Western Gateway Porth y Gorllewin

Western Gateway

Hydrogen Delivery Pathway

(2023 – 2050)

Summary Report

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delivering decarbonisation

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Prepared by:

Joe McQuillen MEng — Principal Energy Consultant

Elliot Reid MA (Hons) MSc — Associate Director

Kerensa Froome MPhys — Energy & Sustainability Consultant

Oli Stradling BSc (Hons) — Energy Consultant

Anna Lawson MEng — Principal Energy Consultant

Reviewed by:

Laurence Oakes-Ash BSc (Hons) MCIHT FCMA CGMA — Director

Approved by:

Laurence Oakes-Ash BSc (Hons) MCIHT FCMA CGMA — Director

Context & Background

The Western Gateway commissioned City Science to produce this Hydrogen Delivery Pathway to 2050. The Western Gateway is the UK's first pan-regional economic powerhouse to span two countries. Extending across South Wales and Western England, the partnership brings together local authorities, a combined authority, city regions, Local Enterprise Partnerships and Governments (in Wales and Westminster) to work together on the big challenges their communities face. The partnership is committed to ensuring that its 4.4 million residents benefit from fairer, greener economic growth and can access opportunities across our area.

This delivery pathway builds on previous work focussing on the Western Gateway geography, such as the Supergen Energy Networks System Study, 2022 and the work undertaken by the Western Gateway Partnership in collaboration with the GW4 Alliance and Swindon and Wiltshire LEP (SWLEP) to map the Western Gateway Hydrogen Ecosystem. This study has several key purposes including:

- Review the existing hydrogen policy context, regulatory framework and funding opportunities
- Develop hydrogen supply and demand scenario projections in the area to 2050
- Identify the most suitable locations for hydrogen production, storage and distribution
- Estimate the carbon emissions savings as a result of the switch to hydrogen
- Quantify the likely approximate level of capital expenditure, investment and funding required
- Assess the potential approximate economic value of the Western Gateway hydrogen opportunity
- Identify the key skills required to realise the potential of hydrogen in the Western Gateway
- Establish key innovation opportunities which could accelerate the hydrogen pathway realisation
- Identify detailed hydrogen pathways to 2050 and accompanying suggested actions

The delivery pathway has been developed in close dialogue with key partners and stakeholders across the Western Gateway through various workshops and meetings held between November 2022 and March 2023 and was supplemented by a consultation exercise in April and May 2023. Its preparation has been overseen by an internal working group, with regular reporting to the Western Gateway Hydrogen Steering Committee. A summary of the key organisations we have engaged with, some of which are likely to be involved in the future delivery of actions identified in this Strategy, includes:

- Hydrogen South West
- Costain
- Milford Haven Port
- Western Gateway Hydrogen Working Group (Local authorities)
- Cardiff Capital Region
- West of England Combined Authority
- Swansea Bay City Deal
- GKN
- Welsh Government Energy Service
- Wales and West Utilities
- AB Ports
- SGN
- National Grid
- Airbus
- EDF / Hynamics
- easyJet
- GW4 Alliance
- Bath University
- University of South Wales
- Bristol University
- South Wales Industrial Cluster (SWIC)
- Bristol Port
- Tower Group
- National Composites Centre (NCC) / High Value Manufacturing Catapult (HVMC)
- Bristol Airport
- The Centre for Future Clean Mobility
- Smart Ports Transitional Energies Ltd
- HydrogenOne Capital
- RWE Generation

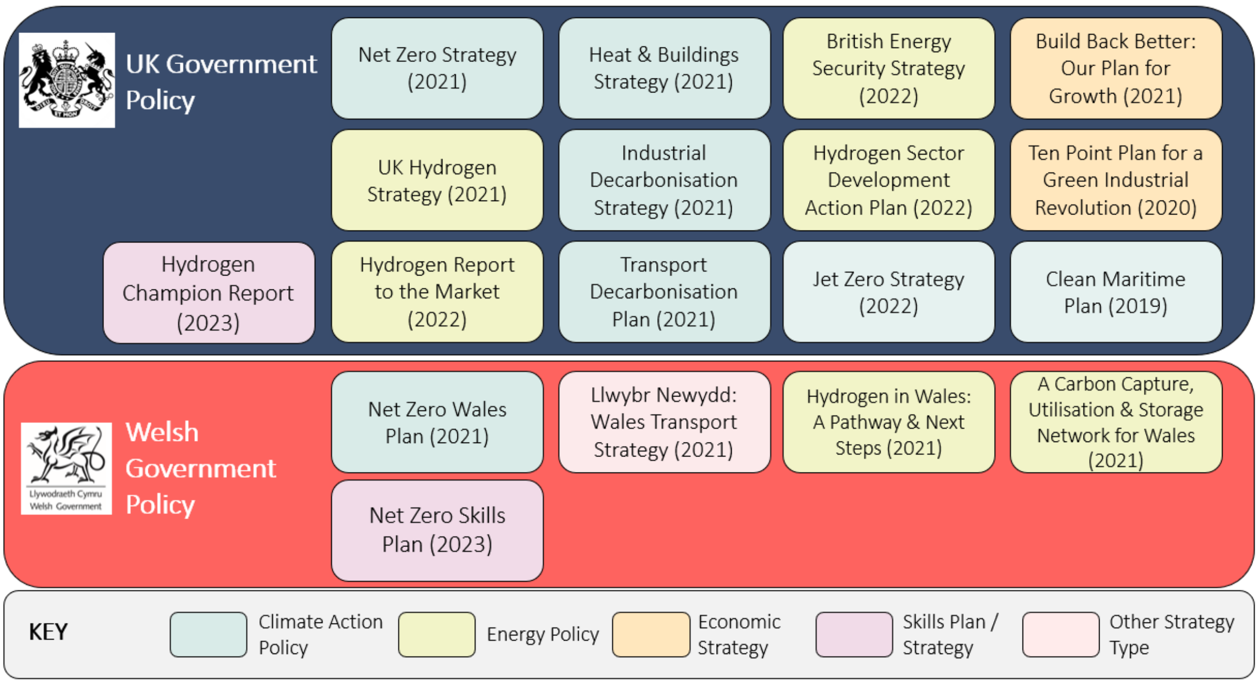
There are a variety of different forms of hydrogen considered within this report, which are summarised in the below table.

Hydrogen Type	Meaning
Green Hydrogen	Green hydrogen is made by using electricity from renewable energy sources, such as solar or wind power using electrolysis.
Blue Hydrogen	Blue hydrogen is produced mainly from natural gas using a process called steam reforming. Blue hydrogen entails using carbon capture and storage (CCS) solutions for carbon dioxide (CO_2) emissions.
Pink Hydrogen	Pink hydrogen is generated through electrolysis powered by nuclear energy. Hydrogen produced using nuclear power can also be referred to as purple hydrogen or red hydrogen depending on the process used.
Grey Hydrogen	Grey hydrogen is produced from natural gas, or methane, using steam methane reformation but without capturing the carbon dioxide (CO_2) emissions. Most hydrogen globally and in the UK is currently produced using this method.

Forms of hydrogen (Western Gateway, 2022)

Policy Context

At a national level, policy related to hydrogen development is driven by both the UK Government and Welsh Government. Both governments' policy focus on hydrogen is underpinned by the ambition to achieve net zero carbon emissions by 2050, as outlined in the Net Zero Strategy: Build Back Greener (2021) and the Net Zero Wales Plan (2021). The UK Hydrogen Strategy (2021) sets out the UK Government's approach to developing a low carbon hydrogen sector which forecasts that between 250 to 460 TWh of hydrogen will be required by 2050, with potential to support 100,000 jobs and £13 billion GVA in 2050 in a high hydrogen scenario.



There is also an array of regional and local policies, such as Climate Action Plans, Local Area Energy Plans and Local Plans. The recently published South Wales Industrial Cluster Plan (2023), assigns a critical role to hydrogen in decarbonising industry which underlines the importance of the HyLine Cymru project and the need to upscale green hydrogen production to meet future industrial demand.

The key policy opportunities which could unlock the potential for hydrogen in the Western Gateway alongside the key policy barriers to overcome are summarised in the below table.

Key Unlocking Policy Opportunity	Key Policy Barrier to Overcome
• Hydrogen's role in meeting net zero • 2035 industry fuel switching and Port Talbot steel production decarbonisation • Western Gateway hydrogen job creation potential • Hydrogen rail opportunity in the Western Gateway • Jet Zero and aviation hydrogen gateway cluster opportunity • Potential to establish Western Gateway zero emission shipping cluster • South Wales hydrogen heating transition opportunity • Project Union as a key enabler to provide a UK hydrogen transmission network • Ongoing Welsh Government Net Zero Skills Plan consultation for hydrogen skills	• 2026 strategic UK Government decision for hydrogen in heating • UK Government 2035 100% renewable power target impact on green hydrogen production • Lack of clear policy direction on CCUS • Environmental constraints of CO_2 pipeline construction in South Wales • Uncertainty of hydrogen's role in meeting Welsh Government's net zero targets • Lack of clear UK hydrogen skills strategy • Uncertainty over future decarbonisation trajectory of Port Talbot steelworks • Hydrogen road transport uncertainty • Increased emphasis on electricity to meet decarbonisation likely to result in local grid capacity constraints • Immature regulatory framework for hydrogen (see below)

Hydrogen Regulatory Standards & Key Barriers

The regulatory framework for hydrogen (including safety) is primarily a reserved matter for the UK Government, with limited jurisdiction for the Welsh Government (Wales Act 2017). The exception to this is planning, where Welsh Government can grant planning consent for renewable energy schemes of up to 350 MW.

Hydrogen currently falls under the definition of a *'gas'* under the Gas Act 1986 and is regulated in this context. Those involved in such activities require a licence via the Office of Gas and Electricity Markets (Ofgem). Key regulatory barriers to overcome include:

- Regulation of water resources for electrolysis to establish water quality standards ensuring high purity deionised and desalinised water
- Air quality regulation in hydrogen project permitting requirements to reduce risk of unintended impacts (e.g. ammonia emissions)
- Hydrogen leakage uncertainty and the potential for further regulation
- VAT differentials for hydrogen use compared to other fuel sources
- Absence of clear and consistent hydrogen storage regulatory standards
- Changes to Gas Safety (Management) Regulations to enable public 20% hydrogen grid blending (subject to UK Government decision due in 2023)
- Potential hydrogen transport by road vehicles regulatory gaps

- Hydrogen purity standard development to establish whether it is cleaned of impurities prior to injection into the gas grid or at the end-use

Emerging Funding Landscape

The UK Government has an ambition to produce 10 GW of hydrogen by 2030, of which at least half is to be electrolytic hydrogen. To support this new market, the UK Government has pledged over £340m in hydrogen demonstrator projects to date with the overarching aim to stimulate up to £9bn of private sector investment by 2030. There has already been a variety of successful projects in the Western Gateway that have secured funding. This includes the ERM Dolphyn project focused on developing green hydrogen demonstrators at scale in the Celtic Sea, the HyDUS project focused on developing a full cycle, modular and low-cost bulk hydrogen energy storage demonstrator and the BIOHYGAS project which involves producing hydrogen from sewage biosolids.

Key emerging funding sources over the short term which could be used for projects in the Western Gateway include the Net Zero Hydrogen Fund (Strands 1 and 2), Net Zero Hydrogen Fund and Hydrogen Business Model (Strand 3 & 4), the Industrial Energy Transformation Fund, the Aerospace Technology Institute (ATI) Programme and potential future rounds of the Clean Maritime Demonstration Competition.

Future Hydrogen Scenarios

Three hydrogen scenarios have been developed to represent the possible hydrogen demand and supply ranges for the Western Gateway for 2030, 2035, 2040 and 2050; all of which align with net zero being achieved by 2050 but with a varying contribution from hydrogen. The initial identification of scenarios commenced with a detailed literature review of existing research and policy ambitions, alongside scenarios applied by others at a national and regional level. The scenarios were then refined through stakeholder engagement, including with industry bodies and academia.

Necessities Only (low hydrogen)

- No hydrogen transported through local distribution networks, HyLine supplies industrial demands only
- No hydrogen used for heating, assumed all heating electrified with heat pumps and direct electric
- No hydrogen used for road transport
- Port Talbot steelworks modelled to switch to hydrogen DRI-EAF
- 70% of other large industrial installation fuel energy demands fulfilled by hydrogen

Balanced Hydrogen (balanced electrification/hydrogen)

- HyLine supplies industrial demands & single local distribution zone
- Single gas-grid local distribution zone converted to 100% hydrogen for heating (equates to 10% of gas-grid heating demands of Western Gateway), assumed remainder of heating electrified with heat pumps and direct electric
- 50% of HGVs, LGVs and buses use hydrogen
- Port Talbot steelworks modelled to switch to hydrogen DRI-EAF
- 70% of other large industrial installation fuel energy demands fulfilled by hydrogen

Widespread Hydrogen (high hydrogen)

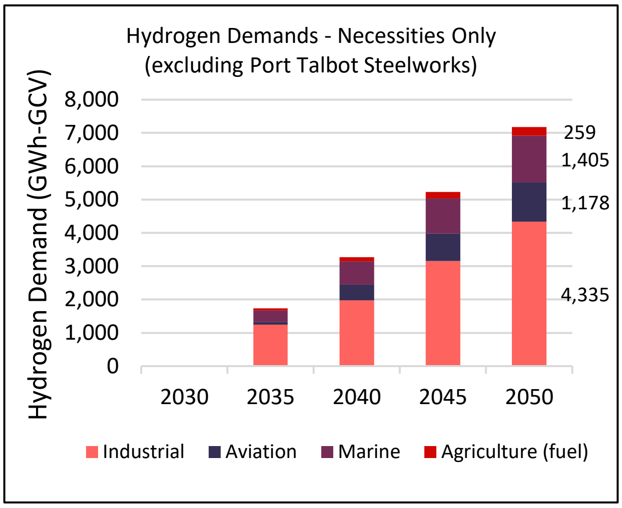
- Gas network converted to 100% hydrogen, HyLine extended across the South of Wales
- Gas-grid heating switches to 100% hydrogen
- Hydrogen used for 100% HGVs, LGVs and buses, 25% cars
- Port Talbot steelworks modelled to switch to hydrogen DRI-EAF
- 100% of other large industrial installation fuel energy demands fulfilled by hydrogen by 2050

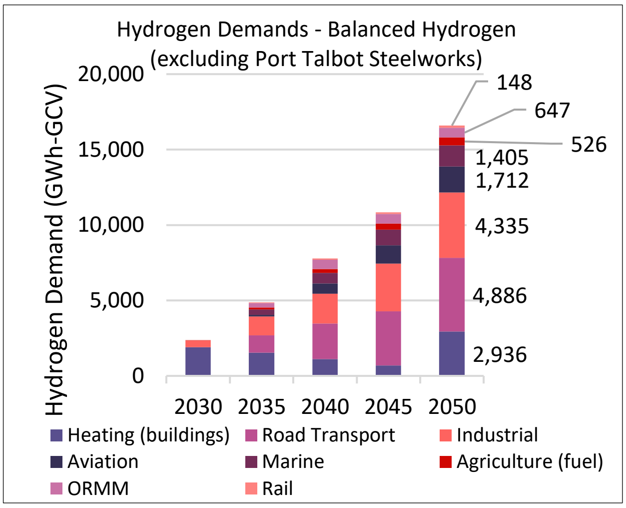
Future Hydrogen Demand

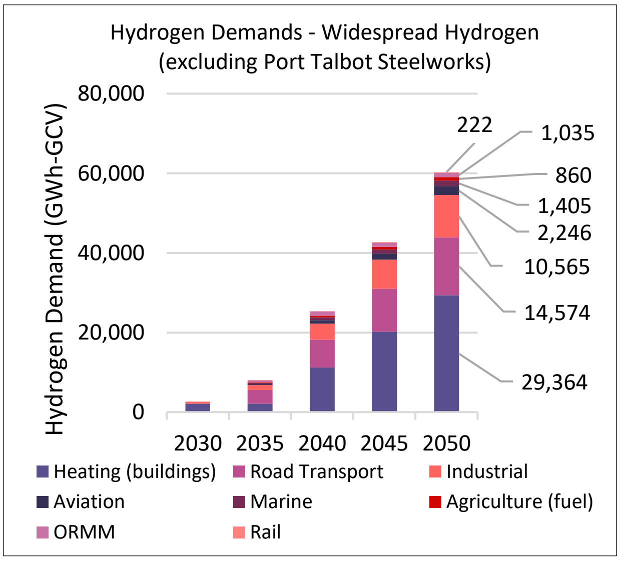
As the graphs demonstrate, the 2050 hydrogen demands are between around 30,000 GWh_{GCV} and 80,000 GWh_{GCV} are across the three scenarios. Heating (domestic and non-domestic buildings), road transport and industry are likely to be the largest demand sectors.

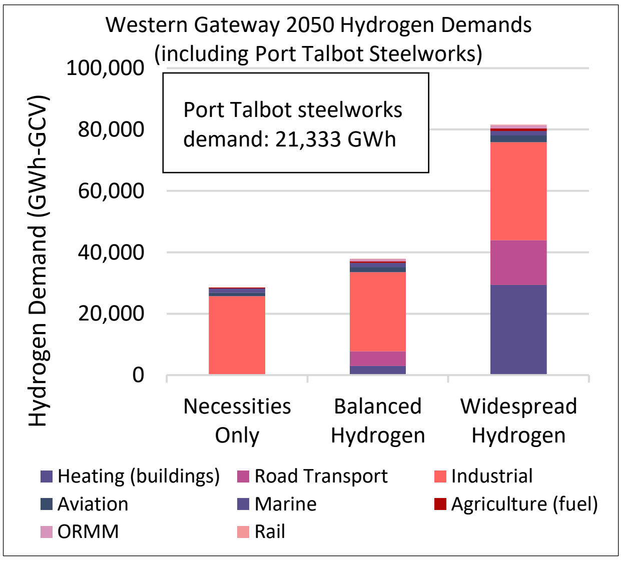
Port Talbot Steelworks has the potential to be a major anchor load for hydrogen demand in the area, however, this is highly uncertain due to a lack of clarity at present on any decarbonisation route. A large jump in hydrogen demand is seen in 2035 due to the modelled conversion Port Talbot switching to a fully hydrogen powered process which alone accounts for 21,300 GWh (equating to 94% of 2035 hydrogen demand in all scenarios).

Due to the significant stakeholder interest in direct hydrogen usage for aviation in the area, this work has developed ambitious assumptions for hydrogen uptake at Bristol and Cardiff airports. It has been assumed that by 2050, for international flights (which dominate in terms of energy demand over domestic), that 20%, 40% and 60% of the international flight energy demands are met by hydrogen respectively.









Future Hydrogen Supply

For each of the scenarios we have calculated the total demand and matched this against potential supply, in particular focusing on the potential supply of green hydrogen from renewable sources. The table below shows the estimated installed renewable generation capacity from wind and solar in the area (e.g. Bridgend, Wroughton, Cardiff) alongside an allocation of generation from the floating offshore wind resources in the Celtic Sea. Note that tidal resources have been considered but hydrogen from tidal has been excluded from the analysis due to delivery uncertainty. The table shows the total green hydrogen production potential at 50,800 GWh_{GCV}, with a far greater potential for the floating offshore wind to provide green hydrogen compared to onshore renewable facilities.

The total green hydrogen production figure should be seen as an upper limit given that a proportion of renewable energy would be expected to be used directly to meet electrical demands; particularly in the short term given the UK Government's targets to meet 100% of electricity from renewables by 2035.

Renewable technology	2050 Estimated Installed Capacity (GW)	Assumed Load Factor (%)	Electricity Generation (GWh)	Potential Hydrogen Production via Electrolysis (GWh_{GCV}) *Uses 83%$_{GCV}$ electrolyser efficiency*
Floating offshore wind (FLOW)	12	50%	52,600	43,600
Onshore wind	1.5	25%	3,290	2,730
Ground mount PV	5.6	11%	5,400	4,480
Total			61,200	50,800

Estimated potential green hydrogen production in 2050

A key finding is that hydrogen demand forecasts range between around 30,000 GWh_{GCV} and 80,000 GWh_{GCV} which indicates that in the Widespread Hydrogen Scenario, demand is likely to exceed maximum supply of green hydrogen. Once wider electrical demands are added to each of the scenarios, the total demand for renewable energy exceeds 80,000 GWh_{GCV} in all cases, suggesting that local renewable energy in the Western Gateway may not be enough to meet all potential demands.

Taking this supply constraint into account, whilst not a long-term solution, the use of blue hydrogen may be necessary in the short term as a steppingstone technology to accelerate the hydrogen economy. An alternative approach may be production of pink hydrogen from nuclear which has the potential to be scalable over the long term, however, this is an area of uncertainty which remains subject to significant ongoing research.

Western Gateway Hydrogen Network

The future hydrogen transmission network across the Western Gateway has been explored, drawing on the outcomes of the future supply and demand scenario forecasts. The SWIC is a prime location for early development of dedicated hydrogen networks. Wales and West Utilities (WWU) is exploring the feasibility of a dedicated hydrogen transmission line (named HyLine Cymru) running from Milford Haven (which is a candidate site for large scale green and blue hydrogen production) across South Wales which would likely feed the demands of heavy industry. The HyLine has the potential to connect to Project Union currently being explored by National Grid.

A key outcome of the scenario modelling also demonstrates that without blue hydrogen to serve the potential needs of the Port Talbot steelworks the Western Gateway is likely to be an importer of hydrogen. Further consideration is required in relation to the suitability of port infrastructure to accommodate hydrogen imports.

The storage of hydrogen will be necessary where production and use do not occur at the same time. The future energy demands of the Western Gateway will be highly variable, both on diurnal and seasonal time scales. This is further complicated by an energy supply that will become more variable with intermittent renewables making up an increasing share of primary energy supply. There is a potential salt cavern site in the Wessex basin which has an estimated storage capacity for 577 TWh of hydrogen which has the potential to meet the inter-seasonal demands of the Western Gateway.

Potential Greenhouse Gas Savings

All scenarios in this study were designed to achieve to a net zero Western Gateway in 2050, but with hydrogen playing a dramatically different role in each. More emissions savings can be attributed to hydrogen where it plays a greater role in the energy system and therefore the Widespread Hydrogen scenario has the greatest emissions savings that can be attributed to hydrogen. The estimated emissions savings in 2050 from hydrogen usage have been detailed in the table below. The emissions savings are the savings made in that year (in 2050) against a 'do-nothing' baseline which accounts for growth and energy efficiency improvements, but with no fuel switching to hydrogen or electrification.

	2050 Green House Gas Savings (kt CO_2e) from Hydrogen Usage*		
	Necessities Only	Balanced Hydrogen	Widespread Hydrogen
Zero lifecycle emissions electrolysis from renewable or nuclear generated electricity	8,660	11,200	20,689
ATR with CCS (uses 49 gCO_2e/kWh_{GCV})	7,270 (Savings 16% lower than zero lifecycle emission hydrogen)	9,360 (Savings 16% lower than zero lifecycle emission hydrogen)	16,720 (Savings 19% lower than zero lifecycle emission hydrogen)

**All scenarios represent a net zero Western Gateway, however, hydrogen results in more emissions savings under Balanced Hydrogen and Widespread Hydrogen as hydrogen plays a bigger role in the energy systems under these scenarios. An equivalent quantity of emissions will be saved under Necessities only, but the savings will be attributed to other technologies such as electrification which have not been accounted for in this table. Hydrogen itself is a greenhouse gas, leakage of hydrogen (which would effectively reduce the carbon equivalents savings here) has not been modelled due to the uncertainty of its leakage throughout the energy system.*

Scenario potential GHG savings from hydrogen usage

Developing the Western Gateway Hydrogen Economy

Given the crosscutting nature of hydrogen, spanning multiple sectors, professions, and supply chains, the economic opportunity from the hydrogen economy, across all modelling scenarios, is extensive. Covering all major use cases and home to international businesses and world-class research institutions, the Western Gateway is ideally placed to demonstrate, scale and commercialise large-scale hydrogen to support a net zero transition. The UK Hydrogen Champion Report: Recommendations to Government called for a clear vision for hydrogen scale-up to plan the connection of hydrogen across the UK regions, including more clarity on the next set of hydrogen clusters. The Western Gateway presents a strong opportunity to lead this development and research and pave the way for future clusters.

The Western Gateway's geography, business make-up and existing strengths make the area a key asset in the UK's goal to become a *'world leader in the development, deployment and build-out of hydrogen infrastructure across the full value chain, covering production, transmission and storage, and the range of potential end uses for hydrogen, including power, heat, and transport.'* This includes delivery of leading UK research and development opportunities to unlock exports and international growth.

Analysis by the now Department for Energy Security and Net Zero (DESNZ) indicates that every GW of hydrogen production could mobilise £0.9bn in investment and create 1,200 jobs by 2030, with additional benefits across the wider supply chain (DESNZ, 2022). DESNZ estimates that the hydrogen economy could support 100,000 jobs in the UK by 2050 (ibid). While there are many complex factors to consider in forecasting, our analysis indicates that the Western Gateway could play a major role in this growth, with investment supporting 12,500 direct jobs, 27,000 jobs in total, while acting to protect essential employment in hard-to-decarbonise sectors. Stalling investment risks a loss of competitiveness for the area which could endanger 60,000 direct jobs in hard-to-decarbonise industries.

Investment in hydrogen will also stimulate sizeable investment, with up to £63bn of capital investment likely to be directed to hydrogen projects under the Widespread Hydrogen (high hydrogen) scenario. Even under the Necessities Only scenarios, levels of investment will still be in the order of £11bn as part of the wider push towards net zero.

Innovation Opportunities & Skills Development

The Western Gateway has an excellent opportunity to position itself as a key hydrogen cluster of the future. The area can be a pioneer in unlocking a dynamic and productive hydrogen ecosystem bringing economic benefits to the area, as well as contributing to wider national imperatives for decarbonisation. This significant potential includes the strength of the Western Gateway Hydrogen Ecosystem in aviation and industrial innovation; the resulting employment boost from hydrogen development; and the revenue and investment in the area that the Western Gateway could attract.

The transition to net zero will also require a significant investment in skills. In total skills provision in hydrogen and associated net zero technologies will need to be sufficient to support approximately 108,000 roles by 2050 including jobs created and re-skilling within existing sectors.

Many of the future jobs forecast are highly specialist and will require expertise and knowledge in hydrogen production, industrial process, propulsion and transport, manufacture of hydrogen-related equipment and skills in installation, operation, maintenance and safety across a wide range of new technologies. To support the hydrogen economy the collaboration with partners across the Western Gateway area, including local education providers, will be required to ensure appropriate skills pathways are developed to meet expected demand.

2050 Delivery Pathways & Suggested Actions

Future hydrogen pathways for the Western Gateway area are shown in the following diagrams, representing supply, networks and demand respectively. This hydrogen pathway incorporates all three scenarios which have been developed and the UK Government and Welsh Government national targets have been considered and incorporated into it.

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Hydrogen Demands Pathway to 2050 Across All Three Scenarios

	2020s	2030 to 2034	2035 to 2039	2040s
All scenarios	• **Aviation**: Acceleration of demonstration/trial projects (e.g. SAF production at Lanzatech) • **Road transport**: Hydrogen demonstrators commence • **Industry**: Feasibility studies into fuel switching to hydrogen	• **Industry**: Demonstrator projects for hydrogen use as a fuel • **Aviation & Shipping:** Demonstrator projects for ammonia ships and hydrogen/SAF aircraft	• **Industry**: Fuel switching to hydrogen begins • **Aviation**: Direct hydrogen aircraft start to enter fleet, synthetic kerosene (SAF) starts to enter aviation fuel mix • **Marine**: Ammonia powered ships start to enter fleet	• **Marine**: 90% of marine fuel demands met with ammonia
Necessities Only	• Based on 2026 decision on hydrogen for heating, no hydrogen blending in the gas grid	• **Heating:** Based on 2026 decision on hydrogen for heating, no hydrogen ready boilers installed • **Road transport:** No uptake of hydrogen road vehicles	• **Heating:** Gas boiler ban in 2035 accelerates electrification of heating	• **Heating**: Heating electrified – no hydrogen used for heating **Transport**: no hydrogen used for road transport, 20% hydrogen uptake in international aviation • **Industry**: 70% of industrial fuel demands hydrogen
Balanced Hydrogen	• **Gas grid demands:** Blending to 20% vol kickstarts demand for hydrogen in heating and industrial sectors	• **Heating:** Installation of hydrogen ready boilers, 20% blend creates significant demand for hydrogen • **Road transport:** Uptake of hydrogen buses, LGVs and HGVs begins.	• **Heating:** Gas boiler ban in 2035 accelerates uptake of hydrogen boilers (in distribution zones identified for hydrogen repurposing) and electrification of heating (for distribution zones not identified for hydrogen repurposing)	• **Heating**: Single local distribution zone converted to hydrogen for heating (10% of total heating demands) • **Transport:** 50% of HGVs, LGVs and buses switch to hydrogen, 40% hydrogen uptake in international aviation • **Industry**: 70% of industrial fuel demands hydrogen
Widespread Hydrogen	• **Gas grid demands:** Blending to 20% vol kickstarts demand for hydrogen in heating and industrial sectors	• **Heating:** Installation of hydrogen ready boilers, 20% blend creates significant demand for hydrogen • **Road transport**: Uptake of hydrogen buses, LGVs, HGVs and a small number of cars begins.	• **Heating:** Gas boiler ban in 2035 accelerates uptake of hydrogen boilers	• **Heating**: 100% of heating demands met with hydrogen • **Transport:** 100% of HGVs, LGVs and buses switch to hydrogen, 60% hydrogen uptake in international aviation • **Industry**: 100% of industrial fuel demands hydrogen

Key Dates

- **2023**: Decision on 20% vol blending
- **2025**: Gas boiler ban for new homes; Gas blending regulatory framework completion
- **2026**: Decision in hydrogen for heating due
- **Early 2030s**: Future of Port Talbot to be determined – align to 2035 policy decisions; Irons Mains Replacement Programme will be complete
- **2035**: UK Government target to fully decarbonise the power system; UK ambition for industrial fuel switching to 50 TWh of hydrogen
- **2040**: Target of removing all diesel only trains in the UK; Sale of new ICE HGVs to be banned
- **2050**: Wales & UK Net Zero Carbon Emissions

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Hydrogen Supply Pathway to 2050 Across All Three Scenarios

	2020s	2030 to 2034	2035 to 2039	2040s
All scenarios	• Small floating offshore wind projects in Celtic Sea (Erebus and Valorous) to be built • Blue hydrogen production plans finalised (Milford Haven and Port Talbot are likely locations)	• Floating offshore wind capacity in Celtic Sea expected to ramp up, large scale electrolytic production increases • Blue production plants building begins	• Electrolytic production continues to increase. Fully decarbonised electricity grid by 2035 enables zero carbon grid top-up for electrolysers • Blue hydrogen production plants built and begin serving industrial demands (e.g. Port Talbot steelworks)	• Large scale electrolytic production active • Blue hydrogen serves industrial demands
Necessities Only		• By 2035 assumed 5% of FLOW, 2.5% onshore wind and 1.25% of solar PV power dedicated to electrolysis	• By 2040, assumed that 10% of FLOW, 5% onshore wind and 2.5% of solar PV power dedicated to electrolysis	• By 2050, assumed that 20% of FLOW, 10% onshore wind and 5% of solar PV power dedicated to electrolysis • No further expansion of blue hydrogen production
Balanced Hydrogen		• By 2035 assumed 7.5% of FLOW, 3.75% onshore wind and 2.5% of solar PV power dedicated to electrolysis	• By 2040, assumed that 15% of FLOW, 7.5% onshore wind and 5% of solar PV power dedicated to electrolysis	• By 2050, assumed that 30% of FLOW, 15% onshore wind and 10% of solar PV power dedicated to electrolysis • Blue hydrogen production expands to serve heating demands of the local distribution zone around the Port Talbot steelworks
Widespread Hydrogen		• By 2035 assumed 12.5% of FLOW, 6.25% onshore wind and 2.5% of solar PV power dedicated to electrolysis	• By 2040, assumed that 25% of FLOW, 12.5% onshore wind and 5% of solar PV power dedicated to electrolysis	• By 2050, assumed that 50% of FLOW, 25% onshore wind and 10% of solar PV power dedicated to electrolysis • Blue hydrogen production expands to serve heating demands across South Wales

Key Dates

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- **2035** – UK Government target to fully decarbonise the power system; UK ambition for industrial fuel switching to 50 TWh of hydrogen
- **2040** – Target of removing all diesel only trains in the UK; Sale of new ICE HGVs to be banned
- **2050** – Wales & UK Net Zero Carbon Emissions

Hydrogen Networks Pathway to 2050 Across All Three Scenarios

	2020s	2030 to 2034	2035 to 2039	2040s
All scenarios	• Feasibility studies for dedicated hydrogen transmission lines (e.g. HyLine)	• Hydrogen transmission line (HyLine) built to connect Milford Haven to Port Talbot • Distribution of hydrogen for road transport refuelling via road tanker begins		
Necessities Only	• Assumes that 2026 decision on heating identifies no or little role for hydrogen, 20% blend not pursued	• No conversion of local distribution zones to 100% hydrogen investigated	• No expansion of hydrogen transmission lines beyond HyLine	• Gas grid distribution networks no longer in use, only natural gas transmission lines for blue production plants remain
Balanced Hydrogen	• Assumes that 2026 decision on heating identifies small role for hydrogen, 20% blend pursued	• Distribution zones to be repurposed for $100\%_{vol}$ hydrogen identified. 20% blend complete	• Repurposing distribution network around Port Talbot steelworks to 100% hydrogen begins • No expansion of hydrogen transmission lines beyond HyLine	• Repurposing of single local distribution zone around Port Talbot steelworks is completed
Widespread Hydrogen	• Assumes that 2026 decision on heating identifies widespread role for hydrogen, 20% blend pursued	• Distribution zones to be repurposed for $100\%_{vol}$ hydrogen identified. 20% blend complete • Extension of HyLne across the rest of South Wales investigated	• Extension of HyLine hydrogen transmission line begins from Port Talbot across the rest of South Wales to serve heating and industrial demands	• Extension of HyLine hydrogen transmission line across the rest of South Wales is completed • Repurposing of all distribution networks for 100% hydrogen is completed • Distribution of hydrogen for transport refuelling can be achieved via dedicated hydrogen network

Key Dates

- **2023**: Decision on 20% vol blending
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- **2050**: Wales & UK Net Zero Carbon Emissions

A set of potential actions have been developed which could be progressed to enable the development of the hydrogen ecosystem. They fall across five key areas: Demand, Supply, Networks, Workforce and Skills and Innovation. They have been proposed through various engagement and explored through the consultation exercise and more widely through the production of this evidence base.

The actions have not been formalised and lead organisations have not been identified, however they form a good basis for continued engagement between industry, academia and the public sector to support the delivery pathway of hydrogen in the Western Gateway area. They represent some of the priority areas and a first pass list which could be built upon and developed, with stakeholders and industry leaders.

The potential action plan is summarised below.

Potential Actions
Supply Action 1: Establish a 'Western Gateway Hydrogen Hub' or online resource that focuses on raising awareness of funding opportunities and highlighting successful project bids which are in the Western Gateway area, such as the Net Zero Hydrogen Fund. This could help to boost local marketing of hydrogen activity and be used to support private sector inward activities.
Supply Action 2: Undertake or accelerate any existing blue hydrogen feasibility studies examining merits of establishing a production site in the Western Gateway. This should include supply routes, identification of key users, proof of carbon capture viability prior to funding, and feasibility assessment for all greenhouse gases (including fugitive methane emissions from natural gas extraction). This would be best led or undertaken by the future supply industry.
Supply Action 3: Undertake an analysis of potential low carbon hydrogen generation site locations to focus on delivering sufficient supply for the anticipated demand. This would require engagement with local authorities, DNO and National Grid to drive forwards an anticipatory investment to map the grid connection constraints, the timeline and plan electricity grid upgrades accordingly.
Supply Action 4: Monitor strategic renewable generation build out and identify opportunities to collaborate to address any emerging barriers including supporting and driving enabling planning policies.
Supply / Demand Action 5: Lobby and make a clear case to the UK Government to accelerate the decision on the decarbonisation of steel at Port Talbot as this will be a critical anchor load for development of hydrogen in the area.
Supply Action 6: Establish an electrolyser implementation group to share best practice and knowledge on the implementation of electrolysers to accelerate their roll-out. This group could operate at a UK level.
Supply Action 7: Monitor Floating Offshore Wind (FLOW) build out capacity in the Celtic Sea against the Crown Estate's ambition of 4 GW by 2035, including engagement with National Grid to understand impact of any connection capacity constraints. Plan for any green hydrogen production shortfall to be met through alternative means such as onshore renewables. This also includes monitoring potential for future rounds of Celtic Sea FLOW tenders and driving anticipatory grid upgrades as required (Supply Action 3).
Supply Action 8: Establish the feasibility for a demonstrator nuclear Small Modular Reactor (SMR) or Advanced Modular Reactor (AMR) for hydrogen production in the Western Gateway area.
Supply Action 9: Analysis and identification of the infrastructure required for importation of bulk hydrogen, led and supported by each port. This would include projection of the volume of importation needed, the supply chain and the infrastructure for delivery.

Potential Actions
Network Action 1: Raise awareness and share best practice amongst planning authorities in relation to the delivery of hydrogen transmission networks in the Western Gateway to improve planning processes, including for the HyLine Cymru project.
Network Action 2: Develop a detailed feasibility study examining the CO_2 transmission infrastructure required to support blue hydrogen production for SWIC covering any infrastructure required at ports or required storage sites. Lobby government to include the cost of shipping within the estimations of levelised cost of CO_2 transmission and storage.
Network Action 3: Undertake a study into the means for inter-seasonal hydrogen storage for the Western Gateway, which could be in collaboration with or lobby for action by a future systems operator in the view of wider, UK-level infrastructure planning.
Network Action 4: Lobby UK and Welsh Governments to accelerate national regulatory framework changes relating to hydrogen transmission and storage (e.g. clarity on Accord Dangereux Routier (ADR) for non-pipeline transport of hydrogen)
Demand Action 1: Offer a funding bid application support service (though the Western Gateway Hydrogen Hub) to businesses seeking to use hydrogen in the area either via the Hydrogen Business Model or other grant funding opportunities.
Demand Action 2: Establish Western Gateway hydrogen demonstrator projects covering rail and heavy road transport.
Demand Action 3: Establish a hydrogen maritime demonstrator project (e.g. ammonia vessels) and explore the implementation of ammonia storage port facilities.
Demand Action 4: Develop an Aviation Decarbonisation Delivery Plan for the area which sets out a roadmap of actions specific to the aerospace industry to unlock its full potential in the transition to SAF including hydrogen
Demand Action 5: Improve public perception on hydrogen and its applications working with local communities. Understand local appetite for a hydrogen heating demonstrator within the Western Gateway prior to any new demonstration projects.
Demand Action 6: Complete early-stage planning of a central online *'one stop shop'* resource that enables easy access and funding option information to homeowners for low carbon heating (hydrogen ready boilers or heat pumps) and household retrofits. To be further developed as hydrogen technology readiness increases and upon 2026 UK Government decision on hydrogen for heating. This could be a national initiative accessed through local authorities.
Workforce and Skills Action 1: Develop a Western Gateway Net Zero Skills Plan which would incorporate hydrogen upskilling into the broader skills transition across renewables. This would call upon existing foresighting work and activities to identify skills gaps now and in the future. This would need to happen at all skill levels, and across the hydrogen economy to understand the required training programmes.
Innovation Action 1: Lobby the UK Government for a Net Zero Innovation Fund for the area to provide early-stage and scale-up investments in new businesses developing and trialling hydrogen technologies across the Western Gateway.
Innovation Action 2: Identify opportunities for innovation grants for business-led hydrogen solutions. Employ a portfolio approach to ensure coverage of generation, storage, safety, integration and demand applications. Convene and support the development of bids for funding

Potential Actions
support. Encourage the existing cohort of hydrogen innovators and innovation networks to provide business funding and growth support.
Innovation Action 3: Proactively seek collaboration opportunities outside of the Western Gateway, to attract hydrogen innovation business to the area which would further grow the ecosystem and value chain.

Western Gateway Hydrogen Potential Action Plan

Western Gateway Porth y Gorllewin

Western Gateway

Hydrogen Delivery Pathway

(2023 – 2050)

Technical Report

CITY SCIENCE

delivering decarbonisation

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Prepared by:

Joe McQuillen MEng — Principal Energy Consultant

Jo Muncaster FCA — Associate Director

Elliot Reid MA (Hons) MSc — Associate Director

Aoife Dudley BA (Hons) — Transport Consultant

Kerensa Froome MPhys — Graduate Energy & Sustainability Consultant

Oli Stradling BSc (Hons) — Energy Consultant

Anna Lawson MEng — Principal Energy Consultant

Reviewed by:

Laurence Oakes-Ash BSc (Hons) MCIHT FCMA CGMA — Director

Approved by:

Laurence Oakes-Ash BSc (Hons) MCIHT FCMA CGMA — Director

Contents

Glossary

Acronym	Meaning
ADR	International Carriage of Dangerous Goods by Road
ATR	Autothermal Reforming
BEVs	Battery Electric Vehicles
BRES	Business Register and Employment Survey
CCC	Climate Change Committee
CCS	Carbon Capture and Storage
CCUS	Carbon Capture, Usage and Storage
COMAH	Control of Major Accident Hazards
COP	Coefficient of Performance
DESNZ	Department for Business Energy Security and Net Zero
DFES	Distributed Future Energy Scenarios
DfT	Department for Transport
DRI	Direct Reduced Ion
DSEAR	Dangerous Substances and Explosive Atmosphere Regulation
EAF	Electric Arc Furnace
ENA	Energy Networks Association
FES	Future Energy Scenarios
FLOW	Floating Offshore Wind
GHG	Greenhouse Gas
GPO	Gas Partial Oxidation
GW	Gigawatts
GW4	Alliance of Bath, Bristol, Cardiff and Exeter Universities
GWh	Gigawatt hours
GWP	Global Warming Potential
HGVs	Heavy Goods Vehicles
HSE	Health and Safety Executive
HVMC	High Value Manufacturing Catapult
LCOH	Levelised Cost of Hydrogen
LDZ	Local Distribution Zone
LEPs	Local Enterprise Partnerships
LGVs	Light Goods Vehicles
LNG	Liquified Natural Gas
LODES	Longer Duration Energy Storage Demonstration
MW	Megawatts
NCC	National Composite Centre
NTS	National Transmission System
NZIP	Net Zero Innovation Portfolio

Acronym	Meaning
Ofgem	Office of Gas and Electricity Markets
ORMM	Off-Road Mobile Machinery
PEM	Polymer Electrolyte Membrane
PSA	Pressure Swing Adsorption
REPD	Renewable Energy Planning Database
SAF	Sustainable Aviation Fuel
SGN	Scotia / Southern Gas Networks
SIC	Standard Industrial Classification of Economic Activities
SMR	Steam Reformation
SWLEP	Swindon and Wiltshire Local Enterprise Partnership
TSA	Temperature Swing Adsorption
TWh	Terawatt hours
WECA	West of England Combined Authority
WWU	Wales and West Utilities

1 Introduction

1.1 Background

The Western Gateway commissioned City Science to produce this Hydrogen Delivery Pathway to 2050 for the area. The Western Gateway is the UK's first pan-regional economic powerhouse to span two countries. Extending across South Wales and Western England, the partnership brings together local authorities, a combined authority, city regions, Local Enterprise Partnerships and Governments (in Wales and Westminster) to work together on the big challenges their communities face. The partnership is committed to ensuring that its 4.4 million residents benefit from fairer, greener economic growth and can access opportunities across our area.

The study includes a future pathway for the production, distribution, and use of hydrogen as a low carbon energy carrier to 2030, 2035, 2040 and 2050. This includes modelling scenarios presenting the current and expected demand and supply of hydrogen across the area. The delivery pathway uses these modelling outputs to quantify the potential economic value of developing the Western Gateway Hydrogen Ecosystem, such as productivity outputs, employment, skills development and opportunities building on research and innovation strengths and carbon reduction.

This study builds on previous work focussing on the Western Gateway geography, such as the Supergen Energy Networks System Study, 2022 and the work undertaken by the Western Gateway Partnership in collaboration with the GW4 Alliance and Swindon and Wiltshire LEP (SWLEP) to map the Western Gateway Hydrogen Ecosystem. In producing this delivery pathway, engagement with a wide range of stakeholders across the area has been undertaken including utility providers, representatives from the industrial, academic, research and innovation fields and local authorities. The delivery pathway reflects their views on how the hydrogen economy could be developed in a cost-effective, efficient, and integrated way to 2050.

1.2 Delivery Pathway Purpose

The delivery pathway has several key purposes which include:

- Review the existing hydrogen policy context, regulatory framework and funding opportunities
- Develop hydrogen supply and demand scenario projections in the area to 2030, 2035, 2040, and 2050
- Identify the most suitable locations for hydrogen production, storage and distribution
- Estimate the carbon emissions savings as a result of the switch to hydrogen
- Quantify the likely approximate level of capital expenditure, investment and funding required
- Assess the potential approximate economic value of the Western Gateway hydrogen opportunity
- Identify the key skills required to realise the potential of hydrogen in the Western Gateway
- Establish key innovation opportunities which could accelerate the hydrogen pathway realisation
- Identify detailed hydrogen pathways to 2050 and accompanying suggested actions

1.3 Western Gateway Geographic Overview

The Western Gateway covers South Wales and Western England and comprises 24 local authorities. The area stretches from Swansea to the west and to Swindon in the east and from Tewkesbury in the north to Salisbury in the south and in doing so spans the Bristol Channel connecting the two countries.

The geographic scope of this study also incorporates consideration of wider strategic opportunities nearby including Milford Haven in Pembrokeshire where a comprehensive hydrogen demonstration project has recently concluded: 'Milford Haven: Energy Kingdom.

The Western Gateway has around 4.4 million residents, with most living in the urban areas of Bath, Bristol, Cardiff, Gloucester, Newport, Salisbury, Swansea and Swindon. The area also includes some of the most sparsely populated rural areas in the UK such as the Cotswolds and Monmouthshire.

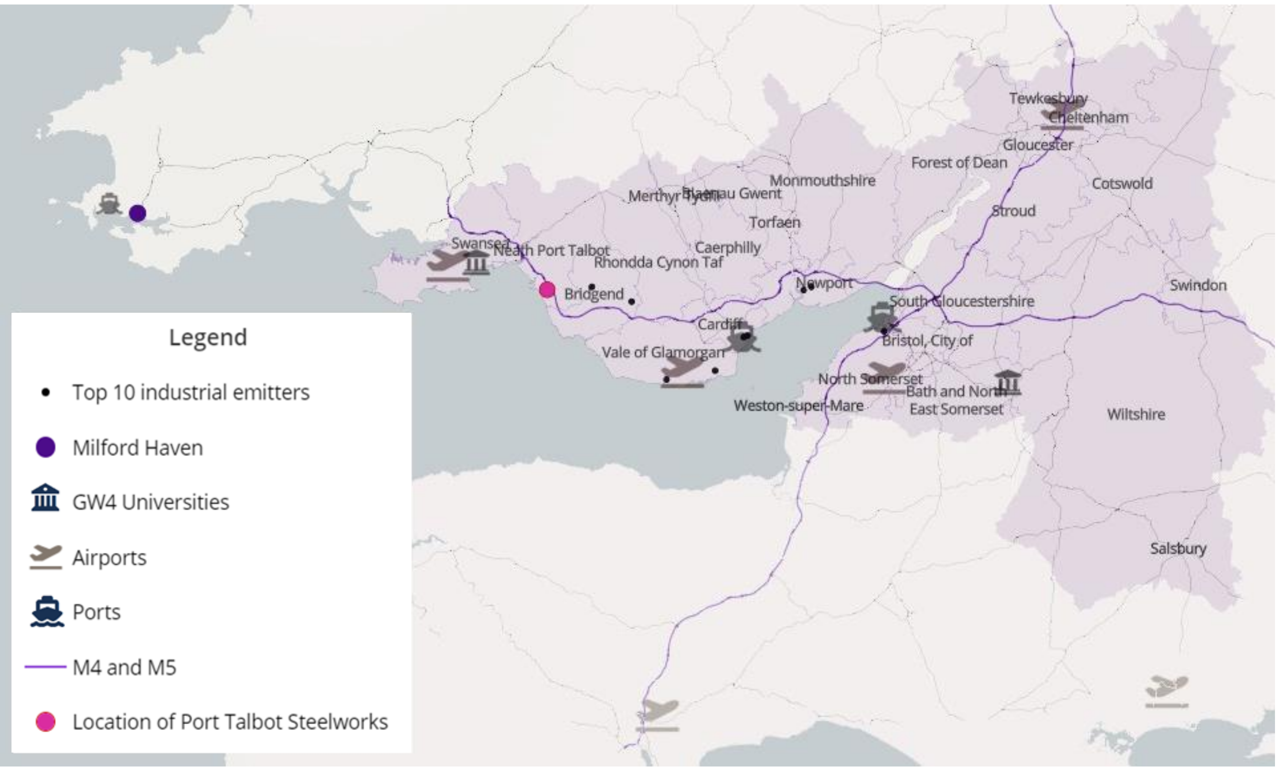


Figure 1-1: Western Gateway

The area has leading advanced manufacturing and knowledge-based clusters, most of which are relevant to hydrogen research, production, distribution, and use as well as the South Wales Industrial Cluster. This includes the Port Talbot Tata Steel facility, nationally and internationally significant aerospace industry, Bristol and Cardiff Airports, and several ports including Bristol, Swansea, Port Talbot, Barry, Cardiff and Newport. The Western Gateway is also home to leading academic research institutions including three of the four GW4 Alliance universities in Bath, Bristol and Cardiff, as well as the University of South Wales, University of the West of England with interest in hydrogen production and application.

There is also significant renewable energy generation potential in or adjacent to the Western Gateway. Current proposals include for Floating Offshore Wind (FLOW) in the Celtic Sea and the potential for tidal lagoon power generation in Swansea Bay. The Western Gateway has also announced a Commission into the potential for low carbon energy production of the Severn Estuary. The role of the nuclear power industry is also of interest in terms of low carbon energy production.

