat decarbonisation policy), some are shorter-term actions (e.g. connection of the Baglan HRS to the e-HRS-AS system[9]). These are listed below and further engagement from UK and Welsh Government and key stakeholders in these areas will help to accelerate these initiatives.

Low carbon hydrogen production	• Review options for hydrogen from nuclear (small modular reactors) at Trawsfynydd and / or Wylfa Newydd. • Continue to follow and liaise closely with HyNET – be ready to take advantages of synergies in NE Wales. • Explore options for hydrogen production from biological methods (anaerobic acidification), as well as supplement anaerobic digesters with hydrogen to increase biomethane yield.
Hydrogen imports	• Prepare strategic sites (e.g. Milford Haven and / Port Talbot) for becoming potential centres for the import of low carbon / renewable hydrogen for use in Wales and / or supply to the rest of the UK.
Transport	• Complete 700 bar upgrade to Baglan HRS and ensure high reliability and connect to the e-HRS-AS system. • Develop strategic network of 700 bar HRS – e.g. along M4 corridor and linking to Bath, Bristol, Swindon and the wider national HRS network. Anchor demands from 700 bar vehicles will be required to justify the new infrastructure – seek opportunities in taxi fleets, police vehicles, and other public sector fleets. • Opportunities for synthetic (renewable) fuel production at Milford Haven (e.g. for the aviation and maritime sector).
Heat	• Trials to blend hydrogen into the gas grid (up to 20% by volume). • Trials of hydrogen boilers / hybrid heat pump + fuel cell CHP in both new & existing housing (Milford Haven Energy Kingdom).

[9] The e-HRS-AS is a system to report the live status of publicly accessible hydrogen refuelling stations across Europe and is designed to support early adopters of FCEVs by notifying them of any issues or downtime and their nearest available hydrogen refuelling station; https://h2-map.eu/

Power	• Undertake a trial of a hydrogen-fuelled gas engine providing responsive, dispatchable power generation. • Ammonia combustion for power generation demonstrator via a gas engine (building on a similar project between Cardiff University, Siemens and Oxford University). • Further research into high hydrogen blends (30%+ by volume) into gas turbines. Demonstrate hydrogen blending at different levels in existing CCGT power station in Wales (e.g. RWE site in Pembroke).
R&D / training / other	• Continue the strong collaboration between academic institutions and industry. • Expand the Gas Turbine Research Centre. • More hydrogen-related activities at Advanced Manufacturing Research Centre (AMRC) Cymru. • R&D for hydrogen production from anaerobic fermentation / supplementing anaerobic digestion with hydrogen to improve methane yield. • Support community-based renewable hydrogen projects (including provision of national-level coordination).

4 Next Steps

The objectives listed in section 3 are based on short-term actions that will develop the hydrogen sector and prepare for scale-up from 2030. This includes roles and opportunities for Welsh Government and the public sector, the private sector and academia. As discussed above these have focused on short-term initiatives to develop momentum and prepare Wales for the larger-scale deployment of hydrogen, which is set to play a critical role in decarbonising industry, transport, heating and the power sector.

The action plan below shows the timescales over which these initiatives can be delivered. There is a focus on the initial deployments by 2025, which can then be replicated on a more commercial scale from 2025 onwards.

The actions required to meet the objectives described above are further detailed in Table 3, which includes a summary of the key stakeholders and target for timeline for delivery.