1.4 Hydrogen Production Basic Principles & Key Terminologies

This report has extensive reference to different forms of hydrogen production throughout. For consistency and to ease understanding, Table 1-1 summarises the key terminology.

Hydrogen Type	Meaning
Green Hydrogen	Green hydrogen is made by using electricity from renewable energy sources, such as solar or wind power using electrolysis.

Hydrogen Type	Meaning
Blue Hydrogen	Blue hydrogen is produced mainly from natural gas using a process called steam reforming. Blue hydrogen entails using carbon capture and storage (CCS) solutions for carbon dioxide (CO_2) emissions.
Pink Hydrogen	Pink hydrogen is generated through electrolysis powered by nuclear energy. Hydrogen produced using nuclear power can also be referred to as purple hydrogen or red hydrogen depending on the process used.
Grey Hydrogen	Grey hydrogen is produced from natural gas, or methane, using steam methane reformation but without capturing the carbon dioxide (CO_2) emissions. Most hydrogen globally and in the UK is currently produced using this method.

Table 1-1: Explanation of Hydrogen Types (Western Gateway, 2022)

1.5 Engagement With Key Partners & Stakeholders

The delivery pathway has been developed in close dialogue with key partners and stakeholders across the Western Gateway through various workshops and meetings held between November 2022 and March 2023 and was supplemented by a consultation exercise in April and May 2023. Its preparation has been overseen by an internal working group, with regular reporting to the Western Gateway Hydrogen Steering Committee. A summary of the key organisations we have engaged with, some of which are likely to be involved in the future delivery of actions identified in this Strategy, includes:

- Hydrogen South West
- Costain
- Milford Haven Port
- Western Gateway Hydrogen Working Group (Local authorities)
- Cardiff Capital Region
- West of England Combined Authority
- Swansea Bay City Deal
- GKN
- Welsh Government Energy Service
- Wales and West Utilities
- AB Ports
- SGN
- National Grid
- Airbus
- EDF / Hynamics
- easyJet
- GW4 Alliance
- Bath University
- University of South Wales
- Bristol University
- South Wales Industrial Cluster (SWIC)
- Bristol Port
- Tower Group
- National Composites Centre (NCC) / High Value Manufacturing Catapult (HVMC)
- Bristol Airport
- The Centre for Future Clean Mobility
- Smart Ports Transitional Energies Ltd
- HydrogenOne Capital
- RWE Generation

1.6 Report Structure

Following this chapter, the report is structured in the following way:

Chapter		Brief Description
2	Western Gateway Hydrogen Policy Context Summary	This chapter includes a brief review of UK Government, Welsh Government and key regional and local policy within the Western Gateway relevant to hydrogen, including a discussion of the key opportunities that could potentially unlock hydrogen in the area and the key barriers to overcome.
3	Hydrogen Planning and Regulatory Standards Review	This chapter reviews the current key planning and permitting regulatory standards relevant to the production, transmission, storage and use of hydrogen. It concludes with an analysis of key constraints which may affect the future roll-out of hydrogen in the Western Gateway.
4	Emerging Funding Landscape	This chapter reviews the historic and emerging government funding landscape relevant to the Western Gateway for hydrogen-related development opportunities.
5	Future Hydrogen Scenario Development	This chapter introduces the future hydrogen scenarios that have been used in this delivery pathway to inform possible supply and demand projections.
6	Hydrogen Demand Scenarios	This chapter sets out the demand scenarios and modelling outputs for hydrogen in the Western Gateway across the full range of use cases. This considers milestone years of 2030, 2035, 2040 and 2050.
7	Hydrogen Supply Scenarios	This chapter sets out the supply scenarios and modelling outputs for hydrogen in the Western Gateway across milestone years of 2030, 2035, 2040 and 2050
8	Western Gateway Hydrogen Network Considerations	This chapter identifies the key hydrogen network development considerations across the Western Gateway area including geospatial consideration of locations for hydrogen production, supply and demand
9	Developing the Western Gateway Hydrogen Economy	This chapter summarises the capital expenditure and investment that is likely to be required to deliver they hydrogen ecosystem in the Western Gateway. It also considers the potential economic benefits including potential employment generation
10	Innovation Strengths & Capabilities	This chapter identifies the key innovation and research capabilities in the Western Gateway that could accelerate the delivery pathway.
11	Workforce and Skills Development	This chapter identifies potential upskilling requirements in the area and outlines current skills development programmes.

Chapter		Brief Description
12	2050 Delivery Pathways	This consolidates the findings of the evidence base and outlines delivery pathways for the Western Gateway to 2050, including the milestone years of 2030, 2035 and 2040.

Table 1-2: Chapters & Description

2 Western Gateway Hydrogen Policy Context Summary

Chapter in Brief

This chapter includes a brief review of UK Government, Welsh Government and key regional and local policy within the Western Gateway relevant to hydrogen, including a discussion of the key opportunities that could potentially unlock hydrogen in the area and the key barriers to overcome. A more detailed policy review can be found in Appendix A – Detailed Policy Context.

2.1 National Policy Context

At a national level, policy related to hydrogen development is driven by the UK Government whilst for Western Gateway local authorities located in Wales, Welsh Government policy also applies. A summary of key national policies related to hydrogen development is summarised in Figure 2-1.

As set out in the most recent Welsh Government Devolution Settlement (Wales Act 2017), the Welsh Government is primarily responsible for energy and hydrogen policy covering areas such as renewable energy, energy efficiency, heat and planning consent for renewable energy schemes (up to 350 MW). The UK Government's responsibility primarily covers energy and hydrogen network regulation (including safety legislation), ensuring overall security of energy supply alongside planning of larger renewable generation projects in Wales beyond 350 MW.

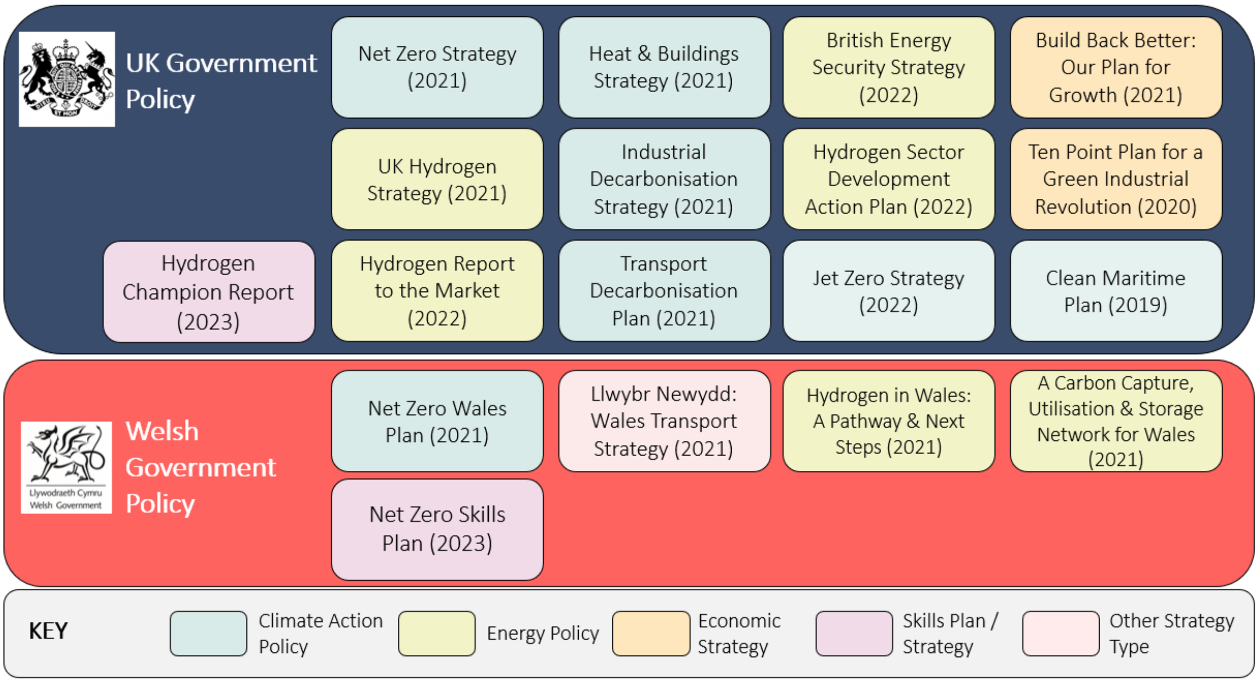


Figure 2-1: UK and Welsh Government Policy Overview

2.1.1 UK Government Policy Context

The UK Government policy focus on hydrogen is underpinned by the ambition to achieve net zero carbon emissions by 2050. The **Net Zero Strategy: Build Back Greener** (2021) consolidates the UK Government approach to achieving decarbonisation, which incorporates a reduction pathway to 2037. This attributes a key role to hydrogen to *'complement the electricity system, especially in harder to electrify areas like parts of industry and heating and in heavier transport such as aviation and shipping*.' This focus on hydrogen to achieve net zero has been reaffirmed by the recent **Independent Review of Net Zero (2023)** which has recommendations such as a 10-year delivery road map to scale up hydrogen production and immediate delivery of transport and storage hydrogen business models.

The **Net Zero Strategy** (2021) also pledges to achieving 100% of electricity to be produced from renewables by 2035 in England, which may directly impact on the relative spare capacity potential available for green hydrogen production in the short term.

The **UK Hydrogen Strategy** (2021) sets out the UK Government's approach to developing a low carbon hydrogen sector. The Strategy forecasts that between 250 to 460 TWh of hydrogen will be required by 2050, comprising around 20-35% of UK energy consumption. The Strategy set an interim hydrogen production target of 5 GW by 2030, which was increased to 10 GW in 2022 in the **British Energy Security Strategy** (2022)**. Project Union** is identified within the Strategy which is examining the development of a UK hydrogen network to connect industrial clusters like South Wales and which presents a key strategic opportunity for the Western Gateway. The Strategy estimates there is a potential to support 100,000 jobs and generate £13 billion GVA in 2050 in a high hydrogen scenario.

The UK Hydrogen Strategy has been followed by the more recent **Hydrogen Sector Development Action Plan** (2022) which identifies a concentration of potential hydrogen-development projects in the Western Gateway. This includes establish projects such as the Bristol Airport Hydrogen Hub (part of the ZEROe agreement between easyJet, Airbus and EDF), Protium Magor (a 17.5 MW green hydrogen plant at a Monmouthshire brewery) and the Net Zero Centre at RWE Pembroke. The UK Government has also recently developed a **Hydrogen Business Model** which is designed to support private sector growth in the production of low-carbon hydrogen.

More recently still has been the **UK Hydrogen Champion Report** (March 2023) which gives recommendations to the UK government and industry to accelerate the development of the UK hydrogen economy. This report consulted with over 100 stakeholders and summarised that greater clarity is needed on upcoming policy decisions for hydrogen users, the funding which could be available and overall delivery of the hydrogen roadmap to 2030 and beyond.

The **Heat and Buildings Strategy** (2021) consolidates the UK Government's approach to decarbonising buildings, which has significant direct implications on the future role that hydrogen could play in heating. Among other pledges, such as the phase out of new gas boilers by 2035 and the installation of 100,000 new heat pumps per year by 2028, this identifies that the UK Government will make a critical decision in 2026 on whether hydrogen should be pursued for heating at a national scale. Should this go ahead, it has the potential to significantly increase future hydrogen demand. It is noted that in the Clean Heat Market Mechanism (CHMM) consultation there is a suggestion that hydrogen-ready boilers will be considered relevant fossil fuel boiler sales and not count towards the CHMM targets.

The **UK Industrial Strategy** (2021)'s key target for 50 TWH of industrial fuel switching to occur by 2035 has direct implications on the future of industry in the Western Gateway, particularly in SWIC encompassing the Port Talbot Steelworks. The Strategy asserts that decarbonisation options at Port Talbot would constitute either hydrogen Direct Reduced Iron (DRI) coupled with an electric furnace or Carbon Capture and Storage (CCUS). Due to local geological constraints identified in the Welsh Government report entitled ***'A Carbon Capture, Utilisation and Storage Network for Wales*** (2021)***'***, this would require the shipping or transmission of carbon dioxide to offshore parts of the UK (e.g. redundant oil and gas fields in the North Sea).

There are strategic opportunities for the Western Gateway identified in transport decarbonisation policies including the **Transport Decarbonisation Plan** (2021)**, Jet Zero Strategy** (2022) and **Clean Maritime Plan** (2019). Principally, the 2040 target of net zero domestic flights presents an opportunity to establish the Western Gateway as the UK's aviation hydrogen hub, building on the area's existing significance as the leading aerospace cluster and several ongoing hydrogen aviation projects, such as the Airbus' Zero Emission Development Centre in Filton.

2.1.2 Welsh Government Policy

The Welsh Government has also committed to achieve net zero by 2050, which is consolidated as part of the **Net Zero Wales Plan** (2021) which establishes a series of hydrogen-related pledges; underpinned by a hydrogen pathway report entitled ***'Hydrogen in Wales: A pathway and next steps for developing the hydrogen energy sector in Wales*** (2021)***'.*** Pledges include establishing a new renewable hydrogen production site of up to 10 MW by 2024, planning large-scale hydrogen production sites and supporting local projects. This may present a key opportunity for Milford Haven Energy Kingdom which has already benefitted from Welsh Government funding.

There is limited existing policy produced by the Welsh Government in relation to potential future uses of hydrogen in Wales, with further detail expected in the upcoming **Wales Heat Strategy**. However, **Llwybr Newydd: the Wales Transport Strategy** (2021) identifies that hydrogen can play a key role in decarbonising transport, including for rail and road transport which could present a strategic opportunity for further trials in the Western Gateway.

The Welsh Government has also recently produced the **Net Zero Skills Action Plan (2023)** which once fully developed will go beyond current UK Government policy to set out a clear skills roadmap. At present there is an absence of specific commitments in upskilling people targeted specifically at the hydrogen economy, however, there is an opportunity to shape proposals during the ongoing consultation period.

2.2 Regional & Local Policy Context

Figure 2-2 underlines the breadth of existing policies at a regional and local level across the Western Gateway which covers those produced by the Western Gateway, the South Wales Industrial Cluster, Local Enterprise Partnerships and the constituent local authorities.

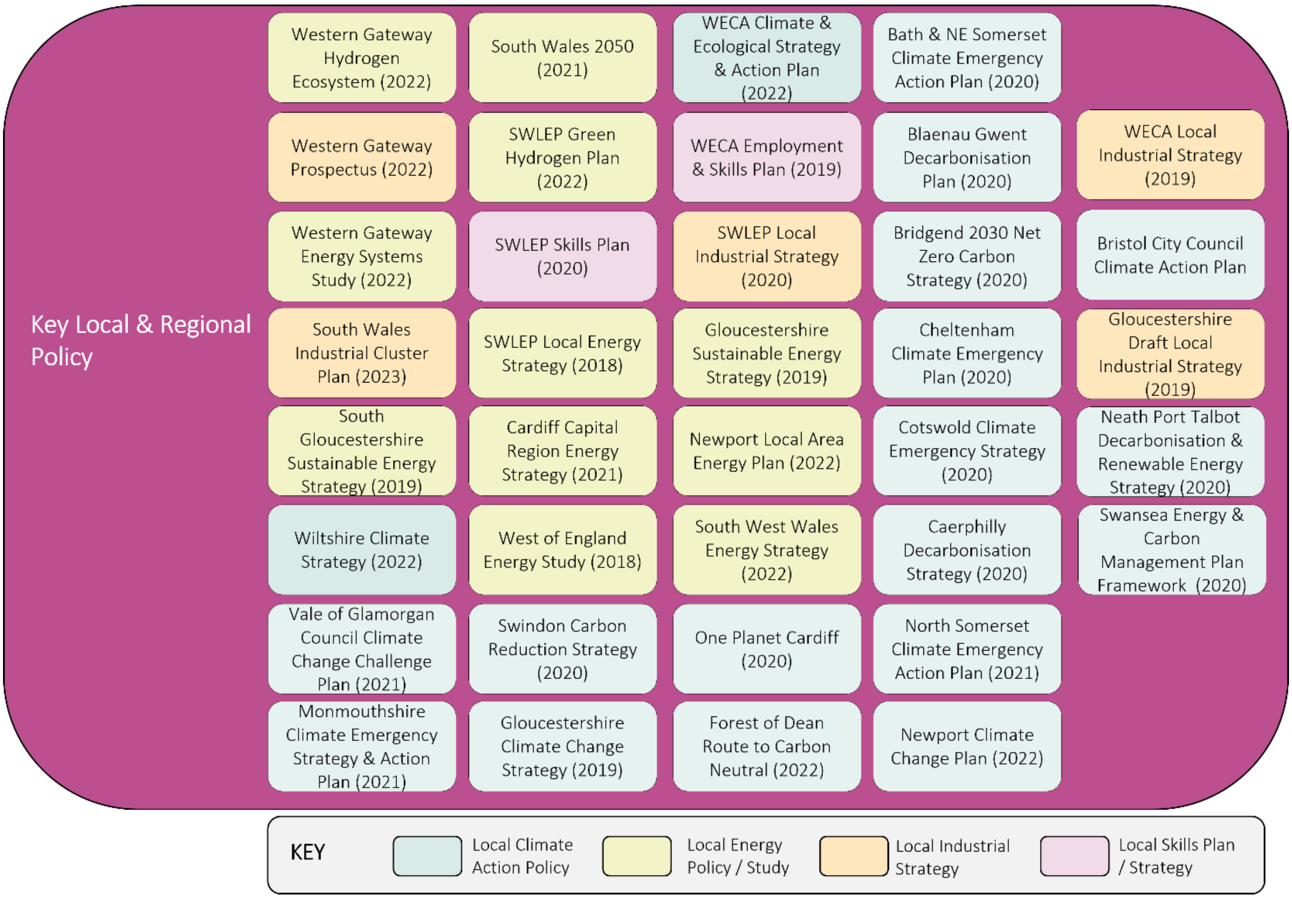


Figure 2-2: Key Local and Regional Policy Context

2.2.1 Regional Policy

Key policies at a regional level include the **Western Gateway Prospectus** (2022) which identifies key ambitions and opportunities to attract inward investment, grow exports and unlock innovation opportunities, including in the hydrogen ecosystem. The **Western Gateway Hydrogen Ecosystem** (2022), which forms part of the evidence base for the development of the Hydrogen Strategy and Delivery Pathway to 2050, identifies the emerging hydrogen ecosystem and key assets to support the transition to a hydrogen economy. It identifies the breadth of hydrogen networks and collaboration, demonstrating the opportunity and drive to develop the hydrogen economy across the two nations.

In addition to this, the **South Wales 2050** (2021) report, produced by Zero 2050, focuses on how the South Wales energy system can achieve net zero by 2050. This emphasises that green hydrogen should be the dominant production method in South Wales, supported by a mix of blue hydrogen in the shorter term.

The **South Wales Industrial Cluster Plan** (2023), assigns a critical role to hydrogen in decarbonising industry in the area. This underlines the importance of the delivery of the HyLine Cymru project (Section 5.3), the need to upscale green hydrogen production in the area to meet future industrial fuel switching demand (which is forecast by the plan as 4.9 TWh/year by 2050 for industry alone), and the need for a clear UK Government strategy on CCUS.

2.2.2 Other Local & Regional Policies

Policies produced at a local, combined authority level or by LEPs broadly fall into four categories:

- **Local Climate Action Policies** (e.g. Wiltshire Climate Strategy, Newport Climate Change Plan)

- **Local energy policies or studies** (e.g. Western Gateway Energy Systems Study, South Gloucestershire Sustainable Energy Strategy)
- **Local Industrial Strategies** (e.g. SWLEP Local Industrial Strategy and Green Hydrogen Production Plan, Gloucestershire Local Industrial Strategy)
- **Local Skills Plan and Strategies** (e.g. SWLEP Skills Plan, WECA Employment and Skills Plan).

Further detail on these policies can be found in Appendix A – Detailed Policy Context.

The key themes that emerged, relevant to the Western Gateway Delivery Pathway, were the need to:

- Harness opportunities to enable economic growth
- Increase highly skilled jobs in the area
- Explore further uses for hydrogen in the decarbonisation of heat, transport and industry
- Secure funding for research and development in order to foster local innovation
- Facilitate access to affordable low carbon energy for the wider community.

2.3 Summary of Key Policy Implications

Table 2-1 summarises the key policy opportunities which have the potential to unlock hydrogen in the Western Gateway and the key policy barriers or areas of uncertainty to overcome. Note this does not include regulation and planning barriers to overcome which are covered in Chapter 3.

Key Unlocking Policy Opportunity	Key Policy Barrier to Overcome
Hydrogen's role in meeting UK net zero targets: The UK Net Zero Strategy attributes a major role for hydrogen in meeting which opens significant potential hydrogen project funding opportunities.	**2026 strategic decision for hydrogen in heating:** The UK Government is due to decide whether to pursue hydrogen for heating in 2026 which presents significant uncertainty on future heating demand
2035 industry fuel switching and steel production decarbonisation: The UK Government has set a target of industrial fuel switching of 50 TWh by 2035 which presents a potential funding opportunity for industrial cluster sites to decarbonise rapidly.	**2035 100% renewable power target impact on green hydrogen production:** The UK Government has a target of achieving 100% electricity from renewables by 2035 which may constrain capacity available for electrolytic hydrogen production in the short term.
Hydrogen job creation potential: The UK Hydrogen Strategy notes that investment in the hydrogen ecosystem could create around 12,000 jobs by 2030 alone	**Lack of clear policy direction on CCUS:** The Western Gateway area has very limited CCUS opportunities given its geology and therefore CO_2 will require export either via pipeline or via shipping.
Hydrogen enabled rail and road transport: The UK Government is actively looking to explore hydrogen rail to meet its target of removing all diesel only trains by 2040. The Global Centre of Rail Excellence in Neath Port Talbot could research and test hydrogen rail further. Proximity to the Centre for Future Mobility is	**Environmental constraints of CO_2 pipeline construction in South Wales**: The construction of any major CO_2 transmission pipeline across South Wales would be constrained by environmental sensitivities and planning requirements.

Key Unlocking Policy Opportunity	Key Policy Barrier to Overcome
Exeter another opportunity for hydrogen transport.	
Jet Zero and aviation hydrogen gateway cluster opportunity: The 2040 target for net zero domestic flights means that the government is looking for research in zero emission flight infrastructure. There is an opportunity for the area to be the UK's aviation hydrogen hub based on its status as the UK's centre of aerospace excellence.	**Uncertainty of hydrogen's role in meeting Welsh Government's net zero targets:** There is limited existing policy published by the Welsh Government in relation to potential future uses of hydrogen. Further detail is expected in the upcoming Wales Heat Strategy due in the Summer 2023.
Zero emission shipping cluster: The UK Government is looking to establish zero emission shipping clusters. There may be potential for ports in the area to develop hubs for the production, storage and distribution of alternative shipping fuel.	**Lack of UK hydrogen skills strategy:** There is an absence of a UK skills strategy which clearly consolidates how hydrogen-related skills can be developed to support the transition from fossil fuels to hydrogen.
Heating transition opportunity: Heating is a major source of carbon emissions. The widespread use of gas in the area could present a future early opportunity for transition to hydrogen e.g. hydrogen town trials.	**Decarbonisation of steel production:** The decarbonisation of steel production in South Wales has yet to be determined. This is a major potential hydrogen anchor load for the Western Gateway area.
Project Union: This is a key enabling project which aims to provide a hydrogen transmission network for the UK; connecting hydrogen supply, demand and storage. The proposed network would connect Milford Haven to wider pipelines to the east.	**Hydrogen road transport uncertainty:** There is an absence of specific policy targets pertaining to the use of hydrogen powered vehicles, particularly cars, at a national level. This creates uncertainty over the extent to which hydrogen powered vehicles may become widespread.
Hydrogen Economy Skills: The Welsh Government is currently consulting on their Net Zero Skills Plan. In addition, organisations across the area are progressing work at a national level and regional level. This presents a strategic opportunity to ensure that the skills need for the future hydrogen economy in the Western Gateway are reflected.	**Existing National Grid electricity connection regulation and grid capacity constraints:** these could restrict the roll out of distributed electrolytic hydrogen production facilities in some locations.

Table 2-1: Summary of key policy opportunities and barriers to overcome

3 Hydrogen Planning & Regulatory Standards Review

Chapter in Brief

This chapter reviews the current key planning and permitting regulatory standards relevant to the production, transmission, storage and use of hydrogen. It concludes with an analysis of key constraints which may affect the future roll-out of hydrogen across these key aforementioned areas in the Western Gateway.

3.1 Regulatory Framework Overview

The regulatory framework for hydrogen (including safety) is primarily a reserved matter for the UK Government, with little to no responsibility applicable to the Welsh Government (Wales Act 2017).

There is currently no comprehensive regulatory framework operational in the UK which can be used to manage the production, transmission, or storage of hydrogen. The existing regulations governing hydrogen are piecemeal, made up of existing legislation, rules and policies primarily associated with natural gas.

Hydrogen currently falls under the definition of a *'gas'* under the Gas Act 1986 and therefore its production, transport and storage is currently regulated in this context. Those involved in such activities require a licence via the Office of Gas and Electricity Markets (Ofgem), who are responsible for the safety of the network.

This Chapter covers the key wider legislation that are currently applicable to the hydrogen production-to-use lifecycle and outlines the key residual gaps that must be resolved to ensure the continued innovation and development of hydrogen as a viable low carbon fuel in the UK (see Figure 3-1).

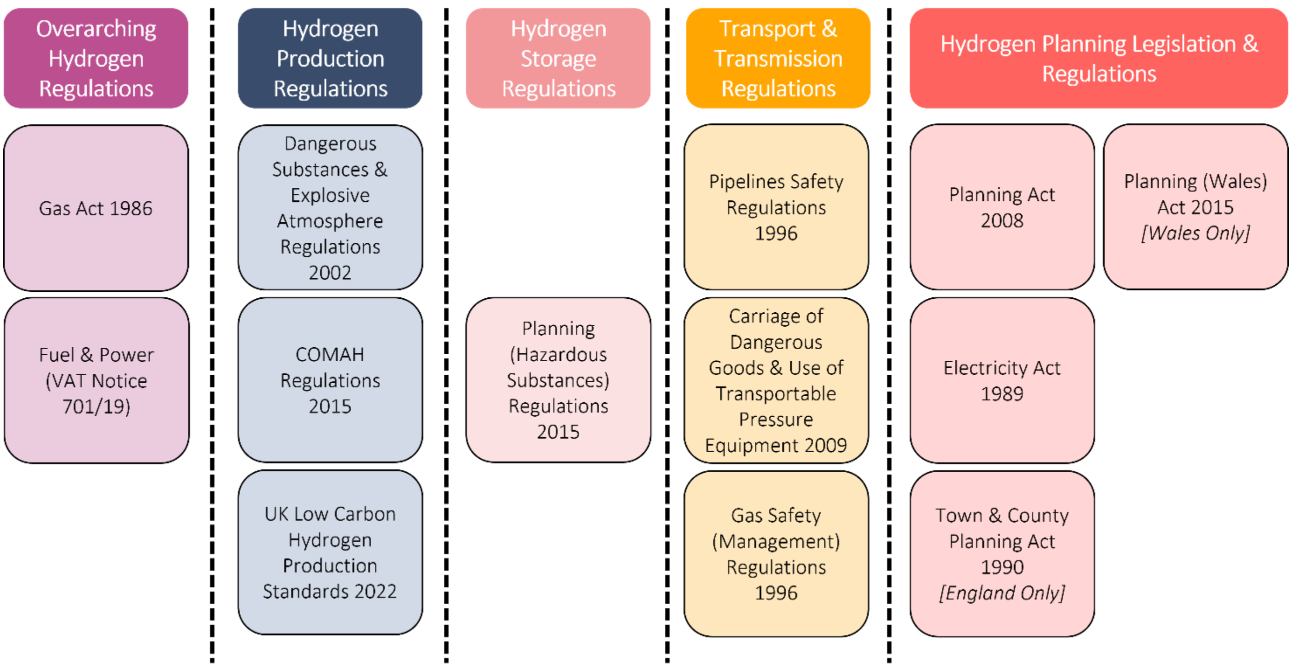


Figure 3-1: Key existing regulatory framework related to hydrogen

3.2 Hydrogen Production Regulations & Standards

As with production of all fuels and other hazardous substances, production of hydrogen is subject to stringent broader safety regulations. As well as Ofgem, primary regulators of hydrogen production at a local level are the Health and Safety Executive (HSE), the Environment Agency and Natural

Resources Wales. The two key pieces of legislation that outline the duties of operators and employers are:

- The **Dangerous Substances and Explosive Atmosphere Regulation (DSEAR) 2002**
- The **Control of Major Accident Hazards (COMAH) Regulations 2015**

These regulations are designed to prevent or limit the harmful effects of energy-releasing events; DSEAR protects workers from risks related to potentially explosive atmospheres, including hydrogen gas under pressure, and COMAH states that *'every operator must take all measures necessary to prevent major accidents and to limit their consequences for human health and the environment.'*

At present, current legislation requires anyone producing hydrogen to obtain an environmental permit, regardless of the size of the operation or amount of hydrogen being produced. Natural Resources Wales recently concluded a consultation (Natural Resources Wales, 2022) on plans to change the regulations in Wales to allow small-scale operators (storage of less than 1 tonne of hydrogen on site) who produce green hydrogen via electrolysis of water to do so without the need for a permit. This does not impact upon permitted development rights.

3.2.1 UK Low Carbon Hydrogen Production Standards (2022)

The UK Government has created guidance and a calculator for hydrogen producers to use for greenhouse gas emissions reporting and sustainability criteria which was subject to consultation in 2021. This standard sets out and defines what constitutes 'low carbon hydrogen' production and the emissions to be included in the calculation, primarily applicable to green and blue hydrogen production. This is necessary to ensure producers benefiting from UK Government funding contracts, for example, the Net Zero Hydrogen Fund, are reducing carbon emissions in relation to fuel switching. Producers are obligated to demonstrate they meet the following key standards:

- Limit greenhouse gas emissions to $20gCO_2e/MJ_{LHV;}$
- Calculate emissions up to the point of production e.g. inclusive of feedstock supply alongside those associated with CCUS; and
- Account for emissions assuming a minimum pressure level of 3 MPa with purity of 99.9%.

The standards also encompass the need for producers to develop risk mitigation plans for fugitive emissions, whilst there are also specific requirements for biogenic inputs where applicable[1].

3.2.2 Fuel & Power Notice (VAT Notice 701/19)

Hydrogen is currently charged at the standard rate of VAT (currently 20%) for all purposes, except for hydrogen piped into domestic properties where it is used as a direct replacement for gas heating where a reduced rate (currently 5%) applies. This means that hydrogen is currently competitively disadvantaged compared to use of other fuels (e.g. hydrogen cars compared to electric vehicles). In addition, no account is made of the relative carbon intensity with the same tax rate applied to both blue and green hydrogen.

[1] Biogenic hydrogen is hydrogen produced through organic matter such as plants or food waste

Key known regulatory gaps / constraints relating to hydrogen production impacting the Western Gateway

- **Water resources for electrolysis regulation:** The UK Government is currently engaging with the Environment Agency to develop a regulatory framework on water quality requirements for electrolysis which requires high purity deionised and desalinised water (in cases where sea water rather than freshwater is used).[2]
- **Air quality regulation in permitting requirements:** Some hydrogen production methods could have potential unintended impacts on air quality (e.g. ammonia emissions). The Department of Environment, Food and Rural Affairs is currently leading development of standards to ensure these requirements are reflected within the hydrogen production process.
- **Hydrogen leakage:** The UK Government is closely monitoring the implementation of the Low Carbon Hydrogen Standard to determine whether further intervention (e.g. through revised Standards or regulation) to manage and avoid hydrogen leakage is required.
- **VAT Differentials:** There is a competitive imbalance on the VAT rates applied between hydrogen and some other fuel sources which requires addressing to support production.

3.3 Hydrogen Storage Regulations

It is widely regarded that the storage of hydrogen is necessary to manage fluctuations in supply and demand and provide greater energy security. There is substantial research progressing on optimum solutions currently, however, underground or underwater hydrogen storage (e.g. in redundant oil fields, salt caverns, aquifers) is unlikely to be possible in the Western Gateway due to geological limitations. As such, storage would most likely be accommodated in purpose-built containers such as those for compressed or liquified hydrogen or metal hydrides.

Permitting regulations for hydrogen storage are required under the **Planning (Hazardous Substances) Regulations 2015** to store two or more tonnes of hydrogen. In addition, as hydrogen is considered a *'dangerous substance'* under COMAH, there are additional requirements; the exact regulations applicable depend on the quantity of hydrogen being stored. Under COMAH there are two levels of sites:

- Lower Tier: Where there are between five and 50 tonnes of hydrogen on site
- Upper Tier: Where there are 50 or more tonnes of hydrogen on site.

If there are hazardous materials present on site other than hydrogen, additional rules apply under COMAH regarding the thresholds for a site moving from the lower to the upper tier. Lower tier sites must notify their Competent Authority, for example the HSE or Environment Agency, before storing or using hydrogen on site, undertake a risk assessment and prepare a major accident prevention policy that outlines the approach to any major hazards on-site including (but not limited to) leaks and spills, explosions and fires. In addition, upper tier sites must prepare a safety report, internal emergency plan and inform local people about their activities which have associated cost and resource implications.

Key Known Regulatory Gaps / Constraints Relating to Hydrogen Storage Impacting the Western Gateway

- **Absence of Clear and Consistent Storage Regulatory Standards:** The UK Government has committed to examining storage regulations in the mid-2020s as research into optimum hydrogen storage solutions emerge.

[2] Water use is approximately between 6-13 kg per kg of hydrogen produced

3.4 Hydrogen Transportation & Transmission Regulations

3.4.1 Hydrogen Transport Regulatory Framework

The **Gas Act 1986** primarily regulates the transport of hydrogen. The exact licensing requirements vary depending on the transport activity and nature of the companies providing hydrogen:

- Those that physically ship gas from one place to another are required to hold gas shipper licenses; and
- Under the **Pipelines Safety Regulations 1996**, gas transporter licenses are required for companies shipping hydrogen gas via a pipeline, which itself must adhere to the Pipeline Safety Regulations in terms of design, build and operation.

Holders of gas shipper licenses must comply with the following industry codes:

- Uniform Network code
- Independent Gas Transporter Uniform Network Code
- Retail Energy code
- Smart Energy Code
- Supply Point Administration Agreement.

The International Carriage of Dangerous Goods by Road (widely known internationally as Accord Dangereux Routier or ADR) is the main regulatory framework for road transport of hydrogen (not direct transport use such as HGVs or buses), which defines hydrogen as Class 2 *'dangerous goods'*. The **Carriage of Dangerous Goods and Use of Transportable Pressure Equipment Regulations 2009** covers the classification, packing and carriage of dangerous materials (including hydrogen) and the construction and approval of the vehicles which are used for transportation. This sets out driver training requirements and vehicle specifications required for transporting hydrogen. Where hydrogen is pressurised for transportation, the Pressure Equipment (Safety) Regulations 2016 regulates the design and manufacture of equipment for transporting, storing and re-gasifying hydrogen that is being transport as a liquid or gas.

3.4.2 Hydrogen Transmission Regulatory Framework

At present, the **Gas Safety (Management) Regulations 1996** (recently updated in April 2023) limit the concentration of hydrogen in public gas pipelines to 0.1% and up to 23% in closed networks. For example, a blend of up to 20% hydrogen has been successfully tested through the HyDeploy project at Keele University.

The next steps are to gather evidence on supplying industry with blended hydrogen to present a full picture of safety issues surrounding delivery of blended hydrogen in the UK gas distribution network, with a decision due to be made in 2023 over whether to permit public gas grid blending up to 20% (Section 2.1.1). Any changes to permitted hydrogen concentration levels will necessitate changes to regulations which are unlikely to be ready for nationwide implementation before 2025 (HM Government, 2021).

Key known regulatory gaps / constraints relating to hydrogen transport and transmission Impacting the Western Gateway

- **Hydrogen Blending in Gas Pipelines Regulation Changes:** Any UK Government decision to progress with up to 20% public gas grid blending would require changes to the Gas Safety Regulations prior to nationwide deployment, including in Wales, which is likely to take at least two years to implement.

- **Potential Hydrogen Road Transport Regulatory Gaps:** The UK Government has committed to a review of the existing non-pipeline distribution regulations (e.g. ADR) to confirm whether they can accommodate hydrogen road transport requirements.
- **Purity Standard Development:** A critical decision needs to be made by the UK Government on the purity standard within dedicated hydrogen transmission and distribution networks. Hydrogen could be cleaned of impurities prior to injection into the grid, or it could be cleaned close to the end-user

3.5 Hydrogen Project Planning Regulations

3.5.1 Existing Regulations

There are no specific planning regulations that cover the approval and development of hydrogen production, transport or storage sites which means that they are currently dealt with a case-by-case basis via local planning authorities.

The **Planning Act 2008** covers Nationally Significant Infrastructure Projects (NSIPs). Hydrogen projects which include power stations, above-ground electricity lines, liquid natural gas facilities, gas storage and reception facilities or a gas pipeline, and meet the thresholds outlined in the Planning Act, require a Development Consent Order (DCO). A DCO requires submission and approval by the Planning Inspectorate rather than the individual planning authority.

Energy Project Type	Key Thresholds Triggering Planning Act (2008)
Generating Stations	• Onshore capacity is greater than 50 MW (in England) • Offshore capacity is greater than 100 MW (in England) • Onshore or Offshore capacity is greater than 350 MW (in Wales or in waters adjacent to Wales)
Above-Ground Electricity Lines	• Electricity line is more than 132 kV • The line is more than 2 km in length • The line is not replacing an existing line (unless higher capacity than the existing line)
Underground Gas Storage	• Working capacity of facilities is at least 43 million standard cubic metres or flow rate of facilities is at least 4.5 million standard cubic metres per day *[Applicable to England Only]*
Liquid Natural Gas Facilities	
Gas (Hydrogen) Transporter Pipeline	• Pipeline must be more than 800 millimetres in diameter and more than 40 km in length • Must convey gas for supply for at least 50,000 customers • Must be wholly or partly located in England

Table 3-1: Summary of key planning thresholds in the Planning Act (2008)

The Energy National Policy Statements *'set out the government's planning policy for NSIPs and are the primary consideration in determining applications for development consent for NSIPs'* (Nardell, et al., 2021, p. 3), and the UK Marine Policy Statement is also considered for offshore projects.

In England, the **Town and Country Planning Act 1990** alongside the National Planning Policy Framework (NPPF) in tandem with Local Plan policies is likely to cover smaller hydrogen projects or pipelines. In Wales, the **Planning (Wales) Act 2015** alongside the Planning Policy Wales (2021) in tandem with Local Development Plan policies is likely to cover smaller hydrogen-related projects.

Where a DCO is not required, developers must gain consent under Section 36 of the **Electricity Act 1989** where the hydrogen project involves constructing, extending or operating a generating station that is:

- Onshore, with a capacity of over 10 MW
- Offshore, with a capacity of over 1 MW and under 100 MW.

There are some limited existing Permitted Development Rights in England related to hydrogen which are covered by the **Town and Country Planning (General Permitted Development) Order 2015.** This primarily relates to laying of gas pipes or maintenance of transmission lines.

3.5.2 Feedback from Local Planning Authorities

City Science engaged with all 26 local authorities in the Western Gateway to establish any local precedence or examples of hydrogen development projects through the current planning system. This was via the Western Gateway's Hydrogen Working Group (local authorities) which is already in operation to support the sharing of hydrogen best practice.

With the exception of a green hydrogen project located at HyBont in Bridgend which is currently progressing through the planning process, limited input has been received to date which may suggest a need to share best practice across the Western Gateway among local authorities to ensure officers are equipped to deal with hydrogen-related applications in future.

4 Emerging Funding Landscape

Chapter in Brief

This chapter reviews the historic and emerging government funding landscape relevant to the Western Gateway for hydrogen-related development opportunities.

4.1 UK Government Funding Overview

As noted in Section 2.1.1, the UK Government has an ambition to produce 10 GW of hydrogen by 2030, of which at least half is to be electrolytic hydrogen. Currently the production market of hydrogen in the UK is up to around 27 TWh per annum of grey hydrogen. Meeting the hydrogen generation target would involve the creation of a new low carbon production market (see Section 3.2.1 on UK Government definition of *'low carbon hydrogen'*).

To support this new market, the UK Government has pledged over £340m in hydrogen demonstrator projects to date with the overarching aim to stimulate up to £9bn of private sector investment by 2030 (DESNZ, 2022). The timeline in Figure 4-1 shows the UK Government funding steams available at the time of publication and in the immediate future to 2024. Note that due to the short-term funding cycles, it is unclear what the funding landscape will look like post 2024.

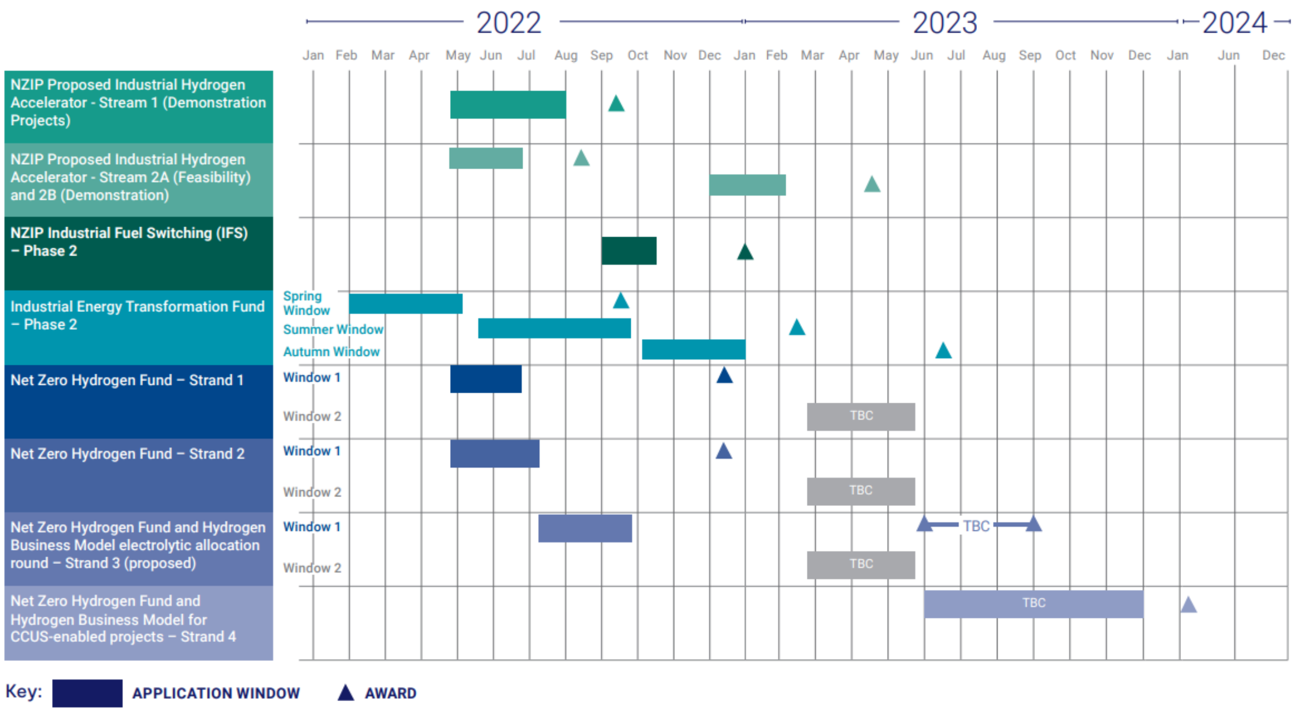


Figure 4-1: Government Investment Roadmap (UK Government, 2022)

4.2 Closed UK Government Hydrogen Funds

The UK Government has already contributed significant investment into hydrogen demonstrator projects via a range of different historic funding sources which were available to apply for in 2021 and 2022. Table 4-1 summarises these funds for which the application date has already passed and there are no further available funding windows or where there are continuity restrictions on who can apply for the next funding round.

Fund Name	Summary	Successful Awards in the Western Gateway
Low Carbon Hydrogen Supply 2 Competition	£60m of competitive funding awarded to projects that developed a wide range of innovative low carbon hydrogen supply solutions.	Successful projects included **ERM Dolphin** focused on producing green hydrogen at scale including at the Dylan site in the Celtic Sea.
Hydrogen Transport Hub Demonstration (Phase 2)	£20m fund which was open to businesses in 2022 to demonstrate how hydrogen can be used to power transport solutions for end users	None
Clean Maritime Demonstrator Competition (Rounds 2 and 3)	£72m fund which was open to applications in 2022 to develop clean innovative maritime technologies including those powered by hydrogen	None
Zero Emission Road Freight Trials	£20 million fund which was used to develop innovative demonstrator solutions to support the transition to zero emission HGVs. This included several hydrogen projects.	None
Net Zero Mobility Programme	£10 million fund which was used for innovative transport technologies including a focus on hydrogen	None
Longer Duration Energy Storage Demonstration (LODES) Competition	£68 million capital funding used to improve the resilience/balancing of the UK energy grid through long duration storage projects to store power in hydrogen.	The **HyDUS project** led by EDF received around £8 million of funding to develop a full cycle, modular and low-cost bulk hydrogen energy storage demonstrator using metal hydrides. University of Bristol was part of the collaboration.

Fund Name	Summary	Successful Awards in the Western Gateway
NZIP Proposed Industrial Hydrogen Accelerator	£26 million fund to demonstrate end-to-end industrial fuel switching to hydrogen to provide evidence on feasibility cost and performance. Steam 1 and Stream 2A has already closed with around £6.3 million already allocated. Stream 2B is open to applications until February 2023, but only to those successful in Stream 2A.	**Costain** were awarded funding to explore innovative hydrogen production from biogas to provide heat for fruit juice pasteurisation in collaboration with Dwr Cymru Welsh Water, WWU and Princes Group One of the other projects awarded funding is looking at the decarbonisation of steel manufacturing **(HYDESS)** in Sheffield which may influence the decarbonisation of Tata Steel at Port Talbot.
NZIP Industrial Fuel Switching	£55m fund to support the development of fuel switching and fuel switch enabling technologies, including hydrogen for UK Industry. Approximately £6m funding for Phase 1 has already been awarded to successful projects. Phase 2 closed in November 2022 with applications under review.	**Bohr Limited** in Cheltenham have been funded for a feasibility project to use sensor technology to monitor gas properties and impurities in green gases, including Hydrogen as part of Phase 1.
Hydrogen BECCS Innovation Programme	£30 million in grant research funding to support innovation in hydrogen bioenergy with CCUS technologies. Phase 1 allocated around £5 million of funding. Phase 2 is open to applications until February 2023 but only open to projects already awarded funding in Phase 1.	The **University of South Wales** was awarded funding of its **BIOHYGAS** in Phase 1 which involves producing hydrogen from sewage biosolids
EPSRC Hydrogen Programme to Establish Hydrogen Research Hubs	£25 million fund which was open to bodies such as those in higher education and research institutes to establish two research hubs, with one focused on research challenges in hydrogen and alternative liquid fuels and the other on systems integration of hydrogen and alternative liquid fuels.	The **University of Bath** has applied for funding to establish a **hub focused on research challenges** which will be based on campus from May 2023 if they are successful.

Fund Name	Summary	Successful Awards in the Western Gateway
UK Research Partnership Innovation Fund	A total of £900 million has been awarded as part of this fund since 2012 which supports higher education facilities to drive research partnerships.	A **green hydrogen manufacturing capability** has been established at the recent IAAPS Bristol and Bath Science Park as a result of £2.5m funding received

Table 4-1: Historic (already awarded and closed to new applications) hydrogen funds available from UK Government

In addition to these funding routes, the UK Government also published an open letter in October 2022 inviting applications from all Gas Distribution Networks to take part in the Hydrogen Heating Town pilot. Applications to participate in this pilot study have since closed in January 2023 with applications received from all Gas Distribution Networks, including WWU. These are currently in the process of being reviewed by the UK Government with a funding decision due to be announced imminently.

4.3 Emerging Open UK Government Hydrogen Fund Opportunities

As noted in Figure 4-1, there are a range of emerging short term funding opportunities from the UK Government that are already open or are due to open for new applications shortly. Table 4-2 summarises the currently known opportunities including where there may be opportunities in the Western Gateway area.

In addition to known opportunities, there could be a further funding opportunity associated with hydrogen transport and storage, reflecting the recent consultation undertaken by the UK Government in August 2022 on business models.

Fund Name	Strategic Aim	Total Funding Pot Available	Funding Type	Fund Eligibility	Current Status (June 2023)	Historic and Potential Future Western Gateway Opportunities
Net Zero Hydrogen Fund (Strand 1 & 2)	To support the development of new low carbon hydrogen production to grow the pipeline of projects in the UK including deployment.	£240 million set over four strands of funding	Grant co-funding for Feasibility, Engineering studies and capital expenditure	Applications are open to UK registered businesses with projects based in the UK	The initial funding round closed in 2022. A second phase of Strand 1 and 2 funding opened in April 2023	• Any organisations (including those in the Western Gateway) successful in the initial round of 2022 are due to be announced shortly. • The UK Government will run a second phase of funding in 2023, there is an opportunity for the Western Gateway to explore partnerships and potential projects for funding applications.
Net Zero Hydrogen Fund and Hydrogen Business Model (Strand 3 & 4)	To support electrolytic hydrogen projects and CCUS-enabled projects in permanent deployment and operation.		Capital grant co-funding and revenue support through the hydrogen business model	No further details available at present	Not yet open for funding applications but Strand 3 currently scheduled to open in March 2023 with Strand 4 due in June 2023	• Applications for this strand have not yet opened. Western Gateway should identify the opportunities in the area for funding and support projects with funding applications. It should be noted that an additional £100m has been allocated by the Government to electrolytic projects through the hydrogen business model.