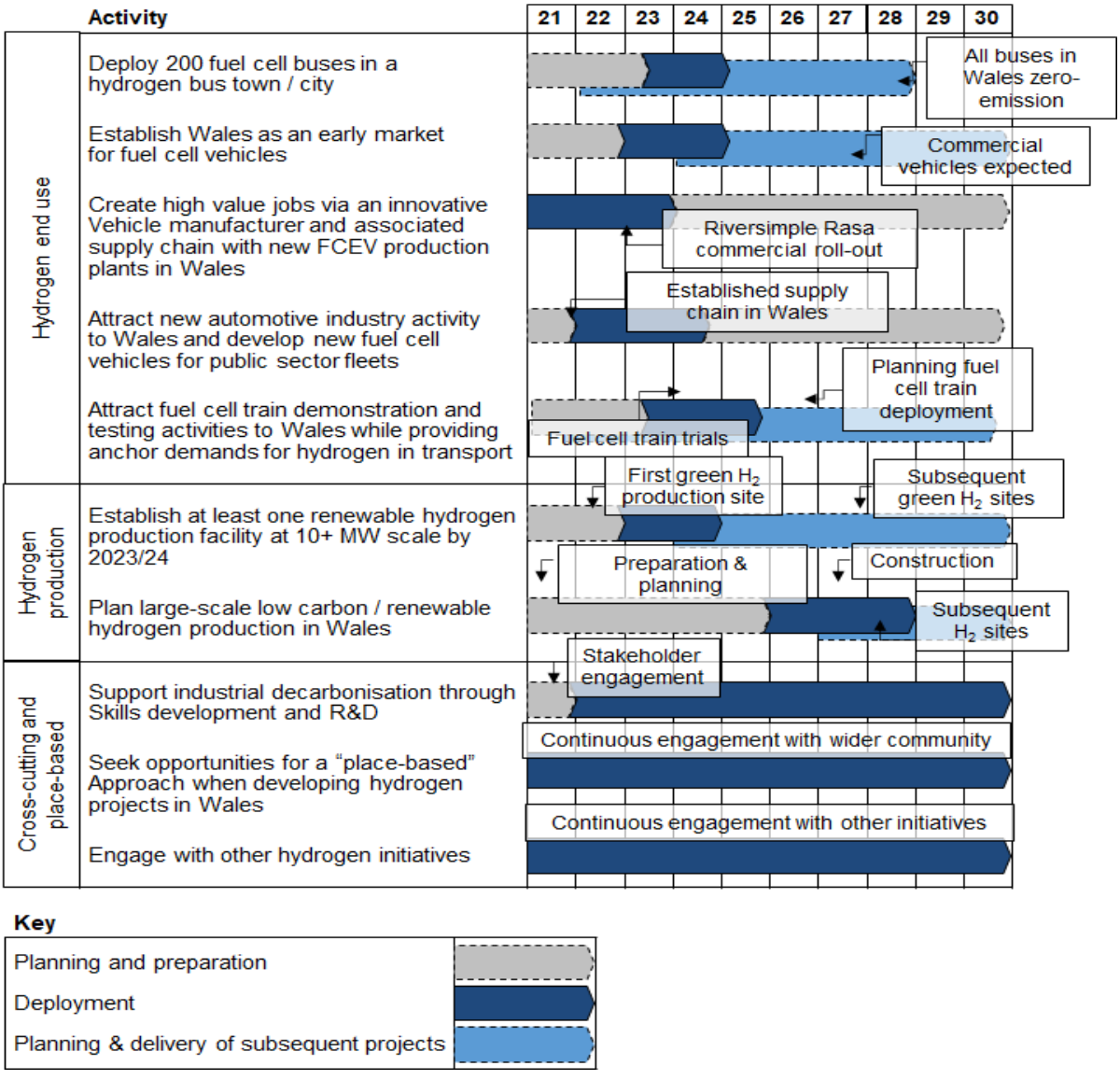


Table 3: Overview of next steps to support the Welsh hydrogen pathway

Objective 1: Deploy 200 fuel cell buses in a hydrogen bus town / city / region			
Actions	**Indicator**	**Delivery partners**	**Timescale**
Engage with bus operators to support transition to zero-emission bus fleet	Bus operators deployed fuel cell buses, which operate on passenger routes	Bus operators (initial focus on town / city / region operations with larger bus fleets) Bus manufacturers Hydrogen suppliers Hydrogen infrastructure providers	Initial 200 fuel cell bus deployment by 2023/24 Wider bus operators, through to 2028 zero emission bus target
Support development of hydrogen production and refuelling infrastructure	Hydrogen refuelling station and bus maintenance facilities commissioned	Hydrogen suppliers Hydrogen infrastructure providers Bus operator	Support through to 2028 zero-emission bus target
Develop plans for hydrogen infrastructure and fuel cell bus deployments across Wales	Identify bus fleets suitable for hydrogen fuel cell buses and plan deployment by 2028	Bus operators (across all Wales including rural routes) Bus manufacturers (wider range of vehicle options, including coaches, minibuses etc.) Hydrogen suppliers Hydrogen infrastructure providers	Support through to 2028 zero-emission bus target
Prepare to access UK Government funding to help deliver initiative	UK Government funding successfully awarded to support delivery of fuel cell buses in Wales	Bus operator UK Government	UK Government announced funding to deliver 4,000 zero emission buses across England and Wales by 2025