Fund Name	Strategic Aim	Total Funding Pot Available	Funding Type	Fund Eligibility	Current Status (June 2023)	Historic and Potential Future Western Gateway Opportunities
Industrial Decarbonisation and Hydrogen Revenue Support	To fund new hydrogen production and CCUS business models	£140 million	Revenue support designed to provide investment certainty to industry	Open to private sector organisations involved in hydrogen production or CCUS for projects operational by 2025	£100m has already been allocated with further funding opportunities available through direct negotiations with DESNZ	• This funding can be used by local businesses in the Western Gateway to provide investment certainty for new hydrogen production
Industrial Energy Transformation Fund	To support the development and deployment of technologies that enable businesses to transition to a low carbon future.	£289 million up to 2027 in England, Wales and Northern Ireland. Phase 2 will allocate around £220 million	Capex grant co-funding	Open to businesses where a project or study could not proceed without government support	Phase 1 has allocated around £73 million in 2020 and 2021. Phase 2 is currently open to new applications as part of the Autumn 2022 competitive.	• **Rockwool** in Bridgewater has been given funding for insulation, but no hydrogen application of the funding has been made • **Sofidel** in Neath has also received funding for increased energy efficient equipment • **Celsa Manufacturing** in Cardiff has obtained funding to install an Electric Arc Furnace for the Cardiff Steelworks, the success of this demonstrator project could impact decarbonisation of Tata Steelworks in Port Talbot

Fund Name	Strategic Aim	Total Funding Pot Available	Funding Type	Fund Eligibility	Current Status (June 2023)	Historic and Potential Future Western Gateway Opportunities
Innovate-KTN Local Industrial Decarbonisation Plan	Develop plans to reduce emissions and avoid carbon leakage. Collaboration between closely located industrial businesses, stakeholders, as well as upskilling capabilities ahead of introducing low-emission technologies	£5m fund for the UK	Revenue	Innovate-KTN Local Industrial Decarbonisation Plan	Develop plans to reduce emissions and avoid carbon leakage. Collaboration between closely located industrial businesses, stakeholders, as well as upskilling capabilities ahead of introducing low-emission technologies	• The opportunity is for dispersed industrial manufacturers, not located within the UK's existing industrial clusters, it is therefore an opportunity for any industrial sites outside of the South Wales Industrial Cluster, such as the Etex plant in Portbury, close to Bristol.

Fund Name	Strategic Aim	Total Funding Pot Available	Funding Type	Fund Eligibility	Current Status (June 2023)	Historic and Potential Future Western Gateway Opportunities
Aerospace Technology Institute (ATI) Programme	To support industrial research and investment to improve the competitiveness of the UK aerospace sector. Managed by DESNZ, Innovate UK and the UK ATI	£685 million between 2022 and 2025	Grant	UK registered business for research projects and UK registered business, research organisation or academic institute for capital infrastructure projects	2022 winners were announced in February 2023. The 2023 funding round is currently open to applications in February 2023	• **HyFlyer II** has been awarded £12.3 million to date from this fund between 2020 and 2023. To date this has included successfully flying a protype hydrogen-electric powertrain 19 seat aircraft from **ZeroAvia** research and development facility at Cotswold Airport in Gloucestershire • A series of projects led by **Rolls Royce** were awarded £83m funding in February 2023 including the **HYEST**, **RACHEL** and **LH2GT** projects • **GKN Aerospace** are leading the £54m **H2GEAR** programme to develop the company's first fuel cell hydrogen propulsion system for sub-regional aircraft.

Table 4-2: Current and upcoming UK Government hydrogen project funding opportunities

4.4 Low Carbon Hydrogen Business Model

The UK Government has recently developed a new business model for low carbon hydrogen production (Section 3.2.1). The business model operates like a *'contract for difference'* to provide revenue top up funding and incentivise producers of hydrogen to address the operational cost differential between low and high carbon emitting hydrogen production methods. Funding for this is administered through the Industrial Decarbonisation and Hydrogen Revenue Support scheme (Table 4-2). No contracts have been issued to date for hydrogen production in the UK.

4.5 UK Infrastructure Bank

The UK Infrastructure Bank is a government-owned policy bank with the opportunity to provide up to £22bn of infrastructure finance to the private sector and local government, backed by HM Treasury.

Eligibility for investment is based on the Bank's four key principles which are:

- **Investment Principle 1:** The investment support's the Bank's objectives to drive growth or support tackling climate change
- **Investment Principle 2:** The investment is in infrastructure assets or networks or new infrastructure technology, with a priority given to clean energy alongside transport, digital, water and waste
- **Investment Principle 3:** Must deliver a positive financial return
- **Investment Principle 4:** Investment is anticipated to crowd in substantial private capital over the long term

The UK Infrastructure Bank is already working with Bristol City Council to unlock finance through the City Leap model to deliver £1bn of net zero infrastructure to 2040, including their strategic heat networks.

4.6 British Business Bank

The British Business Bank is owned by the UK Government which is focused on supporting smaller businesses gain access to finance. Key objectives of the British Business Bank include supporting the UK's transition to a net zero economy and increasing the supply of finance to smaller businesses where markets may not operate well; both of which are pertinent to hydrogen development. Key current funds available through the British Business Bank include:

- **Future Fund:** a scheme supporting UK-based companies from £125,000 to £5 million on the assumption of an equal match from private investors
- **Future Fund: Breakthrough –** a £375m fund focused on encouraging private investors to co-invest with the UK Government in innovative firms focused on achieving high growth
- **Angel CoFund:** Equity investment fund ranging between £100,000 to £1 million targeted at smaller businesses

4.7 Private Sector Funding

The government has issued an investor roadmap that sets out the funding activities and milestones to 2035 including the pipeline of projects it has funded to date. It is expected that the ambitions of the government and its commitment to 10 GW of hydrogen in 2030 will unlock c.£9bn of private sector investment.

5 Hydrogen Scenario Development

Chapter in Brief

This chapter introduces the future hydrogen scenarios that have been used in this delivery pathway to inform possible supply and demand projections.

5.1 Approach to Developing Scenarios

A set of hydrogen scenarios have been developed to represent the possible hydrogen demand and supply ranges for the Western Gateway for 2030, 2035, 2040 and 2050. The initial identification of scenarios commenced with a detailed literature review of existing research and policy ambitions (Chapter 2), alongside scenarios applied by others at a national and regional level. The scenarios were then refined through stakeholder engagement, including with local hydrogen industry and academia.

5.1.1 Literature & Existing Scenario Review

The review of existing hydrogen scenarios included major national publications such as from the Climate Change Committee (CCC) and from the National Grid. Regional publications relevant to the Western Gateway were also reviewed to gain a more localised view of decarbonisation pathways for the area, as well as the key policies related to hydrogen covered in Chapter 2. The publications reviewed included:

- 6th Carbon Budget (CCC, 2020)
- CCC Hydrogen in a Low Carbon Economy (CCC, 2018)
- Future Energy Scenarios (FES) (National Grid, 2022)
- Distributed Future Energy Scenarios (DFES) (National Grid, 2022) *Note: originally produced by WPD*
- Scottish and Southern Energy Networks, Distributed Future Energy Scenarios (Regen, 2019)
- Net Zero South Wales (Regen, 2020)
- Western Gateway Energy Networks Net Zero (Supergen Network study led by the University of Bristol, 2022)
- Western Gateway Energy Networks Net Zero Supergen Network Study (University of Bristol, 2022)
- Zero2050 South Wales (Zero2050, 2021)

5.1.2 Stakeholder Engagement Refinement

In a stakeholder workshop in November 2022, it was agreed that three scenarios would be developed. It was also agreed that the CCC 6th Carbon Budget (6CB) scenarios would be heavily leaned upon in the development of the scenarios. The CCC 6CB is a trusted, authoritative publication which has good sectoral breakdown of assumptions and therefore provided a good basis for the assumptions.

5.2 Future Hydrogen Scenarios

All scenarios are consistent with achieving net zero carbon emissions by 2050, but hydrogen plays a dramatically different role across each. The scenarios effectively form a low, medium and high set of supplies and demands for hydrogen and have been named Necessities Only, Balanced Hydrogen and Widespread Hydrogen respectively. A counterfactual scenario where net zero was not achieved was

Necessities Only (low hydrogen)	Balanced Hydrogen (balanced electrification/hydrogen)	Widespread Hydrogen (high hydrogen)

considered, but was disregarded as our work aims to demonstrate the hydrogen quantities that might be required in order to reach net zero.

Necessities Only represents a scenario where hydrogen is only used where it is seen as absolutely necessary (i.e. there are no, or limited alternatives), this scenario is therefore optimistic on the developments of hydrogen alternatives, namely electrification.

Balanced Hydrogen is a middle ground that has hydrogen use where it is seen as necessary, but also some usage where alternatives such as electrification may dominate.

Widespread Hydrogen represents a future where hydrogen is used widely across the Western Gateway economy, for multiple purposes, including heating and for transport.

The overarching assumptions behind these scenarios have been provided in full in Appendix B - Scenario Assumptions. All scenarios used a set of consistent baseline energy demand projections that account for growth and energy efficiency improvements where relevant. For example, growth of domestic space heating demand has been modelled in line with population growth, but energy reduction due to retrofitting the homes has also been accounted for Appendix B - Scenario Assumptions.

5.3 Key Scenario Assumptions

The section below details the key assumptions related to network considerations across the scenarios. Specific assumptions on demand and supply are included in Chapters 6 and 7 respectively.

5.3.1 Gas Grid Development

How the gas grid will develop to accommodate hydrogen is critical to the expansion of the hydrogen economy and our assumptions on its development underpin each scenario.

Existing hydrogen production and use is currently small scale, the production and consumption sites are therefore typically co-located, requiring transport of hydrogen over small private pipelines, or via road tankers in compressed gaseous or liquefied form.

In the 2020s, there will be critical policy decisions that will influence how hydrogen networks develop and are operated. As noted in Section 3.4, the Gas Safety (Management) Regulations 1996 limits the concentration of hydrogen in public gas grid pipelines to $0.1\%_{vol}$. A decision on blending the existing network to $20\%_{vol}$ is expected in 2023, and a strategic decision on hydrogen's role in heating is expected in 2026 (see section 2.3). In anticipation of these decisions, the development of a national hydrogen transmission network (referred to as the 'backbone') is currently being explored by National Grid via Project Union, which has plans for a transmission line to run from Milford Haven stretching east across to England (National Grid, 2021).

It is envisaged that hydrogen distribution networks could grow incrementally around industrial clusters as the high demands of industry create an anchor load which guarantees a large, consistent demand from which to use as a springboard for further development. The SWIC is therefore a prime location for early development of dedicated hydrogen networks. Wales and West Utilities (WWU) is exploring the feasibility of a dedicated hydrogen transmission line (named HyLine Cymru) running from Milford Haven (which is a candidate site for large scale green and blue hydrogen production) across the coast of South Wales to feed the demands of heavy industry. The HyLine has the potential to connect to Project Union currently being explored by National Grid.

Existing metallic gas networks cannot simply be converted to dedicated hydrogen networks as hydrogen can cause embrittlement of steel. The Iron Mains Risk Reduction Programme which started in 2002 has made good progress in converting existing steel mains to plastic polyethylene which can accommodate 100% hydrogen. This programme is expected to be complete by the early 2030s, however, it will not undertake replacement of 100% of the existing network, therefore, more repurposing work after this programme may be required.

The Iron Mains Risk Reduction Programme decommissions gas distribution iron mains and replaces them with new plastic ones, which are potentially well-suited for transporting hydrogen within the existing gas grid over the long term. This project was introduced in 2002 and is expected to be complete by the early 2030s. The programme replaces existing mains on a risk assessed basis (i.e. replaces those highest risk of failure). It does not replace all existing mains, therefore, repurposing distribution networks for 100% hydrogen will likely require further replacement beyond this programme.

5.3.2 Blending to 20%-vol

Blending hydrogen into the existing gas grid is seen as a way to kickstart the hydrogen economy by creating an early demand, thereby attracting investment in hydrogen infrastructure. Engagement with both WWU and Southern Gas Networks (SGN) confirmed that if $20\%_{vol}$ blend is approved, this is likely to happen throughout the distribution grids. The Balanced and Widespread scenarios have therefore modelled a $20\%_{vol}$ blend across the gas network, which serves heating and industrial demands, which is fully achieved by 2030. The 20% blend has not been modelled in the Necessities Only scenario as this is not seen as a necessary use of hydrogen.

Due to the lower energy density of hydrogen when compared to natural gas, 20% blend by volume is approximately 7% by energy. However, 7% of the gas grid energy demands of the Western Gateway area is still a substantial requirement for hydrogen. In 2019, the total gas grid demand of the Western Gateway was circa 35,000 GWh, a $20\%_{vol}$ blend therefore equates to approximately 2,500 GWh of hydrogen energy.

5.3.2.1 100% hydrogen transmission networks

The UK's National Transmission System (NTS) is a large-scale infrastructure that delivers natural gas from production sites to distribution networks and end-users across the country. It consists of a system of high-pressure pipelines that transport gas from offshore production platforms and onshore processing plants to regional distribution centres. The transmission network feeds Local Distribution Zones (LDZ) which are discussed in the next section.

As one of the UK's industrial clusters, South Wales is likely to see early development of dedicated hydrogen transmission pipelines. There are two natural gas transmission lines running through South Wales (NTS Feeder 28 and NTS Feeder 2). Feeder 28 does not supply any LDZs in South Wales, instead it transports large volumes of natural gas from the Liquified Natural Gas (LNG) terminal at Milford Haven to the core of the NTS in England. Project Union by National Grid is exploring a dedicated hydrogen transmission line which follows a similar route from Milford Haven to the centre of England.

NTS Feeder 2 supplies the LDZs throughout South Wales, it runs from England supplying gas to Newport, Cardiff and Swansea. In all scenarios it is assumed that a dedicated hydrogen transmission line is built starting at Milford Haven running to Port Talbot (as a first stage), this line then extends further across South Wales (see Figure 5-1). This mirrors the HyLine feasibility project that WWU is currently exploring. A hydrogen transmission line is seen as a necessary step to supply the large hydrogen demands of industry throughout South Wales with either green or blue hydrogen production at Milford Haven and/or Port Talbot. The NTS Feeder 2 is assumed to remain as a natural gas transmission line as this could feed blue hydrogen production at Port Talbot.

Under the Widespread Hydrogen scenario, a further hydrogen transmission line is envisaged to run from the Wessex basin where there are salt caverns which can act as a large store of hydrogen (see Figure 5-1 below). In periods of excess hydrogen production, the gas flow into the salt caverns from multiple directions: from the north by hydrogen generated in the south of Wales, from the south west of England, or from the east (engagement with SGN revealed that there could be a flow of hydrogen generated in the Southampton industrial cluster). Hydrogen could then flow out of the salt caverns back into the gas grid when there is demand.

5.3.2.2 100% hydrogen distribution networks

The distribution network is the final stage in the delivery of natural gas to homes and businesses across the country. It consists of a system of lower pressure pipelines that transport gas to individual properties.

In the Necessities Only scenario where no hydrogen is used for heating, no conversion of LDZs is assumed, whereas under the Widespread Hydrogen scenario, a full repurposing of all LDZs in the Western Gateway is assumed as hydrogen supplies 100% of heating demands. The Balanced Hydrogen scenario recognises industrial production of hydrogen (such as blue hydrogen production at Port Talbot) may encourage the conversion of a nearby LDZs to fully convert and tap into the large-scale hydrogen resource. The Balanced Hydrogen scenario has therefore assumed that the Dyffryn Clydach LDZ converts to 100% hydrogen given its proximity to Port Talbot. The gas demand of Dyffryn Clydach LDZ has been approximated to be that of the Swansea and Neath Port Talbot local authorities which equates to approximately 10% of the Western Gateway's gas grid demand.

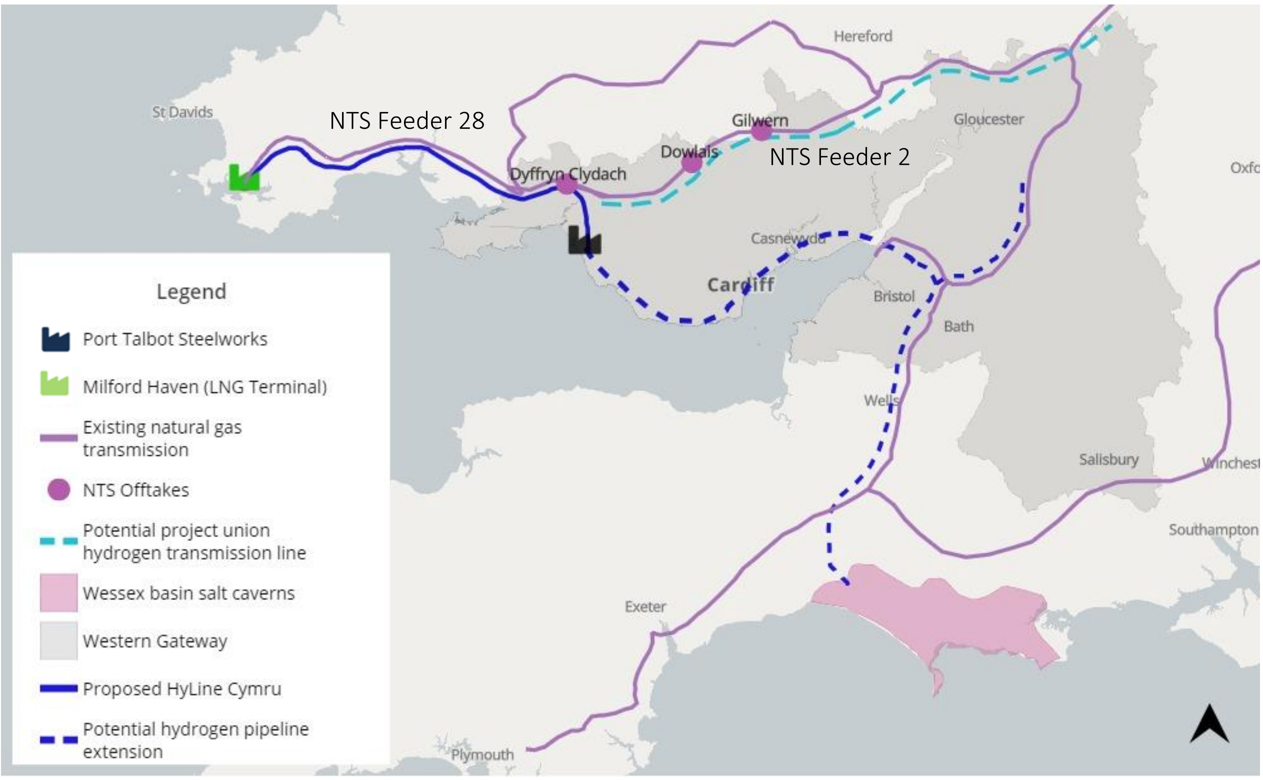


Figure 5-1: Potential future hydrogen transmission lines

6 Hydrogen Demand Scenarios

Chapter in Brief

This chapter sets out the demand scenarios and modelling outputs for hydrogen in the Western Gateway across the full range of use cases. This considers milestone years of 2030, 2035, 2040 and 2050. The year 2019 is provided as a base year of energy consumption as this is the latest year of data available that has not been affected by COVID-19. A compiled table of assumptions used in the demand modelling has been provided in Appendix B. The chapter starts with a summary of the results on a system wide basis, then each sector is addressed individually in the subsequent sections.

6.1 2050 System Demands

The below table provides a summary of the 2050 hydrogen demands determined under each scenario (the demands for all other milestone years are provided in Appendix B). The base year (2019) demands for the gas grid, other fuels (coal, biomass, petrol, diesel etc) and hydrogen use as a chemical feedstock have been given for all end-uses to give the reader an indication of the scale of demand that hydrogen could fulfil.

Heating (domestic and non-domestic buildings), road transport and industry are the largest demand sectors. A high hydrogen demand for industry is seen across all scenarios due to the modelling of the Port Talbot steelworks switching to a 100% hydrogen process in 2035 across scenarios (this is discussed in later sections).

Hydrogen end-uses	2019 Base Year Demands (GWH_{GCV})				2050 Hydrogen Demands (GWH_{GCV})		
	Gas Grid	Other fuels	Chemical feedstock	Base year (2019) total demands	Necessities Only	Balanced Hydrogen	Widespread Hydrogen
Heating	28,800	3,070		31,800	0	2,940	29,400
Road transport		35,700		35,700	0	4,890	14,600
Industrial	14,000	17,900		31,900	25,700	25,700	31,900
Aviation		2,520		2,520	1,180	1,700	2,250
Marine		1,400		1,400	1,400	1,410	1,410
Agriculture (fuel)	84	1,030		1,120	259	526	860
Agriculture (fertiliser)			736	736	Excluded as fertiliser made outside of WG area		
Construction plant equipment (off-road mobile machinery)		1,130		1,130	0	647	1,040
Rail		648		648	0	148	222
			Totals	**107,000**	**28,500**	**37,900**	**81,600**

Table 6-1: 2050 system demands

6.2 Hydrogen Demand Timelines

The following figures show the evolution of hydrogen demand from 2030 to 2050. The potential demands of the Port Talbot Steelworks dominate the total hydrogen demands under some the

Necessities Only and Balanced Hydrogen Scenarios. We have therefore excluded it from the hydrogen demand charts below to provide more insight into the distribution of demands across other sectors. The potential demand of the Port Talbot Steelworks is shown separately in Figure 6-4.

In the Balanced and the Widespread scenarios there is a significant demand in 2030 (circa 2,000 GWh) due to 20%$_{vol}$ blending of the gas grid which serves heating, industrial and agricultural gas demands. The heating demand is zero in the Necessities Only scenario as no blending is modelled and heating is fully electrified (by heat pumps and direct electric). Under the Balanced scenario the heating demand dips in 2035 and 2040 as heating starts to be electrified, however, it increases slightly by 2050 as we have modelled the local distribution network around Port Talbot fully switching to 100% hydrogen.

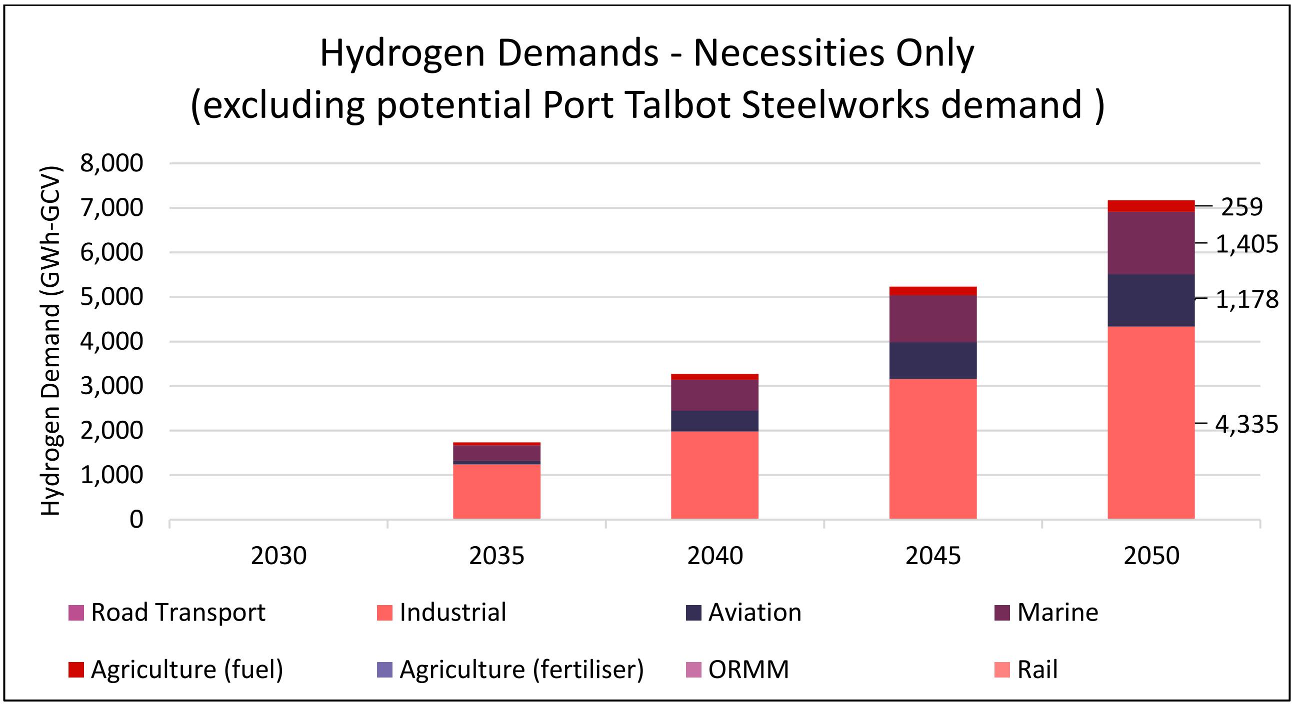


Figure 6-1: Hydrogen demands under necessities only scenario, excluding potential Port Talbot Steelworks demand.

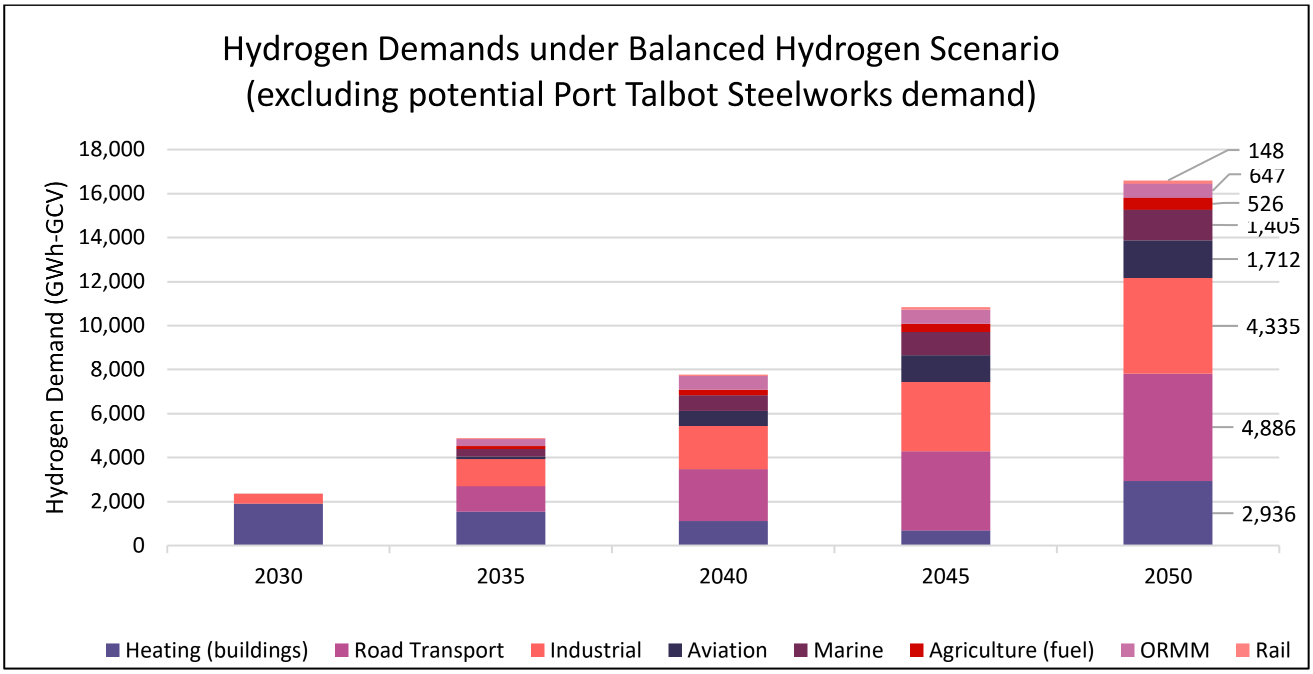


Figure 6-2: Hydrogen demands under balanced hydrogen scenario, excluding potential Port Talbot Steelworks demand.

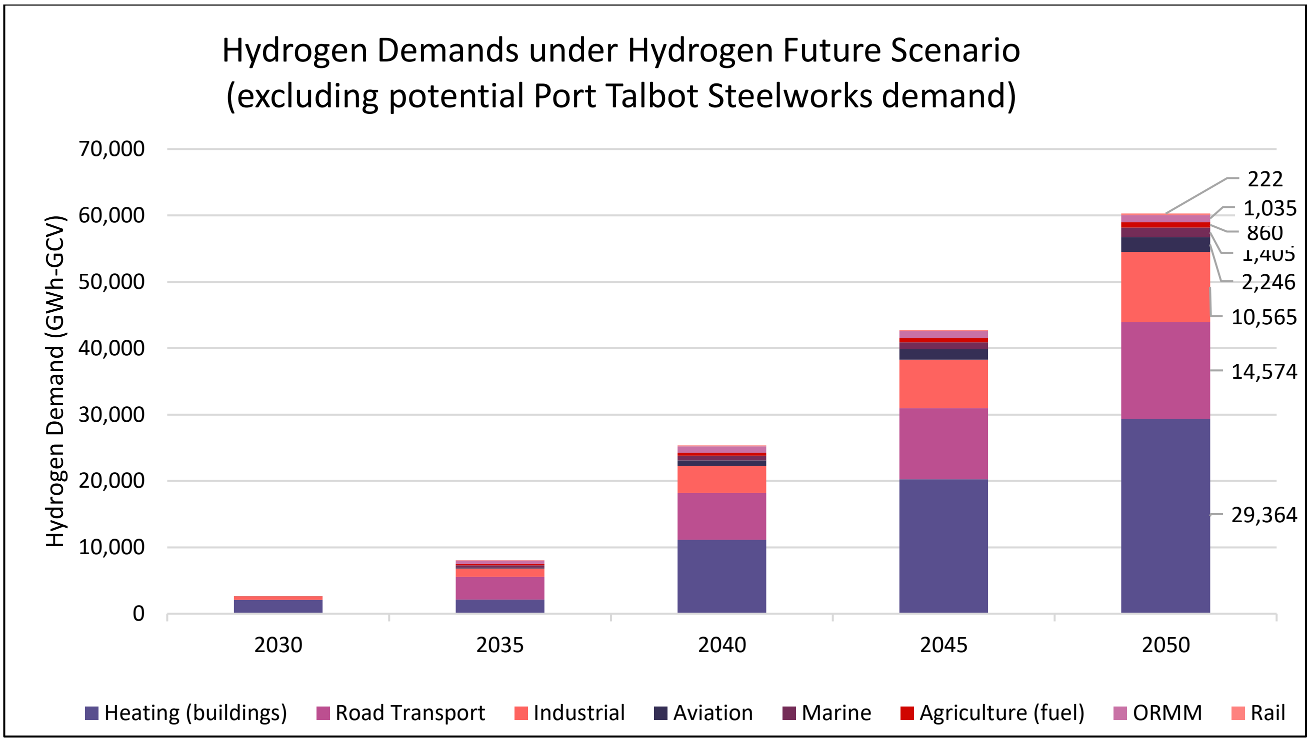


Figure 6-3: Hydrogen demands under hydrogen future scenario, excluding potential Port Talbot Steelworks demand.

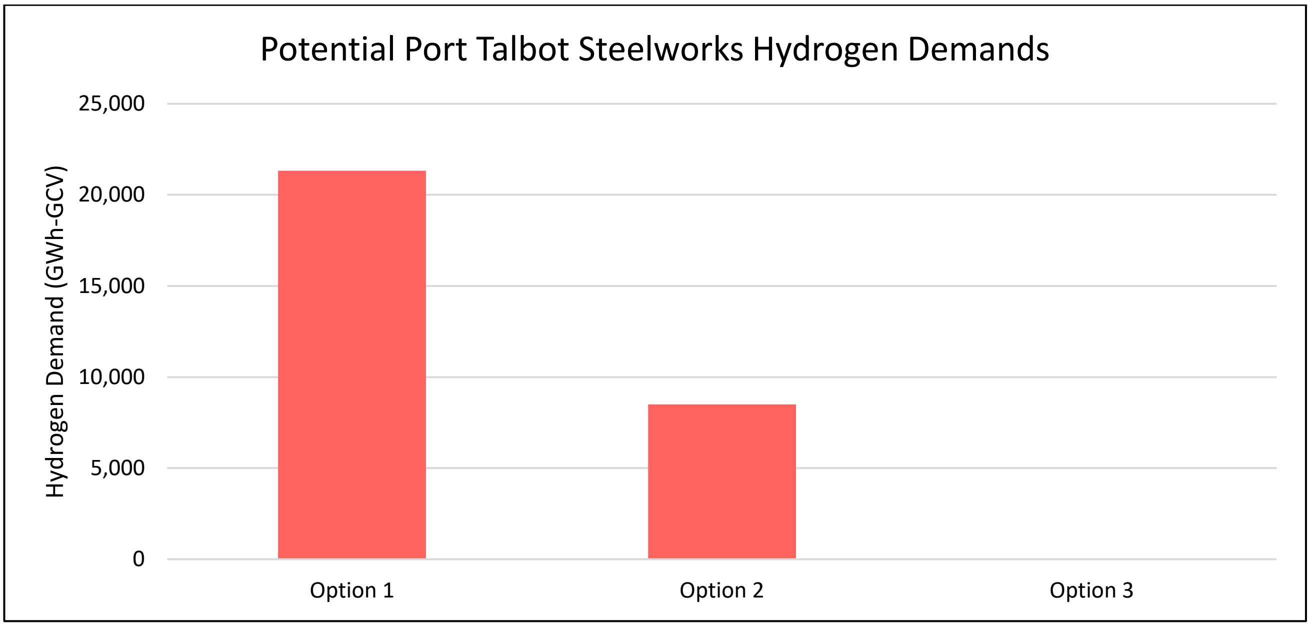


Figure 6-4: Port Talbot Steelworks under decarbonisation scenarios coming online 2035.

The future of Port Talbot Steelworks is highly uncertain, there are several possibilities for its future. The potential hydrogen demands under three possible futures are detailed in Figure 6-4 above and explained below:

- Option 1: Virgin steel production is maintained, but the production route switches to hydrogen DRI-EAF. We assume that the energy intensity per tonne of crude steel is as per existing (24 GJ/tcs), and that hydrogen meets 100% of primary energy demands (including heat and electricity requirements beyond the DRI step).
- Option 2: Virgin steel production capability is lost and production route switches to the EAF route using recycled steel only. Assumed primary energy demand is 40% of the existing energy demand. Hydrogen supplies 100% of primary energy demand.
- Option 3: Existing fossil fuel-based processes remain, and carbon capture is applied throughout the plant to mitigate emissions. No additional hydrogen supplied.

In Figure 6-5 below, the 2050 demands of the three scenarios have been shown side by side, for the whole of the Western Gateway, including the potential Port Talbot steelworks demand under Option 1.

The Widespread Hydrogen demand (81,600 GWh) is over double that of the Necessities Only scenario (28,510 GWh). Both the Necessities Only and Balanced Hydrogen scenarios are dominated by industrial hydrogen demand (25,700 GWh), which itself is dominated by Port Talbot's demand (21,300 GWh).

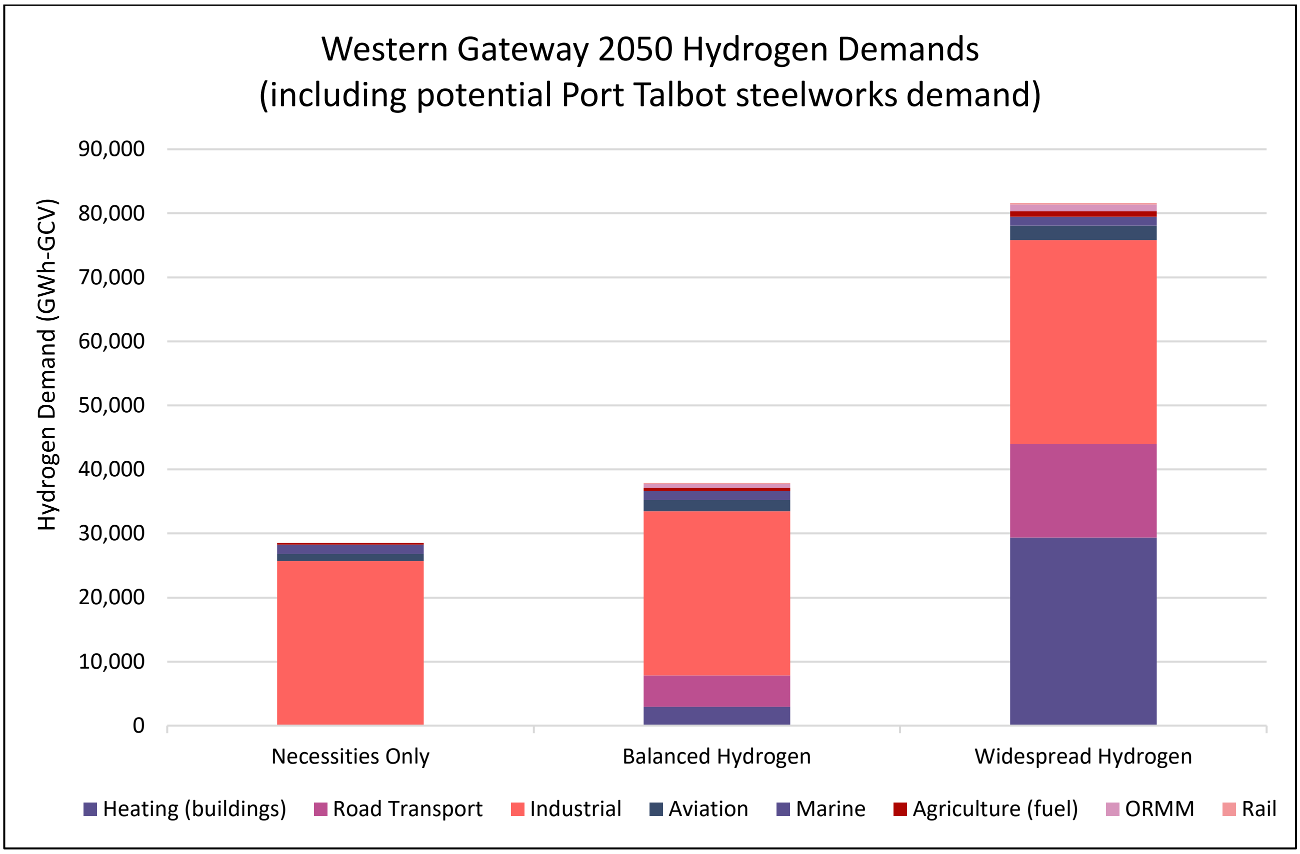
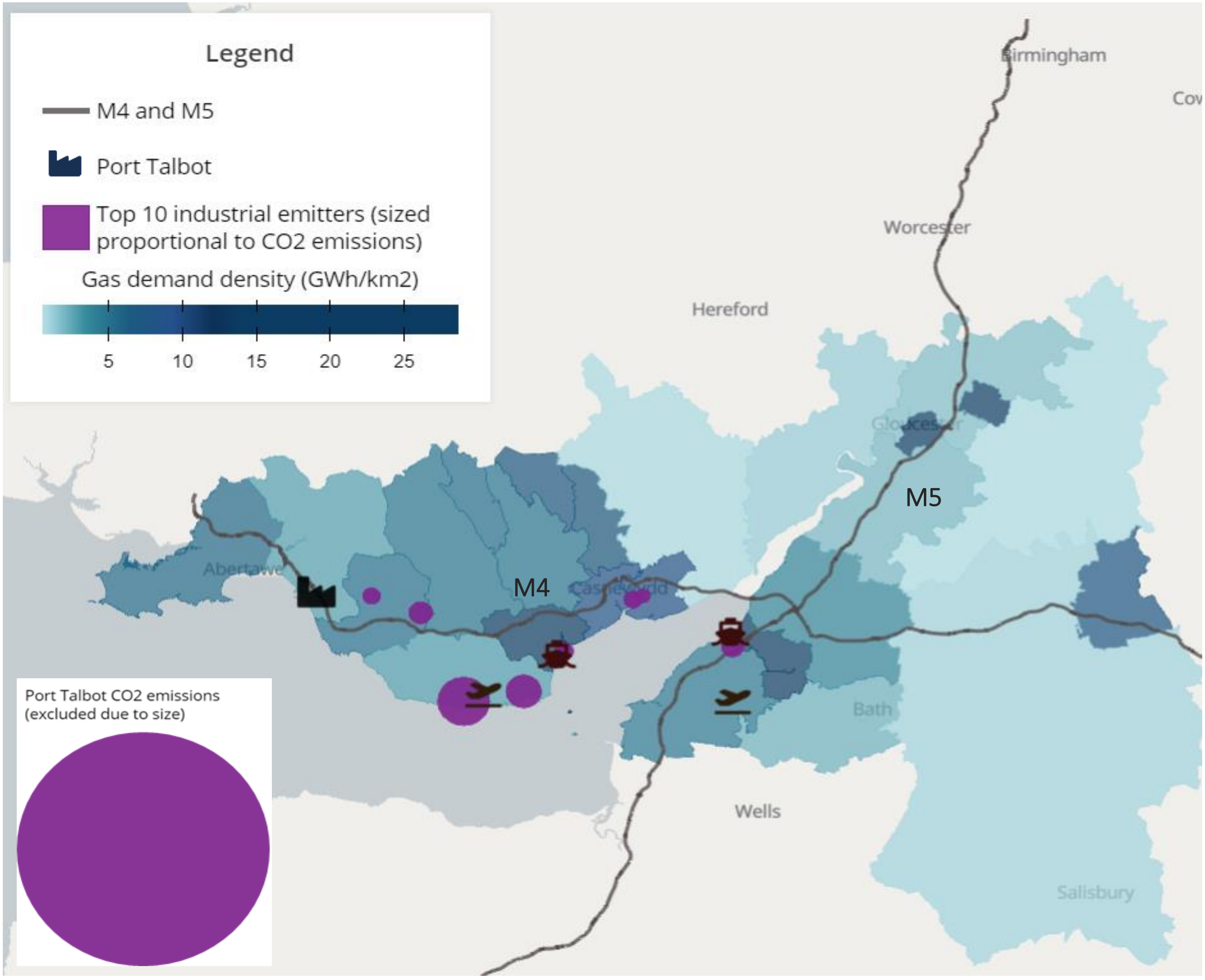


Figure 6-5: Western Gateway 2050 hydrogen demands by scenario, including potential Port Talbot steelworks demand.

6.3 Demands Heat Mapping

Below, in Figure 6-6 we have produced a map to indicate the potential spatial distribution of future hydrogen demand. The top ten industrial emitters in the Western Gateway are plotted in purple. The size of their energy demand is proportional to the size of purple dots. These industrial sites are all located in South Wales, with the exception of the Etex plant in Portbury, Somerset. The Port Talbot steelworks, located on the Welsh side, is responsible for the largest industrial energy demand in the area. It has been excluded from the main section of the map because its size dramatically exceeds that of all the other industrial sites. We expect initial hydrogen development and HyLine investigations to occur on the Welsh side of the Western Gateway to meet the industrial energy demands.



Western Gateway Top 10 Emitters	2020 NAEI Emissions (kt CO2)	Western Gateway Top 10 Emitters	2020 NAEI Emissions (kt CO2)
Tata Steel, Port Talbot steelworks	6,238	CELSA Manufacturing, Tremofa 2	48
Aberthaw Cement Works	366	Solutia UK, Newport	44
Dow Silicones, Barry	169	CELSA Manufacturing, Tremofa Sections Mill	42
Rockwool, Bridgend	76	WEPA UK, Bridgend Paper Mill	42
ETEX Portbury	66	Tata Steel, Llanwern Steelworks	30

Figure 6-6: Potential hydrogen demands heat map

The map also displays the total 2019 gas demand density (GWh/km²) of each Local Authority, with the demand of large industrial sites excluded. This gives an indication of the spatial distribution of the hydrogen demands should the gas grid fully convert to 100% hydrogen (as per the Widespread Hydrogen scenario).

Airports and seaports are included as they are also likely to be future centres of hydrogen demand. Hydrogen is also likely to see an uptake in freight vehicles, so the major motorway routes in the area have been shown.

6.4 Demands by Sector

6.4.1 Heating: Domestic, Commercial & Public Sector

6.4.1.1 Sector background

Almost half of the final energy consumed in the UK is to provide heat, equivalent to the combined consumption of both electricity and transport. The decarbonisation of heat is arguably one of the biggest challenges facing UK energy policy over the next decade. Heat is used for space heating in buildings, domestic hot water production and for industrial processes. The heat demand covered in this section is that of the space heating and domestic hot water demands for domestic and commercial buildings; industrial heat demands are covered separately in Section 6.4.2.

There are two key pathways for decarbonising heat in domestic and commercial buildings: using electricity to power heat pumps, which move heat from the air or ground into the building, or to supply hydrogen through our existing gas network for combustion in boilers, much like our current way of heating via natural gas boilers.

As heat pumps make use of heat from the surrounding environment, they have a significant efficiency benefit over the use of boilers, greatly reducing the energy system demand. However, the retrofitting of heat pumps to the existing building stock will be expensive, and they might not be suitable for all buildings. Also, the increase in electricity demand will require a substantial and costly reinforcement of the electrical grid.

Advocates of hydrogen for heating point out the relative low cost and low disruption of retrofitting an existing building with a hydrogen boiler, compared to the retrofit of heat pumps. However, hydrogen is currently a more expensive fuel than natural gas and substantial research is being conducted on its safety in comparison to the use of natural gas, notably hydrogen leakage, its flammability characteristics and NO_x generation (Hy4Heat, 2021) (Wright & Lewis, 2022). The Hydrogen Champion's Report supports the use of hydrogen for heating strategically, around hard-to-insulate properties and areas with electricity network constraints and encourages it to be considered as part of the wider heat pump solution.

The UK Government has not yet provided clear direction on the future of heating, both options are still being explored and supported via R&D programmes, notably Heat Pump Ready and Hy4Heat. It is possible that a combination of both electrification and hydrogen may be used for heating demands in the future. Hydrogen could be favoured by households that have limited space for heat pump installations (which require an outdoor unit and enlargement of radiators), or by poorly insulated households which are less suited to the lower temperatures delivered by heat pumps.

Recommendations from the Hydrogen Champion Report include further clarity on the nature of the 2026 decision and how hydrogen would be enabled, funded and implemented to enable the required planning process. Business planning for the RIIO 3 process for gas transmission and distribution (2026-2030) will occur early in 2024 and decisions will be made by Ofgem in 2025.

6.4.1.2 Current demands in the area

To determine the gas heating demand that could be supplanted by hydrogen in the Western Gateway, DESNZ's subnational statistics of gas-grid consumption have been used which provide consumption broken down by local authority area. The data are broken down by domestic and non-domestic consumers. To further disaggregate non-domestic consumption, DESNZ's subnational CO_2 emissions data were used to proportion out the gas demand by commercial, public sector, agricultural and industrial buildings. The 2019 gas grid consumption of domestic, commercial and public sector buildings has been provided in Table 6-2.

	Domestic	Commercial	Public Sector	Total
2019 Gas-grid Consumption (GWh_{GCV})	22,900	3,140	2,720	**28,800**
2019 CO_2e Emissions (kt CO_2e)	4,200	575	499	**5,270**

Table 6-2: Heating base year (2019) gas consumption

6.4.1.3 Forecasted hydrogen demands

Under the Necessities Only scenario, electrification (either via heat pumps or direct electric heating) completely replaces the gas grid demand for heating, no hydrogen usage is forecasted. Whereas under the Widespread Hydrogen scenario, there is no uptake of electrification for on-gas buildings and hydrogen completely replaces natural gas.

Under the Balanced Hydrogen scenario, in recognition of possible blue hydrogen production at Port Talbot, the nearby Dyffryn Clydach Local Distribution Zone (LDZ) covering Swansea and Neath Port Talbot has, been assumed to be repurposed to 100% hydrogen. All other gas grid demand for heat has been modelled to be electrified.

The forecasted hydrogen demands under all three scenarios have been provided in Table 6-3 below. In the Balanced and Widespread scenarios, there is hydrogen demand in 2030 due to blending the gas grid to $20\%_{vol}$ hydrogen. Hydrogen demand starts 1,900 GWh_{GCV} in 2030 for the Balanced scenario, this demand decreases over time as heating demands electrify. Under the Balanced scenario, most heat demands electrify over time, reducing dependence on the gas grid, hence the drop in hydrogen demand up to 2040. The switch of the Dyffryn Clydach LDZ to 100% hydrogen is modelled to occur in the 2040s, hence there is an increase in hydrogen demand in 2050.

Scenario	2030	2035	2040	2050
Necessities Only (low) (GWh_{GCV})	0	0	0	0
Balanced Hydrogen (medium) (GWh_{GCV})	1,900	1,540	1,110	2,940
Widespread Hydrogen (high) (GWh_{GCV})	2,110	2,120	11,200	29,400

Table 6-3: Heating hydrogen demands under scenarios

The GHG savings under each scenario can be found in Section 12.1.

6.4.2 Industrial Sector

6.4.2.1 Sector background

Industrial greenhouse gas (GHG) emissions are attributed to manufacturing, and the production of steel, iron and cement amongst other materials. They account for around 12% of the UKs GHG emissions (2018), of which 86% of emissions are from fuel combustion for high- and low-grade heat processes (CCC, 2020). Despite emissions being 56% below 1990 levels it is one the hardest to decarbonise sectors due to the high temperature requirements for key processes, coal usage, and the impact of energy costs on profitability.

Hydrogen is already used in some industrial processes, such as within the chemical industry, where it is used as a feedstock to produce ammonia as an input to the Haber-Bosch process, methanol, and within the petrochemical sectors for hydrogenation processes.

There is significant additional potential for hydrogen within other industrial processes. For example, hydrogen can replace coke (produced from coal) as the reductant for iron when producing steel. Hydrogen may also be preferable means of producing high temperature heat over electrification as the latter will require new grid connections and the supply chain for some high temperature electric technologies is not well established. CCUS is often seen as necessary step to decarbonise heavy industry, either on the post-combustion of fossils fuels, or pre-combustion via the production of blue hydrogen.

6.4.2.2 Current activity in the area

South Wales is one the UK's six[3] industrial clusters therefore it is a key development area for hydrogen and carbon capture. The Port Talbot steelworks is by far the largest industrial consumer in the cluster. Most of its energy demands are met with coal and with some top up of natural gas.

In Figure 6-6, the top ten industrial emitters in the Western Gateway from the National Atmospheric Emissions Inventory (NAEI) have been mapped. Port Talbot is the largest at 7,040 ktCO_2e, the second largest site is Aberthaw Cement Works (366 ktCO_2e). Nine out of ten of the top industrial emitters lie within South Wales. The Etex Building Performance manufacturing site near to Bristol Port is the only top 10 emitter on the English side of the Bristol Channel. Table 6-4 summarises the industrial emissions and fuel consumption in the Western Gateway.

	Port Talbot[1]	Aberthaw Cement Works[2]	Other large point-source emitters from NAEI[3]	Other industrial sites[4]	**Total**
2019 Fuel Consumption (GWh_{GCV})	21,300	799	5,050	4,710	**31,900**
2019 CO_2e Emissions (kt CO_2e)	7,040	366	925	863	**9,190**

Notes:

[1]Energy consumption determined from a crude steel production of 3.2 Mt/year and 24 GJ/tcs as per Tata Steel's annual sustainability report FY2018/19.

[2]Determined from NAEI point-source emission data assuming that 60% of emissions are process emissions arising from the calcination, the remainder of emissions assumed to be from natural gas.

[3]The energy consumption of large point-source emitters was determined from NAEI emissions data by assuming an emissions intensity of natural gas.

[4]Determined from DESNZ Subnational emissions data for industry.

Table 6-4: Fuel consumption and CO_2e emissions at key industrial sites in the Western Gateway

[3] South Wales, Southampton, Black Country, Merseyside, Humberside and Teesside.

6.4.2.3 Forecasted hydrogen demands

It has been assumed that the industrial demand of Western Gateway remains flat out to 2050 as growth of this sector is uncertain. Hydrogen demand is modelled in 2030 under the Balanced and Widespread scenarios due to 20%$_{vol}$ blending of the gas grid. The Necessities Only and Balanced Hydrogen scenarios have assumed that 70% of the fuel demands of large industrial sites are met by hydrogen in 2050, whereas the Widespread Hydrogen scenario has 100% of the fuel demands switching to hydrogen by 2050.

Scenario	2030	2035	2040	2050
Necessities Only (low) (GWh_{GCV})	0	22,600	23,300	25,700
Balanced Hydrogen (medium) (GWh_{GCV})	442	22,600	23,300	25,700
Widespread Hydrogen (high) (GWh_{GCV})	442	22,600	25,400	31,900

Table 6-5: Forecast industrial hydrogen demand in the Western Gateway

A large jump in hydrogen demand is seen in 2035 due to the modelled conversion Port Talbot switching to a fully hydrogen powered process which alone accounts for 21,300 GWh (equating to 94% of 2035 hydrogen demand in all scenarios).

It has been modelled that the Port Talbot steelworks switches to a hydrogen DRI-EAF process which maintains its existing capability to produce virgin steel. We have assumed that its primary energy consumption remains the same as existing (24 GJ/tonne crude steel), and that all this energy is fulfilled with hydrogen (this includes the hydrogen required as the reductant in the DRI process as well as the heat and electricity requirements of other processes on site). Further work is needed to accurately determine what the hydrogen demand would be under the DRI-EAF process, as there would be some efficiency improvements in upgrading to best available technology, and the hydrogen usage could be limited to the DRI step alone. The DRI step requires circa 72 kg of H_2 per one tonne of steel (SWIC, 2023), which equates to approximately 9,000 GWh at an annual output of 3.2 million tonnes.

The future of the steelworks is uncertain, there are alternative routes to its decarbonisation which will require less, or no hydrogen. These routes have been detailed in the box below.

Port Talbot Steelworks

The future of Port Talbot steelworks is uncertain, and the British steel industry is facing challenges with financial support from the UK Government expected. The site currently uses a Blast Furnace – Basic Oxygen Furnace (BF-BOF) method which requires coal in the blast furnace to remove the oxygen from iron ore. There is pressure on Port Talbot to decarbonise, however, the route by which this is achieved is not known. We have outlined three potential routes below:

- **Option 1: Convert to hydrogen based Direct Reduction Iron coupled with an Electric Arc Furnace (DRI-EAF) process**. This continues the manufacture of iron for virgin steel production. Primary energy consumption of DRI-EAF method is similar to that of a BF-BOF but Port Talbot may see some efficiency improvement in upgrading to best available technology if it makes the switch DRI-EAF.

- **Option 2: Convert to a 100% scrap steel plant using an EAF.** This process uses approximately 40% of the primary energy demand compared to BF-BOF as it skips the iron production process. This also means that it does not produce virgin steel and is reliant on scrap steel imports. Hydrogen could still be used under this method for high temperature processes and for generating steam. If the energy required for this process was provided by hydrogen (including the electricity needed for the EAF), hydrogen demand under this route could be in the region of 8,500 GWh.
- **Option 3: Continue use of coal and natural gas and apply carbon capture** throughout the plant. This would continue the use of fossil fuels, but emissions would be mitigated with CCS

6.4.3 Road Transport

6.4.3.1 Sector background

Surface transport emissions are a key GHG emission hotspot that accounts for around 22% of the UK's total GHG emissions (113 $MtCO_2e$) (CCC, 2020). Most of these emissions are tailpipe emissions from internal combustion engine (ICE) vehicles, with cars and LGVs accounting for 78% of the sector's total and HGVs accounting for 17% of emissions.

Good progress is being made to reduce tailpipe emissions from cars and LGVs through electrification and the rollout of battery electric vehicles (BEVs); BEVs for lighter transport vehicles are now widely available and likely to become cost saving by the late-2020s. BEV adoption rates for cars will accelerate over the next decade as a result of the UK Government's target to phase out the sale of new petrol and diesel cars by 2030. Likewise, given BEVs now make up around 5% of new car sales it seems likely that electrification of BEV cars will be the primary decarbonisation route.

However, as acknowledged in the DfT Transport Decarbonisation Plan (Section 2.1.1), zero emission technologies for heavier transport such as HGVs and buses are more difficult to electrify due to comparatively poor energy density of batteries, longer distances required, and load constraints. For example, the volumetric and gravimetric densities of an HGV battery pack are 50-60 times lower than those of a diesel, resulting in excess weight and space constraints (CCC, 2020). Consequently, hydrogen is expected to play a part in decarbonising HGVs.

Hydrogen offers a closer experience to current diesel operations over electrification for HGVs, and consequently given sufficient refuelling infrastructure, offers rapid refuelling times. However, there is currently a hydrogen refuelling station deficit, with around 11 in operation and a need for around 500 in the UK by 2050 (CCC, 2020). Despite hydrogen having a high energy density on mass, it has a poor energy density on volume, requiring high pressure tanks (up to 700 bar) or liquification, in order to store reasonable quantities of energy in reasonable tank sizes.

6.4.3.2 Current activity in the area

Surface transport emissions in the Western Gateway are currently dominated by car (66%), LGV (16%), and HGV (16%). Being an industrial and manufacturing hub with global docks and quick access to strategic freight routes (such as the M4 corridor), LGVs and HGVs are a considerable part of the Western Gateway's demand. Another driver of vehicle demand across the area is the rural nature of some areas, requiring vehicular transport, as opposed to public transport or methods of active travel (walking or cycling).

	Motorcycles	Cars	Buses	LGVs	HGVs	Total
2019 Petrol and Diesel Consumption (GWh_{GCV})	170	23,500	874	5,590	5,510	**35,700**
2019 CO_2e Emissions (kt CO_2e)	39	5,490	20	1,320	1,300	**8,370**

Table 6-6: Road transport emissions in the Western Gateway

6.4.3.3 Forecasted hydrogen demands

The Necessities Only scenario is optimistic towards BEVs and assumes that road transport is able to fully electrify by 2050, whereas the Widespread Hydrogen scenario has 100% of HGVs, LGVs and buses powered by hydrogen in 2050.

The Widespread Hydrogen scenario also has 25% of cars on hydrogen by 2050, whereas the other scenarios are 100% BEV cars by 2050. 25% cars on hydrogen by 2050 is an optimistic assumption given there is limited policy focus on this at present. This has been informed by stakeholder feedback, drawing on international precedence.

All scenarios have no uptake of hydrogen for motorcycles. The Balanced Hydrogen scenario has 50% of HGVs, LGVs and buses powered by hydrogen.

Scenario	2030	2035	2040	2050
Necessities Only (low) (GWh_{GCV})	0	0	0	0
Balanced (medium) (GWh_{GCV})	0	1,150	2,350	4,890
Widespread Hydrogen (high) (GWh_{GCV})	0	3,440	7,020	14,600

Table 6-7: Forecast road transport hydrogen demands

6.4.4 Rail

6.4.4.1 Sector background

Currently, the main rail propulsion fuels are diesel and electric, with around 40% of the UK's rail network electrified and the remainder being diesel powered (CCC, 2020). The CCC scenarios require further electrification up to 55-60% of the network by 2050. There are several key efficiency benefits of rail electrification including quicker acceleration, lower fuel costs, reduced GHG emissions, and reduced breaking energy use and wear.

However, some rail lines may be difficult to electrify with overhead lines or electrified rail options due to spatial or cost constraints. Battery-electric and hydrogen technologies could be suitable for these routes, albeit offer low energy densities compared to diesel. Currently, battery-electric technology for rail is challenged by range constraints with ranges being around the 60-mile mark and therefore battery-electric technologies are likely to only be suitable for category A operations (short distance operations), representing 25-30% of remaining diesel vehicles (CCC, 2020). Hydrogen rail could play a role in bridging this gap, particularly for Category B routes in rural areas (middle distance).

The specific optimal hydrogen deployment is uncertain, but Network Rail analysis suggests the electrification of a further 13,000 km of track, battery operation on around 800km and hydrogen operation on around 1,300 km. However, the Rail Industry Decarbonisation taskforce's analysis assumes a higher proportion of battery-electric and hydrogen, with less direct electrification (CCC, 2020).

At a local level, Network Rail favours electrification with map outputs from the Rail Traction Strategy (2020) recommending that hydrogen trains are only used on the Swansea District / Heart of Wales Line in the Western Gateway.

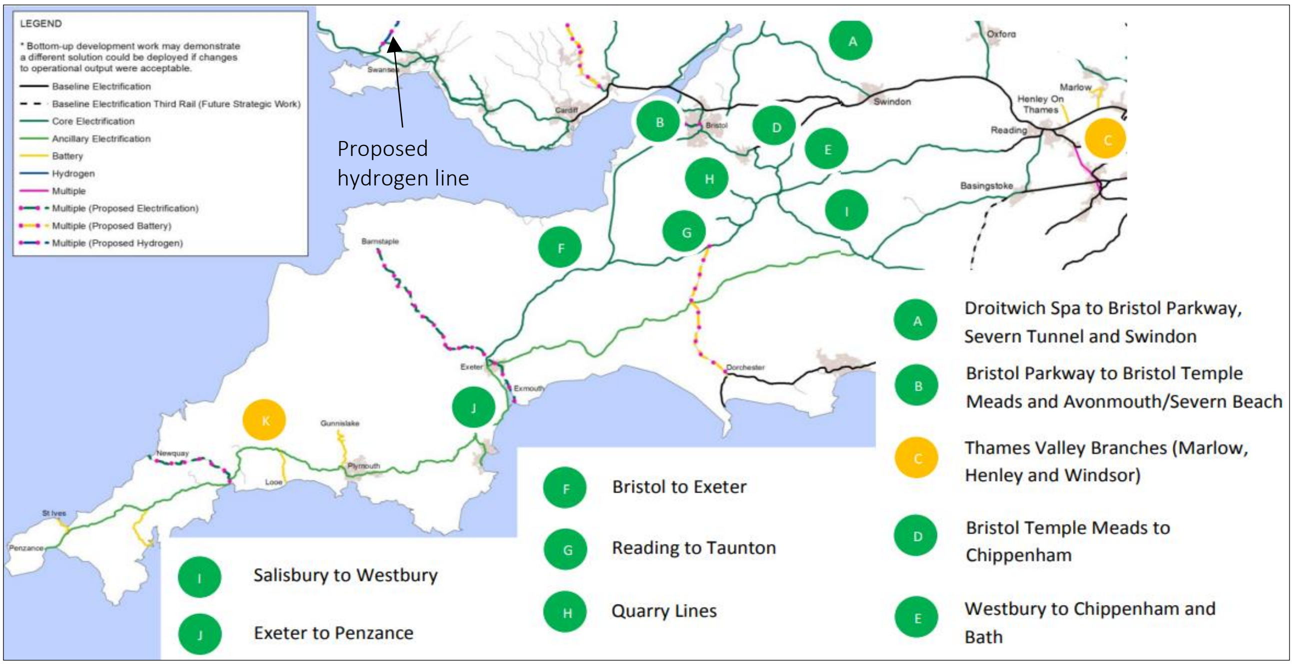


Figure 6-7: Traction Decarbonisation Recommendations for the South West (Network Rail, 2020)

6.4.4.2 Current activity in the area

The Western Gateway area is traversed by key rail infrastructure connecting the area to key internal employment and productivity centres such as Bristol, Cardiff and Newport; Cardiff has strong rail links to Gloucester, Bristol Parkway, and Bristol Temple Meads, with average journey times being around 40 minutes. The area also boasts rail infrastructure of national significance given that Bristol Temple Meads is a national hub and Bristol Parkway is a regional interchange. Regarding rail freight activity in the area, Cardiff is connected to Gloucester and Bristol via the W8 freight routes.

As determined from BEIS's subnational residual fuel data, the diesel consumption for rail in the Western Gateway in 2019 was 644 GWh, which produced 153kt CO_2e of emissions.

	Rail
2019 Diesel Consumption (GWh_{GCV})	644
2019 CO_2e Emissions (kt CO_2e)	153

Table 6-8: 2019 rail diesel consumption and emissions in the Western Gateway

6.4.4.3 Forecasted hydrogen demands

The Necessities Only assumes that all rail lines are electrified (through overhead lines or battery), therefore, no hydrogen uptake is modelled. The Balanced and Widespread Hydrogen scenarios have modelled 20% and 30% of the rail energy demand met by hydrogen in 2050 respectively.

Scenario	2030	2035	2040	2050
Necessities Only (low) (GWh_{GCV})	0	0	0	0
Balanced Hydrogen (medium) (GWh_{GCV})	0	35	71	148
Widespread Hydrogen (high) (GWh_{GCV})	0	52	107	222

Table 6-9: Rail hydrogen demand in the Western Gateway by scenario

6.4.5 Aviation

6.4.5.1 Sector background

Aviation accounts for around 7% of the UK GHG emissions (2018) and it is currently 88% above 1990 levels. It is one of the hardest sectors to decarbonise as the energy density of fuel (on weight and volume) and cost of fuel is such a critical consideration. Key emission mitigation options include demand management (capping numbers of flights), aircraft efficiency, synthetic aviation fuel (SAF), and direct hydrogen usage.

Hydrogen can be used to decarbonise aviation either via its direct use as a fuel in aircraft or as a feedstock to make synthetic kerosene (a form of SAF).

Hydrogen and SAF for decarbonising aviation

The future fuel for aviation is uncertain, though it is likely that hydrogen will be play role in decarbonising this sector either through its direct usage, or as a feedstock for SAF.

SAF is jet fuel (refined kerosene) that is produced sustainably either from biomass sources (bioSAF), or by a synthetic route. Synthetic kerosene is made using electricity to generate hydrogen (via electrolysis) and to pull CO_2 out of the atmosphere (via Direct Air Capture (DAC)), then combining them to make synthetic kerosene in the Fischer-Tropsch process. A key benefit of SAFs over direct hydrogen is that they are 'drop-in' replacements for fossil jet fuel, whereas direct hydrogen has storage and transportation challenges due to its lower energy density on volume than traditional jet fuel. Hydrogen needs to be compressed at high pressures or liquified at -253^{o}C to be a reasonable volume to transport, requiring direct hydrogen aircraft to be redesigned to accommodate larger fuel tanks. Despite this, bioSAF is limited by the land area availability to grow biomass feedstock, and synthetic kerosene is highly energy intensive and expensive.

Hydrogen is therefore seen as a possible alternative to jet fuel. Direct hydrogen can either be used in combustion technologies (e.g. jet engines), or used in fuel cells which offer higher efficiencies and do not generate NO_x pollutants.

Aviation is one of the few sectors which is projected to have significant residual emissions by 2050, under all CCC 6CB scenarios. Even the Widespread innovation scenario which is optimistic towards technology innovation assumes 50% use of fossil jet fuel in 2050 for example. Synthetic kerosene SAF (which requires hydrogen feedstock) is used to meet 25% of fuel share in the Widespread innovation pathway. No direct hydrogen use is projected in the CCC 6CB scenarios. The CCC 6CB scenarios highlight the difficulty in decarbonising aviation using SAFs without reducing aviation demand, leading to the CCC recommending there to be no net expansion of UK airport capacity.

6.4.5.2 Current activity in the area

Hydrogen South West is an industry-led[4] collaboration which was established in the wider Bristol area but is now working across the South West area with the aim of growing a hydrogen economy for the production, storage, transportation and use of hydrogen and SAF. Whilst not currently operational, easyJet aim to begin flying hydrogen aircraft as soon as they are commercially viable and are currently collaborating with Bristol Airport and Airbus to trial hydrogen planes; Airbus plan to produce the world's first zero emissions commercial aircraft by 2035 and a hydrogen-powered demonstrator by 2026 (Hydrogen South West, n.d.).

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[4] Founding members: Airbus, Bristol Airport, Bristol Port Company, Costain, easyJet, GKN, Hynamics, Wales and West Utilities, Wessex Water, Wood/WSP.

ZeroAvia have also established a research hub and operated the world's largest aircraft powered by a hydrogen-electric engine at Cotswold Airport in January 2023. Rolls Royce are also in the process of testing a jet engine running on hydrogen at their site near Salisbury.

Bristol and Cardiff are the major airports within the Western Gateway and their aviation fuel demand has been selected as the scope of aviation demand for this study. Smaller airports/airfields exist in the area, such as Swansea and Gloucester, however, these have been excluded due to lack of data and their fuel consumption is likely to be small in comparison to Bristol and Cardiff.

The aviation energy consumption of the Western Gateway has been obtained from ClimateTrace which follows an International Civil Aviation Organization (ICAO) methodology to determine energy consumption by airport (ClimateTrace, 2022) . The distance required on each flight departing/arriving at the airport is halved, so half of the accounting of energy goes onto the departure airport and half goes to the arrival airport. ClimateTrace split the data by domestic and international flights, the latter dominates in energy demand.

	Bristol	Cardiff	Total
2019 Jet Fuel Domestic Flights (GWh_{GCV})	160	35	**195**
2019 Jet Fuel International Flights (GWh_{GCV})	1,840	490	**2,330**
2019 CO_2e Emissions (kt CO_2e)	495	130	**625**

Table 6-10: 2019 aviation fuel demands and emissions in the Western Gateway

Lanzatech recently announced its DRAGON facility project in South Wales for converting waste gases from Port Talbot into synthetic kerosene. It aims to supply 1% of the UK's jet fuel demand, should this materialise and production ramp up even further, there is potential to supply jet fuel to meet aviation demands outside of the Western Gateway.

6.4.5.3 Forecasted hydrogen demands

Due the significant interest in direct hydrogen usage for aviation in the area and using direct feedback from stakeholders, this work has developed ambitious assumptions for hydrogen uptake at Bristol and Cardiff airports. It has been assumed that by 2050, for international flights (which dominate in terms of energy demand over domestic), that 20%, 40% and 60% of the international flight energy demands are met by hydrogen respectively. Synthetic kerosene (SAF) meets 20% of international flight energy demands across all three scenarios.

Scenario	2030	2035	2040	2050
Necessities Only (low) (GWh_{GCV})	0	80	465	1,180
Balanced Hydrogen (medium) (GWh_{GCV})	0	117	677	1,710
Widespread Hydrogen (high) (GWh_{GCV})	0	153	888	2,250

Table 6-11: Aviation hydrogen demands by scenario in Western Gateway

6.4.6 Marine

6.4.6.1 Sector background

Shipping emissions account for around 3% of UK GHG emissions (2018), which is a 21% reduction since 1990 levels (CCC, 2020), with international shipping having the majority share of shipping emissions. Currently, marine fuel is either heavy fuel oil (HFO) or marine diesel oil (MDO), with HFO being regulated out due to pollutants; specifically, the International Maritime Organisation (IMO) has set a sulphur cap used in HFO.

Net zero mitigation options for the marine sector include improvements in vessel efficiency, electrification and using zero-carbon fuels (DfT, 2019). The use of ammonia is the primary mitigation measure in all CCC 6CB pathways, accounting for over 91% of fuel demand in 2050. Whilst there is a lack of consensus for the primary future zero carbon shipping fuel, ammonia is seen as the frontrunner over direct hydrogen due to its higher energy density allowing smaller fuel tanks and due to the potential to retrofit ship engines for its use at a relatively low cost. Likewise, the larger fuel tank required by hydrogen, due to its lower volumetric energy density, would reduce freight capacity.

Alternatives fuels include hydrogen, methanol (which requires hydrogen as a feedstock), biofuels, synthetic diesel (also requires hydrogen as a feedstock) and liquid natural gas (LNG). Methanol is a more costly option than ammonia and biofuels are excluded from CCC scenarios as its use for the marine sector is less effective than other sectors and its adoption may slow the uptake of ammonia.

Electrification of ships via battery-electric technology will play a small role in all CCC 6CB scenarios, with a minimum of 4% of marine energy demands being met by battery-electric ships in 2050, primarily for short-distance domestic applications.

6.4.6.2 Current activity in the area

The Western Gateway has excellent port infrastructure having three major ports (defined as ports with greater two million freight tonnage annually): Port Talbot, Bristol and Newport. Milford Haven has also been included in the analysis due to its importance to the energy sector across the Western Gateway. Milford Haven is a major LNG import site, accounting for 20-30% of the UK's LNG imports. It is the fourth busiest port in the UK by freight tonnage, handling around 30 million tonnes of freight a year, which is 7% of the UK's total.

The only real way to get an accurate picture of marine fuel demands at the ports is to use bunker fuels sales data. Data from Bristol Port has been released, but data from the other ports are unavailable. An approximate estimation of marine fuel demands has therefore been made using national bunker fuel sales data (DfT, 2022), and then proportioned this down by the percentage of freight tonnage handled by each the major ports in the Western Gateway. In total, the major Western Gateway ports are responsible for 11% of the freight tonnage in the UK. We updated the estimate for Bristol Port using their actual bunker fuels sales. This results in our estimate of marine fuel demands in the Western Gateway area being 12% of UK national total. This is likely to be an overestimate of marine fuel demand for Milford Haven which is dominated by LNG impots which use LNG boil off as the fuel for ships and not marine fuel. It must also be considered that it is common for international ships to avoid fuelling at UK ports due to the relative expense of fuel compared to abroad.

	Milford Haven	Port Talbot	Bristol	Newport	Total
Total Freight tonnage	30,320	7,410	7,030	2,770	**47,530**
% of national freight tonnage total	7%	2%	2%	1%	**11%**
2019 Bunker Fuel Sales Estimate (GWh_{GCV})[1]	834	204	290[2]	76	**1,400**

	Milford Haven	Port Talbot	Bristol	Newport	Total
2019 CO_2e Emissions (kt CO_2e)	217	53	75	20	**365**
Notes: [1] *Using 2019 national total of 11,545 GWh from DfT.* [2] *Actual bunker fuel sales data provided by Bristol Port.*					

Table 6-12: Current maritime activity in the Western Gateway

6.4.6.3 Forecasted hydrogen demands

In all CCC 6CB scenarios approximately 90% of shipping fuel demands are met by ammonia in 2050. The same approach has been taken here, hence the hydrogen demands for each of the scenarios are the same.

Scenario	2030	2035	2040	2050
Necessities Only (low) (GWh_{GCV})	0	351	702	1,410
Balanced Hydrogen (medium) (GWh_{GCV})	0	351	702	1,410
Widespread Hydrogen (high) (GWh_{GCV})	0	351	702	1,410

Table 6-13: Future maritime hydrogen demands by scenario in the Western Gateway

6.4.7 Off-Road Mobile Machinery (Construction Plant Equipment)

6.4.7.1 Sector background

Off-road mobile machinery (ORMM) refers to construction plant equipment such as generators, bulldozers, pumps, construction machinery, industrial trucks, fork lifts and mobile cranes. Currently, ORMM accounts for 10% of construction and manufacturing emissions (CCC, 2020). ORMM emissions are primarily from diesel combustion, which is the incumbent fuel for ORMM.

Mitigation options include electrification, hydrogen and biodiesel, although a combined approach of electrification and hydrogen seem most likely and have the added benefit of creating fuel cost savings. Both hydrogen and battery-electric have challenges such as space for battery swapping for electrification, and proximity to hydrogen infrastructure for hydrogen.

The CCC Balanced Pathway scenario for ORMM mitigation assumes hydrogen will be the key fuel used to decarbonise the sector, with electrification playing a smaller role (CCC, 2020).

6.4.7.2 Current activity in the area

No dataset exists that could supply the ORMM fuel demand for the Western Gateway area, the CCC 6CB scenarios state that 6 $MtCO_2e$ of emissions arise from ORMM in the UK. This figure was proportioned down to the Western Gateway according to its percentage of the UK's Gross Domestic Product (GDP) in recognition that construction activity largely follows GDP. There is potential for double counting in these numbers as it is not stated in DESNZ Subnational residual fuel data (which was used for the road transport estimates) whether the fuel consumption would exclude ORMM.

	ORMM
2019 Diesel Estimate (GWh_{GCV})*	1,130
2019 CO_2e Emissions (kt CO_2e)	268

Table 6-14: Existing ORMM demands in the Western Gateway

6.4.7.3 Forecasted hydrogen demands

The Necessities Only scenario has assumed no uptake in hydrogen, the Balanced and Widespread Hydrogen scenarios assumed uptakes of 50% and 80% respectively.

Scenario	2030	2035	2040	2050
Necessities Only (low) (GWh_{GCV})	0	0	0	0
Balanced Hydrogen (medium) (GWh_{GCV})	0	306	623	647
Widespread Hydrogen (high) (GWh_{GCV})	0	489	996	1,040

Table 6-15: ORMM hydrogen demands by scenario in the Western Gateway

6.4.8 Agriculture (Fuel)

6.4.8.1 Sector background

Agricultural GHG emissions are a key hotspot for the UK, making up 10% of its emissions (2018), and within this mobile and stationary machinery account for 8% of agricultural emissions (CCC, 2020). Key agricultural machinery includes tractors, loaders, ploughs, utility vehicles and combines, which are currently fuelled via petrol and diesel. Agricultural buildings use gas and oil for heating.

Agricultural machinery can be decarbonised through uptake of zero carbon fuels, including biofuels, hydrogen and battery electric. All the CCC 6CB pathways apart from Widespread Engagement utilise hydrogen in addition to electrification to reach net zero. Stationary machinery emissions are reduced to zero by 2050 through electrification, whereas mobile machinery mitigation uses a hybrid electrification and hydrogen approach. Hydrogen could play a role in decarbonising larger on-farm vehicles such as tractors or combines, where battery-electric is not appropriate due to energy density.

6.4.8.2 Current activity in the area

DESNZ Subnational gas grid and residual fuels data provide gas and ‘petroleum’ fuels data for agriculture by local authority. It is not stated what the petroleum fuels include, however, it is presumed this is largely for on-farm mobile and stationary machinery, and some element of using oil for space heating.

	Agriculture (fuels)
2019 Gas Grid Demand (GWh_{GCV})	84
2019 Petroleum Fuels Demand (GWh_{GCV})*	1,030
2019 CO_2e Emissions (kt CO_2e)	253
**Emissions intensity of diesel used for quantification of emissions.*	

Table 6-16: Current agriculture activity in the Western Gateway

6.4.8.3 Forecasted hydrogen demands

The gas grid demand assumptions follow that of the non-domestic building heating demand with zero hydrogen used in Necessities Only and 100% hydrogen used in Widespread Hydrogen. For the petroleum fuel demand, the uptake of hydrogen is assumed to be 25%, 50% and 75% in Necessities Only, Balanced and Widespread Hydrogen respectively.

Scenario	2030	2035	2040	2050
Necessities Only (low) (GWh_{GCV})	5	69	132	259

Scenario	2030	2035	2040	2050
Balanced Hydrogen (medium) (GWh_{GCV})	5	134	262	526
Widespread Hydrogen (high) (GWh_{GCV})	6	200	420	860

Table 6-17: Forecast hydrogen demands for agriculture (fuel)

6.4.9 Agriculture (Fertiliser)

6.4.9.1 Sector background

The production of nitrogenous fertilisers starts with the production of ammonia (NH_3) in the Haber-Bosch process, which requires hydrogen and nitrogen as feedstocks. Ammonia production is one of the largest existing demands for hydrogen. Approximately 152,000 tonnes of hydrogen were required for ammonia production in the UK in 2020, which equates to 30% of the UK's market total (Fuel Cells & Hydrogen Observatory, 2022).

Making green fertiliser

The current method of hydrogen supply for ammonia production is via the steam reformation of natural gas (grey hydrogen). Pure CO_2 is a by-product of this process, which is either sold for food, beverage, chemicals use, or vented. As this CO_2 originates from a fossil fuel (natural gas), its utilisation is unsustainable. For ammonia, and consequently fertiliser production to decarbonise, either carbon capture must be installed on the steam reformation plants (blue hydrogen), or hydrogen must be gained from an alternative low carbon source (such as green hydrogen).

6.4.9.2 Current activity in the area

The Western Gateway has approximately 800,000 hectares of farmed land. Over recent years, the average amount of synthetic nitrogen applied to each hectare has been 109 kgN/ha (DEFRA, 2021). As all synthetic nitrogenous fertilisers start with the production of ammonia, the quantity of hydrogen needed can be approximated based on three hydrogen atoms needed for each atom of nitrogen in ammonia.

Western Gateway Farmed Area (hectares)	Estimated Quantity Synthetic Nitrogen Applied to Soil (using average 109 kgN/ha) (tonnes)	Hydrogen Required for Ammonia Production (tonnes)	Hydrogen Required for Ammonia Production (GWh_{GCV})	Associated CO_2e Emissions (kt CO_2e)*
799,000	87,100	18,700	736	187
**This is the associated emissions from hydrogen production from unabated steam reformation (grey hydrogen). As the fertiliser is likely to be manufactured outside of the Western Gateway, this emission source is outside of the geographic boundary of this study. This does not include for the soil N_2O emissions from the application of nitrogenous fertilisers..*				

Table 6-18: Current agriculture activity in the Western Gateway

6.4.9.3 Forecasted hydrogen demands

No growth has been modelled for agricultural sector, therefore, the estimated hydrogen demand for fertiliser remains flat in the scenarios (736 GWh_{GCV} per year).

7 Hydrogen Supply Scenarios

Chapter in Brief

This chapter sets out the potential supply sources of hydrogen for the Western Gateway and explains the development of supply scenarios across milestone years of 2030, 2035, 2040 and 2050

7.1 Green Hydrogen

Green hydrogen is the generation of hydrogen through the electrolysis of water, when the electrolysis process is powered using 100% renewable electricity. Electrolysers use electricity to split water (H_2O) into hydrogen and oxygen.

Currently, there are two main electrolyser technologies used to produce green hydrogen: alkaline and Proton Exchange Membrane (PEM). Alkaline electrolysers are a mature technology that have been used for hydrogen production for decades, as a result, they are relatively cheap and robust. PEM is better suited to intermittent renewable power input as they can undergo a cold startup in less than five minutes and can shut down in seconds (IRENA, 2020).

Electrolyser efficiency is expected to improve over time. Currently, IRENA state that PEM efficiencies are between 47% to $79\%_{GCV}$, however, by 2050 they project that efficiencies will be > $83\%_{GCV}$[5]. In this work, an electrolyser efficiency $83\%_{GCV}$ has been used (this equates to $70\%_{NCV}$[6]). Efficiency improvements will help reduce green hydrogen production costs in the long term (IRENA, 2020).

The below subsections explore the potential renewable capacity in Western Gateway which could be used to produce green hydrogen.

7.1.1 Onshore Wind & Ground Mount PV

As determined from the Renewable Energy Planning Database (REPD), which logs all installed renewable capacity above 150 kW, operational renewable capacity in Western Gateway is dominated by solar PV, (1,324 MW and 58% of total capacity) and onshore wind (609 MW and 27% of total capacity). This collectively accounts for 85% of total renewable capacity in Western Gateway as shown in Table 7-1, (REPD, 2022). The remaining operational capacity is composed mostly of biomass, energy from waste, landfill gas and advanced conversion technologies (hydrogen from waste discussed in section 7.1.9). As ground mounted PV and onshore wind dominate the capacity in the REPD, the other renewable technologies listed have been excluded in the green hydrogen supply estimations.

The REPD also provides pipeline capacity (projects awaiting development). Solar PV dominates pipeline renewable energy capacity in Western Gateway, with 85% of pipeline capacity attributed to solar PV and 6.7% to onshore wind. The limited pipeline capacity of onshore wind is likely a result of the UK Government ending subsidies and introducing stricter planning regulations in 2016, requiring new applications in England and Wales to apply for planning permission through the Town and Country Planning Act 1990 (DESNZ, 2021). Consequently, UK onshore wind projects have seen a 94% decline in projects since 2015 (BBC, 2022).

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[5] IRENA provide the efficiencies on a kWh of electricity per kg of hydrogen basis. The current PEM efficiency range of 50-83 kWh/kgH_2 equates to 47% to $79\%_{GCV}$. The expected 2050 efficiency of <45 kWh/kgH_2 equates to >$83\%_{GCV}$.

[6] Efficiencies can also be quoted on a Net Calorific Value (NCV) basis. The difference between Gross Calorific Value (GCV) and NCV is the latent heat of the water vapour in the combustion products. This latent heat can be recovered if the water vapour is cooled to liquid water (as is done in condensing boilers).

Renewable technology	Operational Capacity (MWe)	Project Pipeline Capacity (Mwe) add date
Anaerobic Digestion	27	3
Solar Photovoltaics	1,320	845
Biomass (dedicated)	69	36
Advanced Conversion Technologies	43	40
Energy from Waste Incineration	111	0
Wind Onshore	609	67
Small Hydro	0	0
Landfill Gas	40	0
Sewage Sludge Digestion	7	0
Biomass (co-firing)	53	0
Totals	2,280	991

Table 7-1: Operational and pipeline renewable capacity in the Western Gateway data from (REPD, 2022)

Development of onshore renewables is ultimately limited by the amount of land area available once environmental, regulatory, and technical constraints have been considered. This land area will be only a small fraction of the total land area available. Furthermore, the development of onshore renewables is frequently inhibited by local opposition following public consultations.

We estimate that the land area currently occupied by solar PV and onshore wind is 0.4% and 0.7% of Western Gateway land area respectively[7]. In estimating the future potential for onshore renewables, further constraints mapping work using geographical datasets is required to determine the land area availability given technical, environmental, and planning constraints.

We have modelled that the area attributed to ground mount PV and onshore wind is approximately just over doubled from its current deployment to 1% and 1.5% of Western Gateway land area respectively. The installed capacity in 2050 is therefore estimated at 5.6 GW for solar PV and 1.5 GW for onshore wind. We have assumed that the build out of new renewable capacity is linear to 2050.

	Renewable Energy Planning Database (REPD) 2022			2050 Assumptions for Scenarios	
Renewable technology	Operational Capacity (GW	Pipeline Capacity (GW)	Estimated % Land Area of WG Occupied	Assumed % Land Area of WG Covered	Installed Capacity (GW)
Ground mount PV	1.3	0.8	0.4%	1.0%	5.6
Onshore wind	0.6	0.07	0.7%	1.5%	1.5

Table 7-2: Estimated onshore renewable capacity for supply scenarios

7.1.2 Tidal & Wave

With a tidal range of up to 14 metres, the Bristol Channel has one of the largest tidal ranges in the world and has the potential to supply several gigawatts (GW) of capacity of tidal energy. Previous assessments, such as the Severn Tidal Power Feasibility Study concluded that tidal energy schemes

[7] This is based on the known installed capacity from the REPD and by assuming installed power densities (MW/km^2) of 9.0 and 49.2 MW/km^2 for onshore wind and solar PV respectively.

in the Severn Estuary could generate between 1 to 5 GW of electricity, and estimates at the time concluded that the Cardiff-Weston scheme could provide approximately 5% of the UK's electrical consumption (Regen, 2012). While the UK government concluded that it did not see a strategic case for public investment, it did not preclude privately financed schemes that are able to meet all necessary requirements. Other schemes such as the privately funded £1.7 billion 320 MW Blue Eden tidal lagoon project have been proposed in Swansea, and are considering opportunities for hydrogen production.

While the Severn Estuary may have significant potential for tidal energy generation, there is still uncertainty around future proposals and no estimates for potential hydrogen production. Due to the uncertainty of tidal energy development, the supply scenarios have therefore not included any hydrogen production from these technologies.

7.1.3 Fixed Offshore Wind

Whilst offshore wind is well established in Wales in the Irish Sea, where 726 MW has been deployed, progress has been challenging in the Bristol Channel region due to deep water, strong currents, and complex seabed geology. Several developments have failed to be completed such as the 1.5 GW Bristol Channel Atlantic Array Project in 2013, and the 108 MW Scarweather Sands project in 2009 (Trust, 2018). Consequently, due to the challenges faced by offshore wind and fact there are no developments in the area, fixed offshore wind capacity has not been modelled in supply scenarios.

7.1.4 Floating Offshore Wind (FLOW)

Floating offshore wind (FLOW) is a new renewable technology with one active site in the North Sea, the 30 MW Hywind Scotland FLOW park which has been operational since 2017 and is the world's first FLOW project (Equinor, n.d.). It is achieving a high capacity of 54%, compared to typical offshore wind in the UK which is around 40% (Equinor, 2021). Developments typically operate in seabed areas over 60m in depth and are less impacted than seabed geological conditions than fixed offshore wind.

The Celtic Sea surrounding Wales and the South West has excellent wind resources (>8m/s), in deep water offshore locations suitable for FLOW; it is estimated the area has potential for 15-50 GW of FLOW capacity (Catapult, 2020). There are two major upcoming FLOW project developments in area, including the 100 MW Erebus project (close to Milford Haven), which will be the first FLOW development in the Celtic Sea when it is operational in 2026. Additionally, there is the proposed 300 MW FLOW development, Project Valorous. The completion date for this project is not yet known.

The Crown Estate are supporting the Government's ambition to deliver 5 GW of FLOW by 2030, by committing to delivering 4 GW by 2035 in the Celtic Sea. They are currently exploring five zones in the Celtic Sea for potential development, totalling 11,000 km^2 of sea area (The Crown Estate, 2022). These five zones have now been refined down to 4,600 km^2 and are due to undergo further refinement.

For our FLOW capacity estimate, we have assumed that 4,000 km^2 of sea area will be available for FLOW in the Celtic Sea. This capacity for FLOW cannot all be allocated to the Western Gateway, instead it must be shared with the remainder of Wales and South West England. DESNZ subnational electricity consumption data for 2019 showed that the Western Gateway accounted for 50% of the electricity consumption of all Welsh and South West England authorities. Therefore, the Celtic Sea capacity that we have allocated to the Western Gateway is half of the total capacity. This equates to 12 GW of FLOW - see Table 7-3 below.

Variable	Value	Rationale
Celtic Sea Area Available for FLOW	4,000 km^2	Assumed area after The Crown Estates site selection programme
Assumed installed capacity density	6.0 MW/km^2	Typical for European offshore wind farm (European Commission, 2018)
Installed capacity potential	24 GW	-
Proportion of capacity available to Western Gateway	50%	Determined from DESNZ Subnational electricity consumption data which shows that the WG area accounts for 50% of electricity consumption of the South West of England and whole of Wales.
Capacity available to Western Gateway	12 GW	-

Table 7-3: Celtic Sea FLOW capacity estimation

7.1.5 Curtailed Renewables for Hydrogen Production

The intermittent nature of solar and wind power means that renewable power producers are sometimes forced to reduce their output, otherwise known as “curtailment”. In 2020, 6% of Britain’s wind output had to be curtailed because it couldn’t be transported to consumers on the electricity network (Drax Electric Insights, 2020).

There are two key drivers of renewables curtailment:

- Localised oversupply: sudden and unexpected variations in renewable power output, or reductions in demand.
- Network constraints: electricity cannot be transport to where it is needed due to capacity limitations on the grid.

In order to make use of the otherwise curtailed electricity, an attractive idea is to generate hydrogen in electrolysers local to the renewable power sites whenever a curtailment event occurs. However, this idea has several challenges:

- The low number of curtailment hours results in a high cost of hydrogen production due to the capital investment in electrolyser required. Investment is required in the electrolyser which has a low utilisation and thus produces a low amount of hydrogen. The International Energy Agency (IEA) demonstrated in its The Future of Hydrogen study, showing that the levelised cost of hydrogen increases exponentially when an electrolyser is used for fewer than 2,000 hours of full load a year (IEA, 2019).
- Network constraints could be rectified to transmit electricity to where it is needed. The majority of curtailment in Britain occurs because the transmission line which connects wind power generated in Scotland to demand in England reach capacity. At the periods of curtailment, there is demand in England, but it is the transmission line which inhibits its transfer.
- Curtailment is difficult to predict, therefore the supply of hydrogen from this source is unreliable.

- Hydrogen production will compete with other storage technologies which have higher electricity to electricity round trip efficiencies, such as batteries.

The outlook for using hydrogen production as a means to make use of otherwise curtailed renewable power is debatable and needs further investigation. It has therefore has not been modelled as a means of hydrogen supply in the scenarios.

7.1.6 Total Green Hydrogen Production

The potential green hydrogen production – if all renewable power was used to generate hydrogen - in 2050 from floating offshore wind (FLOW), onshore wind and ground mount PV has been detailed Table 7-4 below. The FLOW makes up the majority of the electricity generation (86%) as it has the highest installed capacity and a larger load factor.

This represents an upper limit of green hydrogen potential, as in reality, a proportion of this renewable power will be used directly for electricity demands. The future split of renewable power between direct use as electricity and for production of hydrogen is not known with any certainty. This is discussed further in section 7.2. The FLOW makes up the majority of the electricity generation (86%) as it has the highest installed capacity and a larger load factor.

Renewable technology	2050 Estimated Installed Capacity (GW)	Assumed Load Factor (%)	Electricity Generation (GWh)	Potential Hydrogen Production via Electrolysis (GWh_{GCV}) *Uses $83\%_{GCV}$ electrolyser efficiency*
Floating offshore wind (FLOW)	12	50%	52,600	43,600
Onshore wind	1.5	25%	3,290	2,730
Ground mount PV	5.6	11%	5,400	4,480
Total			61,200	50,800

Table 7-4: Estimated potential green hydrogen production in 2050

7.1.7 Blue Hydrogen

There are two key blue hydrogen technologies: steam reformation (SMR) with CCS and Autothermal Reforming (ATR) with CCS, with a new technology on the horizon developed by Shell: Gas Partial Oxidation (GPO).

SMR without CCS (grey hydrogen) has been conducted for decades and is currently used for generating hydrogen for ammonia production. ATR is a newer technology that offers higher efficiency and better CO_2 capture rates. Both SMR and ATR with CCS have yet to be deployed at a large scale in the UK. All technologies require natural gas as a feedstock and split the hydrogen from natural gas, generating CO_2 as a by-product. The CO_2 is then captured and stored permanently to mitigate CO_2 emissions.

However, the CCS is not 100% effective, and there are upstream fugitive emissions from the extraction of natural gas. Blue hydrogen is therefore not zero carbon, but instead considered low carbon. For example, the lifecycle emissions of natural gas combustion (including fugitive methane emissions from upstream natural gas extraction) is in the region of 210 gCO_2e/kWh (Ricardo, 2020). The UK's Hydrogen Strategy states hydrogen lifecycle emissions from SMR and ATR with CCS to be 65 and 49 gCO_2e/kWh respectively (HM Government, 2021), which on an energy basis, equates to 31%

and 23% of the carbon intensity of natural gas. For this reason, and the fact that it is reliant on a finite fossil resource (natural gas), blue hydrogen is not seen as a long-term solution, but rather a steppingstone technology to accelerate a hydrogen economy.

However, blue hydrogen production is considered as a hydrogen supply source for two reasons: cost and scalability. Blue hydrogen has long been seen as the cheapest form of low carbon hydrogen. The UK's Hydrogen Strategy provides 2020 costs of SMR and ATR blue hydrogen to be £59/MWh and £62/MWh respectively, whereas the 2025 green hydrogen cost is £112/MWh (HM Government, 2021). The costs by 2050 are very similar (see Table 7-6 below). Similar conclusions were found by the Energy Networks Association (ENA) in their Gas Goes Green study, which showed 2020 costs to be circa £40/MWh and £140/MWh for blue and green hydrogen respectively, however, in this study costs are expected to reach parity by 2045 (ENA, 2020). However, these projections were made prior to the 2022 energy crises which saw a huge spike in natural gas prices. The natural gas price will need to be monitored prior to investment in blue hydrogen.

Given the abundance of natural gas and the relatively low land area requirement of blue hydrogen production facilities in comparison to renewables, blue hydrogen production can be scaled up to large production quantities. It is therefore an attractive option where the potential for green hydrogen supply may be limited.

The key requirements for blue hydrogen production are that it needs: a good natural gas supply, a means to dispose of the CO_2 captured and infrastructure to distribute the hydrogen. Two key sites for early blue hydrogen production in the Western Gateway have been identified through this work: Milford Haven and Port Talbot. Milford Haven is an LNG import site and could supply blue hydrogen for the nearby Valero oil refinery and the Pembroke CCGT if it switches to hydrogen. Wales and West Utilities is also exploring the feasibility of a hydrogen transmission line running from Milford Haven close to Port Talbot (HyLine). Both locations have ports so the CO_2 can be shipped away for disposal. Port Talbot is the location of the steelworks which is a potential large hydrogen demand.

As blue hydrogen production is scalable, the total quantities of hydrogen it could supply are large.

7.1.8 Pink Hydrogen (Nuclear)

Nuclear power has suffered several setbacks in the UK with significant delays and cost overruns for newly built reactors. Hinckley Point C, which is situated in just outside the Western Gateway in Somerset (see Section 1.3), has been delayed by a year and will cost an extra £3bn than expected (BBC, 2022). Nuclear power is the most expensive form of electricity and is the only power generation technology which has seen a rise in average levelised cost of electricity over the last 10 years (Our World in Data, 2020). However, there are new nuclear technologies on the horizon which aim to overcome the shortfalls of current reactor designs.

There are three key stages of nuclear reactor technology:

- Large scale reactors: this is the current technology, with capacities in the GW range (e.g. the 3.2 GW Hinckley Point C).
- Small Modular Reactors (SMR): smaller in size (hundreds of MW), use modular, off-site manufacturing for flexible deployment and for reduction in cost.
- Advanced Modular Reactors (AMR): reactors use novel and innovative fuels, coolants, and technologies to generate low carbon electricity, and take advantage of the same modular-build principles as SMRs. High temperatures of AMRs mean that thermochemical production of hydrogen is possible.

All technologies could use the electricity generated from the reactors to power conventional cold-water electrolysis, however, utilising the heat generated from nuclear reactors may be a more attractive route to support hydrogen production.

Nuclear assisted thermal routes for hydrogen production

The vast of amounts of heat generated by nuclear reactors can be utilised for hydrogen production through either high temperature steam electrolysis, the thermochemical water splitting or supporting the steam reformation of natural gas **(Nuclear Industry Association, 2021)**.

Steam electrolysis: high-temperature steam electrolysis takes place between around 600-1000°C and requires a third less energy than cold water electrolysis and is therefore expected to be more efficient.

Thermochemical water splitting: heat between 600-900°C produced by an Advanced Modular Reactor (AMR) in the presence of chemical catalysts can be used to cause water to split into hydrogen and oxygen.

Reforming fossil fuels: waste heat from nuclear power could provide the high temperatures for the steam reforming process instead of fossil fuels. Carbon capture and storage is still needed to mitigate CO_2 emissions.

Neither SMR nor AMR technologies have yet been demonstrated but project opportunities being explored and in November 2021, the government announced up to £210 million for Rolls-Royce to further develop their design for one of the world’s first SMRs (DESNZ, 2023). To give a sense of the scale of hydrogen demand which could be met by an SMR reactor, the proposed Rolls Royce units have an electrical capacity of 470 MW_e. Given a load factor of 95%, and an electrolyser efficiency of $83\%_{GCV}$, approximately 3,200 GWh_{GCV} of hydrogen could be produced annually from a single SMR powering a conventional cold-water electrolyser.

Hydrogen supply from nuclear power has not been modelled because there are currently no plans to generate hydrogen in this way in the Western Gateway area, however the feasibility of demonstration and commercial deployment could be explored as an option to meet the shortfall between the forecast demand and supply of low carbon hydrogen.

However, the new technologies could be an attractive solution if they manage to overcome the pitfalls of conventional reactor designs. Also, the production potential of hydrogen from nuclear is large and scalable, therefore, it could be a solution to supplant blue hydrogen production in the long term.

7.1.9 Hydrogen from Waste

There are several routes that can be used to generate hydrogen from waste feedstocks, some of which include:

- **Gasification:** This process involves heating Municipal Solid Waste (MSW) in an atmosphere with very little oxygen to prevent combustion. This breaks down the waste into a syngas, which consists mostly of carbon monoxide and hydrogen. The hydrogen can be separated from the other gases.
- **Pyrolysis:** This process involves heating MSW in the absence of oxygen, but at a lower temperature than thermal gasification. This results in the breakdown of the organic matter into a solid (char) and a liquid (bio-oil) fraction, as well as a syngas that contains hydrogen.

- **Anaerobic Digestion (AD) with reformation:** This process involves breaking down organic matter in the absence of oxygen using microorganisms. A variety of waste feedstocks can be used, though AD plants can be separated into two categories: wastewater treatment plants (using sewage sludge as key feedstock) and agricultural AD plants which use a variety waste food feedstocks and agricultural energy crops. This process produces a biogas, which is approximately 60% methane (CH_4) and 40% carbon dioxide, the methane can be reformed to separate the hydrogen.
- **Landfill gas:** This method involves burying the MSW in a landfill and using a system of pipes to collect the gases (which contains methane, CH_4) that are produced as the waste decomposes. The methane can then be reformed to separate the hydrogen.