Objective 2: Establish Wales as an early market for fuel cell vehicles			
Actions	**Indicator**	**Delivery partners**	**Timescale**
Coordinate review of public sector and private sector vehicle fleet	Quantified scale of demand and specification for fuel cell vans / trucks	Public sector bodies in Wales Private fleet operators in Wales Hydrogen Reference Group	2021 – 22
Engage with wider aggregated hydrogen vehicle initiatives	Welsh vehicle fleets members of wider aggregated vehicle projects and engaged in discussions with vehicle manufacturers	Aggregated vehicle consortia, and through them vehicle manufacturers	From 2021 through to initial deployment of early-commercial vehicles 2023/24
Support hydrogen refuelling infrastructure	Hydrogen refuelling infrastructure supplier committed to operate refuelling infrastructure in Wales and locations identified to support fleet customers	Hydrogen infrastructure providers Fleet operators Local authorities Utility providers (e.g. electricity / gas)	From 2021 through to commercial roll-out of vehicles 2027/28
Objective 3: Create high value jobs via innovative vehicle manufacturers and associated supply chain with new FCEV production plants in Wales			
Actions	**Indicator**	**Delivery partners**	**Timescale**
Review potential for hydrogen use in public sector fleet including the Riversimple Rasa	Quantified demand for hydrogen including Rasa vehicles across public sector fleet	Local authorities and public sector fleets Car rental companies	2021 – 2022
Consider options to invest in manufacturing relating to hydrogen capacity building such as Riversimple	Investment into / other support for Riversimple	Riversimple and other hydrogen vehicle manufacturers Investors Funding bodies	2021

Support scoping for vehicle manufacturing bases in Wales	Sites for manufacturing bases selected and planning approved	Riversimple and other hydrogen vehicle manufacturers Local authorities	Throughout 2021-2022
Support uptake of hydrogen vehicles including Riversimple Rasa with end users	Hydrogen refuelling infrastructure deployed around a hub to support hydrogen customers	Riversimple, and other hydrogen vehicle manufacturers Local authorities Hydrogen refuelling infrastructure providers	From 2021 onwards until sufficient hydrogen refuelling capacity exists for commercial roll-out of hydrogen vehicles
Objective 4: Attract new automotive industry activity to Wales and develop new fuel cell vehicles for public sector fleets			
Actions	**Indicator**	**Delivery partners**	**Timescale**
Review public sector vehicle fleet	Vehicle specifications for zero-emission vehicle not currently commercially available and quantified demand across public sector fleet.	Public sector vehicle fleets Private vehicle fleet operators	2021
Consider economic support for zero-emission vehicle conversion	Incentive for zero-emission vehicles / penalty for diesel vehicles	Private vehicle fleet operators Funding bodies	2021 – 22
Engage with vehicle integrators to relocate to Wales	Delivery of retro-fitted vehicles and vehicle retro-fit workshop based in Wales	Vehicle integrators Local authorities Electric vehicle and H_2 component supply chain	2021 – 24
Objective 5: Attract fuel cell train demonstration and testing activities to Wales while providing increasing anchor demands for hydrogen in transport			
Actions	**Indicator**	**Delivery partners**	**Timescale**
Ensure future rolling stock orders align with Net Zero and diesel-only	Report detailing routes, train specifications and indicative timelines for hydrogen fuel	Transport for Wales Rail operators	2021 – 22

passenger rolling stock ban	cell trains to be deployed on rail network		
Support fuel cell train pilot demonstration	Initial fuel cell train demonstration completed in Wales	Transport for Wales Rail operators ROSCOs and rolling stock manufacturers developing fuel cell trains	2024 – 26
Objective 6: Establish at least one renewable hydrogen production facility at 10+ MW scale by 2023/24			
Actions	**Indicator**	**Delivery partners**	**Timescale**
Support feasibility assessments of potential sites for hydrogen production	Site identified and planning permission approved for 10+ MW green hydrogen production	Local authorities Natural Resources Wales Hydrogen Reference Group Gov Energy Policy and Planning Renewable developers Hydrogen suppliers Hydrogen end users	2021 – 23
Objective 7: Plan large-scale low carbon / renewable hydrogen production in Wales			
Actions	**Indicator**	**Delivery partners**	**Timescale**
Initiate hydrogen scoping studies	Engage with stakeholders (incl. Hydrogen Reference Group) to identify potential large-scale hydrogen production sites Develop concepts for these potential sites with relevant stakeholders	Hydrogen Reference Group Renewable developers Hydrogen suppliers Hydrogen end users Local authorities Natural Resources Wales Gov Energy Policy and Planning	2021 – 24
Engage with hydrogen	Plans developed for large-scale	Utilities (electricity / gas)	2023 – 28

production projects	hydrogen infrastructure to connect hydrogen supply to demand	Hydrogen suppliers Hydrogen end users Local authorities	
Engage with private sector organisations developing initiatives to import green hydrogen to understand the potential opportunities for Welsh ports	Consider planning required for potential green hydrogen imports at Welsh ports	Hydrogen importers Port authorities Infrastructure / utility owners and operators UK and Welsh Government	2022 – 25
Identify barriers to commercialisation	Identified options to support business case (i.e. carbon price, low cost input electricity etc.)	Hydrogen suppliers Hydrogen end users	2022 – 24
Objective 8: Support industrial decarbonisation through skills development and R&D			
Actions	**Indicator**	**Delivery partners**	**Timescale**
Engage with industry and academia to assess skills gap	Working group, or similar, established to review skills gap for industrial decarbonisation (review to include hydrogen production and carbon capture and storage)	Hydrogen Reference Group Industrial stakeholders across Wales Universities and higher education centres across Wales Utilities (electricity / gas)	2021
Develop plan to address industrial decarbonisation skills gap	Training or R&D centre (or similar initiative) established to support skills development and share decarbonisation and hydrogen fuel switching expertise across industry	Industrial stakeholders across Wales Universities and higher education centres across Wales Utilities (electricity / gas)	2022 – 30

Objective 9: Seek opportunities for a "place-based" approach when developing hydrogen projects in Wales			
Actions	**Indicator**	**Delivery partners**	**Timescale**
Engage with each hydrogen initiative (listed above and wider) and support communication and dissemination through each project	Communication and dissemination plan produced and on-going outreach to wider community	Hydrogen Reference Group Specific project lead organisations	2021 – 30
Encourage hydrogen projects to engage with local authorities and communities and review potential local benefits and community involvement in each project	Tangible benefits of hydrogen projects across local regions (incl. jobs, reduction in GHG emissions etc…)	Hydrogen Reference Group Specific project lead organisations	2021 – 30
Consider options to support local and community ownership model	Local (and community) ownership hydrogen projects delivered	Hydrogen Reference Group Specific project lead organisations	2021 – 30
Objective 10: Engage with other hydrogen initiatives			
Actions	**Indicator**	**Delivery partners**	**Timescale**
Engage with variety of hydrogen initiatives across Wales	Significant hydrogen project pipeline in Wales on GW scale	Hydrogen Reference Group Specific project lead organisations	2021 – 30

5 Summary

Low-carbon hydrogen has been identified as having a critical role in the pathway to achieving Net Zero GHG emissions. Hydrogen provides the most feasible decarbonisation pathway to reach Net Zero across several difficult-to-decarbonise sectors. As such, the demand for low-carbon hydrogen is forecast to increase significantly to 2050. This report outlines a proposed hydrogen pathway for Wales with a focus on the short-term opportunities to build momentum in the hydrogen sector and lay the foundations for scale-up and wider commercial deployment for hydrogen across a range of applications.

The action plan has focused on areas where the commercial case for hydrogen deployment is currently more developed. This includes the deployment of fuel cell buses, which have been successfully demonstrated in passenger operations over several years in other UK cities (London and Aberdeen) and elsewhere in Europe. The UK Government has also announced support towards the deployment of zero emission buses and the Welsh Government has set ambitious zero-emission target for the Welsh bus fleet by 2028. This pathway also emphasises the planning and preparation for larger-scale hydrogen deployment projects, which will build on the learnings from these smaller, earlier projects and lay the foundations for a commercial, low-carbon hydrogen sector. This includes the deployment of fuel cell vans and trucks, although commercial vehicles are not expected in the UK until 2027 / 28, earlier deployment supported by Welsh Government will develop hydrogen refuelling infrastructure and provide a foundation for the commercial roll-out later in the 2020s.