Waste-to-hydrogen technologies are still in their infancy and there are limited demonstrator projects in the UK and none currently operational in the Western Gateway. However, Advanced Biofuel Solutions LTD (ABSL) have expressed plans for hydrogen production from their household waste to biomethane plant (through gasification) at their Swindon plant (ABSL, 2023).

Waste collection data along with the average composition of Municipal Solid Waste (MSW) has been used to calculate the total technical potential of hydrogen from MSW. A previous study on the average composition of UK waste streams found that on average hydrogen accounts for just under 8% of the weight in MSW (Chester, et al., 2008). The quantities of waste have been determined by using local authority waste collection data from StatsWales and DEFRA, for Welsh and English local authorities respectively.

In adherence with the Waste Hierarchy, we have assumed that any reused, recycled or composted waste should remain to be processed in that way. Any residual (non-recycled, reused or composted) could be used for hydrogen production. An upper limit of hydrogen from waste potential has been determined by taking 8% of the weight of MSW. This is a theoretical potential that assumes that all hydrogen atoms could be extracted from MSW (in reality, there would be losses in conversion). The total potential is just under 3,000 GWh_{GCV}, which is substantially less than the green hydrogen potential and a fraction of the total hydrogen demands under all scenarios – hydrogen from waste is therefore not a major supply source.

FY 2020-21	Total MSW Collected (tonnes)	% recycled, reused or composted	Total Residual (tonnes)
Welsh LAs	910,400	58%	385,000
English LAs	1,140,000	50%	576,000
Total for WG	2,050,000	-	961,000
Hydrogen potential (tonnes): using 7.7% hydrogen by weight in MSW			73,900
Hydrogen potential (GWH_{GCV})			2,910

Table 7-5: Hydrogen from waste estimated potential

7.2 Supply Technologies Summary

In Table 7-6, the hydrogen supply technologies investigated have been assessed in terms of their total technical potential, Levelised Cost of Hydrogen (LCOH), lifecycle emissions and technology readiness.

Supply Technology	Estimated Total Technical Potential for the Western Gateway (GWh_{GCV})	Levelised Cost of Hydrogen (LCOH)*	Lifecycle CO_2e Emissions (gCO_2e/kWh_{GCV})	Technology Readiness
Green hydrogen (renewables)	50,830	PEM (10 MW) (with dedicated offshore wind)****: 2025: £112/MWh_{GCV} 2050: £71/MWh_{GCV}	0**	Well established, although FLOW has not yet been demonstrated at large scale
Blue hydrogen	Scalable	ATR (300 MW)****: 2020: £62/MWh_{GCV} 2050: £65/MWh_{GCV} SMR (300 MW)****: 2020: £59/MWh_{GCV} 2050: £67/MWh_{GCV}	ATR with CCS: 49* SMR with CCS: 65*	SMR well established, ATR promising alternative, both have yet to be demonstrated at large scale with CCS
Pink hydrogen (nuclear)	Scalable	Unknown	0	New small and advanced reactors not yet demonstrated
Hydrogen from waste	2,910	Unknown	Variable***	Only small-scale demonstrator plants built

**Figures from UK's Hydrogen Strategy* (HM Government, 2021)

***Lifecycle emissions can be attributed to emissions from manufacturing and construction of plant but these are small per unit of electricity generated so have not been considered here.*

****Lifecycle emissions depend on the biogenic fraction of waste. CCS can be employed to mitigate emissions of non-biogenic element, and net-negative emissions can be achieved on biogenic waste streams with CCS.*

****PEM costs convert to £4.41/kg and £2.80/kg for 2025 and 2050 respectively. ATR costs convert to £2.44/kg and £2.56/kg for 2020 and 2050 respectively. SMR costs convert to £2.32/kg and £2.64/kg for 2020 and 2050 respectively.*

Table 7-6: Hydrogen supply technologies comparison

The total hydrogen demands in 2050 under three scenarios were determined to be 28,500, 37,900 and 81,600 GWh_{GCV}. Given the potential renewable capacities identified in section 7.1.6, if all renewable power was used for hydrogen production, it would be possible to supply all of the Western Gateway's hydrogen demands in 2050 under the Necessities only and Balanced scenarios with green hydrogen alone, which is clearly preferable from an environmental perspective.

Given the scalability of blue and pink hydrogen, the large quantities of hydrogen required under the Widespread Hydrogen could be produced within the Western Gateway boundaries, but there are environmental implications with blue hydrogen and the new reactor technologies required for pink hydrogen are not yet demonstrated. Hydrogen from waste will only supply a modest proportion of demands.

Whilst there is substantial renewable capacity for green hydrogen production, the wider electricity demands of the Western Gateway must also be considered. In Figure 7-1 this has been demonstrated by plotting the electricity that would be required to meet all of the hydrogen demands under each scenario (solid blocks) with the estimated electricity demands of meeting the needs for increased electrification (for electric vehicles, heat pumps etc) and the current (2019) electricity demand of the Western Gateway (dashed outline blocks). The Widespread Hydrogen's total energy consumption is much greater than the other scenarios as it does not benefit from the efficiencies of electrification. It is evident from Figure 7-1 that indigenous green hydrogen production in the Western Gateway may not be enough to meet the potential hydrogen demands in the area.

How much of the Western Gateway's renewable capacity that should be dedicated to hydrogen production requires further investigation. A set of hydrogen supply scenarios have been detailed in the following subsection which make assumptions on the proportion of renewable capacity dedicated to hydrogen production.

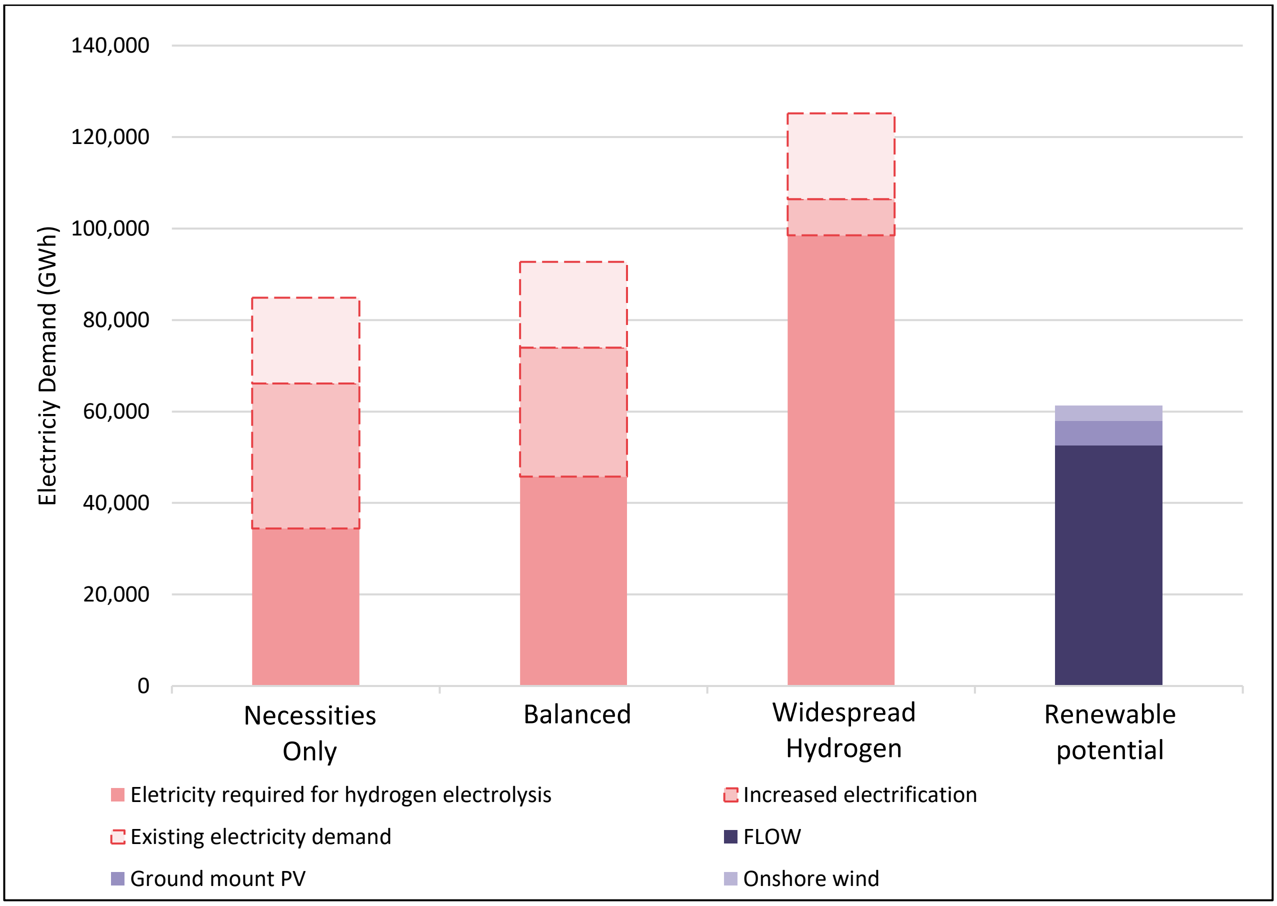


Figure 7-1: Potential electricity demands under scenarios vs renewable potential

7.3 Supply Scenarios

The full set of supply scenario assumptions have been provided in Appendix B. The key assumptions that make the biggest impact on hydrogen supply quantities are that of the FLOW capacities dedicated to hydrogen production, and the sizing on the blue hydrogen production facilities. A simplified set of scenario assumptions have been provided in Table 7-7 below.

Supply Technology	Necessities Only	Balanced Hydrogen	Widespread Hydrogen
Green hydrogen (FLOW)*	20%	30%	50%

Supply Technology	Necessities Only	Balanced Hydrogen	Widespread Hydrogen
Blue hydrogen	Sized to meet Port Talbot steelworks demand – built in 2035	Supplies Port Talbot steelworks plus the local distribution network covering Neath Port Talbot and Swansea - Port Talbot demand built in 2035, then plant increased in 2040s to meet Local Distribution Zone (LDZ) demands	Supplies all distribution network demands in South Wales area of Western Gateway – Port Talbot demand built in 2035, then plant increased in 2040s to meet Local Distribution Zone (LDZ) demands
**Percentages are the capacity dedicated to hydrogen production, assumes linear uptake starting from zero in 2030.*			

Table 7-7: Simplified supply scenario assumptions in 2050

The resulting hydrogen production quantities have been shown in Table 7-8 below. The production of hydrogen has been separated by that without blue (green and waste) and that with blue. This has been done for two reasons: firstly, blue hydrogen production is scalable, therefore, it could be increased to meet demand. Secondly, the green and waste supplies of hydrogen could be considered indigenous to the Western Gateway area (i.e. the energy is resourced from within the area). Whereas the blue hydrogen is reliant on natural gas imports which creates a security of supply consideration (discussed in more detail in section 8.2.2).

The hydrogen demands of the scenarios have been provided in the final row of Table 7-8. Considering indigenous production only (green and waste), there is a deficit in hydrogen supply, but ramping up of blue hydrogen production could meet or exceed the demands of the area. Nuclear could also provide the means of large, scalable hydrogen, but this was not modelled in the main scenarios due to the uncertainty of the technology (see Section 7.1.8).

Hydrogen production	2050 Hydrogen Production (GWh_{GCV})		
	Necessities Only	Balanced Hydrogen	Widespread Hydrogen
Production without blue hydrogen	9,350	14,200	23,500
Blue hydrogen production	21,300	24,600	37,500
Total production (with blue hydrogen)	30,700	38,800	61,000
Total hydrogen demand	28,500	37,900	81,600

Table 7-8: 2050 hydrogen production quantities under supply scenarios

7.4 Potential GHG Savings

All scenarios in this study were designed to achieve a net zero Western Gateway in 2050, but with hydrogen playing a dramatically different role in each. More emissions savings can be attributed to hydrogen where it plays a greater role in the energy system, therefore the Widespread Hydrogen scenario has the greatest emissions savings. The estimated emissions savings in 2050 from hydrogen usage have been detailed in Table 7-9**Error! Reference source not found.** below. The full set of potential CO_2e savings split by end-use and for each of the milestone years has been provided in Appendix G – Potential CO_2e Savings from Hydrogen. The emissions savings are the savings made in that year against a 'do-nothing' baseline which accounts for growth and energy efficiency improvements (as per baseline assumptions in Appendix B), but with no fuel switching to hydrogen or electrification.

	2050 Green House Gas Savings (kt CO_2e) from Hydrogen Usage*		
	Necessities Only	Balanced Hydrogen	Widespread Hydrogen
Zero lifecycle emissions electrolysis from renewable or nuclear generated electricity	8,660	11,200	20,700
ATR with CCS (uses 49 gCO_2e/kWh_{GCV})	7,270 (Savings 16% lower than zero lifecycle emission hydrogen)	9,360 (Savings 16% lower than zero lifecycle emission hydrogen)	16,700 (Savings 19% lower than zero lifecycle emission hydrogen)
*All scenarios represent a net zero Western Gateway, however, hydrogen results in more emissions savings under Balanced Hydrogen and Widespread Hydrogen as hydrogen plays a bigger role in the energy systems under these scenarios. An equivalent quantity of emissions will be saved under Necessities only, but the savings will be attributed to other technologies such as electrification which have not been accounted for in this table. Hydrogen itself is a greenhouse gas, leakage of hydrogen (which would effectively reduce the carbon equivalents savings here) has not been modelled due to the uncertainty of its leakage throughout the energy system.			

Table 7-9: Scenario potential GHG savings from hydrogen usage

Hydrogen has zero greenhouse gas emissions upon combustion or use within a fuel cell. Therefore, its usage can fully displace the emissions that would otherwise arise from the use of fossil fuels. However, the source of hydrogen must be considered. Two scenarios have been presented above for the emissions savings that would occur if the hydrogen supply had zero lifecycle emissions for example from renewable or nuclear electricity sources and the emissions if the hydrogen was supplied by 100% ATR with CCS (49 gCO_2e/kWh_{GCV}).

7.5 Supply Heat Mapping

The following two sections highlight the potential locations for hydrogen production. We have split production by those which are large point sources, and smaller scale production which is likely to be more spatially distributed.

7.5.1 Large Point-Source Production

In the Celtic Sea, the Crown Estate is currently exploring sites for the large-scale development of floating offshore wind (The Crown Estate, 2022). The generated electricity could be carried onshore by transmission lines or direct electrolysis offshore could also be explored. Should the electricity be brought onshore by transmission line, Milford Haven has already been identified as location that could use this electricity for large scale green hydrogen production via electrolysis. This green hydrogen could be directly injected into a hydrogen transmission line (such as the HyLine project being explored by WWU) to be transmitted across the South of Wales and potentially into England. The electricity could also be carried onshore at some point in the South West of England, the favoured location for which is not yet known. Large-scale green hydrogen production could then be transported easterly across the South West England with possible storage at Dorset salt caverns.

To have effective blue hydrogen production, you need a secure supply of natural gas; ideally a large, localised demand for hydrogen, and the capacity for CO_2 offtake. Milford Haven and Port Talbot satisfy these criteria, and therefore are prime candidates for future blue hydrogen generation.

Whilst we have not modelled hydrogen from nuclear in the area before 2050, we have mapped two potential sites: Hinckley Point and Oldbury. These are potential sites for new nuclear development as they are already known to be policy compliant for nuclear (Supergen Energy Networks Hub, 2022).

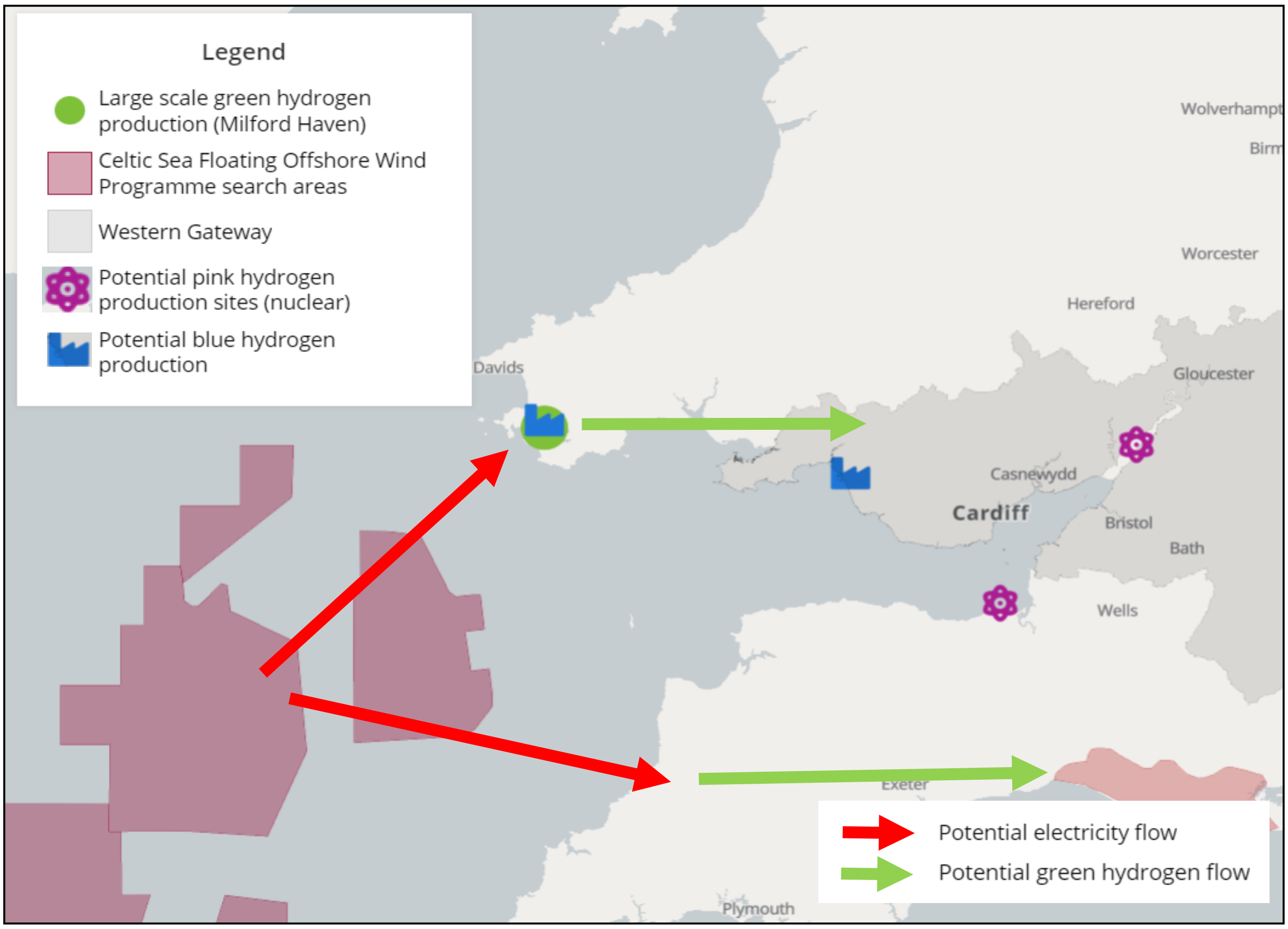


Figure 7-2: Potential future hydrogen supply map

7.5.2 Distributed Production

Previous work by Supergen mapped the locations of current installed renewable capacity across the Western Gateway (see Figure 7-3 below), using the REPD. The solar PV capacity is distributed fairly equally across the area, however, the wind capacity is more concentrated around the Neath Port Talbot local authority in the South of Wales. The REPD also provides the locations of applications for new development. The new development of solar PV is skewed towards the eastern side of the Western Gateway, particularly in Wiltshire and the Cotswolds. Some new wind capacity has been proposed in Neath Port Talbot and Bridgend.

The siting of any new distributed production of hydrogen could be demand-led, i.e. electrolysers could be sited near to demand centres. This would allow for private supply of hydrogen via private pipeline. Alternatively, if the gas distribution networks allow for 20%$_{vol}$ blending, or be repurposed for 100%$_{vol}$ hydrogen, then there is opportunity for distribution production to feed directly into the distribution grids. Electrolysers seeking to use grid electricity as the source of power can be more flexible in terms of location deployment, provided they are sited within an economically viable distance to a grid connection, and there is sufficient capacity on the grid to support the electrolyser load.

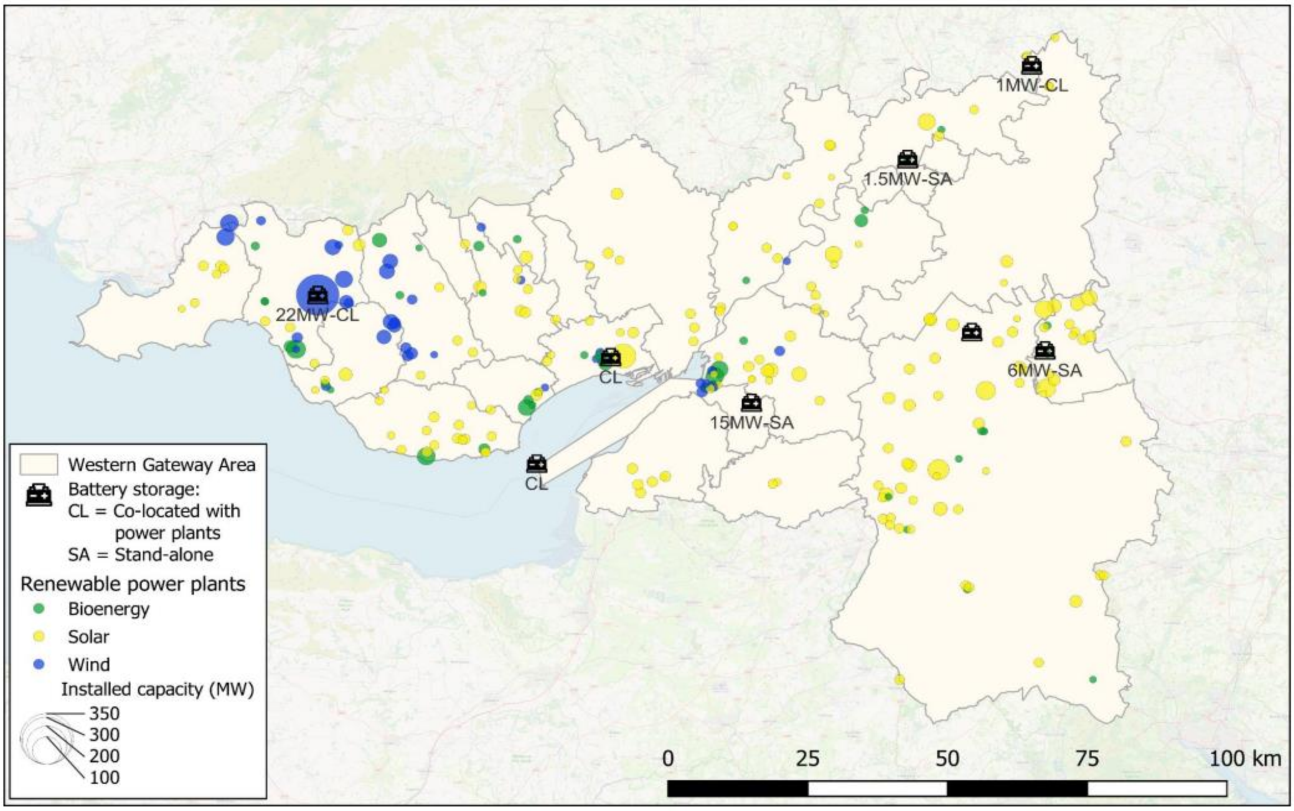


Figure 7-3: Renewable installed capacity across Western Gateway from REPD data. Image source: Supergen Energy Networks Hub, 2022

8 Western Gateway Hydrogen Network Considerations

Chapter in Brief

Accounting for the demand and supply scenarios, this chapter identifies the key hydrogen network development considerations across the Western Gateway area to enable a hydrogen energy system.

8.1 Hydrogen Transportation Infrastructure

Hydrogen needs to be transported from its point of production to its point of use. The development of the network infrastructure to facilitate the transport of hydrogen is critical to the expansion of the hydrogen economy in the area.

Hydrogen can be transported by pipeline and non-pipeline (road, rail, marine) routes. The most appropriate means of transportation will be determined on a case-by-case basis given the scale of demand and the requirements of the end application.

Any existing hydrogen networks in the Western Gateway will be either small scale private pipelines (there are two small scale grey hydrogen plants serving industrial demands in South Wales) and by road tanker. As the hydrogen economy develops, significant scale-up in transportation infrastructure will be required.

8.1.1 Transmission Pipelines

Transmission pipelines provide the means for mass transport of hydrogen at low cost over long distances. Any large-scale production sites and potentially large-scale consumers are likely to tap into transmission networks.

As identified in Figure 7-2, large scale production of hydrogen has been assumed to occur at blue production facilities at Milford Haven and Port Talbot. Large scale electrolysis is likely to occur where the electricity from FLOW is brought onshore from the Celtic Sea, either in West Wales (possibly at Milford Haven) or South West England.

Investigation is already underway with WWU's HyLine project to explore the feasibility of a hydrogen transmission line running from Milford Haven going easterly across to the rest of the South of Wales. Under all scenarios in this study, it has been assumed this transmission line is built in order to serve the industrial hydrogen demands in the South of Wales. Another possible transmission route could be to bring FLOW powered electrolysis of hydrogen easterly across the South West of England. This could make use of the Wessex basin salt-cavern for storage of hydrogen.

The build of new hydrogen transmission lines, as opposed to repurposing existing natural gas transmission lines, is considered likely. Existing steel transmission lines may not be suitable for 100% hydrogen due to embrittlement issues, and blue hydrogen production plants will need large of natural gas supplies, so the future energy system will continue to need natural gas transmission lines.

Dedicated hydrogen transmission lines may see additional use beyond that of current natural gas networks. New large-scale consumption in sectors such as aviation and marine may tap into future transmission lines.

8.1.2 Distribution Pipelines

Distribution pipelines are fed by the transmission network and supply gas to the end-consumer. They also provide the means for smaller scale, distributed producers to feed gas directly into the network (e.g. biomethane from AD plants is fed into the natural gas distribution networks in this way).

The conversion of the existing distribution network for 100% hydrogen rests upon hydrogen's future role within our future energy system. Where the use of hydrogen for heating is widespread (e.g. Widespread Hydrogen scenario), the repurposing of the existing natural gas distribution network will be necessary. However, under a scenario where electrification meets heating demands (e.g. Necessities Only) conversion of the existing distribution network may not take place, instead the gas networks may be decommissioned. Conversion of distribution zones may occur in isolation. For example, under the Balanced Hydrogen scenario, it has been assumed that the Local Distribution Zone (LDZ) surrounding Port Talbot is converted to 100% hydrogen and serves the heating demand of the associated properties. This is due to the large-scale localised supply of blue hydrogen which is first built to supply the demands of Port Talbot steelworks.

Much of the existing distribution network will be suitable for 100% hydrogen through the conversion of existing steel pipes to polyethylene via the Iron Mains Replacement Programme (expected to be complete by early 2030s). However, the programme replaces pipes on a risk-assessed process, replacing those at most risk of failure. Sections deemed low risk will not necessarily be replaced. Further work will therefore be required before distribution networks can be commissioned for 100% hydrogen.

Should full scale conversion of the distribution networks take place, this could open up opportunities to supply demands that the current natural gas network does not. For instance, the refuelling stations for road transport.

8.1.3 Road & Rail Transport

The transportation of hydrogen via road is more appropriate for small hydrogen quantities. Road transport is most likely for small users that are not connected to a hydrogen gas grid and possibly for reaching refuelling stations. The lower volumetric energy density of hydrogen (even when highly compressed or liquified) compared to fossil fuels means that many more road tankers will be required to transport an equivalent amount of energy. This increases transportation costs and increases the volume of road traffic.

Given rail's abilities to transport large quantities of freight, this could be an option to transport larger quantities than what road can achieve, but it is limited to the locations of rail infrastructure.

8.1.4 Marine Transport

The Western Gateway has excellent port facilities, having three major ports at Port Talbot, Newport and Bristol and Milford Haven just outside the area's boundaries. Ships can transport large volumes of hydrogen either in gaseous or liquified form, or within a hydrogen carrier such as ammonia (NH_3). Due to the Western Gateway's marine infrastructure, it has the opportunity for international import and export of hydrogen (discussed in section 8.2.2).

8.1.5 Refuelling Infrastructure

The UK has comprehensive refuelling infrastructure for the road, rail, aviation and marine sectors. Should these sectors transition to hydrogen, then equivalent refuelling infrastructure will need to be built. Large quantities of hydrogen could be required from these sectors. Where this demand is distributed (e.g. road refuelling stations), then road transport of hydrogen to refuelling points may be more appropriate, whereas large point-source demand (e.g. airports and marine ports) could warrant the build of dedicated pipelines.

The purity of hydrogen delivered is of particular importance to refuelling as the transportation sector includes the use of PEM fuel cells as a means of propulsion. The purity requirements could mean that additional hydrogen upgrading equipment is built at the point of refuelling. Hydrogen purity is discussed further in section 8.3.4 below.

8.2 Matching Supply & Demand

8.2.1 Storage Requirements

The storage of energy is necessary where production and use do not occur at the same time. The future energy demands of the Western Gateway will be highly variable, both on diurnal and seasonal time scales. This is further complicated by an energy supply that will become more variable with intermittent renewables making up an increasing share of primary energy supply. Storage can also act as a means of supporting security of supply, by holding large scale reserves.

There are a number of ways hydrogen can be stored, the methods of storage have varying merits and are applicable for different purposes – these have been compared in Table 8-1 below.

Storage Method	Description	Scale	Use
Specialist tanks and storage vessels	Can be stationary (on-ground) or mobile (road tanker). Storage as compressed gas could be useful for small scale storage at refuelling stations and for areas without wider infrastructure (e.g. construction sites). Storage as liquefied hydrogen or as a hydrogen carrier (ammonia, metal hydride) provide a route to store at greater energy density.	Small to Medium (MWh to GWh)	Small scale back-up and balancing.
Line-packing	Applicable for hydrogen transmission lines only. Storage of gas under pressure in pipeline systems. Currently used by natural gas network to meet intra-day variability.	Medium (GWh)	Meeting diurnal variability on gas grid
Salt-cavern	Able to provide large storage volumes (TWh) at low cost. Current method of large-scale onshore storage of natural gas. Wessex basin salt-caverns a possible storage site.	Large (TWh)	Large scale inter-seasonal storage.
Offshore Geo-storage	Depleted oil and gas fields offer very large storage volumes. Possible sites in the North Seas, requires further investigation for hydrogen use. Also need to consider competing demands for CO_2 storage	Large (TWh)	Large scale inter-seasonal storage.

Table 8-1: Comparison of hydrogen storage methods

The use of small-scale tank storage will be necessary for balancing local supply and demand at the end application. For example, a small renewably powered electrolyser serving a local demand will need to balance out the intermittent supply from the renewable power. However, tank storage will likely be limited to small scale applications due to cost. For truly large-scale storage to support the wider energy system, geological storage will be necessary.

Under a scenario of mass hydrogen for heating (e.g. Widespread Hydrogen), line packing will be a useful tool for meeting diurnal variability using the storage quantities in dedicated hydrogen transmission lines.

Meeting the seasonal heating demands of our future energy system will be challenging. Current electricity and transport demands remain relatively flat throughout the year, whereas heating demand is highly seasonal. The winter peak demand for gas can be six times greater than the peak demand for electricity. This variability is currently managed by the ability of the gas grid to meet peak demands, and by the storage and import of natural gas in winter to manage the seasonal fluctuation.

Even under a high electrification scenario (e.g. Necessities Only), the use of hydrogen to meet peak electricity demands (through flexible power generation) and to meet inter-seasonal fluctuation (with large scale storage) may be necessary.

An area where hydrogen is attractive is large-scale inter-seasonal storage as it can be stored in large quantities in underground formations (much like how natural gas is stored onshore today). There are other technologies which will compete will hydrogen as a method of large-scale storage, but there is good reason to see hydrogen as a front-runner. Pumped hydro storage is the current means of mass storage but it is subject to geological constraints. Lithium based batteries have advanced tremendously in recent years, but their capacities are still relatively small. The largest battery installation to date was installed by Tesla in South Australia, with a capacity of 129 MWh, its purpose is for grid balancing as opposed to large-scale storage (Hornsdale Power Reserve, 2017). The cost per GWh storage capacity for this battery is estimated to be £220m/GWh, whereas cost of gas storage in salt caverns could be as small as £0.234m/GWh – though this could increase to £100m/GWh with cost of electrolysers and fuel cells (for reconversion to electricity) (Global Warming Policy Foundation, n.d.).

There is a potential salt cavern site in the Wessex basin which has an estimated storage capacity for 577 TWh of hydrogen (Solution Mining Research Institute, 2004). This size could easily meet the inter-seasonal demands of the Western Gateway as demonstrated below.

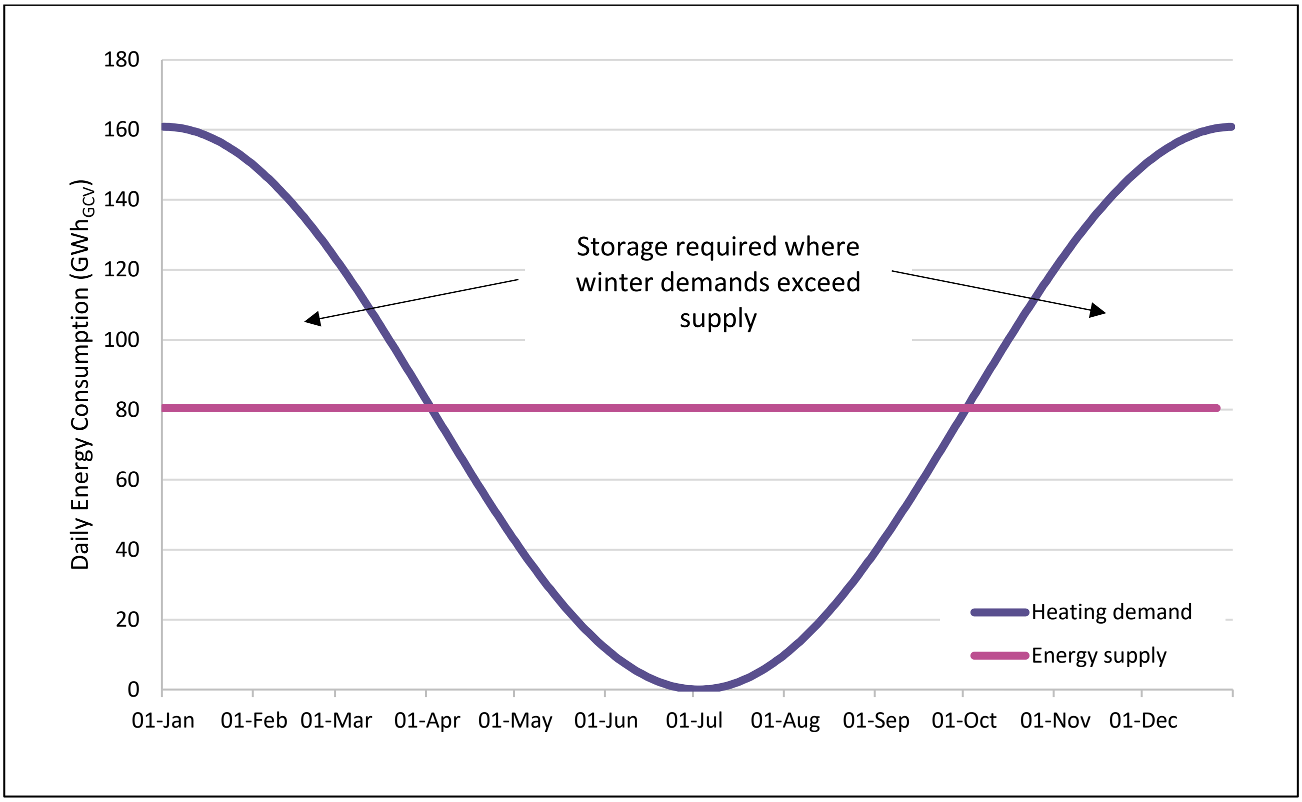


Figure 8-1: Indicative estimate of inter-seasonal storage demands under Widespread Hydrogen scenario

To give an indication of the hydrogen storage which might be required to meet inter-seasonal heating demands of the Western Gateway, a simplistic simulation has been run which assumes a sinusoidal[8] heating demand and a flat energy supply across the year. The energy required from storage is that which is above the flat energy supply line.

In Figure 8-1 above, such a scenario has been plotted for the Widespread Hydrogen scenario which would need a daily hydrogen production of just over 80 GWh to meet the annual heating hydrogen demand of 29,400 GWh. The annual hydrogen demand has then been plotted over the sinusoidal wave which serves as a reasonable approximation of seasonable heating demand profile. The areas above the flat energy supply line would require hydrogen from storage. Accounting for a 3% hydrogen energy loss from storage, and a 1% hydrogen transmission loss, the inter-seasonal hydrogen storage demand under this scenario is 9,730 GWh (less than 2% of Wessex basin capacity).

In the Necessities Only scenario, where heating is provided by heat pumps and direct electric, the stored hydrogen must be converted to electricity. If we assume an average Coefficient of Performance (COP) of 2.5 and a gas boiler efficiency of 85%, then the equivalent electricity required for heating under Necessities Only is 9,980 GWh. This would require daily electricity supply of 27 GWh, and 3,178 GWh of electricity to be supplied from inter-seasonal storage. Accounting for a 3% hydrogen energy loss from storage, 50% efficiency of power generation from hydrogen and a 2% electricity transmission loss, the inter-seasonal hydrogen storage demand under this scenario is 6,690 GWh.

In reality the situation will be more complex, the supply of energy will be variable with higher wind output in winter and higher solar PV output in summer, but this will also be by design with flexible generation. Blue hydrogen production plants could be oversized and run variably throughout the year

[8] For the purposes of this calculation, the heating profile has been simplified as a sine wave.

with increasing output in the winter months. Gas power stations with CCS could also increase output during the winter. Imports of hydrogen from abroad could also be ramped up in winter months. Further analysis is required to determine the most cost optimal means of large-scale energy storage for the Western Gateway.

8.2.2 Import & Export

The Western Gateway has excellent port facilities which could be used to import or export hydrogen internationally or to elsewhere in the UK. Hydrogen could also be transported over its land boundaries either by road, rail or pipeline.

In all scenarios modelled in this study, it was concluded that without blue hydrogen to serve the potential needs of the Port Talbot steelworks, considering only green and waste to be truly indigenous supplies, the Western Gateway is likely an importer of hydrogen (see Table 8-2 below). The UK imports approximately 50% of its natural gas (Heatable, 2022), therefore, blue hydrogen is reliant on an imported feedstock and has therefore not been considered a true supply source.

Hydrogen production	2050 Hydrogen Production (GWh_{GCV})		
	Necessities Only	Balanced Hydrogen	Widespread Hydrogen
Indigenous production (green and waste)	9,350	14,200	23,500
Total hydrogen demand*	28,500	37,900	81,600
Hydrogen surplus/deficit**	-19,200	-23,700	-58,100
Potential demand required to support the Port Talbot steelworks	21,300	21,300	21,300
Sensitivity: Total hydrogen demand without Port Talbot steelworks	7,180	16,600	60,300
Sensitivity: Hydrogen surplus/deficit without Port Talbot steelworks	2,180	-2,380	-36,800

**Possible extra demand for inter-seasonal storage as detailed in section 8.2.1.*

***Hydrogen deficit could be met by scalable production methods (blue and pink hydrogen) or by domestic and international imports. Negative figures indicate deficit.*

Table 8-2: Import and export analysis

Import could come from elsewhere in the UK, the North Sea has high offshore wind capacity, and so could be a large source of green hydrogen supply. Another option would be to import green hydrogen where there are cheap and abundant renewable power supplies. A study by Ricardo estimated the costs of generating green hydrogen in Morocco and Saudi Arabia (high solar potentials) with transportation to Rotterdam by pipeline and ship (Ricardo, 2020). It determined the LCOH from shipping hydrogen, as liquid H_2 or ammonia (NH_3), and pipeline transportation of gaseous hydrogen. The pipeline from Morocco worked out to be €95/MWh. The shipping of ammonia was cheaper than transport of liquid hydrogen and came to €161/MWh and €153/MWh for Morocco and Saudi Arabia respectively. Whilst further analysis is required to determine the cost for transport to the Western Gateway, these costs are greater than the blue hydrogen and green hydrogen costs provided in Table 7-6, and so indicate that import of hydrogen, even from locations with abundant renewable potential, is likely to be expensive. Importing hydrogen does not support the UK's energy security and it is unknown how the international market for hydrogen will develop.

While in all modelled scenarios the Western Gateway would be an importer of hydrogen, if Port Talbot were to decarbonise using an alternative technology to hydrogen, there may be an opportunity to export hydrogen. To demonstrate this, an additional sensitivity has been run in which Port Talbot has zero hydrogen demand (see Table 8-2).

The main scenarios modelled the steelworks to convert to a 100% hydrogen powered DRI-EAF process, with energy consumption the same as the existing plant (21,300 GWh). This makes up a large proportion of the area's total hydrogen demands by 2050 (75% and 56% of the total hydrogen demands under the Necessities Only and Balanced Hydrogen scenarios respectively). Under the sensitivity with zero hydrogen demand at Port Talbot, there is potential for hydrogen export from truly indigenous alone supply under the Necessities Only scenario. This shows the scale of impact of the Port Talbot steelworks on the future of the development of the hydrogen economy in the Western Gateway.

8.3 Other Network Considerations

8.3.1 Hydrogen Leakage

Hydrogen is the smallest atom in the universe and has a high propensity for leakage. This is problematic in terms of useful energy loss, but also because hydrogen itself is a greenhouse gas. Previous estimates have determined hydrogen to have a Global Warming Potential (GWP) of 4.3 over a 100-year time horizon (Derwent, 2018). Which means that over a period of 100 years, 1 kg of hydrogen would cause the same amount of climatic warming as 4.3 kg of carbon dioxide. However, new research by the University of Reading and University of Cambridge has concluded that the GWP of hydrogen could in the region of 11 ± 5 (Warwick, et al., 2022).

Mitigating leakage therefore needs to be considered to maintain carbon savings from its use in displacing fossil fuels.

8.3.2 CO_2 Infrastructure for Blue Hydrogen

Blue hydrogen must have the necessary infrastructure to support the capture and permanent storage of the carbon dioxide by-product in underground geological formations. Blue hydrogen production entails carbon capture and storage solutions in geological formations. A review of the Welsh Government's Petroleum and Planning Policy has shown that it is unlikely for CO_2 to be stored onshore in Wales (Welsh Government, 2021) but depleted oil and gas sites could be an option.

Storing captured carbon in these offshore sites require secure transportation across England. It may be possible to build a CO_2 pipeline from South Wales to Northern England. However, while this has been considered and modelled by the Welsh Government, there are multiple factors that make this an unattractive solution for the area. The pipeline would cause significant environmental disturbances and securing the planning permission for such a long-distance pipeline would be difficult. Also, using a pipeline for transportation limits flexibility in the volume of CO_2 transportation, as it will have to be sized to meet an expected demand. Should CO_2 volumes reduce for example as production moves away from blue hydrogen longer-term, the pipeline would be oversized and therefore a become a sunk cost (Welsh Government, 2021).

The alternative to using a pipeline for transportation, is shipping. Although, forecast to be marginally more expensive than the pipeline alternative, shipping provides greater flexibility to ramp-up and ramp-down CCS with future demand. Shipping is currently seen as the most viable method of CO_2 disposal for Wales, by the Welsh Government (Welsh Government, 2021). Port Talbot and Milford Haven have been identified as possible blue hydrogen production sites due to their port facilities which could accommodate CO_2 disposal via shipping.

8.3.3 Water Demands for Electrolysis

Large volumes of purified fresh water are required for electrolysis. Seawater cannot be directly used due to the presence of dissolved salts which cause corrosion on the electrodes. When there are a lack of alternatives, seawater may be pre-treated in a desalination plant, however this is undesirable because the purification requires additional energy (Ricardo, 2020). Water availability and depletion risk are therefore a very important consideration in the development of hydrogen production facilities.

To produce hydrogen via electrolysis, around 9 litres of purified water is required per kilogram of hydrogen (Ricardo, 2020). Therefore, 270 litres of purified water (or 655 litres of seawater) are needed per 1 MWh of hydrogen. The quantities of hydrogen production from electrolysis under the supply scenarios are 9,210 and 22,900 GWh_{GCV} under Necessities Only and Widespread Hydrogen respectively. This equates to 2,490 and 6,180 million litres of water respectively. To put this in context, the population of the Western Gateway is estimated to consume around 625 million litres of water every year, based on a population of 4.4 million people consuming the UK average domestic water consumption of 142 litres a day per person (Western Gateway, 2019). Further analysis is required to determine the means of supporting such a large increase in freshwater demand for electrolysis.

8.3.4 Hydrogen Purity Requirements

Chemical purity defines how much of a single compound or element a substance contains. It is often quoted as a percentage of (e.g. 99.99% hydrogen) and therefore also defines the quantity of impurities in the substance. Impurities can interfere with the proper functioning of the end-use application and so consideration of the chemical purity is important. In particular, the impact on PEM fuel cells is more significant than other technologies. PEM fuel cells require "ultrapure" hydrogen, whereas combustion technologies are more accommodating. PEM fuel cells are most likely to find application in transport (road, aviation) and power generation.

Furthermore, different hydrogen production technologies produce hydrogen to differing levels of purity. Green hydrogen is produced at a higher purity level than blue hydrogen. Hydrogen can be upgraded to remove impurities prior to use in a fuel cell either via Temperature Swing Adsorption (TSA) or Pressure Swing Adsorption (PSA).

As noted in Section 3.4, a critical decision needs to be made on the purity standard within dedicated hydrogen transmission and distribution networks. Hydrogen could be cleaned of impurities prior to injection into the grid, or it could be cleaned close to the end-user.

The Hy4Heat programme commissioned by DESNZ produced a series of specifications and recommendations on hydrogen purity (DESNZ, 2019). They conducted a cost-benefit analysis to determine a proposed purity specification for the grid. It was found that for some scenarios (i.e. a scenario with high hydrogen transport demand and lower heat / combustion hydrogen demand), the ratio of hydrogen PEM fuel cell demand to hydrogen combustion demand may make it more cost-effective for the grid to deliver hydrogen at the ISO/DIS 14687 standard suitable for vehicle PEM fuel cells, rather than at the lower purity level. However, many of their scenarios showed the opposite, and the overall system cost was lower when hydrogen was delivered at a lower purity level. The two largest uncertainties were the costs of purification at the point of use for PEM fuel cell applications, and the future demands for hydrogen from the grid used in PEM fuel cell and combustion applications. Also, through stakeholder engagement with gas network operators, it was found that the general view was that it is not feasible to distribute high purity hydrogen through the gas distribution network.

The Hy4Heat study proposed a draft specification of a hydrogen purity standard for the grid which is suitable for most domestic end-use applications, but not suitable for PEM fuel cells. It recognised that delivery of hydrogen through an established pipeline network may result in pick-up of existing trace contamination. This proposed hydrogen purity specification had the following implications on green and blue hydrogen production:

- Hydrogen produced by electrolysis and then dried with TSA would meet this standard.
- Hydrogen produced by an ATR or SMR with carbon capture and no further purification would not meet this standard (due to high CO and higher methane, carbon dioxide and total hydrocarbon content). However, with purification using PSA, which is currently industry standard practice, this standard could be met.

9 Developing the Western Gateway Hydrogen Economy

Chapter in Brief

This chapter summarises the capital expenditure and investment that is likely to be required to deliver they hydrogen ecosystem in the Western Gateway. It then considers the potential economic benefits including potential employment generation.

9.1 Economic Modelling & Analysis Approach

The transition to a hydrogen economy has several complex effects. Some of these effects can be identified as being hydrogen-specific while others may also be associated with alternative decarbonisation pathways, for example in large-scale renewable energy. Some effects may be permanent, while others may be more temporary; for example, associated with the major construction and retrofit works required to transition to a net zero economy.

It should be noted that opportunities to deliver economic benefits exist across all technology-led transition pathways. Our economic modelling approach and analysis seeks to identify the benefits that could be attributable to hydrogen under different future scenarios. Our analysis naturally builds on our hydrogen scenarios, assessing the implications in each case on capital investment and employment, considering the role of hydrogen production, end-use and relevant network infrastructure. While export of hydrogen from the area is a feature in only a limited number of future scenarios, wider opportunities to export knowledge, products, services and solutions are widespread. To frame the scale of the export opportunity we assess local strengths and capabilities against emerging export opportunities.

Section 9.3 to Section 9.3 summarise the outcomes of our analysis, with full modelling results also available in Appendix F.

9.1.1 Economic Benefits & Risks

The transition to a net zero economy can provide significant benefits to the Western Gateway through three core mechanisms:

- **Direct employment** and **local multiplier effects** within the economy
- **Improvements to productivity** through process efficiency and cost reduction and
- **Export potential** of technologies, products and services.

At the same time, the transition to a net zero economy presents risks for the local economy, such as hard-to-decarbonise industries which represent high-value within the Western Gateway.

The quantitative element of our analysis focuses on the net local job creation and capital investment requirements for the area. The analysis aims to identify areas of additionality associated with hydrogen as a technology, while framing this within the wider opportunity of the transition to net zero.

9.1.2 Limitations of Approach

An economic model for the hydrogen economy is a complex and multifaceted undertaking, with several important limitations. One of the primary challenges is the scale of the hydrogen economy, which involves a vast number of possible pathways and a wide range of different sectors, from production and transportation to storage and end-use applications. Additionally, research in many of these sectors is still emerging, making it difficult to fully understand the potential costs, benefits, and trade-offs of different hydrogen pathways. Furthermore, it is important to consider the potential impact on employment, as some jobs may be created through other net-zero pathways. Despite these limitations, the development of an economic model for the hydrogen economy is an important step in understanding the potential benefits and costs of this emerging technology. Below we list some important limitations of, and explicit exclusions from the model.

- **Renewable Energy:** All scenarios include a sizeable increase in the deployment of renewable energy. As this is common to all scenarios the additional employment effects of renewable energy scale-up (including scale-up to 5.6 GW of solar) are not included in the figures.
- **Cost-Competition:** There are multiple competing technologies within each sector and transition pathway including sector such as Steel. The future cost pathway of each technology is highly uncertain and depends on a range of factors, including efficiency impacts, technological learning, scalability, long-term input costs, government support, future carbon taxes, operational impacts and competition within the market. Availability of cost evidence also varies based on the maturity of the technology in question, with a lack of consistency regarding the availability of future projections. While the hydrogen up-take assumptions within our scenarios are fixed based on the earlier technical scenarios, the cost-optimal pathways may differ considerably.
- **International Competition:** International competition and regulation will also have a significant effect on the long-term evolution of key industries in particular Steel and Cement which play an important role within the Western Gateway. For example, if international products with high carbon intensities are allowed to compete freely with domestic supplies, this could disadvantage key industries within the Western Gateway. Under such a scenario, jobs within these key sectors might be at risk even if there has been strong delivery on decarbonisation. Our future scenarios assume that decarbonised sectors will be insulated from such competition through regulatory mechanisms such as carbon pricing.
- **Sectors:** Transition jobs and costs have been estimated for the most significant sectors based on the number of sites and processes within the Western Gateway area. As this site-based assessment includes sites used within Marine, Aviation and Rail etc., care was taken to ensure no double counting of the effects. However, there may be additional specific cost or job impacts within these sectors that are not identified through this approach.
- **Technology Costs and Sources:** The figures used in the model have been drawn from numerous sources across multiple sectors. In each case we have made assumptions regarding the most likely technologies in-use by 2050 (for example Autothermal Reformation vs. SMR) using the most authoritative cost estimates identified for the relevant technology. Despite this, different sources often apply different methods or assumptions which influence the cost estimates. To mitigate this, where possible, cost estimates / forecasts have been compared across multiple sources.
- **Investment Timings:** There is high uncertainty regarding the timings of investment. Dates have been drawn from public documents and research where possible. However, given the uncertainty regarding the precise dates for investment, discounting could have a material impact on the results. In addition, to secure competitive advantage for the area, it is preferable that investment is pulled forward – discounting might imply a preference for delaying these large investments. Capital investment figures are therefore presented in current prices based on our expected timing without discounting applied.

9.2 Key Considerations & Assumptions

The economic scenarios largely mirror the technical scenarios set out in Chapter 5. In this section we set out some of the key considerations and assumptions used in assessing capital expenditure requirements and potential economic benefits.

9.2.1 Port Talbot

Tata Steel's plant at Port Talbot is one of the most important private sector employment sites in Wales in terms of direct employment, indirect and supply chain impacts. Tata Steel employs around 8,000 people through Wales, with around 4,000 employed at the Port Talbot site with operations estimated to directly generating 3% of total Welsh GVA (Pinto, 2012).

The multiplier effect of these jobs in the economy has been previously estimated at 2.22, suggesting that every job at Port Talbot supports another 1.22 jobs in the wider economy. Written evidence to parliament provided in 2021 contains a detailed discussion of the decarbonisation options and possible costs for the Port Talbot site. The upper end of the quoted range (£2.2bn) has been used as the base case for the transition of Port Talbot to hydrogen (Tata Steel, 2021; Vogl, 2018).

9.2.2 Aberthaw Cement Works

As per the technical scenarios, Aberthaw Cement Works is split out for treatment separately. In this case, technology costs (approximately £892m) for retrofit of a hydrogen-based cement process were sourced from the DESNZ Innovation Programme. Note that the cost figures used cite an uncertainty of +/- 35%. Costs can be applied based on an estimate of clinker tonnage for the site, which is estimated at 1,110 $t_{clinker}$/day-1,200 $t_{clinker}$/day.

9.2.3 Hydrogen Production

Hydrogen production jobs and capital investment have been estimated based on the GW of production from the technical scenarios and cost data from DESNZ's hydrogen production cost review (DESNZ, 2021). For new dedicated green hydrogen, we have assumed adoption of Proton Exchange Membrane electrolysers based on expectations for cost-reduction post 2025 and expectations of improved pairing with renewables. For blue hydrogen we have assumed widespread adoption of Autothermal Reformation again based on technical advice and expectations of future cost reductions. We also estimate the potential for Energy from Waste (EfW) assuming gasification as the core technology [note that retrofit of existing EfW with an electrolyser may be more cost-effective where EfW plant already exists]. Finally, operational jobs are estimated based on DESNZ 's operational expenditure forecasts and appropriate average sectoral wages.

9.2.4 Transmission & Distribution

Again, our forecasts seek to mirror the technical scenarios as set out in Chapter 5 where the key sensitivity relates to the national strategy on use of the gas grid (expected in 2026). In the Necessities Only scenario the gas grid is not switched to hydrogen which raises questions as to whether it would be decommissioned and at what cost. Due to the lack of evidence identified through our review it has not been possible to include decommissioning costs in any of the scenarios. We believe it is essential that more work is done in this area to understand the likely costs and how these would be addressed. This is consistent with the conclusions of previous reviews of this area (DNV, 2022; Deasley, 2016).

In each scenario we have assumed a net jobs impact; for example, in necessities only we assume 100% of gas grid jobs are lost, but that some are replaced by increased jobs in electrical networks. The Widespread Hydrogen Scenario also includes expectations for the build of a new pipeline. The impact of this has been estimated based on a cost of £10.5m/km and an expected pipe length of 120km (based on research estimates that hydrogen pipelines will be 3.7x more costly than natural gas pipeline modification) (Lee, 2022). This would equate to a total cost of £1.3bn. We have taken the high-end of cost ranges in this case to accommodate the risk of additional infrastructure and wider network pre-requisites not yet known.

9.2.5 Hydrogen Demand/End-uses

Demand scenarios are complicated by the fact that the precise decarbonisation route for each sector is not yet known. In some sectors there is high competition from alternatives to hydrogen. In these sectors, it is important to note that irrespective of whether the future decarbonisation pathway includes hydrogen or not, there are likely to be major shifts in jobs and skills. For example, irrespective of whether hydrogen or heat pumps become the main technology for decarbonising heat, 1.9m households within the Western Gateway would need to be transitioned to a new fuel. This transition would require new business propositions, new jobs and new skills with opportunities on offer if the pathway is hydrogen-based or electric-based.

In contrast there are some sectors where there are very few alternatives to hydrogen; often in so-called *'hard-to-decarbonise'* sectors. While there is some residual possibility that non-hydrogen alternatives are found within these sectors the most likely pathway at this point is that hydrogen will play a major role in these areas. Table 9-1 sets out our categorisation of hydrogen's likelihood of being the predominant decarbonisation pathway within each sector. Alongside this, Table 9-1 also presents the associated sectoral employment within the Western Gateway based on an analysis of granular Business Register and Employment Survey (BRES) data based on Standard Industrial Classification of Economic Activities (SIC) codes.

Sector	Western Gateway Existing Employment (2021)*	Likelihood and Impact of Hydrogen on Decarbonisation
Aviation / Aerospace	23,400	High
Marine / Shipping	3,130	High
Industry (Steel)	10,800	High
Industry (Cement)	2,260	High
Industry (Chemicals)	19,700	High
Industry (Other)	146,000	Medium
Rail	3,360	Medium
Road Freight	15,900	Medium
Heating	9,120	Medium
Construction	85,700	Low
Agriculture	27,500	Low
** Latest available data at the time of report production*		

Table 9-1: Likelihood and Impact of Hydrogen on Decarbonisation

Table 9-2 sets out more detail about the meaning of these categories and the implications for the Western Gateway investment strategy.

Category	Description	Impact	Suggested Response
High	Hydrogen is highly likely to play a role in decarbonisation of the sector, either as a direct fuel or as part of a new fuel or process.	Without investment in hydrogen, it is unclear that these sectors can successfully decarbonise creating long-term risks such as increased competitive pressures or reduced demand.	Western Gateway will need to secure investment in these areas to ensure the area remains competitive while also identifying opportunities to secure long-term competitive advantage.
Medium	Hydrogen faces competition from other decarbonisation technology options such as electric.	If the area fails to invest in hydrogen and hydrogen becomes the dominant pathway, competitive advantage will be lost.	Western Gateway will need to invest in both hydrogen and alternatives to ensure it remains competitive under all transition scenarios.
Low	The roles hydrogen could play represent a smaller part within a wider system where competition from alternatives is also present.	Hydrogen-specific risks are more limited, but investment will still be needed across a wide-range of decarbonisation technologies.	Industry-specific deep-dives will support identification of wider technology needs that can be matched to local expertise.

Table 9-2: Sector categories and their implications for the area.

9.2.5.1 The Importance of Developing Cost-Effective Hydrogen

As set out above, hydrogen options are being developed within an increasingly competitive market for decarbonisation technologies. Long-term transition to hydrogen will depend heavily on the cost compared to existing options, the lifetime cost to the consumer (including both direct CAPEX, operational costs and wider system costs), and the cost progress of other technologies, most notably electric alternatives.

Consideration of the competitive dynamics is especially important in areas of net zero transition where there is high competition from alternative decarbonisation technologies; for example heating and road transport (see Table 9-1). In these areas there is significant opportunity in the transition to net zero, but hydrogen's role will depend heavily on its competitiveness. Table 9-3 summarises some of the evidence reviewed in these key competitive areas. In these areas it will be important for the Western Gateway to invest across different decarbonisation technologies to ensure it remains resilient and competitive under different economic scenarios.

Sector	Cost and Competition Considerations
Heating (e.g. Domestic)	There is some uncertainty over the relative cost of hydrogen compared to heat pumps. If hydrogen infrastructure can safely provide a direct replacement, then the capital cost of switching could be comparable with existing gas boilers in the region of £730-£1,300 by 2030 (Hydrogen Council, 2020). Another evidence review puts the total cost at £3,000-£4,000 (Castec, 2021). However, the latter study notes that appliances may need to be replaced with hydrogen-ready ones. Other studies have raised the risk that hydrogen would increase costs for home heating compared to gas meaning that over the life-time heat from hydrogen is not cost-competitive (Cornwall-Insights, 2022) (Baldino, 2021). Long-term adoption therefore depends on both capital and operational costs in comparison to both existing gas and electric heat pump alternatives.
Road Transport (Freight)	Another area of significant uncertainty is the future trajectories for longer-distance transport such as HGVs. Again, different sources provide different views on the relative competitiveness of hydrogen vs. electric. For example, Sharpe (2022) states that the cost of battery-electric trucks will range from the equivalent of £160,000-£650,000 while fuel-cell equivalents will range from £160,000-£490,000. Other studies question the competitiveness of hydrogen (Plötz, 2022). On the infrastructure side, research for the CCC finds that hydrogen is a cost-effective zero emission option in terms of infrastructure costs. However, when considering the impact of fuel and infrastructure, battery electric emerges as more economically attractive (Weldon, 2020). Long-term adoption of hydrogen therefore depends on the competitiveness of both vehicles, infrastructure and fuel.

Table 9-3: Hydrogen Cost Comparison to Alternatives

Cost competitiveness also has a potential impact on demand in certain sectors such as aviation. Higher costs of aviation fuels could reduce overall sectoral demand. Research reviewed indicates that the aviation sector could manage the cost increases associated with the transition to sustainable aviation fuels, with ticket prices rising by no more than 15% compared with a no-intervention baseline. However, such an increase would likely suppress demand by ~14% (Dray, 2022). The decarbonisation pathways identified will require discounted investments on the order of US$0.5–2.1 trillion over a 30-year period. The modelling undertaken does not include any scenarios for different levels of overall service/sector demand.

9.3 Capital Expenditure Requirements & Timescales

In July 2021, the Hydrogen Council estimated total global investment into the hydrogen economy at $500bn by 2030. Investment in hydrogen will also stimulate sizeable investment within the Western Gateway, with up to £63bn of capital investment likely to be directed to hydrogen projects under the Widespread Hydrogen (high hydrogen) scenario. Even under the Necessities Only scenarios, levels of investment will still be in the order of £11bn as part of the wider push towards net zero.

Table 9-4 sets out the capital investment requirements under each of the hydrogen scenarios including investment in new hydrogen production, new (known) transmission networks and investments required to transition end-uses to hydrogen. Under the Widespread Hydrogen scenario, £13bn will be required for new production infrastructure, at least £1.3bn will be required for transmission lines and £48bn could be required for the transition of end-uses. Transport represents a significant component of this transition activity given the number of HGVs registered within the Western Gateway area, cost of conversion and associated re-fuelling infrastructure.

Total Capital Expenditure to 2050	Necessities Only (£m)	Balanced Hydrogen (£m)	Widespread Hydrogen (£m)
Production Related Capital Expenditure			
New dedicated green hydrogen electrolysis	2,120	3,300	5,180
Blue Hydrogen from ATR + CCUS	3,620	5,550	7,730
Energy from Waste (Gasification)	48	95	153
Total Production (£m)	**5,790**	**8,940**	**13,100**
Transmission and Distribution (T&D) Capital Expenditure			
New Gas Transmission Network	1,010	1,010	1,260
Total T&D (£m)	**1,010**	**1,010**	**1,260**
Transition Capital Expenditure			
Domestic sector investment	0	946	6,620
Port Talbot Hydrogen Conversion (all scenarios)	2,200	2,200	2,200
Aberthaw Cement Works	892	892	892
Other Industry	1,620	1,620	2,310
Freight sector and associated infrastructure	0	18,100	36,200
Total Transition (£m)	**4,710**	**23,700**	**48,200**
Total Capital (£m)	**11,500**	**33,700**	**62,500**

Table 9-4: Direct Capital Expenditure Impacts Under Hydrogen Scenarios

Table 9-5 sets out the potential timing of the capital expenditure under the Widespread Hydrogen scenario based on the evidence reviewed. However, we believe that to secure competitive advantage it may be necessary to pull-forward investment to earlier years where possible as delay will allow other regions to take a lead.

	2020	2025	2030	2035	2040	2045	2050
Total Production (£m)	0	0	0	1,630	3,050	3,730	4,660
T&D Investment (£m)	0	0	0	0	1,260	0	0

	2020	2025	2030	2035	2040	2045	2050
Transition Investment (£m)	0	175	819	4,790	21,000	18,800	2,660
Total Investment (£m)	0	175	819	6,420	25,300	22,500	7,330

Table 9-5: Capital Expenditure by Period, Widespread Hydrogen Scenario

It is important to note that most of this investment is expected to be funded by the private sector, however appropriate incentives will need to be in place to ensure that hydrogen is supported to compete.

Section 9.2.5.1 sets out the need to ensure there is national support in key sectors to encourage private sector investment. Key decisions, such as the decarbonisation pathway for Port Talbot (assumed at £2.2bn), are expected to require national government backing. Support for investment in production and transition activities will also need to be forthcoming in the 2025-2030 period to stimulate activity at the scale required.

9.4 Potential Economic Benefits to the Western Gateway

Above we have set out the complex factors that have been considered in forecasting jobs associated with the hydrogen economy. Our analysis indicates that the Western Gateway could play a major role in the growth of the hydrogen economy within the UK, with investment supporting 12,500 direct jobs. Once appropriate job multipliers are applied, the total employment benefit could be 27,000. Early investment in hydrogen will also act to protect essential employment in hard-to-decarbonise sectors. Stalling investment risks a loss of competitiveness for the area which could endanger 60,000 direct jobs in hard-to-decarbonise industries.

Direct Jobs: Table 9-6 sets out the direct job forecasts for each of the hydrogen scenarios including the net effect of job gains (from production and transition) and job losses (from decommissioning effects of the gas grid network under Necessities Only and Balanced Hydrogen scenarios). The table shows that under the Widespread Hydrogen scenario we expect 12,400 jobs within the Hydrogen sector. Even in the Necessities Only scenario there is expected to be net job creation within the Hydrogen sector in particular focused on decarbonisation of industry and associated production.

Direct Jobs by 2050	Necessities Only	Balanced Hydrogen	Widespread Hydrogen
Production			
New dedicated green hydrogen electrolysis	513	790	1,260
Blue Hydrogen from ATR + CCUS	756	871	1,330
Energy from Waste (Gasification)	17	35	55
Total Production Jobs	**1,290**	**1,700**	**2,640**
Transmission and Distribution			
Losses from Distribution	(1,330)	(667)	0
Gains / Losses from Transmission	(148)	(74)	74

Direct Jobs by 2050	Necessities Only	Balanced Hydrogen	Widespread Hydrogen
Total T&D Jobs	**(1,483)**	**(741)**	**74**
Transition Activities			
Domestic sector installations and maintenance	0	471	3,300
Industrial sector installations and maintenance	797	797	1,140
Freight sector conversions and infrastructure	0	2,640	5,280
Total Transition Jobs	**797**	**3,910**	**9,720**
Total Jobs	**601**	**4,860**	**12,400**

Table 9-6: Direct Job Impacts Under Hydrogen Scenarios

Table 9-7 sets out the expected jobs growth under the Widespread Hydrogen Scenario. Earlier investment is expected to enable these jobs to be bought forward and so accelerated investment is expected to be beneficial for the area.

	2020	2025	2030	2035	2040	2045	2050
Total Production Jobs	0	0	0	875	1,710	2,100	2,600
T&D Jobs	0	0	15	30	44	59	74
Transition Jobs	0	124	520	2,220	9,720	9,720	9,720
Total Jobs	0	124	535	3,130	11,500	11,900	12,400

Table 9-7: Jobs by Period, Widespread Hydrogen Scenario

Job Protection: Section 9.2.5 sets out the risks to hard-to-decarbonise industries in the case that decarbonisation is not achieved. Table 9-8 summarises the current employment within these hard-to-decarbonise sectors. Employment in these sectors is considerable representing 2.8% of Western Gateway's employment. Given the likely dependence on these sectors to hydrogen within a net zero future, investment in research, development and demonstration within these industries is expected to be essential to ensure jobs are protected. Early decisions regarding transition pathways in key sectors will also support the development of the wider hydrogen economy.

Sector	Western Gateway Employment
Aviation / Aerospace	23,400
Marine / Shipping	3,130
Industry (Steel)	10,800
Industry (Cement)	2,260
Industry (Chemicals)	19,700
Total Hard-to-Decarbonise	**59,300**

Table 9-8: Jobs in Hard-to-Decarbonise Sectors

9.5 Summary

Given the crosscutting nature of hydrogen, spanning multiple sectors, professions, and supply chains, the economic opportunity from the hydrogen economy, across all modelling scenarios, is extensive. Covering all major use cases and home to international businesses and world-class research institutions, the Western Gateway is ideally placed to demonstrate, scale and commercialise large-scale hydrogen to support a net zero transition.

The Western Gateway's geography, business make-up and existing strengths make the area a key asset in the UK's goal to become a *'world leader in the development, deployment and build-out of hydrogen infrastructure across the full value chain, covering production, transmission and storage, and the range of potential end uses for hydrogen, including power, heat, and transport'* (HM Government, 2021). This includes delivery of leading UK research and development opportunities to unlock exports and international growth.

Analysis by DESNZ indicates that every GW of hydrogen production could mobilise £0.9bn in investment and create 1,200 jobs by 2030, with additional benefits across the wider supply chain (DESNZ, 2022). DESNZ estimates that the hydrogen economy could support 100,000 jobs in the UK by 2050 (ibid). While there are many complex factors to consider in forecasting, our analysis indicates that the Western Gateway could play a major role in this growth, with investment supporting 12,500 direct jobs, 27,000 jobs in total, while acting to protect essential employment in hard-to-decarbonise sectors. Stalling investment risks a loss of competitiveness for the area which could endanger 60,000 direct jobs in hard-to-decarbonise industries.

Investment in hydrogen will also stimulate sizeable investment, with up to £63bn of capital investment likely to be directed to hydrogen projects under the Widespread Hydrogen (high hydrogen) scenario. Even under the Necessities Only scenarios, levels of investment will still be in the order of £11bn as part of the wider push towards net zero.

10 Innovation Strengths & Capabilities

Chapter in Brief

This chapter identifies the innovation capabilities in the Western Gateway, showcased through academia, research, industry and academia working in a collaborative and cross-sector effort. The broad organisational landscape of collaborations and innovators has been detailed to highlight the variety of activities underway across the Western Gateway and present why the Western Gateway is a leading hydrogen cluster.

10.1 Western Gateway Strengths, Collaborations and Clusters

The Western Gateway has grown to be a well-placed and potentially transformative test bed for developing the UK hydrogen economy. The area benefits from industry, research and development collaborations and umbrella organisations which are bringing together hydrogen innovators to form unique regional strengths. The broad mix of organisations yields a diverse landscape of development (such as mobility, industry, aerospace and infrastructure) which is showcased from cutting edge scientific research to industrial integration and testing.

By leaning on many of these organisations' technical strengths and domain expertise, innovation within the Western Gateway area can drive delivery of national imperatives for a wider hydrogen economy. The area is home to a breadth of organisations with vast experience as market leaders in their fields and in tackling the integration of technical challenges, such as improving efficiencies to reduce carbon emissions and embed circular economy principles.

These partnerships support an accelerated development of the hydrogen economy by combining expertise and uniting a supply chain to develop and deliver technology from design and development through to implementation and use. The collaborations also offer economic potential for SME growth in the area through joint ventures and the establishment of an end-to-end value chain within the Western Gateway.

Some of the key clusters and collaborations in the Western Gateway include:

- The **GW4 Alliance** which brings together four of the most research-intensive and innovative universities in the UK: Bath, Bristol, Cardiff and Exeter. The alliance promotes collaboration and innovation by drawing together the research capabilities of the four member universities.
- **Hydrogen South West** is a collaboration covering the South West region to establish links between supply and demand centres in the region, and enabling cross-sector partnerships that will drive the development of hydrogen infrastructure and technology. Its founding members include: Airbus, Bristol Airport, Bristol Port Company, Costain, easyJet, GKN, Hynamics, Wales and West Utilities, Wessex Water and Wood/WSP.
- The UK's largest **aerospace cluster** is within the Western Gateway area, being home to 14 out of 15 of the world's leading aerospace organisations which are driving forward innovation with the use of hydrogen for flight. With this strength of potential and expertise, the cluster will have a significant role in driving the transition to sustainable aviation fuels and direct hydrogen use in aviation. Such organisations include: Lanzatech, Airbus, easyJet, GKN, Rolls-Royce and ZeroAvia.
- Representing the second largest industrial cluster in the UK, the **South West Industrial Cluster (SWIC)** is a collaboration of over 40 industrial organisations working together to drive forward decarbonisation of industrial activities in South Wales. Key to that is a unified ambition to

understand the future role of hydrogen in industrial decarbonisation, whilst further strengthening the profile of the area nationally.

- **Significant maritime activity** across several ports including Bristol Port, and those operated by Associated British Ports (ABP): Swansea, Port Talbot, Barry, Cardiff and Newport. As well as being potential demands for hydrogen for use as a shipping fuel (or as a derivative such as ammonia or methanol), ports provide the infrastructure to import or export hydrogen to neighbouring regions, and could support the shipping of carbon to storage facilities.

10.2 Hydrogen Innovation in the Western Gateway

Facilities and organisations within the Western Gateway are pioneering initiatives and technologies in the industries which could help to shape a national hydrogen economy. Hydrogen innovation within the Western Gateway area will unlock the vast benefits to the economy locally, as well as extending far beyond its borders. Innovation within the area can have a direct local impact through supply chain building, SME growth, and the potential to develop whole value chains from design to manufacture in the area. Over time, innovation can be translated into commercial offerings, opening the potential for the export of technologies and ideas.

10.2.1 Organisations involved in Hydrogen Innovation

Some of the key organisations leading hydrogen innovation in the Western Gateway are summarised below.

The number of organisations which are currently involved or could be involved in hydrogen innovation is extensive. It is difficult to comprehensively determine all innovation activities due to the confidential nature of some of the research which will be happening. This chapter therefore does not present an exhaustive list of all activities within the Western Gateway, but gives an appreciation of

Universities

- University of Bath
- University of Bristol
- Cardiff University
- University of Exeter (via GW4 alliance)
- University of South Wales
- University of Swansea

Research & Innovation Centres

- Global Centre of Rail Excellence
- Institute for Advanced Automotive Propulsion Systems (IAAPS)
- National Composites Centre (NCC) (part of High Value Manufacturing Catapult (HVMC))
- University of South Wales Hydrogen Research and Demonstration Centre

Figure 10-1: Universities and Research & Innovation Centres in the Western Gateway the breadth and excellence of innovation activities which complements the work already undertaken to map the area's hydrogen assets: Western Gateway's Hydrogen Ecosystem Interactive Map.

The diagram above presents some of the key organisations involved in hydrogen innovation across the Western Gateway, as of 2023. A snapshot of hydrogen innovation activities currently underway amongst these organisations is given in the following section, alongside some examples of private sector led research and innovation. It should be noted that innovation activities change and develop rapidly, and therefore progression of activities since time of writing should be expected.

10.2.2 Hydrogen Innovation Activities

10.2.2.1 Universities

- The **Bath Beacon** is an interdisciplinary research group within the **University of Bath** focused on the production, storage, distribution and end use of hydrogen and hydrogen carriers such as ammonia. Assets within the **University of Bath** may be further supported in the near term if successful in securing funding for the **UK-HyRES** project which seeks to drive the growth of low carbon hydrogen and alternative liquid fuels.
- Working with industry, the **University of Bristol** is developing a novel hydrogen storage demonstrator (**HyDUS**), in which hydrogen is absorbed on a depleted uranium 'bed', which can then release the hydrogen when needed for use. The hydrogen storage approach is aimed at longer-term energy storage, and to enable improvements in energy storage density.
- Research groups at **Cardiff University** are developing an **Ammonia Centre** to support research into future use of ammonia as a fuel. The **Hydrogen and Electric Propulsion Innovation Centre (HEPIC)** at St Athan, part of **Cardiff University**, is developing new hydrogen fuel cell flights systems as part the Design and development of hybrid electric propulsion system for regional aircraft (DragonFLY) project.
- Through the **GW4 alliance** the area has access to solar powered hydrogen production expertise from the **University of Exeter's Penryn Campus**. In addition, the **Centre for Future Clean Mobility based** at the **University of Exeter** specialises in developing powertrain technology for cleaner mobility of humans and goods. Through the university, the area has access to wider maritime propulsion research such as that being carried out at the Appledore Clean Maritime Innovation Centre.
- The **Sustainable Environment Research Centre** at the **University of South Wales** is a world-leading research centre investigating sustainable hydrogen production, storage and application at the Baglan Energy Park in Port Talbot and Laboratories in Pontypridd.

10.2.2.2 Research & Innovation Centres

- The **National Composite Centre (NCC)** has specialist capabilities in composites to support innovation in the design and development of hydrogen pressure vessels, pipes and sustainable storage solutions. This includes research and development into high-cycle, flight-worthy cryogenic storage tanks.
- The **Institute for Advanced Automotive Propulsion Systems (IAAPS)** is a centre of excellence for research, innovation, enterprise, and education supporting the future direction of the propulsion industries. In Spring 2023 its green hydrogen manufacturing capability was set to become operational, forming the centrepiece of the newly created **Hydrogen Sustainable Transport Economic Acceleration Hub at the Bristol and Bath Science Park**. 50% of their business is in aerospace including a major partnership with **GKN**.

- The **Global Centre of Rail Excellence** is currently being developed in Newport and could become a testing area for hydrogen rail.
- The University of South Wales **Hydrogen Research & Demonstration Centre** provides a platform for the experimental development of renewable hydrogen production and novel hydrogen energy storage. The centre enables further research and development of hydrogen vehicles, fuel cell applications and overall hydrogen energy systems. The Centre is the focal point for a series of collaborative projects between the University of South Wales and other academic and industrial partners.

10.2.2.3 Private Sector

It is particularly difficult to comprehensively represent all the private sector hydrogen innovation activities across the Western Gateway, not just due to the sheer number of private sector actors across a variety of industries, but also due to the confidential nature of the work. This section therefore provides a summary of some key strength areas and lists just a few specific examples. It is not a complete list of all innovation activities, and the activities mentioned do not necessarily cover all of those which are the most important or impactful, instead they are exemplars of the wide-ranging innovation activity in the Western Gateway area.

The **aerospace cluster** containing 14 out of 15 of the world's leading aerospace organisations has leading research which is at the forefront of decarbonising one of the most hard-to-decarbonise sectors: aviation. **GKN** in collaboration with the UK Government, opened the Global Technology Centre (GTC), where it is now leading a ground-breaking UK collaboration programme, H2GEAR, to develop the company's first hydrogen fuel cell propulsion system for sub-regional aircraft. **ZeroAvia** operates its research hub at Cotswold Airport and has undertaken the test flight of the world's largest aircraft powered by a hydrogen-electric engine at Cotswold Airport in January 2023. The **Airbus** Zero Emissions Development Centre based in Filton in Bristol is focused on developing a cost-competitive cryogenic fuel system for passenger aircraft by 2035.

The potential for hydrogen innovation in **industrial processes** is huge given the South Wales Industrial Cluster. There is opportunity for the area to be a test bed for hydrogen powered industrial processes, particularly given the access to large potential supplies of green or blue hydrogen and distribution projects such as WWU's HyLine Cymru (see section 7). **Lanzatech** have recently announced plans for an alcohol-to-jet facility in Port Talbot which can convert sustainable ethanol to sustainable jet fuel. The exact details of this process have yet to be announced but it could be a demand for hydrogen in the future.

The Western Gateway is home to several **road transport** innovators, with a variety test projects for hydrogen road vehicles. **Riversimple** is producing hydrogen vehicles that will offer customers a complementary option to battery electric vehicles in the mission to decarbonise personal transportation. Riversimple is currently trialling its vehicles with customers in Abergavenny, Monmouthshire and Milford Haven. Private hire operator **Hyppo Hydrogen Solutions** is working with South Wales Transport to trial a hydrogen fuelled bus for Swansea University students. The hydrogen fuel is being produced and supplied by green hydrogen developer Protium, using an installation at University of South Wales Hydrogen Research & Demonstration Centre.

10.3 Summary

The Western Gateway has an excellent opportunity to position itself as a key hydrogen cluster of the future. The area can be a pioneer in unlocking a dynamic and productive hydrogen ecosystem bringing economic benefits to the area, as well as contributing to wider national imperatives for decarbonisation.

This significant potential includes the strength of the Western Gateway Hydrogen Ecosystem in aviation innovation; the resulting employment boost from hydrogen development; and the revenue and investment in the area that the Western Gateway could attract. The recent Hydrogen Champion Report supported the South-West of England (incorporating the English side of the Western Gateway) as one of the next set of hydrogen clusters, stating 'though further behind in its planning than Scotland, [it] has an outstanding hydrogen opportunity centred around aviation innovation which could deliver £20bn in regional GVA and 15,000 FTE jobs by 2050' (DESNZ, 2023). The Western Gateway alone is 'aiming to add £34bn to the UK and attract £4bn investment by 2030'.

To support this, there is a need for increased funding centred around hydrogen innovation, to support early-stage and scale-up investments for trialling of hydrogen technologies across the Western Gateway. To accompany this, an innovation grant scheme could support business-led hydrogen solutions to encourage hydrogen innovation and growth. The existing breadth of innovation networks in the area offers the opportunity to further promote hydrogen development by supporting and encouraging new collaborations or other businesses to transition into hydrogen.

11 Workforce and Skills Development

Chapter in Brief

This chapter presents an overview of the workforce and skills development programmes and the future skills need in the Western Gateway. It highlights the current leading-edge initiatives to understand and develop the future hydrogen skills needs, both in the Western Gateway and further afield; and quantifies the retraining that may be required to develop a hydrogen economy to its full potential.

11.1 Hydrogen Skills Development and Requirements in the Western Gateway

The benefits of the development of the hydrogen economy will require a combination of upskilling or reskilling, and new skills development entirely. The Western Gateway area already has a highly skilled industrial workforce which offers an ideal opportunity for retraining.

DESNZ predicts that the UK hydrogen industry could provide 12,000 FTE jobs by 2030, expanding up to 100,000 jobs by 2050. In the section below, it has been determined that approximately 12,000 new jobs may be required in the Western Gateway in 2050, and more than 100,000 existing positions will require retraining for hydrogen. Investment in skills development needs to happen at all levels, from early education to research, industry and academic leaders. Plans will be needed for the short-term as well as investing in those which will increasingly be in demand over the next five years and beyond. The UK Hydrogen Champion Report details the national efforts to begin a systemic, robust and evidence-based approach to the process, such as through Skills Boot Camp programmes, the launch of T-levels and Local Skills Improvement Plans (DESNZ, 2023). Skills leads in the Western Gateway are already active in responding to this recommendation.

11.1.1 Quantification of Hydrogen Skills Requirement in the Western Gateway

Table 11-1 sets out the skills need in the Western Gateway under the Widespread Hydrogen scenario. This table combines the re-training needs for current roles with the forecast additional roles required under the hydrogen economy and discusses the skills requirements within each sub-sector.

In total, hydrogen and associated net zero technologies will require skills provision and action to support approximately 108,000 jobs in the Widespread Hydrogen scenario by 2050. There are numerous roles within hard-to-decarbonise industries, that will need to be upskilled to understand the opportunities afforded by hydrogen, including 14,000 roles in the manufacture of aircraft and related machinery. Transport and heating represent significant potential areas for skills provision with 30,100 and 12,300 potential roles requiring re-skilling to support hydrogen use respectively. Roles in transmission and distribution will also need to be provided training in the management of hydrogen within gas networks under the Widespread Hydrogen scenario.

As noted by the Hydrogen Sector Development Action Plan (DESNZ, 2022), many of the skills needed for a thriving hydrogen economy are shared by other low-carbon or ‘green’ technologies and many of these skills already exist in the UK. Skills such as engineering, procurement, construction and maintenance, project structuring, design and manufacturing, health and safety, commercial finance and legal services are part of the rich portfolio of jobs across higher-carbon sectors such as oil and gas, chemicals and wider engineering sectors that could be re-purposed towards hydrogen projects. The Western Gateway area is well-placed to support the skills agenda, but resources will be required to enable an evidence-based response to skills provision, bringing together skills and education providers with industry to plan for and meet current and future demands. This is aligned to skills development requirements to support low carbon energy production, distribution and use.

Skills Area	Net Jobs Gain (2050)	Total Training Need	Key Skills
Hydrogen Production	2,600	2,600	Jobs in hydrogen production will cover installation, operation and maintenance of electrolysers across multiple technologies. Given the need to integrate electrolysers with energy sources, skills in systems integration are likely to be required.
Transmission and Distribution	75	3,000	While the net gain in the Widespread Hydrogen scenario is 75 jobs, the existing employment base of 3,000 gas grid engineers within the Western Gateway will need to be re-skilled in the transmission and distribution of hydrogen.
Domestic Heating	3,300	12,300	There are currently 9,000 plumbing, heat and air-conditioning installers within the Western Gateway. The workforce is expected to grow by 3,300 to support the net zero transition. Under the Widespread Hydrogen scenario, all 12,300 of these roles would need to be reskilled in the installation, maintenance and safety certification of hydrogen heating systems.
Industrial Hydrogen	1,100	60,500	There are currently 59,300 jobs in hard to decarbonise sectors that are expected to transition to hydrogen under the Widespread Hydrogen scenario. These roles include manufacture of numerous products including 14,000 jobs in the manufacture of aircraft and related machinery. Outside of the key identified sectors there are 146,300 further jobs in other industry. Roles include engineering, design, procurement, construction and maintenance and associated corporate services. Even under the Necessities Only scenario existing professionals will need upskilling and new entrants will need to understand technologies associated with industrial decarbonisation.
Transport & propulsion	5,300	30,100	Other industry referenced above, includes 7,300 jobs in the manufacture of road and rail vehicles (excluding other specialist vehicles). There are a further 17,500 jobs in the maintenance and repair of motor vehicles. We estimate 20% of these (3,500) may need skills in hydrogen transport systems. The sector overall will require re-skilling to support the manufacture and maintenance of zero emission vehicles, with a significant proportion of these being hydrogen under the Widespread Hydrogen scenario.

Table 11-1: Skills Needs (Widespread Hydrogen Scenario)

11.1.2 Hydrogen Skills Development

The continued development of the Western Gateway's hydrogen ecosystem will require a flexible hydrogen skills framework that will allow new and existing employees to access skills development pathways, some of which will be required by other low carbon sectors developing within the energy system. There is still significant uncertainty in the speed of development, scale of the hydrogen economy and impact of the development of the industry elsewhere in the UK, therefore the skills framework will need to be adaptable, with regular foresighting exercises to understand the emerging demands for skills.

Hydrogen Skills Alliance (HSA)

The NCC (part of HVMC) is leading on the Hydrogen Skills Alliance (HSA) in partnership with Cogent - a national skills foresighting programme. It forms part of the cross-catapult Hydrogen Innovation Initiative programme to foresight hydrogen technology, supply chain requirements and skills need.

The HSA convene industry, academia, research organisations, industrial clusters, government and skills bodies and has developed working groups to help define the skills problem, including across production, distribution and aerospace. It aims to ensure that the education and skills system supports the needs of employers through design and availability of the requisite training. The HSA are working with DESNZ and the Green Jobs Delivery Group in government to have a broader view of all hydrogen skills activities nationally.

The development of a hydrogen skills framework has been started across the Western Gateway, with some key examples listed below. These initiatives are being driven by the early hydrogen adopters in the area, and the existing research into future hydrogen skills needs. If the developing framework and initiatives can be linked into national endeavours, such as the Hydrogen Skills Alliance (HSA), it will promote a national, collaborative approach.

- The **Hydrogen South West (HSW) Skills Consortium** has convened skills providers to respond to emerging skills issues.
- Hydrogen Boot Camps are available with delivery led by the **Western England IoT.**
- A programme of hydrogen business awareness webinars has also been produced, drawing on the expertise of Hydrogen South West's members which is hosted by **Business West**.
- **HSW** has established working groups to help define the skills problem and foresighting. working groups include: transportation, gas distribution, marine. HSW Skills Consortium currently comprises: NCC, West of England Institute of Technology, Business West and the West of England Combined Authority.
- **HyCymru**, the Welsh hydrogen trade association, also provides an excellent platform for communication and knowledge-sharing.

11.2 Summary

The transition to net zero will require a significant investment in skills. In total, skills provision in hydrogen and associated net zero technologies may need to be sufficient to support approximately 108,000 roles in the Western Gateway area by 2050 including both new jobs created and re-skilling within existing sectors (under the Widespread Hydrogen scenario).

Many of the future jobs forecast are highly specialist and will require expertise and knowledge in hydrogen production, industrial process, propulsion and transport, manufacture of hydrogen-related equipment and skills in installation, operation, maintenance and safety across a wide range of new technologies. The area would benefit from the development of a Western Gateway Net Zero Skill Plan to map the need for future skills based on existing foresighting work and to understand the range of skills training which will be needed across different areas of the sector and at different education levels. This could then be incorporated into planning with education and skills providers, to understand feasibility for education paths such as degree apprenticeships in hydrogen, and to expand on training which is currently available based on industry feedback.

To support the hydrogen economy in the Western Gateway area, local education providers will need to work with industry to ensure appropriate skills pathways are developed to meet expected demand.

12 2050 Delivery Pathways

Chapter in Brief

This chapter presents the delivery pathways for the Western Gateway area to reach net zero by 2050 for each of the three supply and demand scenarios. They have been developed by consolidating the evidence gathered through the one-to-one interviews with key organisations and the feedback from the consultation exercise, and in doing so, they highlight the opportunities which hydrogen use presents in decarbonising the economy. Key barriers, and constraints to achieving each scenario are also presented to help inform the development of the long-term delivery pathway for the area to achieve net zero.

12.1 Introduction

The benefits of developing the hydrogen economy in the Western Gateway are wide ranging including large scale greenhouse gas savings, the creation of new jobs and safeguarding existing employment through to driving research and innovation, securing capital investment, and attracting new investors. These opportunities are not unique to the Western Gateway area, but the scale of the work underway between the public and private sectors working collaboratively with academia and research and innovation organisations to deliver low carbon energy solutions presents the area with strong foundation to achieve its net zero ambitions and develop a productive hydrogen economy.

The Western Gateway area is home to world leading industry, innovative businesses, leading research organisations, and is positioning itself to become the UK's test bed for hydrogen production, distribution, and use. This ambition can be brought to fruition by building on existing collaborations and accessing research and innovation excellence in the area, such as in propulsion systems, future fuels, hydrogen storage and nuclear energy aligned to hydrogen production.

Realising this ambition would enable the Western Gateway area to take its place on the national stage in driving productive, low carbon hydrogen energy solutions to be developed and delivered, attracting capital investment, and securing international investment projects. In turn, this would unlock additional supply chain development benefits for businesses of all sizes across the whole value chain from design to manufacture in the area, driving business growth and jobs creation. There would be wider benefits through the development of complimentary sector strengths such as in aerospace, as well the extending circular economy benefits including hydrogen from waste and carbon capture and utilisation.

12.2 Strategic Opportunities

A wide range of hydrogen opportunities in the Western Gateway area have been identified through the interviews and consultation exercise which require further investigation, prioritisation and investment set against the emerging hydrogen policy nationally. However, there are some opportunities which can be highlighted now as warranting early investigation.

12.2.1 Jet Zero & Hydrogen Aviation

The 2022, the UK Hydrogen Champion report flagged that the area 'has an outstanding hydrogen opportunity centred around aviation innovation'. The Western Gateway is home to an internationally recognised and embedded aerospace cluster, with 14 out of the 15 world's largest aerospace engineering firms based in the area. Global aviation companies in the Western Gateway area are undertaking world leading research into hydrogen aircraft design and engineering, hydrogen and hybrid engine design and cryogenic fuels with the potential to secure the UK's position as an international leader in sustainable and low carbon flight.

12.2.2 Decarbonising Energy Intensive Industry

Industrial processes are one of the major sources of carbon emissions globally. Finding solutions to decarbonising these are critical to the UK reaching net zero by 2050. The South Wales Industrial Cluster Plan clearly articulates the levers required from governments to support large scale decarbonisation of industry and in doing so generate a potential base load demand for hydrogen production in the area, facilitating the development of the infrastructure required to distribute hydrogen across the South Wales as part of the national distribution network 'Project Union'.

12.2.3 The Ports

The ports can play a crucial role in delivering the infrastructure required to deliver net zero through supporting the construction of major renewable energy projects such as floating offshore wind in the Celtic Sea and ensuring the import of equipment and distribution of low carbon fuels. They will be essential in supporting the shipping of carbon captured from heavy industries to storage facilities elsewhere in the UK or overseas. Work is already in development to decarbonise port operations with the potential to extend this to neighbouring industrial activity. Solutions could draw on a combination of renewable energy and hydrogen production and use as well as carbon capture.

12.2.4 Rail

The Western Gateway area is a centre for rail innovation with industry leaders like CAF in Newport, Siemens in Chippenham, Bristol's Station Innovation Zone and the forthcoming Global Centre for Rail Excellence (GCRE) in South Wales. Opening in 2025, GCRE will provide world class research, testing and certification of rolling stock, infrastructure and innovative new rail technologies. The area is well placed to combine its rail innovation assets with the need to trial new solutions for rail the UK and overcome the challenges that decarbonising its operations present especially in hilly and mountainous areas and where routes are harder to electrify.

12.3 Delivering the Hydrogen Pathway to 2050

The amount of low carbon hydrogen the Western Gateway will need is dependent on many variables but there are critical points in determining the scale of demand for hydrogen in the area, the way in which this supply could be met and distributed, and therefore the delivery pathway the area will follow through to 2050. These include:

1. The UK Government's decision to move to 20% blend and 100% hydrogen in the gas network, with decisions due in 2023 and 2026 respectively.
2. The decision on the use of hydrogen in decarbonising the UK's steel industry. 2035 is a critical milestone for this decision and could establish a base load for hydrogen demand and the infrastructure to support it.
3. The capacity of the national grid to support new connections and its ability to transmit electricity from large and smaller scale, distributed renewable energy generation projects.

12.4 Barriers to Overcome

National policy: Having the right policy, planning, regulatory and financial business models in place will be critical in enabling projects to be developed and delivered within reasonable timescales. This will require local planners and regulatory teams to have the right skills and capacity to respond effectively to manage the pipeline of projects seeking approvals.

Capital investment: The scale of capital investment the Western Gateway requires to build out the supporting hydrogen infrastructure to 2050 is substantial, ranging from £8bn to cover the Necessities Only scenario to primarily to meet existing demands for low carbon hydrogen by industry, through to £62bn if hydrogen has widespread use and incorporates the demand for hydrogen for industrial process, domestic and commercial heating and transport uses. Access to sufficient finance, from both the private and public sector sources, will be a critical in delivering the area's ambition.

Workforce and Skills: The transition to a low carbon economy will not progress without investment in workforce development and new skills as well as the reskilling of the existing workforce and inspiring the future pipeline of workers to support a net zero economy. The Western Gateway area will need to develop the right skills, at the right time and in sufficient quantities and skills demands are likely to be far-reaching and will require industry and skills providers to work together to resolve.

The remaining barriers and constraints to developing a hydrogen ecosystem are presented in Table 12-1 and impact all three of the scenarios presented for the Western Gateway area. These are not unique to the Western Gateway; they are experienced nationally, and many will need national solutions and/or government interventions.

12.4.1 Key Barriers & Constraints for Each Scenario

Table 12-1 summarises the key barriers and constraints to developing a hydrogen energy system across each of the three scenarios proposed.

Key Barriers and Constraints		
Supply	**Distribution**	**Demand / Use**
• Supply chain may not have capacity for the build out rate required for renewables and electrolysers for green production • Indigenous production of hydrogen (green and waste) likely not enough to meet hydrogen demands of the area, therefore blue hydrogen or imports will be required, adding a security of supply threat • Large amounts of freshwater required for electrolysis putting strain on local water supplies or requiring build of desalination plants • Grid connections/network capacity • Investment capital	• Sufficient supply of hydrogen may not be available in 2020s to support blending to 20% volume in gas grid • Repurposing of distribution networks for 100% hydrogen will require conversion work beyond the Irons Mains Replacement Programme • Gaining necessary planning approval for new hydrogen transmission lines which is the responsibility of WWU • Uncertainty on hydrogen leakage rates and its climate warming impact • Investment capital	• Delayed decisions on future of Port Talbot creating uncertainty on a significant hydrogen anchor load • Uncertainty of future hydrogen purity standards creating uncertainty on upgrading infrastructure required for transport refuelling infrastructure • Investment capital

Table 12-1: Key barriers and constraints to successful delivery of hydrogen economy in the Western Gateway

12.5 Future Western Gateway Hydrogen Pathways

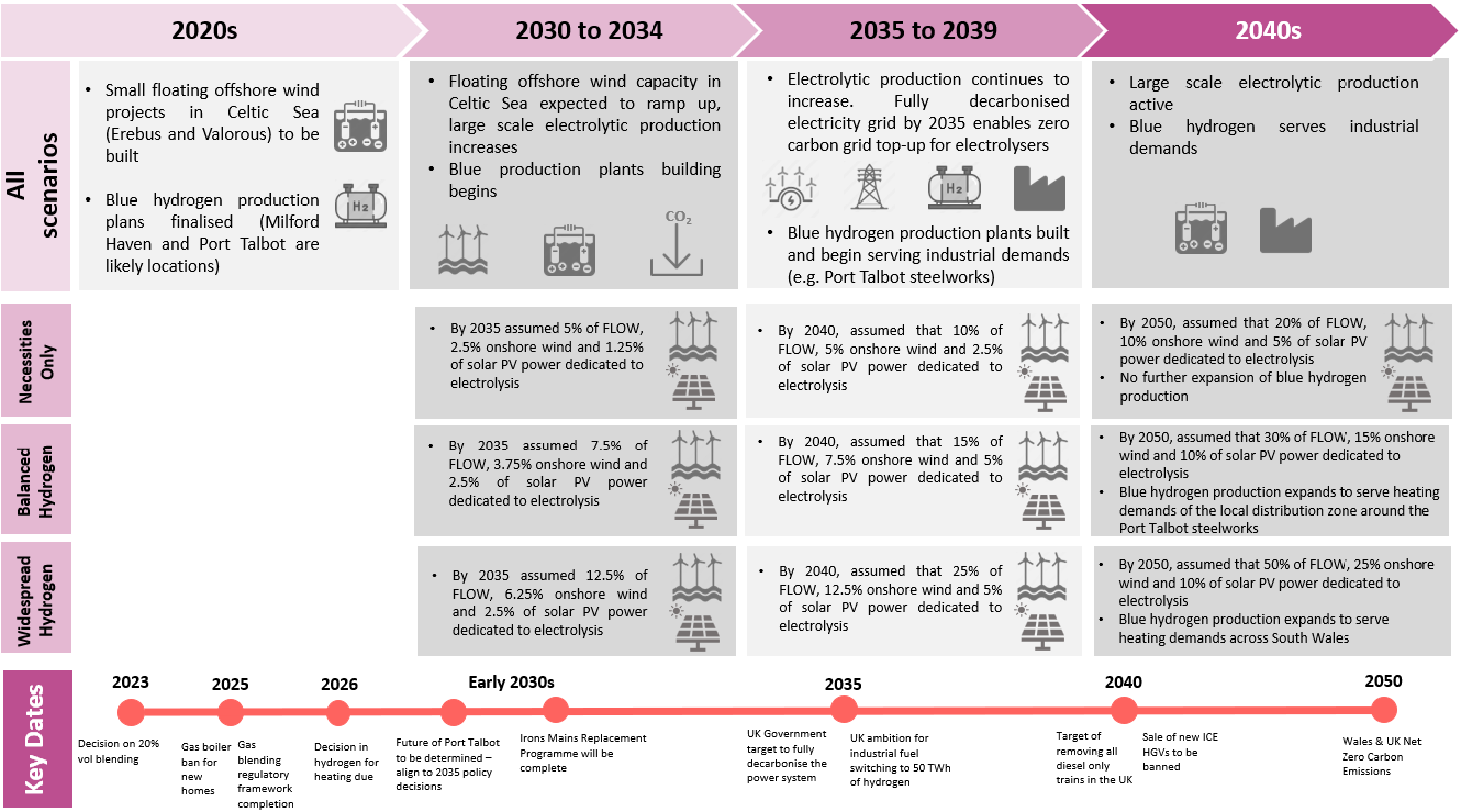
Future hydrogen pathways for the Western Gateway area are shown in Figure 12-1 to Figure 12-3, representing supply, networks and demand respectively. This hydrogen pathway incorporates all three of the developed hydrogen scenarios previously described, and has taken into account the UK Government and Welsh Government national targets.

	2020s	2030 to 2034	2035 to 2039	2040s
All scenarios	• **Aviation**: Acceleration of demonstration/trial projects (e.g. SAF production at Lanzatech) • **Road transport**: Hydrogen demonstrators commence • **Industry**: Feasibility studies into fuel switching to hydrogen	• **Industry**: Demonstrator projects for hydrogen use as a fuel • **Aviation & Shipping:** Demonstrator projects for ammonia ships and hydrogen/SAF aircraft	• **Industry**: Fuel switching to hydrogen begins • **Aviation**: Direct hydrogen aircraft start to enter fleet, synthetic kerosene (SAF) starts to enter aviation fuel mix • **Marine**: Ammonia powered ships start to enter fleet	• **Marine**: 90% of marine fuel demands met with ammonia
Necessities Only	• Based on 2026 decision on hydrogen for heating, no hydrogen blending in the gas grid	• **Heating:** Based on 2026 decision on hydrogen for heating, no hydrogen ready boilers installed • **Road transport:** No uptake of hydrogen road vehicles	• **Heating:** Gas boiler ban in 2035 accelerates electrification of heating	• **Heating**: Heating electrified – no hydrogen used for heating **Transport**: no hydrogen used for road transport, 20% hydrogen uptake in international aviation • **Industry**: 70% of industrial fuel demands hydrogen
Balanced Hydrogen	• **Gas grid demands:** Blending to 20% vol kickstarts demand for hydrogen in heating and industrial sectors	• **Heating**: Installation of hydrogen ready boilers, 20% blend creates significant demand for hydrogen • **Road transport:** Uptake of hydrogen buses, LGVs and HGVs begins.	• **Heating:** Gas boiler ban in 2035 accelerates uptake of hydrogen boilers (in distribution zones identified for hydrogen repurposing) and electrification of heating (for distribution zones not identified for hydrogen repurposing)	• **Heating**: Single local distribution zone converted to hydrogen for heating (10% of total heating demands) • **Transport:** 50% of HGVs, LGVs and buses switch to hydrogen, 40% hydrogen uptake in international aviation • **Industry**: 70% of industrial fuel demands hydrogen
Widespread Hydrogen	• **Gas grid demands:** Blending to 20% vol kickstarts demand for hydrogen in heating and industrial sectors	• **Heating**: Installation of hydrogen ready boilers, 20% blend creates significant demand for hydrogen • **Road transport:** Uptake of hydrogen buses, LGVs, HGVs and a small number of cars begins.	• **Heating:** Gas boiler ban in 2035 accelerates uptake of hydrogen boilers	• **Heating**: 100% of heating demands met with hydrogen • **Transport:** 100% of HGVs, LGVs and buses switch to hydrogen, 60% hydrogen uptake in international aviation • **Industry**: 100% of industrial fuel demands hydrogen

Key Dates

- **2023** – Decision on 20% vol blending
- **2025** – Gas boiler ban for new homes; Gas blending regulatory framework completion
- **2026** – Decision in hydrogen for heating due
- **Early 2030s** – Future of Port Talbot to be determined – align to 2035 policy decisions; Irons Mains Replacement Programme will be complete
- **2035** – UK Government target to fully decarbonise the power system; UK ambition for industrial fuel switching to 50 TWh of hydrogen
- **2040** – Target of removing all diesel only trains in the UK; Sale of new ICE HGVs to be banned
- **2050** – Wales & UK Net Zero Carbon Emissions

Figure 12-1: Western Gateway Hydrogen Delivery Pathway To 2050 Across All Three Scenarios (Demands)



Figure

Figure 12-2: Western Gateway Hydrogen Delivery Pathway To 2050 Across All Three Scenarios (Supply)

	2020s	2030 to 2034	2035 to 2039	2040s
All scenarios	• Feasibility studies for dedicated hydrogen transmission lines (e.g. HyLine)	• Hydrogen transmission line (HyLine) built to connect Milford Haven to Port Talbot • Distribution of hydrogen for road transport refuelling via road tanker begins CO_2		
Necessities Only	• Assumes that 2026 decision on heating identifies no or little role for hydrogen, 20% blend not pursued	• No conversion of local distribution zones to 100% hydrogen investigated	• No expansion of hydrogen transmission lines beyond HyLine	• Gas grid distribution networks no longer in use, only natural gas transmission lines for blue production plants remain
Balanced Hydrogen	• Assumes that 2026 decision on heating identifies small role for hydrogen, 20% blend pursued	• Distribution zones to be repurposed for 100%$_{vol}$ hydrogen identified. 20% blend complete	• Repurposing distribution network around Port Talbot steelworks to 100% hydrogen begins • No expansion of hydrogen transmission lines beyond HyLine	• Repurposing of single local distribution zone around Port Talbot steelworks is completed
Widespread Hydrogen	• Assumes that 2026 decision on heating identifies widespread role for hydrogen, 20% blend pursued	• Distribution zones to be repurposed for 100%$_{vol}$ hydrogen identified. 20% blend complete • Extension of HyLIne across the rest of South Wales investigated	• Extension of HyLine hydrogen transmission line begins from Port Talbot across the rest of South Wales to serve heating and industrial demands	• Extension of HyLine hydrogen transmission line across the rest of South Wales is completed • Repurposing of all distribution networks for 100% hydrogen is completed • Distribution of hydrogen for transport refuelling can be achieved via dedicated hydrogen network

Key Dates

- **2023** – Decision on 20% vol blending
- **2025** – Gas boiler ban for new homes; Gas blending regulatory framework completion
- **2026** – Decision in hydrogen for heating due
- **Early 2030s** – Future of Port Talbot to be determined – align to 2035 policy decisions; Irons Mains Replacement Programme will be complete
- **2035** – UK Government target to fully decarbonise the power system; UK ambition for industrial fuel switching to 50 TWh of hydrogen
- **2040** – Target of removing all diesel only trains in the UK; Sale of new ICE HGVs to be banned
- **2050** – Wales & UK Net Zero Carbon Emissions

Figure 12-3: Western Gateway Hydrogen Delivery Pathway To 2050 Across All Three Scenarios (Networks)

12.6 Potential Actions

Table 12-2 presents a set of potential actions which could be progressed to enable the development of the hydrogen ecosystem. They fall across five key areas: Demand, Supply, Networks, Workforce and Skills and Innovation. They have been proposed through various engagement and explored through the consultation exercise and more widely through the production of this evidence base.

The actions have not been formalised and lead organisations have not been identified, however they form a good basis for continued engagement between industry, academia and the public sector to support the delivery pathway of hydrogen in the Western Gateway area. They represent some of the priority areas identified through this work and a first pass list which could be built upon and developed, with stakeholders and industry leaders.

Action	Source of Action							
	Hydrogen Policy Context	Planning & Regulatory Standards Review	Emerging Funding Landscape	Hydrogen Demand Scenarios	Hydrogen Supply Scenarios	Hydrogen Network Considerations	Developing the Western Gateway Hydrogen Economy	Innovation Opportunities and Skills Development
Supply Action 1: Establish a 'Western Gateway Hydrogen Hub' or online resource that focuses on raising awareness of funding opportunities and highlighting successful project bids which are in the Western Gateway area, such as the Net Zero Hydrogen Fund. This could help to boost local marketing of hydrogen activity and be used to support private sector inward activities.			✓				✓	✓
Supply Action 2: Undertake or accelerate any existing blue hydrogen feasibility studies examining merits of establishing a production site in the Western Gateway. This should include supply routes, identification of key users, proof of carbon capture viability prior to funding, and feasibility assessment for all greenhouse gases (including fugitive methane emissions from natural gas extraction). This would be best led or undertaken by the future supply industry.					✓	✓		
Supply Action 3: Undertake an analysis of potential low carbon hydrogen generation site locations to focus on delivering sufficient supply for the anticipated demand. This would require engagement with local authorities, DNO and National Grid to drive forwards an anticipatory investment to map the grid connection constraints, the timeline and plan electricity grid upgrades accordingly.					✓	✓		
Supply Action 4: Monitor strategic renewable generation build out and identify opportunities to collaborate to address any emerging barriers including supporting and driving enabling planning policies.		✓		✓		✓		

	Source of Action							
Action	Hydrogen Policy Context	Planning & Regulatory Standards Review	Emerging Funding Landscape	Hydrogen Demand Scenarios	Hydrogen Supply Scenarios	Hydrogen Network Considerations	Developing the Western Gateway Hydrogen Economy	Innovation Opportunities and **Skills** Development
Supply / Demand Action 5: Lobby and make a clear case to the UK Government to accelerate the decision on the decarbonisation of steel at Port Talbot as this will be a critical anchor load for development of hydrogen in the area.	✓			✓				
Supply Action 6: Establish an electrolyser implementation group to share best practice and knowledge on the implementation of electrolysers to accelerate their roll-out. This group could operate at a UK level.					✓	✓		✓
Supply Action 7: Monitor Floating Offshore Wind (FLOW) build out capacity in the Celtic Sea against the Crown Estate's ambition of 4 GW by 2035, including engagement with National Grid to understand impact of any connection capacity constraints. Plan for any green hydrogen production shortfall to be met through alternative means such as onshore renewables. This also includes monitoring potential for future rounds of Celtic Sea FLOW tenders and driving anticipatory grid upgrades as required (Supply Action 3).					✓	✓		
Supply Action 8: Establish the feasibility for a demonstrator nuclear Small Modular Reactor (SMR) or Advanced Modular Reactor (AMR) for hydrogen production in the Western Gateway area.	✓				✓	✓		

Action	Source of Action							
	Hydrogen Policy Context	Planning & Regulatory Standards Review	Emerging Funding Landscape	Hydrogen Demand Scenarios	Hydrogen Supply Scenarios	Hydrogen Network Considerations	Developing the Western Gateway Hydrogen Economy	Innovation Opportunities and Skills Development
Supply Action 9: Analysis and identification of the infrastructure required for importation of bulk hydrogen, led and supported by each port. This would include projection of the volume of importation needed, the supply chain and the infrastructure for delivery.					✓	✓		
Network Action 1: Raise awareness and share best practice amongst planning authorities in relation to the delivery of hydrogen transmission networks in the Western Gateway to improve planning processes, including for the HyLine Cymru project.						✓		
Network Action 2: Develop a detailed feasibility study examining the CO_2 transmission infrastructure required to support blue hydrogen production for SWIC covering any infrastructure required at ports or required storage sites. Lobby government to include the cost of shipping within the estimations of levelised cost of CO_2 transmission and storage.	✓	✓			✓	✓		
Network Action 3: Undertake a study into the means for inter-seasonal hydrogen storage for the Western Gateway, which could be in collaboration with or lobby for action by a future systems operator in the view of wider, UK-level infrastructure planning.					✓	✓		
Network Action 4: Lobby UK and Welsh Governments to accelerate national regulatory framework changes relating to hydrogen transmission and storage (e.g. clarity on Accord Dangereux Routier (ADR) for non-pipeline transport of hydrogen)		✓				✓		

Action	Source of Action: Hydrogen Policy Context	Planning & Regulatory Standards Review	Emerging Funding Landscape	Hydrogen Demand Scenarios	Hydrogen Supply Scenarios	Hydrogen Network Considerations	Developing the Western Gateway Hydrogen Economy	Innovation Opportunities and Skills Development
Demand Action 1: Offer a funding bid application support service (though the Western Gateway Hydrogen Hub) to businesses seeking to use hydrogen in the area either via the Hydrogen Business Model or other grant funding opportunities.		✓						
Demand Action 2: Establish Western Gateway hydrogen demonstrator projects covering rail and heavy road transport.			✓				✓	✓
Demand Action 3: Establish a hydrogen maritime demonstrator project (e.g. ammonia vessels) and explore the implementation of ammonia storage port facilities.	✓		✓	✓			✓	✓
Demand Action 4: Develop an Aviation Decarbonisation Delivery Plan for the area which sets out a roadmap of actions specific to the aerospace industry to unlock its full potential in the transition to SAF including hydrogen	✓		✓	✓			✓	✓
Demand Action 5: Improve public perception on hydrogen and its applications working with local communities. Understand local appetite for a hydrogen heating demonstrator within the Western Gateway prior to any new demonstration projects.	✓		✓	✓				✓
Demand Action 6: Complete early-stage planning of a central online *'one stop shop'* resource that enables easy access and funding option information to homeowners for low carbon heating (hydrogen ready boilers or heat pumps) and household retrofits. To be further developed as hydrogen technology	✓			✓		✓		

Action	Source of Action: Hydrogen Policy Context	Planning & Regulatory Standards Review	Emerging Funding Landscape	Hydrogen Demand Scenarios	Hydrogen Supply Scenarios	Hydrogen Network Considerations	Developing the Western Gateway Hydrogen Economy	Innovation Opportunities and Skills Development
readiness increases and upon 2026 UK Government decision on hydrogen for heating. This could be a national initiative accessed through local authorities.								
Workforce and Skills Action 1: Develop a Western Gateway Net Zero Skills Plan which would incorporate hydrogen upskilling into the broader skills transition across renewables. This would call upon existing foresighting work and activities to identify skills gaps now and in the future. This would need to happen at all skill levels, and across the hydrogen economy to understand the required training programmes.	✓			✓			✓	✓
Innovation Action 1: Lobby the UK Government for a Net Zero Innovation Fund for the area to provide early-stage and scale-up investments in new businesses developing and trialling hydrogen technologies across the Western Gateway.							✓	✓
Innovation Action 2: Identify opportunities for innovation grants for business-led hydrogen solutions. Employ a portfolio approach to ensure coverage of generation, storage, safety, integration and demand applications. Convene and support the development of bids for funding support. Encourage the existing cohort of hydrogen innovators and networks to provide business funding and growth support.			✓					✓
Innovation Action 3: Proactively seek collaboration opportunities outside of the Western Gateway, to attract hydrogen innovation business to the area which would further grow the ecosystem and value chain.							✓	✓

Table 12-2: Potential Actions Plan with Key Evidence Base Sources Behind the Actions

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Appendix A – Detailed Policy Context

14.1 UK Government Policy Context

14.1.1 Net Zero Strategy: Build Back Greener (2021)

The UK Government's Net Zero Strategy (2021) sets out how net zero greenhouse gas emissions will be achieved by 2050 across all sectors of the economy. This is intended to deliver upon 2019 amendments to Section 14 of the Climate Change Act (2008) as part of the 2015 Paris Climate Agreement to limit global temperature rises to no more than 1.5°C above pre-industrial levels.

The Strategy accounts for publications prepared by the independent Climate Change Committee (CCC), including the Sixth Carbon Budget which is a document to guide policy decisions consistent with a Net Zero pathway 2050, focusing on the requirements to 2030 (Section 2.2.2).

The Strategy incorporates a detailed cross-sector carbon emission reduction pathway to 2037 (Figure 0-1). This aspires for the following sector-specific reductions in emissions by 2035, relative to 1990 levels:

- Power: 80-85% reduction
- Fuel Supply: 53-60% reduction
- Industry: 63%-76% reduction
- Heat and Buildings: 47-62% reduction
- Transport: 47-59% reduction
- Natural Resources: 39-51% reduction

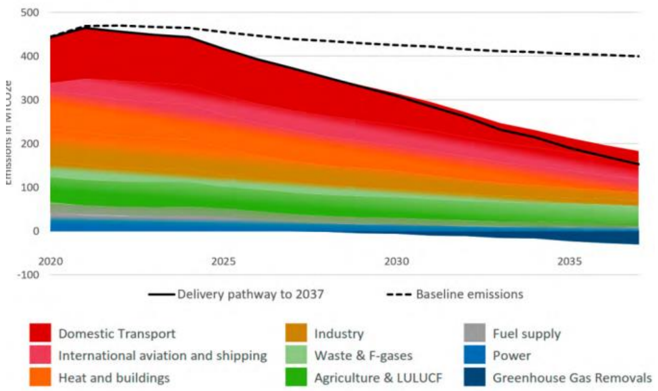


Figure 0-1: Net Zero Strategy Carbon Reduction Pathway by Sector (HM Government, 2021)

Following a court decision in July 2022, the Net Zero Strategy is due to be revised by March 2023 which will set out further detail on carbon reduction pathways to 2050.

14.1.1.1 Key Government Targets & Role of Hydrogen

The Net Zero Strategy attributes a key cross-sector role to hydrogen development to meet these reduction targets on the basis it can *'complement the electricity system, especially in harder to electrify areas like parts of industry and heating and in heavier transport such as aviation and shipping*.'

It aspires that low carbon hydrogen production capacity will reach 5 GW by 2030 **(note: this has since been revised to 10 GW in more recent government strategies)**. Production capacity targets beyond 2030 are more unclear and will be dependent on demand including the role of hydrogen to heat buildings, with a key strategic decision on this planned for 2026 following trials.

Table 0-1 summarises the proposed role of hydrogen across each of the key sectors in the Strategy.

Sector	Key Relevant Government Policies / Targets
Power	• Electricity supply to be from 100% renewables by 2035, with potential for hydrogen to be used to generate electricity during periods of high demand • 40 GW of offshore wind by 2030 including 1 GW of floating offshore wind in the Celtic and North Seas • One Carbon, Capture, Usage and Storage (CCUS) facility by mid 2020s
Fuel Supply & Hydrogen	• 5 GW (now 10GW) hydrogen production by 2030 • Introduction of new low carbon hydrogen standard

Sector	Key Relevant Government Policies / Targets
	• Implementing of new funding sources to kickstart investment and innovation in hydrogen e.g. Net Zero Hydrogen Fund • Supporting 10,000 jobs by 2030 in the hydrogen sector • Repurposing of existing infrastructure around oil refineries and scale up of hydrogen networks in the vicinity
Industry	• Delivery of 6MtCO_2 per year of industrial CCUS by 2030 and 9MtCO_2 by 2035 • Increase fuel switch to low carbon alternatives including hydrogen to 50 TWh by 2035 • Decarbonising steel production sites including Port Talbot through consideration of hydrogen-based Direct Reduced Iron (DRI) and CCUS
Heat & Buildings	• Make strategic decision on blending hydrogen (up to 20%) into gas grid in 2023 • Make strategic decision on hydrogen's role in heating by 2026 following trials, including a village scale trial by 2025 • Phase out installation of new and replacement gas boilers by 2035 • Consulting on installing hydrogen-ready boilers by 2026 • 600,000 heat pump installations per year by 2028
Transport	• End the sale of all new non-zero emission HGVs and buses by 2040 • Net zero rail network by 2050 including removal of all diesel-only trains by 2040 through electrification of network and use of hydrogen and battery trains • Phase out sale of new non-zero emission shipping vessels • Deliver 10% Sustainable Aviation Fuels (SAF), including hydrogen, by 2030 • Delivery of 4,000 new zero emission buses, including hydrogen buses

Table 0-1: Summary of key cross-sector ambitions and stated role of hydrogen in the Net Zero Strategy

14.1.1.2 Skills Development

The Strategy underlines the importance of upskilling the UK workforce to deliver net zero including the following key commitments:

- Publishing sector and supply chain development plans for low carbon sectors
- Reform the skills system to incentivise training providers, employers and learners
- Deliver a Lifetime Skills Guarantee in accordance with the needs of the green economy
- Introduction of a sustainability and climate change strategy for young people

14.1.2 Build Back Better: Our Plan For Growth (2021)

The Build Back Better strategy sets out how the government will deliver transformational economic growth following COVID-19 that has the potential to create high-quality jobs across all regions of the UK.

Supporting the transition to Net Zero is identified as a critical element of the Strategy, including delivering *'50,000 jobs in CCUS and up to 8,000 in hydrogen in our industrial clusters.'*

14.1.3 UK Hydrogen Strategy (2021)

14.1.3.1 Context & Future Vision

The UK Hydrogen Strategy (2021) was originally released at the same time as the Net Zero Strategy and sets out the government's approach to developing a low carbon hydrogen sector as a core element of meeting net zero by 2050.

The Strategy forecasts that between 250 to 460TWh of hydrogen will be required by 2050, comprising around 20-35% of overall energy consumption in the UK. The Strategy sets an interim target of 5 GW by 2030 **(note: this has since been revised to 10 GW in more recent government strategies).** It estimates that this level of generation has the potential to support 100,000 jobs and £13 billion of GVA in 2050 in a high hydrogen scenario.

UK Hydrogen Strategy (2021) 2030 Vision & Key Principles

Vision

'Our vision is that by 2030, the UK is a global leader on hydrogen, with 5 GW ***[now 10 GW]*** *of low carbon hydrogen production capacity driving decarbonisation across the economy and clear plans in place for future scale up towards Carbon Budget 6 and net zero, supporting new jobs and clean growth across the UK.'*

Key Principles

- Long term value for money for taxpayers and consumers
- Growing the economy whilst cutting emissions
- Securing strategic advantages for the UK
- Minimising disruption and cost for consumers and households
- Keeping options open, adapting as the market develops
- Taking a holistic approach

14.1.3.2 Key Challenges

The strategy recognises that to become viable, there are some significant barriers to overcome including price, supply consistency and development of a sufficiently low carbon emitting production process.

Key Challenges Identified

- Cost of hydrogen relative to existing high carbon fuels
- Technological uncertainty and scalability
- Policy and regulatory infancy
- New infrastructure requirements
- Supply and demand coordination development
- Technology development and cost of innovation

14.1.3.3 Future Hydrogen Roadmap

As identified in Table 0-2, the strategy sets out key actions and milestones to support the development of a hydrogen economy, including delivery of the 2030 production target.

Archetype	Mid-2020s	Late 2020s	Mid-2030s onwards
Production	Large-scale CCUs-enabled production in at least one location; electrolytic production increasing in scale	Several large-scale CCUS-enabled projects & several large-scale electrolytic projects	Increasing scale & range of production – e.g. nuclear, biomass
Networks	Dedicated small-scale cluster pipeline network; expanded trucking & small-scale storage	Large cluster networks; large-scale storage; integration with gas networks	Regional or national networks & large-scale storage integrated with CCUS, gas & electricity networks
Use	Industry applications; transport (HGV, rail & shipping trials) village heat trial; blending (tbc)	Wide use in industry; power generation & flexibility; transport (HGVs, Shipping); heat pilot town (tbc)	Full range of end users incl. steel; power system; greater shipping & aviation; potential gas grid conversion
Actions and Milestones	Aiming for 1 GW of production by 2025 2 CCUS clusters by 2025 Heat Village trial 2025 Hydrogen heating decision by 2026 Decision on HGVs mid-2020s	Ambition for 5 GW production capacity 2030 **(now 10GW)** 4 CCUS clusters by 2030 Potential pilot hydrogen town by 2030 Ambition for 40 GW offshore wind by 2030	Sixth Carbon Budget

Table 0-2: Summary of Hydrogen Roadmap (HM Government, 2021)

14.1.3.4 Hydrogen Demand and Use Cases

A range of uses cases are set out in the Strategy which cumulatively forecasts hydrogen demand projections of 38TWh by 2030 and between 55 and 165TWh by 2035 (see Figure 0-2).

Of these use-cases, industry and transport are forecast to be highest, with heat in buildings more uncertain until the strategic decision is made in 2026.

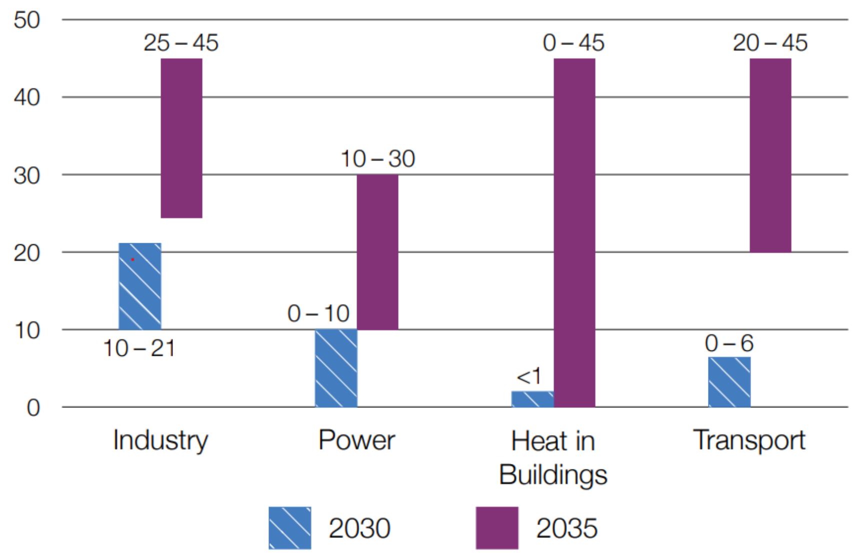


Figure 0-2: Illustrative hydrogen demand forecasts by 2030 and 2035 (HM Government, 2021)

As noted in Table 0-1, the Net Zero Strategy consolidates all pledges and actions across each of these sectors to enable decarbonisation. Further detail on action in each sector specifically related to hydrogen (as detailed in the UK Hydrogen Strategy) is provided in Table 0-3.

Sector	Summary of Key Ambitions & Actions
Industry	• **Decarbonise current hydrogen production:** away from steam methane reformation (without CCUS) through consultation and development of a new UK standard for low carbon hydrogen production • **Switching industrial fuels to low carbon hydrogen:** particularly in the steel sector through switching to electric arc furnace technology (which can utilise recycled steel only), hydrogen DRI or CCUS
Power	Hydrogen can be utilised for flexible power generation to meet short- and longer-term peaks in demand which the government will pursue through engagement and funding: • **Flexible power generation ('Gas to Power'):** such as through rapid operating 'peaker' plants and Combined Cycle Gas Turbines • **Electrolysis & Storage ('Power to Gas'):** through drawing on 'excess' renewable electricity constrained by the grid when it cannot be transmitted, therefore providing an ability to balance the grid when generation by renewables exceeds demand
Heat in Buildings	• **Decision on blending up to 20% hydrogen into the gas grid by 2023** • **Further investigation of hydrogen's relative potential for heating with a strategic decision made in 2026:** such as through the 2023 and 2025 trials • **Consultation on enabling new gas boilers to be hydrogen ready by 2026**
Transport	• **4,000 Zero Emission Buses:** some of which will be fuelled by hydrogen • **Hydrogen to fuel HGVs:** through hydrogen fuel cell trials and ban on new non-zero emission HGVs • **Hydrogen Powered Vessels:** through establishing a UK Shipping Office for Reducing Emissions (UK-SHORE) and trialling approaches, such as through combustion or in fuel cells, or as feedstock • **SAF:** Through supporting trials including H2GEAR in Bristol which is a £54.4m trial led by GKN to develop zero emission technology flights

Table 0-3: Summary of UK Hydrogen Strategy Key Cross-Sector Actions (HM Government, 2021)

14.1.3.5 Overcoming Cost & Market Barriers

The strategy notes that CCUS-enabled methane reformation is currently the lowest cost hydrogen production technology, but that the cost of electrolysis is expected to decrease and potentially become cost-competitive from 2025 onwards.

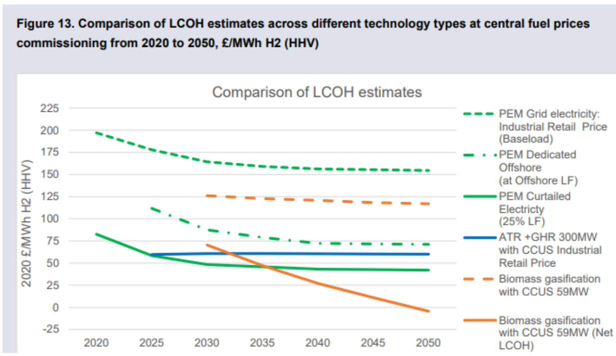


Figure 0-3: UK Hydrogen Strategy Costs of Low Carbon Hydrogen

14.1.3.6 Job Creation & Upskilling

The Strategy reiterates the importance of ensuring the UK has the right skills to unlock hydrogen's potential. This includes a series of commitments including:

- Setting up an early career professionals forum under the Hydrogen Advisory Council
- Re-skilling workers from oil and gas
- Monitoring of the hydrogen sector to ensure sufficient private investment in skills and supporting good quality jobs.

14.1.3.7 Hydrogen Reports to the Market (2022)

The UK Hydrogen Strategy is complemented by two more recent market update documents which were produced in July and December 2022 which provide progress updates. The update highlights the government's increased focus on driving significant private sector investment in the hydrogen sector. It also reiterates the governments' intention to publish a response to the 20% blending of the gas grid with hydrogen in Q2 of 2023. This will potentially provide a baseline demand for hydrogen, enabling the private sector to increase production to a stable demand requirement.

The update notes the launch of the first Electrolytic Hydrogen Allocation Round – funding for the Net Zero Hydrogen Fund (NZHF) and the Hydrogen Production Business Model, as well as the Hydrogen Sector Development Action Plan.

The update includes a summary of the different funding competitions and resulting projects that have been commenced in the year.

- **Production:** As a result of funding competitions, the Government has identified up to 20 GW of potential hydrogen projects through to 2037
- **Networks and Storage:** The Government has undertaken consultation on hydrogen and has published an independent consultancy study
- **Demand:** The Government continues to focus on key large 'anchor sites' in industrial clusters. The use of hydrogen for heating still relies on ongoing decision making for blending to 20% (2023) and full deployment (a strategic decision will be made in 2026)

The Government has looked to the private sector to consult on hydrogen-ready industrial boiler equipment and external research to support decision making. The Industrial Energy Transformation Fund and the Industrial Hydrogen Accelerator competition have been used to support private sector investment in hydrogen fuel switches.

Hydrogen Delivery Highlights to date

- £7.5 million awarded to ITM's Gigastack project in the Humber (250 MWE capacity), an early mover in the market, with potential to support up to 2,000 jobs over time
- Preparing to allocate up to £100 million of revenue support to initial electrolytic projects
- Launch of a series of new funding opportunities e.g. £240m Net Zero Hydrogen Fund (see Section 4)
- Publishing of responses to the consultation on hydrogen-ready boilers
- Continued commitment to make a decision in 2023 whether to allow 20% hydrogen blend in gas distribution networks
- Further exploration of opportunities for export of hydrogen to continental Europe
- Appointment of Jane Toogood as UK hydrogen champion to author a wide-ranging report in 2023

14.1.4 Heat & Buildings Strategy (2021)

The Heat & Buildings Strategy (2021) consolidates the governments' strategy to decarbonising heat in buildings and sits alongside the Net Zero Strategy.

Five Policy Core Principles of the Heat & Buildings Strategy (2021)

1. A whole buildings and whole-system approach to minimise costs of decarbonisation
2. Innovation is essential to driving down costs, improving options and informing future decisions
3. Accelerate 'no and low regrets' action now
4. Balance certainty and flexibility to provide stability for investment and an enabling environment for different approaches for different buildings
5. Target support to enable action for those most in need

The Strategy provides further detail on a series of key commitments identified in the Net Zero Strategy (see Table 0-4). This focuses on the immediate upscaling of building energy efficiency measures and the rollout of heat pumps followed by the potential conversion from gas to hydrogen from 2028 onwards dependent on successful trials.

Heating Topic Area	Summary of Key Commitments Relevant to Hydrogen
Net Zero Heating	• Phase out installation of new gas boilers from 2035 • Ensure heat pumps are no more expensive to buy and run than gas boilers by 2030 • Market interventions to grow heat pump supply chain • Deliver 600,000 new heat pumps a year by 2028 • Ensure all new buildings are Net Zero ready by 2025 as part of the Future Homes Standard
Hydrogen for Heating	• Assess the feasibility of hydrogen for heating buildings by 2025 and make strategic decision by 2026 • Make policy decision on blending of hydrogen in gas network by up to 20% in 2023 • Consult on hydrogen ready boiler requirement by 2026
Greener Buildings	• Improve energy efficiency of homes including supporting low-income households • Significantly reducing energy consumption of commercial and industrial buildings by 2030

Table 0-4: Summary of Heat and Buildings Strategy Key Commitments (HM Government, 2021)

The strategy also provides further detail on the need for new and retrained skills to deliver the commitments, including in hydrogen. It identifies that hydrogen boiler engineers would require similar training to natural gas boilers engineers and is developing a skills standard as part of the DESNZ Hydrogen Skills and Standards for Heat programme.

14.1.5 Industrial Decarbonisation Strategy (2021)

The Industrial Decarbonisation Strategy (2021) brings together the governments' strategy to decarbonising industry and sits alongside the Net Zero Strategy To avoid repetition, this review will focus on additional commitments not already mentioned in Section 14.1.1.

The Strategy asserts that carbon emissions from industry need to reduce by two thirds by 2035 to meet net zero which incorporates recommendations made by the CCC to set targets for ore-based steelmaking to reach near net-zero emissions by 2035. Key ambitions of the strategy to meet this include:

- Linking up four of the major industrial regions to required decarbonisation infrastructure by 2030
- Capturing 3 $MtCO_2$ from industry emissions by 2030 and between 8 and 14 $MtCO_2$ by 2050
- Replacing fossil fuels with low carbon fuels including hydrogen, electricity and bioenergy, with a target of 20 TWh per year of fossil fuel use replaced by 2030 and between 24 and 86 TWh by 2050
- Establish opportunities to equip the workforce and local residents as part of the transition

Port Talbot in South Wales alongside Scunthorpe make up 95% of emissions in the UK from iron and steel and around 15% of the total industrial emissions. The Strategy asserts that decarbonisation options at Port Talbot would constitute either hydrogen DRI coupled with an electric furnace or CCUS, however, notes that Port Talbot would require shipping of carbon dioxide to utilise CCUS or hydrogen.

14.1.6 Decarbonising Transport: A Better, Greener Britain (2021)

The Transport Decarbonisation Plan (2021) sets out the Department for Transports' approach to achieving net zero from transport by 2050 and complements the Net Zero Strategy (Section 14.1.1).

The strategy asserts that *'hydrogen is a key strategic component to fully decarbonising the UK's economy.'* It identifies that it is likely to be most useful in decarbonising transport where it cannot be undertaken via batteries, such as weight and volume restrictions or where refuelling times prove a constraint.

Transport Sector	Key Proposals Related to Hydrogen
Road Freight	• All new HGVs to be zero emission by 2040 • Hydrogen fuel cell research to investigate its feasibility for HGVs
Buses	• Ongoing consultation on future ban of new diesel buses • 4,000 new zero emission buses; of which some are hydrogen
Rail	• Removal of all diesel-only trains by 2040 • Battery and hydrogen trains likely to be used on more rural lines given likelihood of better value for money than full electrification
Aviation	• Target to reach 'Jet Zero' by 2050 and 2040 for domestic flights if feasible • Investment in Zero Emission Flight Infrastructure R&D • Commercialisation of SAF and a new SAF mandate consultation
Maritime	• Consultation planned on the phase out of new non-zero emission domestic vessels • Further research into the use of advanced fuels including hydrogen

Table 0-5: Summary of hydrogen related proposals (Department for Transport, 2021)

14.1.7 Jet Zero Strategy (2022)

The Jet Zero Strategy (2022) outlines how net zero aviation will be delivered by 2050. The Strategy includes a series of interim targets to achieve this including:

- A minimum of 10% SAF in the UK aviation fuel mix by 2030

- Zero emission routes connecting different parts of the UK by 2030
- At least five commercial scale SAF plants under construction by 2025
- All UK domestic flights net zero by 2040

The Strategy notes that a key element of this is SAF and hydrogen-powered aircraft and showcases the launch of the Zero Emission Flight Development Centre by Airbus in Bristol as an exemplar project. This ZEROe demonstrator aims to test hydrogen propulsion technology on an A380 platform.

14.1.8 Clean Maritime Plan (2019)

The Clean Maritime Plan is a route map, outlining the UK's pathway to reducing emissions of greenhouse gases from shipping by 50% by 2050 (compared to 2008), while pursuing efforts to phase them out completely.

The Plan announced a study that will be undertaken on zero emission shipping clusters. To include a detailed assessment of the infrastructure required to enable the uptake of alternative fuelled vessels, including whether there are particular geographic locations suitable for the production, storage and synergies with other economic sectors such as heating or other transport modes. The study will consider where clusters have particular advantages in producing fuels with the greatest emission reduction potential (e.g. CCUS opportunities and renewable energy availability).

14.1.9 British Energy Security Strategy (2022)

The UK Government released the British Energy Security Strategy (BESS) (2022) in response to the rising costs of energy in 2022 associated with the legacy of COVID-19 and the Russian invasion of Ukraine. The Strategy sets out the delivery plan to address these immediate challenges and transition to a low-carbon energy supply over the longer term.

To respond to these challenges, the BESS doubles the ambition made in the original UK Hydrogen Strategy for hydrogen production from 5 GW to 10 GW by 2030, with 50% coming from electrolytic hydrogen. It also sets a short-term target of 1 GW of electrolytic hydrogen production by 2025.

BESS commits to the development of new business models for hydrogen transport and storage infrastructure to be designed by 2025 to support the growth of the hydrogen economy. The Strategy also sets out a plan to create a hydrogen certification scheme by 2025 to demonstrate high-grade British hydrogen for export and standards for import.

14.1.10 Hydrogen Sector Development Action Plan (2022)

This action plan looks to highlight the nature and scale of opportunities across the hydrogen economy in the UK focusing on four key areas of investment, supply chains, jobs and skills and exports.

14.1.10.1 Investment

The action plan estimates that significant investment in the hydrogen economy is required to meet government targets, which includes £9bn of private sector co-investment to meet the 10 GW production target by 2030.

A series of key actions are noted in the plan to support investment in the hydrogen economy, including:

- **Production of an investment profile for the hydrogen value chain:** across production, transport and storage and industrial/end use
- **Engaging investors:** Through roundtable discussions
- **Development of tools to improve the project pipeline visibility:** such as a map showing potential UK hydrogen projects.

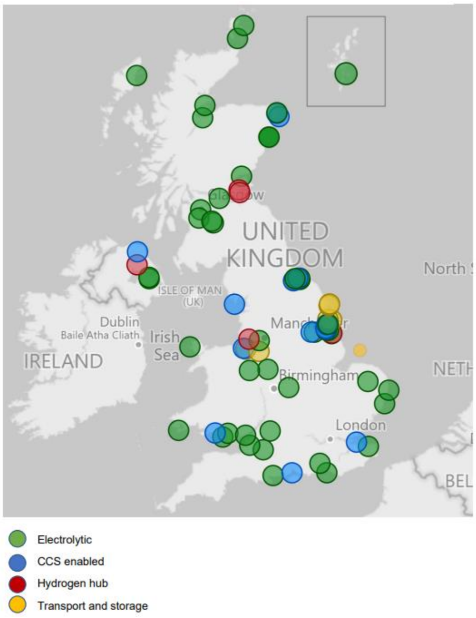


Figure 0-4: Potential hydrogen projects identified (DESNZ, 2022)

Potential projects in the Western Gateway area include:

- Bristol Airport Hydrogen Hub: as part of the ZEROe agreement between easyJet, Airbus and EDF
- Octopus Hydrogen
- Protium Magor: project involving installation of a 17.5 MW green hydrogen plant at a Welsh brewery in Monmouthshire
- RWE Pembroke: project involving development of a Net Zero Centre at Pembroke Power Station and potential for an electrolyser at the site

14.1.10.2 Supply Chains

The action plan identifies that supply chains are critical to underpin commercial-scale hydrogen projects across its production, transmission, distribution, storage and end use. Key actions include:

- **Mapping supply chain capabilities and opportunities**
- **Improving visibility of future projects and supply chain opportunities**: such as through supply chain events
- **Asking industry to lead a process to voluntarily set levels of ambition for supply chain participation in UK hydrogen projects**

14.1.10.3 Jobs & Skills

The Government plans to drive forward action on hydrogen jobs and skills through the green Jobs Delivery Group and by launching the Hydrogen Early Career Professionals Forum. The government is using data from existing projects and funding to identify the skillsets required and training provided to set a baseline requirement for the future.

14.1.10.4 Exports

The Government is looking at what the export opportunity through the Global Market Intelligence Tracker.

14.1.11 Hydrogen Investor Roadmap (2022)

The investor roadmap looks to signpost the opportunities in the UK hydrogen economy for investors. This includes ambitions for 2035 of:

- 25-45 TWh demand in Industry
- 10-30 TWh demand by Power
- 0-45 TWh demand for heat in buildings
- 20-45 TWh demand in Transport

The roadmap sets out the ambition of the government and their achievements to date across investment, jobs and skills, regulatory, infrastructure and funding. The roadmap also sets out key pipeline projects across the UK relating to hydrogen production and demand including in the Western Gateway area (see Section 14.1.10.1 for further detail on local projects).

14.1.12 Low Carbon Hydrogen Standard

The UK Government has created guidance and a calculator for hydrogen producers to use for greenhouse gas emissions reporting and sustainability criteria. This standard sets out and defines what constitutes "low carbon hydrogen" and the emissions to be included.

The methods for production include:

- Electrolysis
- Natural gas with CCUS
- Biomass/Waste conversion to hydrogen

This standard not only sets out the requirements for the UK, but also paves the way for import requirements of hydrogen to ensure high quality.

14.1.13 Net Zero Review (2023)

The Net Zero Review considers how the UK's Net Zero target could create opportunities for investment, economic growth and energy security, and how these could be maximised. It identifies net zero as *'the economic opportunity of the 21st century'*.

The review notes that of the emerging technologies that the Government's Net Zero Strategy most relies upon, it is hydrogen and CCUS where the investment landscape currently appears to be most uncertain and therefore needing clear signalling of support from the Government.

The key recommendations for the hydrogen sector are to:

- By the end of 2023, develop and implement an ambitious and pragmatic '10 year' delivery roadmap for the scaling up of hydrogen production
- Deliver transport and storage hydrogen business models as soon as legislation allows and confirm the long-term funding envelope available for hydrogen revenue support, to incentivise timely investment
- Continue hydrogen heating community trials and consider whole system costs of the mass roll out of hydrogen for heating

14.1.14 Hydrogen Business Model Consultation

The Government has been working on the design of a business model for low-carbon hydrogen to support private sector growth in the production of low-carbon hydrogen. In 2021 the Government ran a consultation on the proposed business model (at the time with an ambition of 5 GW by 2030). Key input was required from project developers, financial investors and trade associations.

In December 2022 the Government released the Heads of Terms which constitute a set of non-binding agreements for the Low carbon hydrogen production business model. These provide a framework for the principal terms and conditions that will be included in any future agreements for initial hydrogen projects. It clarifies that the government will only provide financial support in instances where hydrogen is produced which conforms to the Low Carbon Hydrogen Production standards and sell it according to the eligibility criteria (see below).

The business model supports producers of low carbon hydrogen by paying them a premium over the market rate (referred to as a reference price) and the cost of production (referred to as the strike price), with the market rate being assumed as the most relevant fossil fuel alternative.

Producers are only eligible for the business model if they are selling hydrogen for power generation, transportation or industrial use, and not for export or blending into the gas grid. It is a similar model to a Contract for Difference (CfD) however, includes hydrogen-market specific clauses. This therefore limits the funding availability and support for the hydrogen production market where they have matched industrial, transport and power users. It also demonstrates the need for the Western Gateway scenarios to closely match production with demand outside of the gas grid, to maximise financial incentives for the private sector.

14.2 Welsh Government Policy Context

14.2.1 Net Zero Wales Plan (2021)

14.2.1.1 Context

The devolved Welsh Government have set the same target to achieve net zero carbon emissions by 2050 made as part of a legally binding pledge in March 2021. Proposals and action to deliver this are consolidated as part of the Net Zero Wales Plan which is a series of policy documents, most notably the Second All Wales Low Carbon Delivery Plan which sets out how the Welsh Government will deliver upon Carbon Budget 2 (2021 – 2025) (2021).

14.2.1.2 Role of Hydrogen

This Plan identifies that hydrogen *'may provide one of the few ways to decarbonise heavy industry through fuel switching, and to reduce emissions in hard-to-abate modes of transportation, notably in heavy goods vehicles, aviation and shipping.'* It also notes that *'hydrogen may also displace natural gas in heating systems or be used as storage medium for renewable electricity.'*

The Plan goes on to establish a series of pledges related to hydrogen in advance of a Hydrogen Pathway being developed for the country. These are:

- Establishing a new renewable hydrogen production site with capacity of up to 10 MW by 2023/2024
- Begin planning large-scale hydrogen production sites
- Support local hydrogen-related projects
- Explore opportunities such as hydrogen boilers and hybrid heat pumps

The Plan specifically references the government support provided to Milford Haven Energy Kingdom project. This involves a front-end engineering design plus demonstration project, including use of hydrogen vehicles and smart hybrid heating systems through exploiting the strategic opportunities of the future floating wind farm in the Celtic Sea.

14.2.1.3 Hydrogen Use-Cases

The Plan sets out several potential use-cases for hydrogen including:

- **Rail:** The plan notes that hydrogen may be utilised where overhead line equipment is not feasible, however, notes that it is only around 25% efficient
- **HGVs:** The plan identifies the potential of hydrogen fuel cells for HGVs

- **Fuel Switching:** Switching fossil fuels for low carbon hydrogen, including a commitment to grow hydrogen use as a fuel in industrial processes by an average of 3% by 2025
- **Aviation**
- **Farming:** including for tractors and using hydrogen to produce ammonia fertiliser

14.2.1.4 Skills

The Welsh Government acknowledges the need for new skills among the working population and intends to publish a Net Zero Skills Action Plan imminently.

14.2.2 Hydrogen In Wales: A Pathway and Next Steps for Developing the Hydrogen Energy Sector In Wales (Welsh Government, 2021)

This document sets out the proposed pathway and next steps for developing the hydrogen energy sector in Wales. The document was open for consultation following its release and sets out a clear pathway of actions in Wales to 2030 to support the creation of a hydrogen economy within Wales.

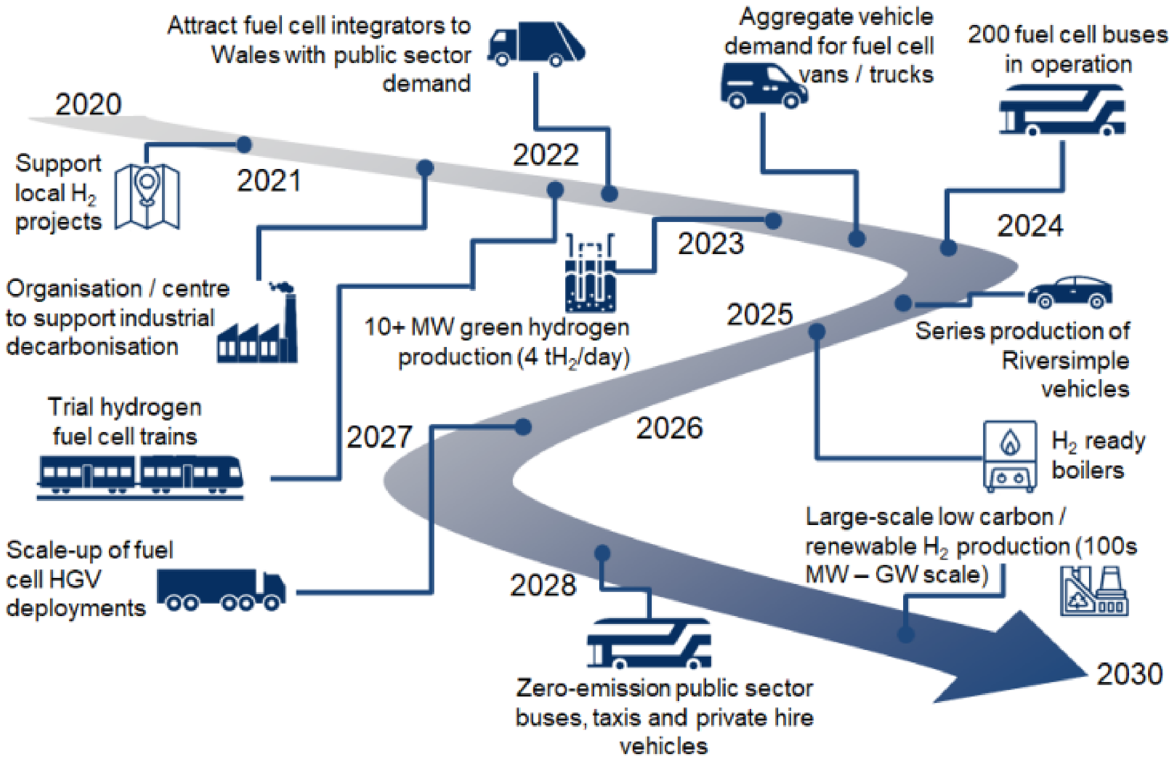


Figure 0-5: Hydrogen in Wales Pathway (Welsh Government, 2021)

The objective of the pathway is to heavily explore the development of demand whilst establishing two production sites. Recommendations include:

1) **Deployment of 200 fuel cell buses in Wales.** Successful deployment of fuel cell buses has been demonstrated in Aberdeen, but no clear plans have been made in Wales to emulate this initiative.
2) **Establish Wales as an early market for commercial fuel cell vehicles.** The UK Government has funded several fuel-cell HGV projects as part of the decarbonisation of transport, but to date, Wales has supported one electric HGV project.
3) **Consider support for vehicle manufacturers such as Riversimple, a Wales-based designer and manufacturer of fuel cell electric vehicles.** Riversimple has developed a fuel-cell vehicle,

however their circular economy design has limited the ability to scale production and skills development in Wales to date.

4) **Attract vehicle integrators to Wales.** This is a new market that has not yet demonstrated any private sector development.
5) **Deploy fuel cell trains in Wales.** In 2022 Ballard Motive and Arup undertook a study to assess the viability of hydrogen-fuelled trains in Wales.
6) **Establish at least one renewable hydrogen production site 10+ MW by 2023/24.** Currently the largest renewable energy source is expected to come from the Celtic Offshore wind which is still under development.
7) **Scope large-scale hydrogen production sites.** This process has been supported by the government's policy changes regarding the abatement of fossil fuels and the need to transition the existing natural gas plants in South Wales in the Western Gateway area.
8) **Support industrial decarbonisation through skills development and R&D.** A summary of the projects undertaken in relation to hydrogen has been performed as part of this strategy, however the projected skills requirement to meet hydrogen production and demand is far greater and the need to support training of existing skills-based workers is key (for example heating engineers, vehicle maintenance etc).
9) **Support local projects and place-based approaches.** Community engagement is key to transition. To date hydrogen projects have not been publicly demonstrated and engagement has been limited.
10) **Engage with other hydrogen initiatives.** In the Western Gateway area, the wider group, Hydrogen South West has looked to engage and develop a network of hydrogen opportunities, bringing together industry and production.

The pathway focuses heavily on the opportunity for transport and states that low-carbon hydrogen can reach cost parity with other low carbon technologies by the mid-2030s. In part this is because it recognises the transport sector as being one of the most technically mature sectors for hydrogen application and an area closest to commercial viability due to the relatively high value of fuel.

The report places a strong emphasis on transport as a soft and flexible market for hydrogen where demand will increase over time.

14.2.3 A Carbon Capture, Utilisation, & Storage Network for Wales (Welsh Government, 2021)

This report lays out a series of options for the Welsh Government to consider in regard to CO_2 storage. These considerations will be key for the Western Gateway area if the production of blue hydrogen is pursued.

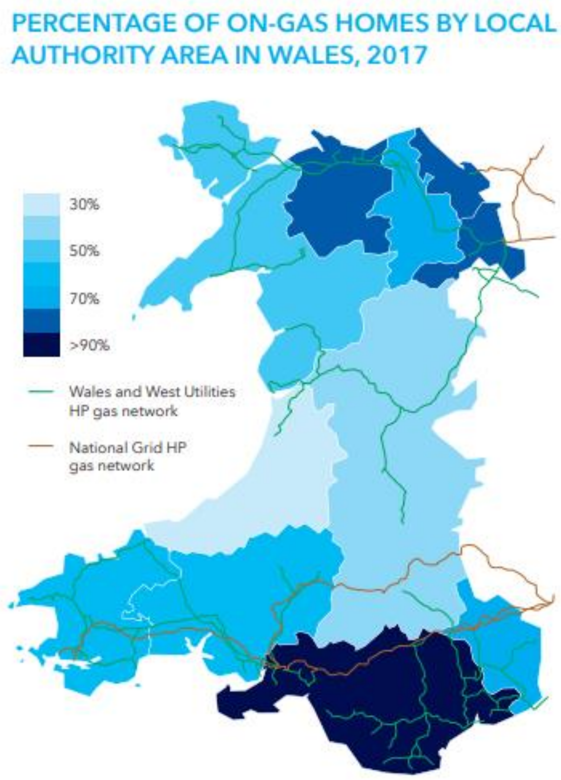
The report recognises that the utilisation of CO_2 is preferable, but that the level of demand identified is unlikely to make a significant impact on the levels being generated.

Specifically for South Wales, it is noted that *'It is unlikely that onshore storage of CO_2 at sites in Wales such as coal mines or coal seams would be permitted. A review of the Welsh Government's Petroleum Policy and Planning Policy, and discussions with Welsh Government officials have indicated that this would not be likely. As a result, storage options outside Wales would need to be prioritised.'*

The North of Wales has potential access to the NW HyNet project, which involves geological storage of CO_2 in exhausted hydrocarbon offshore fields. For South Wales, the cheapest option has been identified as a pipeline from Milford Haven, across England and terminating in Immingham for storage, however, the report notes that any pipeline would cross areas of environmental sensitivity in South Wales.

The report however recommends that the best strategy is likely to be shipping CO_2 as this provides a flexible export depending on demand.

The report recognises that the use of green hydrogen can reduce the need for CCUS as its production does not generate CO_2.



Fuel switching to hydrogen is noted in the report as a key option to reduce “on site” CO_2, providing the ability for sectors to reduce their emissions. The use of blue hydrogen requires CCS at the point of production, the lead times for production are longer than green hydrogen, and result in the need to store the resulting CO_2 from the process, as well as the hydrogen produced. The CO_2 produced requires a geological storage permit, which can take between 3-10 years to obtain.

The report also looks at alternatives such as electrification and switching to biomass.

Notable for South Wales, the report looks at the decarbonisation options for steel production that Port Talbot will need to follow. The use of an Electric Arc Furnace is projected to reduce carbon emissions from a steel works site by 95%.

Under existing infrastructure, the report identifies that South Wales has a significant number of homes connected to the gas network, resulting in an increased opportunity to decarbonise heat through hydrogen.

The report identifies Milford Haven as a key site requiring CCUS and notes that Port Talbot is a complex site with the impact and requirement of CCS depending significantly on the steelworks and its decarbonisation plans. The report identifies Baglan power plant as providing the second highest need for CCS in South Wales.

In relation to skills, the report identifies the opportunity to repurpose the skills base from the hydrocarbon sector that will be scaled down as the CCS sector increases. STEM skills are identified as a key requirement, and whilst this report notes that many STEM graduates move into finance and banking roles, in recent years the market has seen an increase in graduates looking for more sustainable roles that support the transition to Net Zero.

14.2.4 Llwybr Newydd: The Wales Transport Strategy 2021 (2021)

Llwybr Newydd (2021) constitutes Wales’s transport strategy with an overarching vision of *‘an accessible, sustainable and efficient transport network.’*

Decarbonisation is a central theme of the Strategy and it identifies that hydrogen can play a role in meeting this target. This includes exploring the use of hydrogen for rail and road transport through delivery of new refuelling infrastructure.

14.3 Regional & Local Policy Context

14.3.1 Western Gateway Hydrogen Ecosystem (2022)

The Western Gateway partnership has ambitions to become the UK's first Green Energy Super Cluster, leading the way to net zero by 2050. Hydrogen is set to play a major role in this, from low-emission air travel to making the transition away from gas heating networks.

The strategic vision for hydrogen in the area is linked not only to the need to deliver on the government's net zero targets, but also to ensure energy security for the future and the economic benefits of a hydrogen technology cluster for the area. The commitment from Western Gateway is as follows:

'Our partnership is committed to harnessing the potential of hydrogen to power clean, inclusive growth across our area and maximise our hydrogen assets and capabilities which can be found across our entire area.'

Current activity within the Western Gateway area supporting hydrogen research, production, storage, transport and application is shown in Table 0-6.

Area	Organisation	Activities
Research	GW4 Alliance	• Research and innovation consortium between Bath, Bristol, Cardiff and Exeter Universities. • The Alliance is working with academics to understand the challenges of using hydrogen as an alternative fuel source.
	Sustainable Environment Research Centre	• Based at the University of South Wales. • Undertakes research into sustainable hydrogen production, storage and application.
Innovation	National Composite Centre	• Developing the next generation of hydrogen storage and transportation solutions. • Part of the High-Value Manufacturing Catapult.
	Institute for Advanced Automotive Propulsion Systems	• Supports research into and education about the future direction of the propulsion industries. • Green hydrogen production and storage facility is to become operational in Spring 2023. • Developing a Hydrogen Enterprise and Education Hub to support SMEs focused on hydrogen and sustainable transport.
Commercialisation	Hydrogen South West	• Focused on growing a hydrogen economy, with a partnership of industrial, delivery, economic and regional knowledge-holders.

Table 0-6: Hydrogen Cluster Activities within the Western Gateway Area (Western Gateway, 2022)

Figure 0-6 shows the range of activity taking place across the Western Gateway area as part of the developing hydrogen cluster.

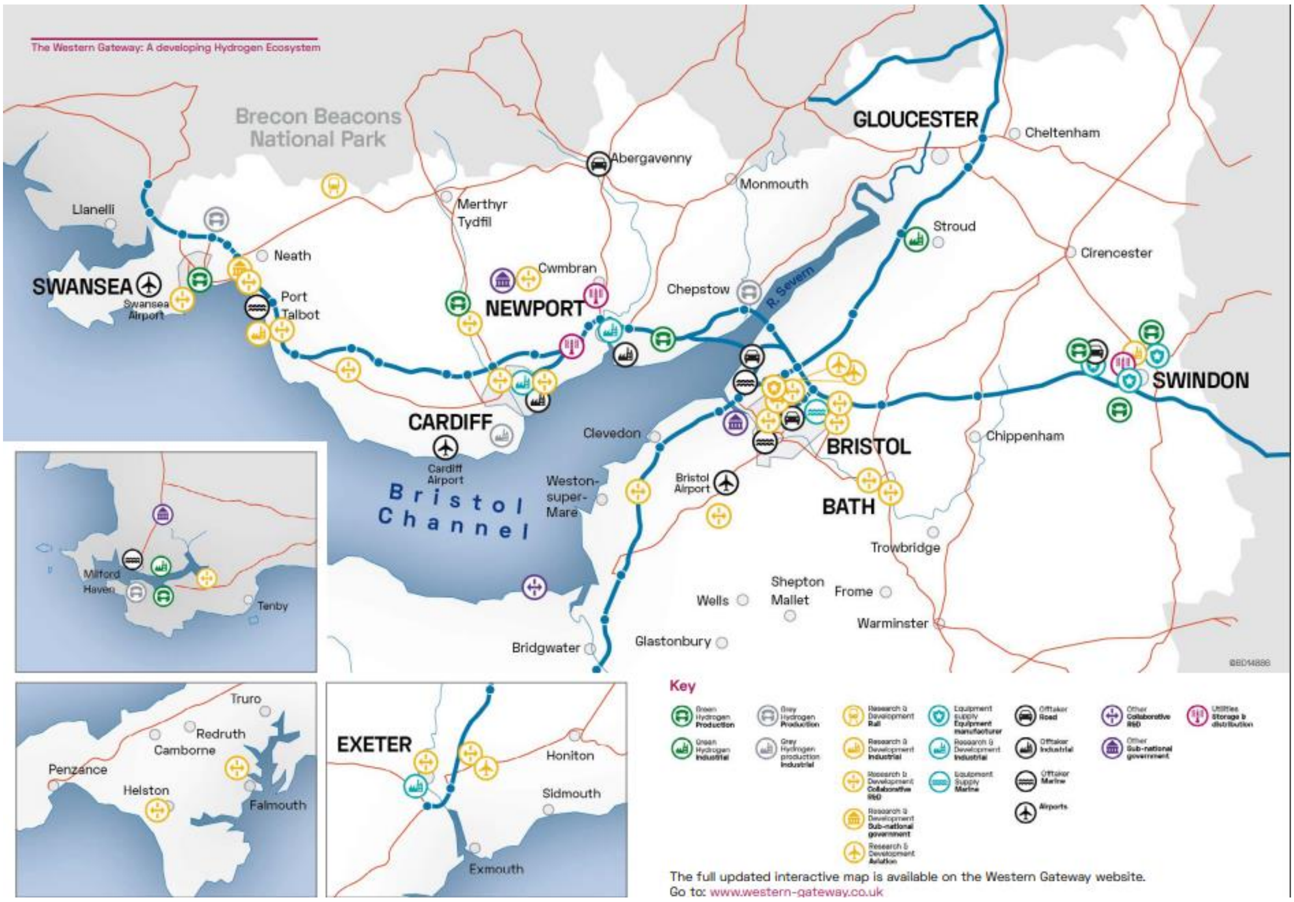


Figure 0-6: Map of Hydrogen-Related Activities within the Western Gateway Area (Western Gateway, 2022) https://westerngateway.maps.arcgis.com/apps/webappviewer/index.html?id=10353829d5074ec6abd3db36815f1db0

The Western Gateway area hosts centres of excellent in several fields, which support its ambitions to become a hydrogen ecosystem. These fields include:

- **Aviation**: home to 14 of the 15 largest global aerospace companies, as well as the UK Global Technology Centre and the Aerospace Technology Institute. These organisations are working to deliver on the government's Jet Zero ambitions and focusing on the production of both sustainable aviation fuel and zero-emissions aircraft
- **Maritime**: Western Gateway is home to Bristol Port, and several other major ports owned and run by the Associated British Ports (including Swansea and Cardiff). Hydrogen and hydrogen-based fuels are being trialled as a means to powering the low-carbon maritime industries of the future, and ports in the Western Gateway area will generate major demand for clean fuels to continue their work transporting the UK's people and goods
- **Industrial decarbonisation**: The south Wales Industrial Cluster is an area of focus for transformation into a low-carbon or net zero carbon industrial cluster by 2040. Organisations in this area include the University of South Wales, National Composite Centre and Johnson Matthey, all of which are working towards high value marketing and innovative approaches to hydrogen generation, storage and application in industry

There is great potential within the Western Gateway area to harness the activities occurring across the hydrogen lifecycle and reap the benefits from the proximity and collaboration potential that these organisations bring. The delivery of a productive hydrogen economy will have a national impact in terms of the UK's net zero ambitions but will also support a thriving local economy and bring opportunities to upskill workers in the area.

14.3.2 Western Gateway Prospectus (2022)

The Western Gateway Prospectus sets out the mission of the Western Gateway partnership, and its ambitions to deliver economic opportunity, access to good jobs and education opportunities to those in the South West and South Wales. The five missions of Western Gateway are:

- **Mission 1**: Contribute £34 billion to the economy
- **Mission 2**: Attract investment and grow exports by £4 billion
- **Mission 3**: Decarbonise our economy
- **Mission 4**: Connect communities
- **Mission 5**: Unlock innovation

Across these missions, Western Gateway seeks to leverage its specialisms in advanced engineering and manufacturing, cyber and fintech to deliver innovation and opportunity across the area. Mission 3 focuses on the strengths of the emerging low-carbon fuel industries from South Wales to Swindon.

14.3.3 South Wales 2050 (2021)

This report, which was produced by Zero 2050 is the culmination of a project to consider how the energy system in South Wales can achieve net zero by 2050. The project included modelling of future energy demands, energy generation, infrastructure and network requirements.

Their final model identifies hydrogen for heat (combined with electricity) and the majority of transport demand being met by electricity.

Included in the low-regret measures for South Wales are:

- the development of a pilot hydrogen production from autothermal reforming and electrolysis. Autothermal reforming, providing combined with CCUS, is a low carbon way to produce hydrogen which involves producing syngas made up of carbon monoxide, carbon dioxide and hydrogen
- the investigation of salt caverns for hydrogen storage at a UK scale (outside of South Wales)
- network studies to understand feasibility and cost of transitioning networks to use hydrogen; and
- investigate options for carbon capture, use and storage and CO_2 export from South Wales.

The access to cheap hydrogen storage in salt caverns outside South Wales is considered to be a critical sensitivity, as was the percentage of hydrogen for domestic heat.

The model assumes that industrial demand will be met through fuel switching to hydrogen and electrification, with blue hydrogen seen as a transition fuel.

Tipping points to monitor in the report include the cost of hydrogen imports, and the cost of generating hydrogen as well as the availability of hydrogen business models (see UK policy review above).

14.3.4 Other Local & Regional Policies

Local / Regional Policy	Authority	Summary of Relevance
SWLEP Green Hydrogen Plan (2022)	Swindon & Wiltshire Local Enterprise Partnership (SWLEP)	• Sets out the role of SWLEP's role in the production of hydrogen using renewable energy • This includes convening private and public sector stakeholders and collaborative working to facilitate delivery, and leading on local projects • The three key outcomes for the strategy are:

Local / Regional Policy	Authority	Summary of Relevance
		1. The stimulation of small-scale production through identifying suitable locations for small scale electrolysers and identifying appropriate funding. 2. Stimulating the demand for hydrogen fuel in phases. 3. Increases investment into green hydrogen R&D. • Integrating with the Strategy will allow for coordinated funding applications and Western Gateway will benefit from the stimulation in demand and opportunities for R&D in the SWLEP area
SWLEP Skills Plan (2020)	Swindon & Wiltshire Local Enterprise Partnership (SWLEP)	• The priority of the skills plan is to maintain the balance between the skill supply and demand • This requires increasing the proportion of highly skilled jobs, improving productivity in the area which is below the national average • Expanding opportunities for highly skilled individuals will come from investment in existing low carbon and hydrogen clusters in the area, through the Western Gateway Hydrogen Strategy.
SWLEP Local Industrial Strategy (2020)	Swindon & Wiltshire Local Enterprise Partnership (SWLEP)	• One of the key infrastructure issues covered by the Local Industrial Strategy is the exploration of further uses for hydrogen as a source of reliable energy. • Strategic Priority 6 is the development of new vehicle fuelling infrastructure, including investigating potential demonstrator projects in collaboration with Oxfordshire, GFirst, Thames Valley, Berkshire and the West of England LEPs. • There is a clear objective to increase uptake of hydrogen-fuelled vehicles and support the clean growth agenda.
WECA Climate & Ecological Strategy & Action Plan (2022)	West of England Combined Authority (WECA)	• WECA's key priorities for tackling the climate and ecological emergency include maximising investment in the green economy and working to decarbonise the energy system and increase the generation of renewable energy locally. • One of the medium-term actions is for WECA to explore the feasibility of hydrogen power as an alternative fuel by 2025, and develop the business case to implement it. • The Action Plan includes key asks to government, such as opening further innovation funds for hydrogen energy development to support activity in the region.

Local / Regional Policy	Authority	Summary of Relevance
		• Western Gateway's Hydrogen Delivery Pathway will support the lobbying of government, demonstrating the importance of hydrogen power to the region.
WECA Local Industrial Strategy (2019)	West of England Combined Authority (WECA)	• The West of England region will look to contribute to the Clean Growth Grand Challenge by building on exiting energy strengths to deliver reliable and affordable energy which enables economic growth whilst reducing greenhouse gas emissions. • There is an opportunity to build on existing funding for this, including the Transforming cities fund and funding for the South West Energy Hub. • Integrating existing funding streams will strengthen the coherence of the delivery pathway.
WECA Employment & Skills Plan (2019)	West of England Combined Authority (WECA)	• Productivity has flat lined in the West of England region. • There is a skills shortage in growth sectors including advanced manufacturing, technology, and engineering. • There is an established innovation cluster in the area, centred around high tech and digital sectors, aerospace and advanced engineering – aiming to bring low carbon energy businesses into the cluster through the delivery pathway will help attract new people to the area, increase productivity and support the wider ambitions of the Western Gateway.
West of England Energy Study (2018)	Centre for Sustainable Energy	• One of the strategic ambitions of this Study is a clear regional plan to decarbonise heat demand in the West of England by 2040. • Injection of green hydrogen into the gas network is likely to be necessary to fully decarbonise heat. • It is recommended that research into the role and production of hydrogen is begun as soon as possible, and these activities can be supported by the Western Gateway Hydrogen Delivery Pathway.
Gloucestershire Sustainable Energy Strategy (2019)	GFirst LEP	• Sets out how Gloucestershire can contribute to the UK's net zero targets by 2050, while also tackling energy supply security and the cost of energy • The county's gas and electricity network operators are engaged with opportunities to switch to hydrogen power

Local / Regional Policy	Authority	Summary of Relevance
		• The strategy commits to a 60% reduction in carbon emissions by 2030 (although this has since been superseded by the Gloucestershire Climate Change Strategy (2019) target of 80% reduction by 2030), and net zero by 2050 along with an increase in renewable energy generation and heat decarbonisation by 2040 • As part of the 'taking the lead on decarbonising heat' objective, GFirst LEP commits to establishing an 'ultra-low carbon' thermal energy cluster which could be applied to the production of hydrogen
GFirst LEP Draft Local Industrial Strategy (2019)	GFirst LEP	• Gloucestershire is located in a strategic position on the border of Wales, the Midlands and the South West, and the Local Industrial Strategy seeks to develop Gloucestershire as a hub for a number of growth industries in the region. • It seeks to establish Gloucestershire as a leader in sustainable growth, put clean growth at the heart of investment decisions and new developments, and to build on green capabilities in the private sector. • Locally based innovation is a key focus of the strategy, including companies such as Ecotricity and Green Fuels who are at the forefront of hydrogen production and application research.
South West Wales Energy Strategy (2022)	Welsh Government Energy Service	• South West Wales has long been a hub of hydrogen development in South Wales with the Flexis hydrogen demonstration project based across Swansea and Neath Port Talbot. • 1% of the commercial and industrial energy demand is expected to be supplied by hydrogen through energy clusters by around 2030. • There is a commitment to green hydrogen production in order to align with the region's net zero ambitions, which fits well with the high potential for renewable generation in the area. • Hydrogen vehicles may also have a part to play, particularly HGVs, buses, coaches and trains, led by the Hydrogen Centre.
Cardiff Capital Region Energy Strategy (2021)	Welsh Government Energy Service	• The vision within this energy strategy is for a transition to a carbon neutral economy and society within the Cardiff Capital Region (CCR), using low carbon energy as an enabler of economic regeneration.

Local / Regional Policy	Authority	Summary of Relevance
		• Hydrogen is expected to play a role in decarbonisation of industrial activity by around 2035. • It is noted that there is strong support for the CCR region to lead the way in the development of hydrogen production, storage and use technologies. • Hydrogen will be produced using excess renewable energy to power electrolysis or through methods such as steam methane reformation with effective carbon capture and storage. • Hydrogen as an alternative fuel for HGVs is also mentioned.
Newport Local Area Energy Plan (2022)	Newport City Council	• The objective of the Local Area Energy Plan is to develop a net zero energy system for Newport, as a city on the rise. • The plan includes a 2050 scenario of high demand for energy with high levels of hydrogen uptake. • It is projected that significant amounts of hydrogen will be required to decarbonise Newport's industrial installations. • There are plans for a local industrial innovation programme around low carbon energy in the industrial cluster. This includes large industrial users who could be pilot sites for hydrogen use and production.
Decarbonisation and Renewable Energy Strategy (2020)	Neath Port Talbot Council	• Neath Port Talbot Council have already begun trialling hydrogen operated vehicles in their fleet, including a hydrogen bin-lifting unit on a refuse freighter. • Longer term, the Council is seeking to commission a feasibility study into the identification of a strategic site to develop a hydrogen filling station – a first for Wales. • The Council is also seeking to deliver an 'energy positive' building that will connect to the Hydrogen Centre to export surplus electrical generation for production of hydrogen to be used in the public sector transport fleet.
Energy and Carbon Management Plan Framework 2020-2030 (2020)	Swansea Council	• Relevant objectives in this Strategy are: 1. To invest in renewable technologies that will benefit Swansea Council and the wider community 2. To secure or facilitate community access to affordable low carbon/renewable energy

Local / Regional Policy	Authority	Summary of Relevance
		3. Explore and maximise commercial opportunities to benefit community wellbeing and/or financial gain • The Strategy supports the Welsh Government's aspirations for 70% of energy consumed in Wales to be from renewable sources generated in Wales by 2030

Table 0-7: Summary of wider local and regional policies relevant to hydrogen within the Western Gateway area

There are several climate strategies and action plans within in the Western Gateway area which contain ambitions and targets for the decarbonisation of both transport and heating as the major sources of greenhouse gases in the area. Hydrogen is mentioned relatively infrequently, however investment into hydrogen research and production will support all Local Authorities in the area with their net zero goals.

Climate Strategy	Authority
Bath & North East Somerset Climate Emergency Action Plan (2020)	Bath & North East Somerset Council
Blaenau Gwent Decarbonisation Plan 2020-2030 (2020)	Blaenau Gwent Council
Bridgend 2030 – Net Zero Carbon Strategy (2020)	Bridgend County Borough Council
Bristol City Council Climate Action Plan (2022)	Bristol City Council
Cheltenham Climate Emergency Action Plan	Cheltenham Borough Council
Cotswold Climate Emergency Strategy 2020 - 2030 (2020)	Cotswold District Council
Decarbonisation Strategy: Reduce – Produce – Offset – Buy (2020)	Caerphilly County Borough Council
Forest of Dean Route to Carbon Neutral (2022)	Forest of Dean District Council
Gloucestershire Climate Change Strategy (2019)	Gloucestershire County Council
Monmouthshire Climate Emergency Strategy and Action Plan (2021)	Monmouthshire County Council
Newport Climate Change Plan (2022)	Newport City Council
North Somerset Climate Emergency Action Plan (2021)	North Somerset Council
One Planet Cardiff (2020)	Cardiff City Council

Climate Strategy	Authority
South Gloucestershire Climate Change Strategy 2018 – 2023 (2020)	South Gloucestershire Council
Swindon Borough Council Carbon Reduction Strategy 2020 (2020)	Swindon Borough Council
Think Climate RCT (2022)	Rhondda Cynon Taff County Borough Council
Vale of Glamorgan Council Climate Change Challenge Plan (2021)	Vale of Glamorgan Council
Wiltshire Climate Strategy (2022)	Wiltshire Council

Table 0-8: Climate Strategies and Action Plans in the Western Gateway Area

Appendix B - Scenario Assumptions

Baseline Demand Assumptions (Consistent Across All Scenarios)

Hydrogen end-uses	Growth	Energy Efficiency
Heating	Follows ONS population growth trajectory for the Western Gateway (average 0.4% year-on-year increase)	Existing building retrofit: Based on CCC 6CB analysis of economic potential for retrofit. Assumed all buildings where it is economic to apply retrofit, that 100% will be retrofitted by 2050. This equates to 8% overall heating reduction across existing building stock. New builds: Assumed new builds require 30% less heat than existing average.
Road transport	Follows ONS population growth trajectory for the Western Gateway (average 0.4% year-on-year increase)	Assumed number of miles travelled remains constant, no mode shift or demand reduction applied.
Industrial	Growth of industry is unknown, assumed current levels of demand stays flat out to 2050	Level of demand reduction through industrial energy efficiency is unknown, assumed flat demand out to 2050.
Aviation	As per Cardiff's masterplan, assumed 3% year-on-year growth, bringing current passengers from 1.6 million per annum (mpa) to 4 mpa by 2050. Bristol is likely to gain approval to expand to 12mpa (currently circa 9 mpa), assumed 12mpa is achieved by 2027, after which passenger numbers are flat.	As per CCC 6CB Balanced pathway, assumed 1.4% year-on-year aircraft efficiency improvement
Marine	Future growth of marine sector unknown, assumed flat demand out to 2050	Assumed energy efficiency of marine fleet remains constant – no improvement
Agriculture (fuel & fertiliser)	Assumed agriculture demand remains constant out to 2050	No efficiency improvement modelled
Construction plant equipment (off-road mobile machinery)	Follows ONS population growth trajectory for the Western Gateway (average 0.4% year-on-year increase)	No efficiency improvement modelled

Hydrogen end-uses	Growth	Energy Efficiency
Rail	Follows ONS population growth trajectory for the Western Gateway (average 0.4% year-on-year increase)	Assumed train efficiency remains constant – no improvement

Gas Grid Development Assumptions

Network	Necessities Only	Balanced Hydrogen	Widespread Hydrogen
Gas grid Distribution networks	By 2050: No hydrogen transported through distribution networks No fossil gas transported through distribution networks, large consumers tap into transmission networks (blue hydrogen plant for Port Talbot) Prior to 2050: Blending to 20% not pursued	By 2050: Local distribution zone near to Port Talbot (covering Swansea and Neath Port Talbot) converts to 100% hydrogen using blue production from Port Talbot No fossil gas transported through other distribution networks Prior to 2050: All distribution networks blended to 20% vol by 2030	By 2050: Gas distribution networks converted to 100% hydrogen Large consumers tap into natural gas transmission networks (blue hydrogen plant for Port Talbot) Prior to 2050: All distribution networks blended to 20% vol by 2030
Gas grid Transmission networks	Development of hydrogen transmission network from Milford Haven running through to Port Talbot and through South Wales industrial cluster (HyLine project by WWU) – supplies industrial demands only Fossil gas transmission will remain for large consumers only (e.g. Port Talbot blue hydrogen production)	Development of hydrogen transmission network from Milford Haven running through to Port Talbot and through South Wales industrial cluster (HyLine project by WWU) HyLine would be extended across the rest of South Wales to feed other industrial demands and distribution zones for heating demands Fossil gas transmission will remain for large consumers only (e.g. Port Talbot blue hydrogen production).	Development of hydrogen transmission network from Milford Haven running through to Port Talbot and through South Wales industrial cluster (HyLine project by WWU) HyLine would be extended across the rest of South Wales to feed other industrial demands and distribution zones for heating demands Fossil gas transmission will remain for large consumers only (e.g. Port Talbot blue hydrogen production).

Demand Scenario Assumptions

<table>
<tr><th>Hydrogen end-uses</th><th>Necessities Only</th><th>Balanced Hydrogen</th><th>Widespread Hydrogen</th></tr>
<tr><td>Heating (domestic and commercial buildings)</td><td>No hydrogen used for heating
All on-gas and many off-gas buildings are electrified through heat pumps and electric resistive heating
Off-gas buildings either electrified or use alternative low carbon fuels (e.g. bio-LPG, bio-methane)</td><td>Distribution zone (covered Swansea and Neath port Talbot) around Port Talbot blue hydrogen production converted into hydrogen for heat
Remaining on-gas are electrified through heat pumps and electric resistive heating
Off-gas buildings either electrified or use alternative low carbon fuels (e.g. bio-LPG, bio-methane)</td><td>All on-gas buildings are heated with hydrogen
Off-gas buildings either electrified or use alternative low carbon fuels (e.g. bio-LPG, bio-methane)</td></tr>
<tr><td>Industrial processes (Port Talbot steelworks)</td><td colspan="3">Assumed Port Talbot remains as an iron producer via Hydrogen-Direct Reduced Iron (DRI) – Electric Arc Furnace (EAF)
Conversion in 2035, supply of hydrogen from on-site Auto-thermal Reformer (ATR) with CCS (blue hydrogen)
Conversion of Port Talbot to 100% scrap steel plant via EAF added as sensitivity</td></tr>
<tr><td>Industrial processes (Aberthaw cement works)</td><td colspan="3">Conversion to hydrogen for fuel demands in 2035 – requires CCS for process emissions</td></tr>
<tr><td>Industrial processes (other large sites)</td><td colspan="2">Largest sites switch to hydrogen, remainder are electrified – 70% conversion of energy demands fulfilled by hydrogen in 2050</td><td>100% switch to hydrogen by 2050</td></tr>
</table>

Hydrogen end-uses	Necessities Only	Balanced Hydrogen	Widespread Hydrogen
Other industrial buildings: Factory, warehouse and logistics	To follow pathway for domestic and commercial buildings – fully electrified	To follow pathway for domestic and commercial buildings – mostly electrified	To follow pathway for domestic and commercial buildings – full switch to hydrogen
Road transport: Split by: Motorcycles, Cars, Buses/coaches, LGVs and HGVs	Whole of road transport fleet is 100% electrified (including LGVs and HGVs)	Hydrogen used for 50% HGVs, 50% LGVs and 50% buses/coaches, Cars and motorcycles 100% electrified	Hydrogen used for 100% HGVs, 100% LGVs and 100% buses/coaches, remainder of fleet is electrified Cars 75% electrified, 25% hydrogen Motorcycles 100% electrified

Hydrogen end-uses	Necessities Only	Balanced Hydrogen	Widespread Hydrogen
Aviation (international flights)	20% synthetic kerosene uptake 20% hydrogen uptake	20% synthetic kerosene uptake 40% hydrogen uptake	20% synthetic kerosene uptake 60% hydrogen uptake
Aviation (domestic flights)	10% synthetic kerosene uptake 20% hydrogen uptake	10% synthetic kerosene uptake 50% hydrogen uptake	10% synthetic kerosene uptake 80% hydrogen uptake
Marine	Ammonia is key driver of decarbonisation, with 90% of marine fuel demands met by ammonia (which requires hydrogen feedstock)		
Rail	No hydrogen uptake in rail	20% of rail demand fulfilled by hydrogen, remainder is electrified	30% of rail demand fulfilled by hydrogen, remainder is electrified
Agricultural (fertiliser)	Fertiliser plants (SMR for production of ammonia) assumed to be fitted with CCS (blue hydrogen) – no fertiliser plants are within the WG area		
Agricultural (fuel)	Gas grid demand for agriculture to follow pathway set out for non-domestic buildings Other fuel use (oil for heating and diesel for vehicles), assumed 25%, 50% and 75% hydrogen uptake for low, balanced and high scenarios respectively – remainder electrified		
Construction plant equipment (off-road mobile machinery)	100% electrified, no hydrogen uptake	50% hydrogen uptake	80% hydrogen uptake

Supply Scenario Assumptions

Supply source	Necessities Only	Balanced Hydrogen	Widespread Hydrogen
New dedicated green hydrogen electrolysis % capacity fitted with dedicated electrolyser by 2050. All have linear uptake of electrolysers starting from 0% in 2030, to the %'s shown here by 2050.	Offshore wind: 20% Onshore wind: 10% Solar PV: 5%	Offshore wind: 30% Onshore wind: 15% Solar PV: 10%	Offshore wind: 50% Onshore wind: 25% Solar PV: 10%
Green hydrogen production from curtailed renewables	Making use of curtailed electricity is limited by low load factors of electrolyser and by network constraints Any electrolyser for the purpose of making use of curtailed electricity would likely have to be topped up by grid electricity We have therefore assumed no electrolyser deployment for the sake of capturing curtailed renewables		
Blue hydrogen (natural gas reforming with CCS)	Blue hydrogen production site at Port Talbot – used for Port Talbot steelworks only – built in 2035	Blue hydrogen production site at Port Talbot and supply to Local Distribution Zone (LDZ) covering Swansea and Neath Port Talbot (Dyffryn Clydach LDZ) – Port Talbot demand built in 2035, then plant increased in 2040s to meet LDZ demands Assumed blue hydrogen site developed at Milford Haven with transmission via HyLine project to Port Talbot and South Wales Industrial Cluster	Blue hydrogen production site at Port Talbot and supply to Local Distribution Zones (LDZ) covering Swansea, Cardiff and Newport (Dyffryn Clydach LDZ, Dowlais LDZ and Gilwern LDZ) – Port Talbot demand built in 2035, then plant increase in 2040s to meet LDZ demands Assumed blue hydrogen site developed at Milford Haven with transmission via HyLine project to Port Talbot and South Wales Industrial Cluster

Supply source	Necessities Only	Balanced Hydrogen	Widespread Hydrogen
Pink Hydrogen (nuclear)	No hydrogen production via nuclear power New small modular and advanced modular reactors could present opportunity for hydrogen production in the future, but there is current uncertainty on whether the technology will develop sufficiently for hydrogen production prior to 2050		
Hydrogen from waste: Municipal Solid Waste (MSW)	5% of hydrogen potential from MSW realised	10% of hydrogen potential from MSW realised	20% of hydrogen potential from MSW realised

Appendix C – Baseline Demands

Hydrogen end-uses	2019 Existing Demands (GWh_{GCV})		
	Gas grid	Other fuels	Hydrogen as chemical feedstock
Heating	28,800	3,070	
Road transport		35,700	
Industrial	14,000	17,900	
Aviation		2,520	
Marine		1,400	
Agriculture (fuel)	84	1,030	
Agriculture (fertiliser)			736
Construction plant equipment (off-road mobile machinery)		1,130	
Rail		648	
Totals	**42,800**	**63,400**	**736**

Appendix D – Hydrogen Demands

Hydrogen end-uses	Hydrogen Demands (GWH_{GCV}) under Necessities Only scenario			
	2030	2035	2040	2050
Heating	0	0	0	0
Road transport	0	0	0	0
Industrial	0	22,600	23,300	25,700
Aviation	0	80	465	1,180
Marine	0	351	702	1,410
Agriculture (fuel)	0	69	132	259
Agriculture (fertiliser)	Excluded as fertiliser made outside of WG area			
Construction plant equipment (off-road mobile machinery)	0	0	0	0
Rail	0	0	0	0
Totals	**2,350**	**24,600**	**25,600**	**28,500**

Hydrogen end-uses	Hydrogen Demands (GWH_{GCV}) under Balanced Hydrogen scenario			
	2030	2035	2040	2050
Heating	1,900	1,540	1,110	2,940
Road transport	0	1,150	2,352	4,890
Industrial	442	22,600	23,300	25,700
Aviation	0	117	677	1,710
Marine	0	351	702	1,410
Agriculture (fuel)	5	134	262	526
Agriculture (fertiliser)	Excluded as fertiliser made outside of WG area			
Construction plant equipment (off-road mobile machinery)	0	306	623	647
Rail	0	35	71	148
Totals	2,350	26,200	29,100	37,900

Hydrogen end-uses	Hydrogen Demands (GWH_{GCV}) under Widespread Hydrogen scenario			
	2030	2035	2040	2050
Heating	2,110	2,120	11,200	29,400
Road transport	0	3,440	7,020	14,600
Industrial	442	22,600	25,400	31,900
Aviation	0	153	888	2,250
Marine	0	351	702	1,410
Agriculture (fuel)	6	200	420	860
Agriculture (fertiliser)	Excluded as fertiliser made outside of WG area			
Construction plant equipment (off-road mobile machinery)	0	489	996	1,040
Rail	0	52	107	222
Totals	**2,560**	**29,400**	**46,700**	**81,600**

Appendix E – Hydrogen Supplies

	Hydrogen Production (GWhGCV) under Necessities Only Scenario			
Hydrogen supplies	2030	2035	2040	2050
Offshore wind	0	585	2,230	8,710
Onshore wind	0	46	108	275
Ground mount PV	0	33	82	225
Hydrogen from Waste	0	36	73	146
Pink (nuclear)	0	0	0	0
Production without blue	0	701	2,490	9,350
Blue	0	0	21,300	21,300
Production with blue	0	701	23,800	30,700

Hydrogen supplies	Hydrogen Production (GWh_{GCV}) under Balanced Hydrogen Scenario			
	2030	2035	2040	2050
Offshore wind	0	877	3,350	13,060
Onshore wind	0	70	162	413
Ground mount PV	0	66	164	451
Hydrogen from Waste	0	73	146	291
Pink (nuclear)	0	0	0	0
Production without blue	0	1,090	3,820	14,200
Blue	0	21,300	24,600	24,600
Production with blue	0	22,400	28,400	38,800

Hydrogen supplies	Hydrogen Production (GWh_{GCV}) under Widespread Hydrogen Scenario			
	2030	2035	2040	2050
Offshore wind	0	1,460	5,580	21,800
Onshore wind	0	116	270	688
Ground mount PV	0	66	164	451
Hydrogen from Waste	0	146	291	583
Pink (nuclear)	0	0	0	0
Production without blue	0	1,790	6,300	23,500
Blue	0	21,300	37,500	37,500
Production with blue	0	23,100	43,800	61,000

Appendix F – Western Gateway Hydrogen Economy Forecasts

Necessities Only Scenario

	Necessities Only Scenario Job Creation						
Direct Jobs	2020	2025	2030	2035	2040	2045	2050
Production							
New Dedicated Green Hydrogen Electrolysis (see Chapters 7 & 8)	0	0	0	41	140	298	513
Blue Hydrogen from ATR + CCUS	0	0	0	0	756	756	756
Energy from Waste (Gasification)	0	0	0	5	9	13	17
Hydrogen Production Jobs	**0**	**0**	**0**	**46**	**905**	**1,067**	**1,286**
Transmission & Distribution							
Losses from distribution	0	0	(267)	(534)	(801)	(1,067)	(1,334)
Gains / Losses from Transmission	0	0	(30)	(59)	(89)	(119)	(148)
Hydrogen Transmission & Distribution Jobs	**0**	**0**	**(297)**	**(593)**	**(890)**	**(1,186)**	**(1,483)**
Transition Activities							
Domestic sector installations and maintenance	0	0	0	0	0	0	0
Industrial sector installations and maintenance	0	18	63	223	797	797	797
Freight sector conversions and infrastructure	0	0	0	0	0	0	0
	0	**18**	**63**	**223**	**797**	**797**	**797**
Total Hydrogen Jobs	**0**	**18**	**(234)**	**(324)**	**813**	**678**	**601**

Capital Investment	Necessities Only Scenario Capital Investment (£m)							
	2020	2025	2030	2035	2040	2045	2050	Total
Production								
New Dedicated Green Hydrogen Electrolysis (£m)	0	0	0	98	307	638	1,077	2,121
Blue Hydrogen from ATR + CCUS (£m)	0	0	0	0	1,287	1,206	1,131	3,624
Energy from Waste (Gasification) (£m)	0	0	0	5	10	14	19	48
Hydrogen Production (£m)	0	0	0	103	1,604	1,858	2,227	5,792
Transmission & Distribution								
New Gas Transmission Network*	0	0	0	0	0	0	0	0
Hydrogen Transmission & Distribution Jobs	0	0	0	0	0	0	0	0

Capital Investment	Necessities Only Scenario Capital Investment (£m)							
	2020	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**	**Total**
Transition Activities								
Domestic sector installations and maintenance	0	0	0	0	0	0	0	0
Port Talbot Hydrogen Conversion (all scenarios)					2,200			2,200
Aberthaw cement works				892				892
Other industry	0	11	38	134	478	478	478	1,617
Freight sector conversions and infrastructure	0	0	0	0	0	0	0	0
	0	11	38	1,026	2,678	478	478	4,709
Total Hydrogen Investment	**0**	**11**	**38**	**1,129**	**4,282**	**2,337**	**2,705**	**10,501**
* Note - no decommissioning costs have been assumed for the gas grid.								

Balanced Hydrogen Scenario

	Balanced Hydrogen Scenario Job Creation						
Direct Jobs	2020	2025	2030	2035	2040	2045	2050
Production							
New Dedicated Green Hydrogen Electrolysis (see Chapters 7 & 8)	0	0	0	65	218	460	790
Blue Hydrogen from ATR + CCUS	0	0	0	756	871	871	871
Energy from Waste (Gasification)	0	0	0	9	18	27	35
Hydrogen Production Jobs	**0**	**0**	**0**	**830**	**1,107**	**1,358**	**1,696**
Transmission & Distribution							
Losses from distribution	0	0	(133)	(267)	(400)	(534)	(667)
Gains / Losses from Transmission	0	0	(15)	(30)	(44)	(59)	(74)
Hydrogen Transmission & Distribution Jobs	**0**	**0**	**(148)**	**(297)**	**(445)**	**(593)**	**(741)**
Transition Activities							
Domestic sector installations and maintenance	0	8	32	123	471	471	471
Industrial sector installations and maintenance	0	18	63	223	797	797	797
Freight sector conversions and infrastructure	0	21	104	523	2,641	2,641	2,641
	0	**46**	**198**	**869**	**3,910**	**3,910**	**3,910**
Total Hydrogen Jobs	**0**	**46**	**50**	**1,403**	**4,572**	**4,675**	**4,864**

Capital Investment	Balanced Hydrogen Scenario Capital Investment (£m)							
	2020	2025	2030	2035	2040	2045	2050	Total
Production								
New Dedicated Green Hydrogen Electrolysis (£m)	0	0	0	157	481	992	1,669	3,300
Blue Hydrogen from ATR + CCUS (£m)	0	0	0	1,370	1,483	1,390	1,304	5,548
Energy from Waste (Gasification) (£m)	0	0	0	10	20	29	37	95
Hydrogen Production (£m)	**0**	**0**	**0**	**1,537**	**1,984**	**2,411**	**3,010**	**8,942**
Transmission & Distribution								
New Gas Transmission Network*	0	0	0	0	0	0	0	0
Hydrogen Transmission & Distribution Jobs	0	0	0	0	0	0	0	0
Transition Activities								

Capital Investment	Balanced Hydrogen Scenario Capital Investment (£m)							
	2020	2025	2030	2035	2040	2045	2050	Total
Domestic sector installations and maintenance	0	5	19	74	283	283	283	946
Port Talbot Hydrogen Conversion (all scenarios)					2,200			2,200
Aberthaw cement works				892				892
Other industry	0	11	38	134	478	478	478	1,617
Freight sector conversions and infrastructure	0	63	316	1,594	8,053	8,053	0	18,078
	0	**78**	**372**	**2,694**	**11,014**	**8,814**	**761**	**23,733**
Total Hydrogen Investment	0	78	372	4,231	12,998	11,225	3,771	32,675
*** Note - no decommissioning costs have been assumed for the gas grid.**								

A summary chart of the totals across the milestone dates would be handy or bar charts to conclude the overview

Widespread Hydrogen Scenario

	Widespread Hydrogen Scenario Job Creation						
Direct Jobs	2020	2025	2030	2035	2040	2045	2050
Production							
New Dedicated Green Hydrogen Electrolysis (see Chapters 7 & 8)	0	0	0	100	343	731	1,262
Blue Hydrogen from ATR + CCUS	0	0	0	756	1,327	1,327	1,327
Energy from Waste (Gasification)	0	0	0	19	36	53	55
Hydrogen Production Jobs	**0**	**0**	**0**	**875**	**1,707**	**2,112**	**2,644**
Transmission & Distribution							
Losses from distribution	0	0	0	0	0	0	0
Gains / Losses from Transmission	0	0	15	30	44	59	74
Hydrogen Transmission & Distribution Jobs	**0**	**0**	**15**	**30**	**44**	**59**	**74**
Transition Activities							
Domestic sector installations and maintenance	0	58	224	859	3,297	3,297	3,297
Industrial sector installations and maintenance	0	25	89	319	1,139	1,139	1,139
Freight sector conversions and infrastructure	0	41	207	1,046	5,283	5,283	5,283
	0	**124**	**520**	**2,224**	**9,719**	**9,719**	**9,719**
Total Hydrogen Jobs	**0**	**124**	**535**	**3,129**	**11,470**	**11,890**	**12,437**

Capital Investment	Widespread Hydrogen Scenario Capital Investment (£m)							
	2020	2025	2030	2035	2040	2045	2050	Total
Production								
New Dedicated Green Hydrogen Electrolysis (£m)	0	0	0	237	748	1,560	2,639	5,184
Blue Hydrogen from ATR + CCUS (£m)	0	0	0	1,370	2,260	2,118	1,986	7,734
Energy from Waste (Gasification) (£m)	0	0	0	20	39	57	37	153
Hydrogen Production Investment	**0**	**0**	**0**	**1,628**	**3,047**	**3,734**	**4,663**	**13,072**
Transmission & Distribution								
New Gas Transmission Network*	0	0	0	0	1,260	0	0	1,260
Hydrogen Transmission & Distribution Jobs	**0**	**0**	**0**	**0**	**1,260**	**0**	**0**	**1,260**
Transition Activities								

Capital Investment	Widespread Hydrogen Scenario Capital Investment (£m)							
	2020	2025	2030	2035	2040	2045	2050	Total
Domestic sector installations and maintenance	0	35	134	516	1,978	1,978	1,978	6,620
Port Talbot Hydrogen Conversion (all scenarios)					2,200			2,200
Aberthaw cement works				892				892
Other industry	0	15	54	191	683	683	683	2,310
Freight sector conversions and infrastructure	0	125	631	3,189	16,105	16,105	0	36,156
	0	**175**	**819**	**4,787**	**20,967**	**18,767**	**2,662**	**48,178**
Total Hydrogen Investment	**0**	**175**	**819**	**6,415**	**25,274**	**22,502**	**7,325**	**62,510**
*** Note - no decommissioning costs have been assumed for the gas grid.**								

A summary chart of the totals across the milestone dates would be handy or bar charts to conclude the overview

Appendix G – Potential CO_2e Savings from Hydrogen

The following tables provide the estimated CO_2e savings from hydrogen usage for each of the end-uses. Savings have been calculated assuming zero lifecycle emissions associated with hydrogen. This can be achieved with green or pink hydrogen production. Blue hydrogen and hydrogen from waste have lifecycle emissions associated with the hydrogen production and therefore would reduce the emissions savings shown below.

		Hydrogen Emissions Savings (kt CO_2e) under Necessities Only scenario			
Hydrogen end-uses	2019 Base Year Emissions (kt CO_2e)	2030	2035	2040	2050
Heating	5,271	0	271	184	0
Road transport	8,365	0	0	0	0
Industrial	9,193	0	7,186	7,402	7,834
Aviation*	625	0	17	99	250
Marine	365	0	82	164	329
Agriculture (fuel)	253	0	16	31	61
Agriculture (fertiliser)	187	0	0	187	187
Construction plant equipment (off-road mobile machinery)	268	0	0	0	0
Rail	154	0	0	0	0
Totals	**24,681**	430	7,573	8,068	8,662
**Has not accounted for the non-CO_2 effects of aviation such as contrails as the science on this matter is currently too uncertain. However, it must be considered that including these effects could result in CO_2e emissions being 2 or 3 times greater than CO_2 emissions alone.*					

		Hydrogen Emissions Savings (kt CO_2e) under Balanced Hydrogen scenario			
Hydrogen end-uses	2019 Base Year Emissions (kt CO_2e)	2030	2035	2040	2050
Heating	5,271	348	281	204	538
Road transport	8,365	0	383	780	1,620
Industrial	9,193	81	7,186	7,402	7,834
Aviation*	625	0	26	151	383
Marine	365	0	82	164	329
Agriculture (fuel)	253	1	31	62	124
Agriculture (fertiliser)	187	0	0	187	187
Construction plant equipment (off-road mobile machinery)	268	0	72	147	153
Rail	154	0	8	17	35
Totals	**24,681**	430	8,071	9,115	11,202

**Has not included the non-CO_2 effects of aviation such as contrails as the science on this matter is currently too uncertain. However, it must be considered that including these effects could result in CO_2e emissions being 2 or 3 times greater than CO_2 emissions alone.*

		Hydrogen Emissions Savings (kt CO_2e) under Widespread Hydrogen scenario			
Hydrogen end-uses	2019 Base Year Emissions (kt CO_2e)	2030	2035	2040	2050
Heating	5,271	387	388	2,044	5,378
Road transport	8,365	0	1,136	2,314	4,808
Industrial	9,193	81	7,186	7,783	8,975
Aviation*	625	0	35	204	515
Marine	365	0	82	164	329
Agriculture (fuel)	253	1	47	98	199
Agriculture (fertiliser)	187	0	0	187	187
Construction plant equipment (off-road mobile machinery)	268	0	116	236	245
Rail	154	0	12	25	53
Totals	**24,681**	469	9,003	13,055	20,689

**Has not included the non-CO_2 effects of aviation such as contrails as the science on this matter is currently too uncertain. However, it must be considered that including these effects could result in CO_2e emissions being 2 or 3 times greater than CO_2 emissions alone.*