There are also opportunities to support local manufacturing within the hydrogen sector, this includes opportunities to attract smaller companies with potential to expand as the demand for low-carbon options increases and as the hydrogen sector grows. This will help to establish supply chains and attract further businesses in the hydrogen sector to Wales.

Alongside the generation of demand for hydrogen, there is a need to encourage hydrogen production in Wales, initially at a scale that will meet the demands created from the proposed vehicle deployment initiatives. Planning for larger-scale use of hydrogen in energy applications (including industrial hydrogen demand and heating) needs to begin in parallel given the time required to develop and implement hydrogen production / delivery projects at scale.

The Welsh Government is well placed to support knowledge sharing and learnings developed from these proposed hydrogen initiatives and encourage the place-based approach and local ownership that would benefit the local community and encourage investment in Wales. The hydrogen pathway presented here will be further refined through wider public consultation and responses to strategic questions posed as part of the consultation exercise and set out in section 7.

6 References

1. **United Nations Framework Convention on Climate Change.** Cut Global Emissions by 7.6 Percent Every Year for Next Decade to Meet 1.5°C Paris Target - UN Report. [Online] 2019. https://unfccc.int/news/cut-global-emissions-by-76-percent-every-year-for-next-decade-to-meet-15degc-paris-target-un-report.

2. **Welsh Government.** What is the Welsh Government doing to tackle climate change? [Online] 2019. https://gov.wales/what-is-the-welsh-government-doing-to-tackle-climate-change.

3. —. Power: Sector Emission Pathway. [Online] 2019. https://gov.wales/sites/default/files/publications/2019-06/power-sector-emission-pathway-factsheet.pdf.

4. **European Commission.** A hydrogen strategy for a climate-neutral Europe. [Online] July 2020. https://ec.europa.eu/energy/sites/ener/files/hydrogen_strategy.pdf.

5. **Hydrogen Council.** *Hydrogen Scaling up: A sustianable pathway for the glocal energy transition.* 2017.

6. —. *Path to hydrogen competitiveness: A cost perspective.* 2020.

7. **Hydrogen Europe.** Coalition statement: Another milestone in the uptake of fuel cell trucks. [Online] 2020. https://www.hydrogeneurope.eu/news/coalition-statement-another-milestone-uptake-fuel-cell-trucks.

8. **NEOM.** [Online] 2020. https://www.neom.com/en-us/sector/energy/.

9. **Committee on Climate Change.** *Hydrogen in a low-carbon economy.* 2018.

10. **Zero2050.** Zero 2050 South Wales. [Online] 2020. https://www.zero2050.co.uk/.

11. **Welsh Government.** Transport: Sector Emisson Pathway. [Online] 2019. https://gov.wales/sites/default/files/publications/2019-06/transport-sector-emission-pathway-factsheet.pdf.

12. **DfT.** Major boost for bus services as PM outlines new vision for local transport. [Online] 2020. https://www.gov.uk/government/news/major-boost-for-bus-services-as-pm-outlines-new-vision-for-local-transport.

13. **Hyundai.** Hyundai XCIENT Fuel Cell Heads to Europe for Commercial Use. [Online] 2020. https://www.hyundai.news/eu/brand/hyundai-xcient-fuel-cell-heads-to-europe-for-commercial-use/.

14. **NEL.** Nel ASA: Establishes joint venture to supply green hydrogen to Hyundai trucks in Norway. [Online] 2019. https://nelhydrogen.com/press-release/nel-asa-establishes-joint-venture-to-supply-green-hydrogen-to-hyundai-trucks-in-norway/.

15. **Arcola Energy.** Arcola Energy introduces production-ready hydrogen fuel cell powertrain platform for heavy-duty vehicles. [Online] 2020. https://www.arcolaenergy.com/arcola-energy-introduces-production-ready-hydrogen-fuel-cell-powertrain-platform-for-heavy-duty-vehicles/.

16. **ULEMCo.** ULEMCo to Deliver Hydrogen Fuelled Gritters for Glasgow. [Online] 2020. http://ulemco.com/?p=2977.

17. **Hypermotive.** Hypermotive: Fuel Cell Systems. [Online] 2020. https://www.hyper-motive.com/fuelcell.

18. **Renault.** Renault runs on hydrogen with Master Z.E. Hydrogen and Kangoo Z.E. Hydrogen. [Online] 2019. https://en.media.groupe.renault.com/assets/2019-press-kit-groupe-renault-introduces-hydrogen-into-its-light-commercial-vehicles-range-press-kit-e043-989c5.html?dl=1.

19. **DfT.** Let's raise our ambitions for a cleaner, greener railway. [Online] 2018. https://www.gov.uk/government/speeches/lets-raise-our-ambitions-for-a-cleaner-greener-railway.

20. **The Engineer.** On track: advances in UK hydrogen rail. [Online] 2020. https://www.theengineer.co.uk/on-track-advances-uk-hydrogen-rail/.

21. **Railway Gazette.** Bimode and hydrogen trains as Abellio wins next East Midlands franchise. [Online] 2019. https://www.railwaygazette.com/uk/bimode-and-hydrogen-trains-as-abellio-wins-next-east-midlands-franchise/48347.article.

22. **Scottish Enterprise.** Hydrogen train project moves to next phase. [Online] 2020. https://www.scottish-enterprise-mediacentre.com/news/greener-train-project-moves-to-next-phase.

23. **Rolling Stock Strategy Steering Group.** Sixth edition. [Online] March 2018. https://www.raildeliverygroup.com/files/Publications/2018-03_long_term_passenger_rolling_stock_strategy_6th_ed.pdf.

24. **Scottish Construction Now.** 'First of its kind' green hydrogen production plant planned near Glasgow. [Online] 2020. https://www.scottishconstructionnow.com/article/first-of-its-kind-green-hydrogen-production-plant-planned-near-glasgow.

25. **ITM Power.** 'Green Hydrogen for Scotland' to help reach net zero targets: First project to deliver a 10MW electrolyser to Glasgow facility. [Online] 2020. https://www.itm-power.com/news/first-project-to-deliver-a-10mw-electrolyser-to-glasgow-facility.

26. **Ryse Hydrogen.** [Online] 2020. https://rysehydrogencanterbury.co.uk/.

27. **Orsted.** Industrial scale renewable hydrogen project advances to next phase. [Online] 2020. https://orsted.co.uk/media/newsroom/news/2020/02/gigastack-phase-2.

28. **EDF.** Sizewell C seeks partners to develop Hydrogen and Direct Air Capture. [Online] 2020. https://www.edfenergy.com/energy/nuclear-new-build-projects/sizewell-c/news-views/sizewell-c-seeks-partners-develop-hydrogen-and-direct-air-capture.

29. **IRENA.** *Renewable Power Generation Costs in 2019.* Abu Dhabi : International Renewable Energy Agency, 2020.

30. **BloombergNEF.** A Behind the Scenes Take on Lithium-ion Battery Prices. [Online] 2019. https://about.bnef.com/blog/behind-scenes-take-lithium-ion-battery-prices/.

31. **Welsh Government.** Public serice vehicles (buses and taxis). [Online] 2019. https://gov.wales/sites/default/files/statistics-and-research/2019-03/public-service-vehicles-buses-and-taxis-april-2017-to-march-2018_0.pdf.

32. **DfT.** Data on licensed and registered buses and coaches, produced by Department for Transport (VEH06). [Online] 2020. https://www.gov.uk/government/statistical-data-sets/veh06-licensed-buses-and-coaches#licensed-vehicles.

33. **Bus and train user.** [Online] 2020. https://busandtrainuser.com/2020/03/05/end-of-the-road-for-pioneering-hydrogen-buses/.

34. **Hyundai.** Hyundai today delivered the first seven units of its XCIENT Fuel Cell. [Online] https://www.hyundai.news/eu/brand/hyundai-today-delivered-the-first-seven-units-of-its-xcient-fuel-cell/.

35. **Riversimple twitter.** [Online] 2020. https://twitter.com/riversimple/status/1326563058441981955/photo/1.

36. **Essential Fleet Operator.** Yorkshire Ambulance: Hydrogen Ambulances – change is in the air. [Online] 2019. https://myessentialfleet.co.uk/yorkshire-ambulance-hydrogen-ambulances-change-is-in-the-air/.

37. **BBC (Image originally from Transport for Wales).** New Wales rail franchise - the timetable to 2024. [Online] 2019. https://www.bbc.co.uk/news/uk-wales-44355934.

38. **Committee on Climate Change.** *Net Zero Technical Report.* 2019.

39. **National Grid.** Future Energy Scenarios. [Online] 2020. https://www.nationalgrideso.com/document/173821/download .

40. **Aurora Energy Research.** Hydrogen for a Net Zero GB: An integrated energy market perspective. [Online] 2020. http://www.auroraer.com/wp-content/uploads/2020/06/Aurora-Hydrogen-for-a-Net-Zero-GB-An-integrated-energy-market-perspective.pdf.

41. **H2FC Supergen.** The role of hydrogen and fuel cells in future energy systems. [Online] 2017. http://www.h2fcsupergen.com/wp-content/uploads/2015/08/J5212_H2FC_Supergen_Energy_Systems_WEB.pdf.

42. **Department for Business, Energy and Industrial Strategy.** Energy Innovation Needs Assessment. [Online] 2019. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/845658/energy-innovation-needs-assessment-hydrogen-fuel-cells.pdf.

43. **Committee on Climate Change.** Hydrogen in a low-carbon economy. [Online] 2018. https://www.theccc.org.uk/wp-content/uploads/2018/11/Hydrogen-in-a-low-carbon-economy.pdf.

7 Questions and Consultation Response Form

Consultation Response Form

Your name:

Organisation (if applicable):

email / telephone number:

Your address:

Questions

Strategic Vision

1 Public and private sector representatives are developing a hydrogen pathway for Wales based on evidence that hydrogen will be required to play a part in the future energy mix if we are to meet our climate change aspirations.

Do you agree this activity is needed to ensure Wales is well positioned to take advantage of potential opportunities arising from use of hydrogen? If not, why? Do you have any evidence to support these views?

2 Why are you supportive/not supportive of Wales pursuing hydrogen opportunities?

If supportive, what actions can you / your organization, take to contribute towards the development of the hydrogen sector in Wales (and under what conditions)?

3 Do you have any evidence on the best sources of energy for low carbon / renewable hydrogen production? Should Wales seek to generate hydrogen within the country or seek import opportunities, or pursue both options?

4 In your view, does the proposed hydrogen pathway complement on-going and planned hydrogen initiatives across the UK? What other actions should be considered in the hydrogen pathway that would further distinguish Wales, or support other UK activities? Do you have any evidence to support these views which you can share?

Hydrogen Pathway Scope

5 Are there other areas where you believe hydrogen and fuel cell

technologies have a role to play in Wales in the short term (period to 2025)?

6 Do you believe the pathway strikes the right balance between being ambitious yet proposing actions which can be delivered?

Hydrogen Pathway Delivery

7 In addition to the points set out in the objectives, are there any other "no regrets" actions that you believe Welsh Government / industry should take in the short term to develop the hydrogen sector in Wales? Do you have evidence you can share in support of that view?

8 What are the key barriers, risks and challenges to realise the opportunities described? In your view, what measures would help to overcome these and what are the key enabling factors?

Welsh Language Considerations

9 We would like to know your views on the effects that 'Hydrogen in Wales' and the next steps for developing the hydrogen energy sector in Wales would have on the Welsh language, specifically on opportunities for people to use Welsh and on treating the Welsh language no less favourably than English. What effects do you think there would be? How could positive effects be increased, or negative effects be mitigated?

10 Please also explain how you believe the proposed opportunities could be formulated or changed so as to have positive effects or increased positive effects on opportunities for people to use the Welsh language and on treating the Welsh language no less favourably than the English language, and no adverse effects on opportunities for people to use the Welsh language.

Summary

11 If you have any related comments which we have not specifically addressed in this consultation, please respond under question 11, supported by any relevant evidence.

Responses to consultations are likely to be made public, on the internet or in a report. If you would prefer your response to remain anonymous, please put a cross here: