Orkney Hydrogen Strategy

The Hydrogen Islands 2019 – 2025

Energy of ORKNEY


ITM POWER
Energy Storage | Clean Fuel
Orkney's hydrogen future
BIG HIT
Building Innovative Green Hydrogen
Systems in Isolated Territories
Community Wind Turbine
1 MW Electrolyser
SHAPINSAY
No smoking in this area
NOTICE

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Surf 'n' Turf launch event, Kirkwall harbour, Orkney, 2017. (Photo credit: Colin Keldie)

Endorsements

Graham Sinclair

North Isles Councillor, Chair of Development and Infrastructure Committee – Orkney Islands Council

“Through the development of a hydrogen economy Orkney is continuing its tradition of innovation. The hydrogen projects already underway put Orkney in a world leading position with organisations from across the world looking to the hydrogen projects to provide them with solutions to their own energy needs. While it is impossible to look into the future with any certainty, Orkney will continue to influence the low carbon energy landscape of tomorrow by demonstrating that it is possible to deliver positive outcomes with technology that exists today.”

Neil Kermode

European Marine Energy Centre – Managing Director

“EMEC is delighted to see this Strategy. The clear drive to produce green hydrogen from renewable energy exactly chimes with the planet’s urgent needs to de-carbonise.“

Steven Bews

Shapinsay Development Trust – Chairman

“Developing the hydrogen economy will be a useful step in utilising power that is generated locally reducing the need to rely upon imported fuels and energy from further afield. In terms of the social benefit it is ideal to be reducing the carbon footprint across the entire Orkney energy landscape, from industrial and domestic applications.”

Eday Renewable Energy Ltd. - Chairman

“Eday Renewable Energy are proud to have been involved in the early stages of this innovative technology and welcome further opportunities to help ensure Eday and Orkney become a centre of excellence for Hydrogen development. We are also encouraged by the way that technologies such as Surf n Turf and Big Hit hold the potential to facilitate curtailment reclamation, which, if successful will create more revenue for local communities”

Board of Directors

Orkney Renewable Energy Forum

“Green Hydrogen has the potential to play an important role in Orkney’s low carbon economy continuing the strong tradition of innovation on our islands. The ability to develop renewable local energy solutions is essential if we are to allow rural areas to fully capitalise on the unique opportunities they possess in order to address the climate emergency.”

ORKNEY
Our hydrogen future

Executive Summary

In 2009 the community in Orkney published the Sustainable Orkney Energy Strategy defining three overarching aim to bring a strategic direction to its energy ambitions.

These three aims sought to:

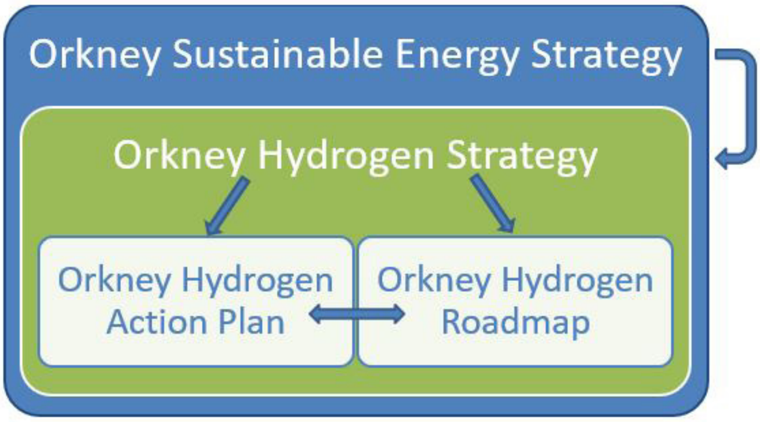
- Ensure Orkney uses energy as efficiently as possible and has a secure and affordable energy supply to meet its future needs.
- Add value to Orkney's renewable energy resources, for the benefit of the local economy and local communities, whilst minimising damage to the environment
- To reduce Orkney's carbon footprint.

In 2017, the community in Orkney retained these strategic aims when it reviewed and subsequently launched the Orkney Sustainable Energy Strategy: 2017-2025. The reviewed strategy agreed the following vision statement:

Orkney: a secure, sustainable low carbon island economy driven uniquely by innovation and collaboration, enabling the community to achieve ambitious carbon reduction targets, address fuel poverty and provide energy systems solutions to the world.

The 'Orkney Hydrogen Strategy: The hydrogen islands' sits within the Orkney Sustainable Energy Strategy as a community owned document which seeks to identify how hydrogen can best be applied to energy systems in Orkney to maintain the early mover advantage by building on the success Orkney has had in attracting and demonstrating a number of world leading hydrogen projects already active on the Islands.

There is significant opportunity to maintain a course of development of renewable hydrogen energy systems for economic vibrancy and rural sustainability to fulfil wider strategic development goals set by the governments of both Scotland and the United Kingdom which will help society towards net zero carbon by 2045.



Orkney Energy strategy hierarchy

Orkney seeks to become the global exemplar on green hydrogen integration into a robust rural-centric and sustainable hydrogen economy, aiding delivery and access to ultra-low carbon energy on demand across a wide spectrum of end-users.

Hydrogen solutions developed in Orkney will be applicable to other communities facing similar energy related challenges of their own as we transition to a low carbon society. This strategy seeks to encourage a wide range of hydrogen stakeholders to aid development of the associated economy and create conditions to promote the increased application of hydrogen technologies and developing the use of hydrogen in the community while investment opportunities are available. Orkney will use the aims of this hydrogen strategy to continue to develop the commercialisation of green hydrogen and as such:

Hydrogen Infrastructure in Orkney.

(Photo credit: Colin Keldie)

Development of an appropriately scaled hydrogen economy shall fulfil the goals applied in the Orkney Sustainable Energy Strategy to create a positive and lasting impact on the local community, private enterprise, industry and the public sector by developing a set of hydrogen specific strategic development themes.

These five hydrogen development themes are:

1. **Innovative local energy systems and hydrogen economies** – using existing a new technologies, software and techniques to deliver locally produced energy to regional users, reducing waste and managing economics in balance with social and environmental impacts.

2. **Renewably produced low carbon hydrogen** – focus on green hydrogen production through electrolysis from renewable sources to minimise impact on the environment.

3. **Energy security, system flexibility and self-sufficiency** – to reduce reliance on imported energy streams and to use local energy in a smarter and more efficient way to the benefit of local communities.

4. **Just transition** – ensuring that the benefits from developing new ways to deliver energy are available across the broadest range of society.

5. **Promoting innovative research and development using a collaborative approach** – continuing to innovate, not just the technology, but systems as a whole. Particularly how these systems interact with the end-users and continue to work in partnership where possible to increase efficacy of information flows.

With continued concerted effort from the variety of community members, as well as with wider stakeholders, collaborators and suppliers, it is possible for Orkney to transition to a low carbon future that meets the demands of all users without such significant reliance on costly and polluting fossil fuels. Innovation needs to continue to be fostered to allow mass uptake of low carbon technologies, including hydrogen technologies, into every household with a view to reducing wide reaching issues such as fuel poverty, climate change and more sustainable tourism that particularly affect the future prosperity of rural regions.

Foreword

In May 2019 Orkney Islands Council called a special general meeting in order to declare a climate emergency to reaffirm the Council's existing commitment to a vibrant carbon neutral economy and to publicly express concern about climate change.

Council leader James Stockan said: "This declaration serves to leave no doubt of the Council's focus on and commitment to reducing our carbon footprint. We'll seek to continue to support the pioneering renewables scene in Orkney – whether that is tidal, wave, wind, hydrogen or biofuels."

Orkney Islands Council agreed to continue partnership working and promote the understanding of the climate emergency, identify and implement actions that contribute to carbon reduction and develop further targets for consideration.

Numerous energy stakeholders in Orkney from the community to private enterprise, public bodies and charity groups in Orkney have been working towards defining sustainable solutions in response to some of the uncertainty around the applications that will be required in transition to a low carbon future for decades.

The decisions that we make now regarding the future of our energy supply have the potential to positively shape the vibrancy of the economy in Orkney and correct the course of the aging population demographic. Determining best-fit energy systems can provide a means of delivering clean, affordable and secure energy supply that is fit for purpose as well beginning to address the social impacts dominating energy conversations in Orkney today.

Hydrogen trailer being loaded onto Shapinsay ferry. (Photo credit: Colin Keldie)

Why develop Hydrogen in Orkney?

The importance of rural communities was identified by the Scottish Government in 'The future of energy in Scotland: Scottish energy strategy (2018)' which outlines an aspiration to develop affordable, clean and secure energy system in which hydrogen technologies can provide significant advantages for rural communities.

In 2009 the community in Orkney published the Sustainable Orkney Energy Strategy defining three overarching aim to bring a strategic direction to its energy ambitions.

- Ensure Orkney uses energy as efficiently as possible and has a secure and affordable energy supply to meet its future needs.
- Add value to Orkney's renewable energy resources, for the benefit of the local economy and local communities, whilst minimising damage to the environment.
- To reduce Orkney's carbon footprint.

In 2017 the energy community in Orkney published the updated Sustainable Orkney Energy Strategy 2017-2025. Orkney recognised the importance of "A secure, sustainable low carbon island economy driven uniquely by innovation and collaboration, enabling the community to achieve ambitious carbon reduction targets, address fuel poverty and provide energy systems solutions to the world" (SOES, 2017).

This Orkney Hydrogen Strategy is designed to sit within the Orkney Sustainable Energy Strategy as a community owned document (See Figure 1). Hydrogen spans all five strategic action thematic pillars as set out in the Orkney Sustainable Energy Strategy, to support the achievement of Orkney's low carbon economy.

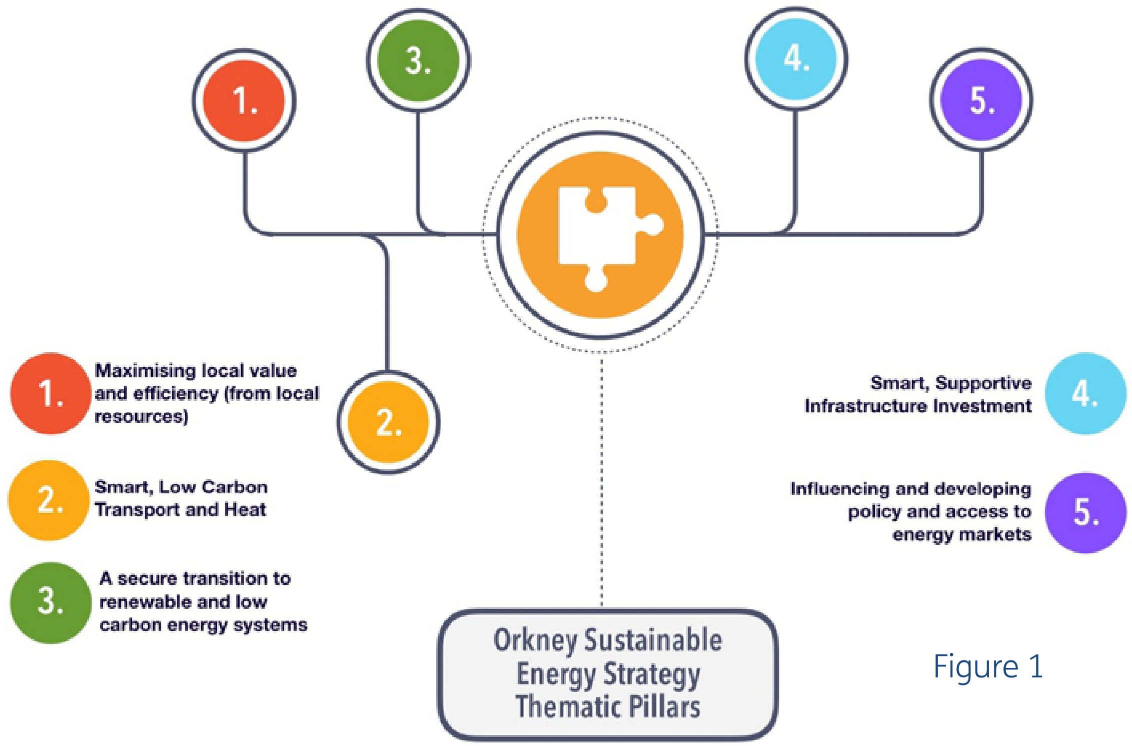


Figure 1

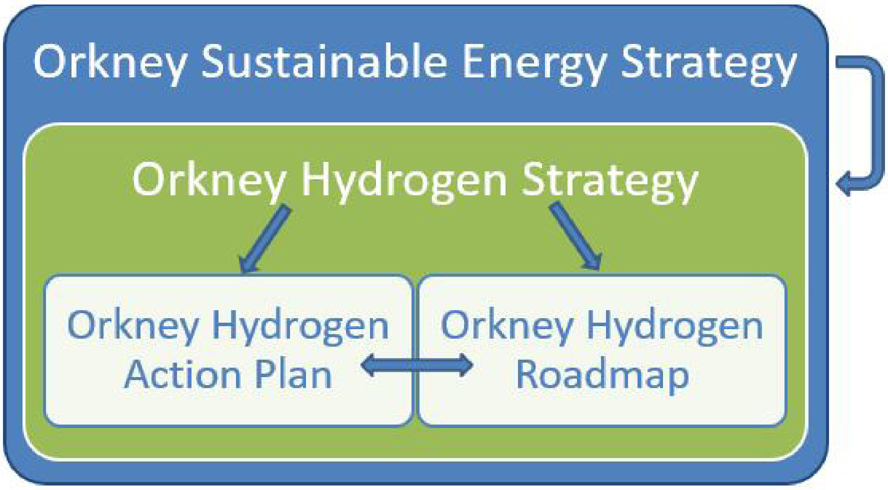


Figure 2

Hydrogen can be produced from electricity generated using renewable sources via a process called electrolysis (see Figure 3). The hydrogen produced can be used for multiple applications, such as heat, power and transport, across a number of sectors (see Table 1 below).

The challenge for hydrogen lies in the absence of 'off the shelf solutions' to put bespoke local energy systems in practice. This creates a challenge in developing the policy environment required for integration of hydrogen into any energy system.

With continued concerted effort from the variety of community members, as well as with wider stakeholders, collaborators and suppliers, it is possible for Orkney to invent a low carbon future that meets the demands of all users without such significant reliance on costly and polluting fossil fuels. Innovation needs to continue to be fostered to allow mass uptake of low carbon technologies into every household with a view to reducing wide reaching issues such as fuel poverty, climate change and more sustainable tourism that particularly affect the future prosperity of rural regions

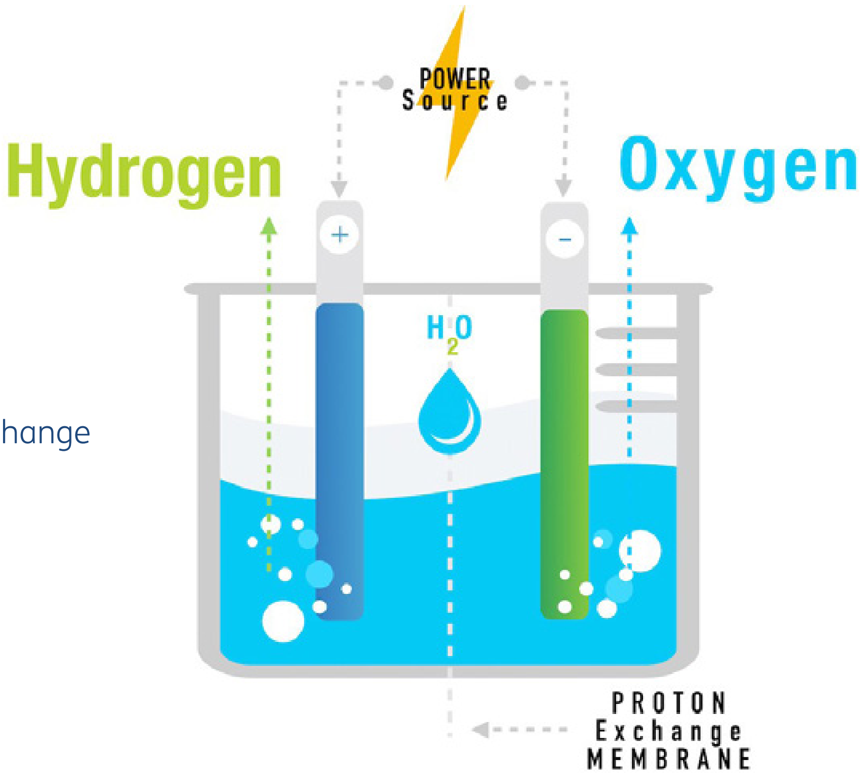
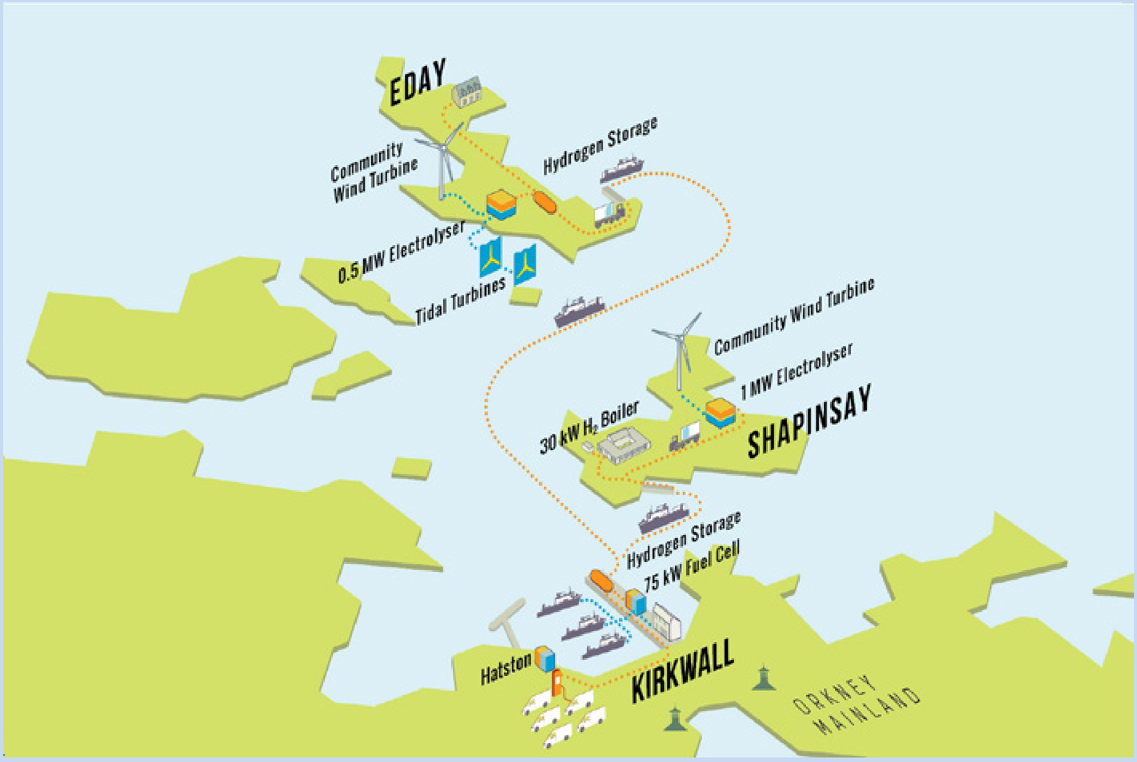


Figure 3: Proton exchange membrane (PEM) electrolyses.

Orkney has been a demonstration region for numerous 'green' hydrogen demonstration projects that have generated hydrogen through electrolysis powered by renewable sources such as community wind and tidal energy (see Table 1). Producing hydrogen during periods of wind turbine curtailment can minimise the potential for lost earnings for community development trusts allowing the trusts to collect Feed in Tariffs (FiTs) as well as producing a product with commercial value (hydrogen) that can be used in a multitude of applications including: heat, power, mobility, grid balancing and storage (see **Quick Glimpse – Surf 'n' Turf and BIG HIT**).

Hydrogen in combination with other renewable energy solutions can provide energy systems solutions to aid decarbonisation. There is potential for Orkney to define a bespoke energy system that fits the needs of the local community and make best used of energy generated in the locale. Solutions developed in Orkney will help shape how communities, countries and nations approach energy production, consumption and supply. Demonstrating that it is achievable to accelerate decarbonisation and lead by example in reaching the Scottish Government net zero carbon emission target by 2045 as suggested the Committee on Climate Change in May of 2019.

Quick Glimpse – Surf 'n' Turf and BIG HIT



The Surf 'n' Turf and BIG HIT Hydrogen projects active in Orkney are demonstrating the principles of green hydrogen production from curtailed community wind and tidal turbine energy generation. The hydrogen logistics and storage are being managed to match supply with demand across a number of end-uses including heat, power and transport.

Project	Timeline	Outcomes	Value
Surf 'n' Turf	2016-2022	Orkney's first hydrogen demonstration project. 0.5MW electrolysis in Eday from tidal and community wind. Developing logistics for hydrogen transport and generating power for harbour-side vessels.	TOTAL BUDGET £3m
BIG HIT – Building Innovative Green Hydrogen Systems in Isolated Territory	2016-2022	Developing upon the principles of Surf 'n' Turf and implementing a fully integrated model of hydrogen production, storage, transportation and utilisation for heat, power and mobility. 1MW electrolysis on Shapinsay from community wind.	EU FUNDING € 5m TOTAL BUDGET €7.3m
Dual Ports	2016-2019	DUAL Ports aims to decarbonise Regional Entrepreneurial Ports (REPs) resources through a shared eco-innovation port programme that minimises their environmental footprint.	TOTAL BUDGET €5.2m
HyDIME	2018-2019	Design and physical integration of a hydrogen injection system on a commercial passenger and vehicle ferry which will be the first of its kind worldwide.	TOTAL BUDGET £1.2m
HySEAS III	2019-2023	Integration of hydrogen fuel cell propulsion system onboard Kirkwall to Shapinsay ferry.	EU FUNDING €9.3m TOTAL BUDGET €12.6m
ITEG - Integrating Tidal energy into the European Grid	2017-202	Development of an all-in-one solution for the generation of clean predictable energy, grid management, and the production of hydrogen from excess capacity.	EU FUNDING €6.46 m TOTAL BUDGET €11.79 m

ReFLEX Orkney – Responsive flexibility	2019-2023	Demonstration of a first-of-its-kind VES interlinking local electricity, transport, and heat networks into one controllable, overarching system	TOTAL BUDGET £28.5m

Table 1. Ongoing hydrogen projects in Orkney.

Mission

Hydrogen is fast becoming a key energy resource in the world transition to a low carbon future. The Orkney Hydrogen Strategy seeks to aid development towards an Orkney appropriate sustainable hydrogen economy to provide economic benefits such as: local jobs; establishing a local supply chain; and an increased resilience in the local energy system.

Orkney will maintain its leading edge on the development of local energy systems that make use of a range of renewable technologies, develop local hydrogen economies and assess the potential to use hydrogen to increase the efficacy of local grid infrastructure to better meet the needs of the local population.

Orkney seeks to develop and proliferate best practice in integrating smarter local energy models, including generation of renewable hydrogen to other 'islanded' communities where there is ambition to transition to a low carbon future. Integrating hydrogen to Orkney's energy system has the potential to reduce reliance on carbon intensive costly fossil fuels and measures should be considered as to how the low carbon transition can reduce energy costs and contribute to access to energy at fairer cost to reduce high levels of fuel poverty in the area in line with the Just Transition principles as set out by the Scottish Government (2018a) and set out by the International Labour Organisation (international Labour Organisation, 2018).

Vision: Orkney seeks to become the global exemplar on green hydrogen integration into a robust rural-centric and sustainable hydrogen economy, aiding delivery and access to ultra-low carbon energy on demand across a wide spectrum of end-users.

Orkney's world leading hydrogen demonstration projects will provide a basis for the development of a proactive approach to establish hydrogen within the local context for Orkney. Hydrogen developments in Orkney will continue to support the removal of barriers currently inhibiting rural communities to realise the full benefit that the wider electricity network provides to more central communities at present (Scottish Government, 2018b). Outputs already delivered from Orkney hydrogen projects continue to inform the global hydrogen economy and can continue to solidify Orkney's ability to attract additional inward investment.

Targets and Policy Drivers

There are numerous policies established at a local, national and international level that support the proliferation of hydrogen technologies. A ‘hydrogen future’ was envisioned in the Scottish Governments ‘The future of energy in Scotland: Scottish energy strategy’ which stated the need to support ‘smarter, local energy systems (Scot Gov, 2018a). This aids communities become more invested in their energy choices.

Developing a hydrogen economy in Orkney in the short to medium term can contribute to reduced greenhouse gas and particulate emissions, increase the security of energy supply, contribute to decarbonisation of transport, increase and economise renewable electricity generation, aid in the development of a fairer model of electricity transmission that could lead to reduced consumer costs by supporting storage for intermittent generation and addressing market failure as experienced by many rural energy users.

There are a wider range of policies and targets that will relate to the introduction of hydrogen into local energy systems to varying degrees. Table 2 provides a summary of the policies and targets that directly affect a strategic approach to hydrogen integration in Orkney.

Strategy/Policy/Plan	Target/Aim
UK	
Clean Growth Strategy 2017	Accelerate pace of clean growth
Industrial Strategy 2018	UK shift to clean growth
Clean Air strategy 2019	Targeted air quality reduction targets
25 Year Environmental Plan 2019	Protect air and water quality and threatened plants, trees and wildlife species
Climate Change Act 2008	Reduce greenhouse gas emissions by at least 80% by 2050
Road to Zero 2017	End sale of conventional petrol and diesel cars and vans by 2040
Emissions Intensity Ratio (EIR)	Measurement proxy for economic progress associated with carbon emissions - 720tonnes/£m 1990 - 270tonnes/£m 2017 - 100tonnes/£m to meet targets
Maritime 2050 - TBP	Targets to decarbonise the marine industry
Aviation 2050 – TBP	Targets to decarbonise the aviation industry
The Climate Change Committee	Net zero carbon emissions for Scotland by 2045 and England by 2050

Scotland	
Climate Change (Scotland) Act 2009	Reduction of greenhouse gas emissions of at least 80% by 2050
Climate Change (Emission Reduction Targets) (Scotland) Bill 2018	Reduction of greenhouse gas emissions of at least 75% by 2030 and 90% by 2040
Public Bodies Climate change duties 2011	Climate responsibility for public bodies
Scottish Energy Strategy: The future of energy in Scotland 2017	Whole system approach to power heat and transport
Scotland's Network Vision 2019	Whole system view, inclusive transition, smarter local energy models

Orkney	
Council Plan 2018-2023	A vibrant carbon neutral economy which supports local businesses and stimulates investment in all our communities.
Orkney Sustainable Energy Strategy 2017-2025	A secure, sustainable low carbon island economy driven uniquely by innovation and collaboration, enabling the community to achieve ambitious carbon reduction targets, address fuel poverty and provide energy systems solutions to the world.
Orkney's Fuel Poverty Strategy 2017-2022	To help meet the objective of eradicating fuel poverty by 2032
Orkney local development plan 2017-2022	Policy support has been established to ensure that all appropriate energy generation schemes will be supported in the county and that local solutions to storing energy for alternative uses are encouraged where there is not an opportunity to distribute energy through more traditional routes.
Carbon Management programme 2016-2026	Reduce our Total Carbon Dioxide emissions in the financial year 2025 by 42% of the baseline year 2004-05.

Table 2: Policy drivers that support and encourage the development of a green hydrogen economy.

How should we support Green Hydrogen Growth in Orkney?

In The future of energy in Scotland: Scottish energy strategy (2018a) the Scottish Government has set out three principles designed to deliver on Scotland's ambitions to decarbonise economic growth whilst also delivering economic growth and ensuring that everyone is able to benefit. These are; a whole system view, an inclusive transition and smarter local energy models.

While there are numerous hydrogen production methods such as Steam Methane Reformation (SMR), coal gasification and biomass gasification (sometimes known as brown hydrogen), this strategy will focus on the production of green hydrogen from electrolysis using renewably generated electricity. The carbon footprint of hydrogen depends upon the source of the power for generation. There is scope to improve on hydrogen production rates, longevity of the electrolysers, reduction of capital costs and further research into potential for electrolysis. The sections below will provide more details on the five hydrogen development themes specific to Orkney.

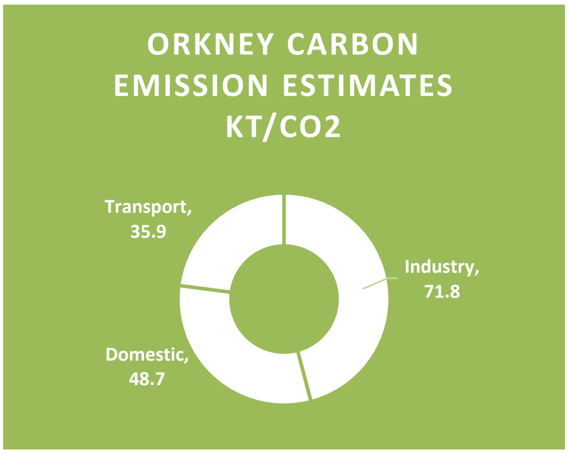
Innovative Local Energy Systems and Hydrogen Economies

Contributes towards the following Orkney Sustainable Energy Strategic Action Themes

- **Maximising local value and efficiency (from local resources).**
- **Smart, Low Carbon Transport and Heat.**
- **A secure transition to renewable and carbon energy systems Smart, Supportive Infrastructure Investment.**
- **Influencing and developing policy and access to energy markets.**

Across all energy consumer levels - industry, public, commercial and community – Orkney is reliant on fossil fuels for heat, power and transport. Despite Orkney generating a large amount of electricity from renewable sources, according to national statistics 19% of Orkney's carbon emissions can still be attributed to electricity consumption across end users (domestic to industrial). This figure rises to nearly 50% when looking at domestic electricity use alone (BEIS, 2016). Figure 4 below gives an indication of Orkney's carbon emissions by sector and how overall carbon emissions for energy use compare with wider figures across the UK. Figure 5 shows a cross-sectoral energy usage by fuel type in Orkney.

Although, at times, Orkney generates much of its local electricity demand from renewable sources there are periods of import from the wider UK network and as such Orkney's electricity generation is broadly classified along the same lines as the rest of the UK.



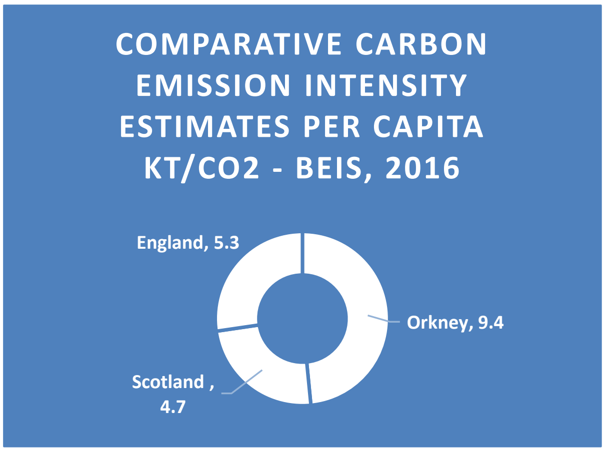


Figure 4. Orkney Carbon Emission Estimated by sector, Kt/CO2 and Orkney's comparative carbon emissions figures with Rest of UK average, per head of population – Source: BEIS, 2016.

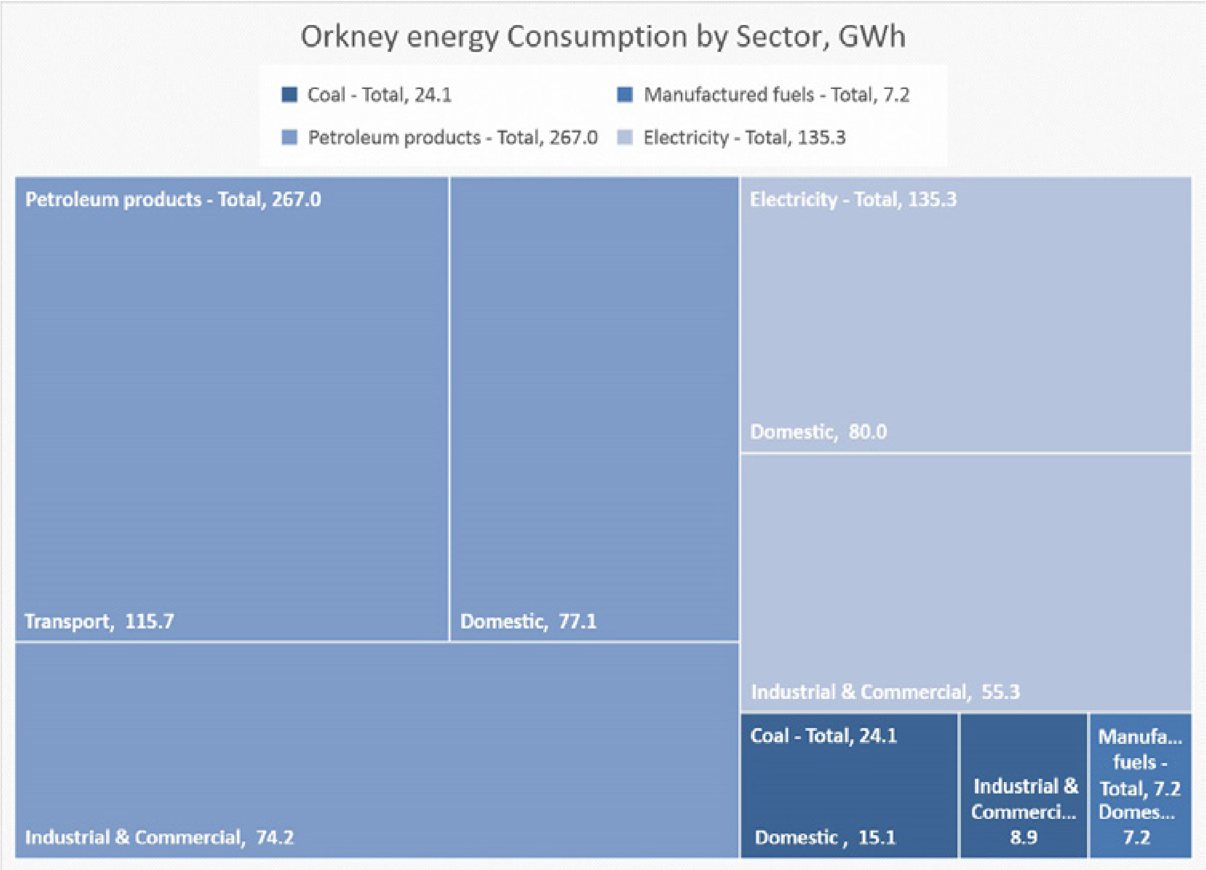


Figure 5: Total Orkney Energy Consumption by type by sector, GWh – Source: BEIS, 2016.

A major strength in developing localised energy systems is that the system can be built around the relevant local resource and can closely match and deliver energy to the end user when required. Wind, wave and tidal are likely to be the resources required for generation of energy within a decentralised local energy system. The carbon intensity of the system can also be monitored and reported in manner that more closely reflects the true carbon density as opposed to a national average.

Smarter management of the grid will allow for additional renewable resource to be connected.

While arguably the most efficient way to do this is to produce electricity directly from the natural resource using a turbine (wind/tidal) or otherwise it is well established that renewable generation is intermittent which requires a back-up generation from fossil fuel sources in times where generation does not match demand. At present, the variability of renewable generation not only creates a problem for the end user of the electricity but for the current electricity network operator who is responsible for managing the electricity network. In addition to the intermittency issues when generating from renewable resource there is also intermittency on behalf of the renewable generators accessing the grid for export. In times of peak renewable generation in Orkney renewable generators are curtailed. To which they receive neither the Feed in Tariff (FiT) or the grid export payment nor do renewable generators get financial recompense in the form of constraint payments (UK Government, 2013) or the trading system known as the 'balancing mechanism' to bid for payment to voluntarily curtail (Elexon, 2019) leading to loss in potential income and zero carbon electricity generation.

Despite Orkney generating in excess of its regional electricity demand from renewable sources, the community, across all energy end-users, is heavily reliant on fossil fuel generation sources.

Despite Orkney generating in excess of their regional demand from renewable sources, the community at all levels are heavily reliant on fossil fuel generation sources. Fossil fuels, for all applications, require import from out-with Orkney.

In addition to the reliance on fossil fuel from large demand to heating and power on the individual level. Consumers in Orkney rely on electricity to generate heat, power and transport. Hydrogen has the potential to cut across all these sectors as has been demonstrated with the early projects and utilise a fuel source that has been generated in the County and supported a local supply chain throughout.

Renewably Produced Ultra Low Carbon Hydrogen

Contributes towards the following Orkney Sustainable Energy Strategic Action Themes
• **Maximising local value and efficiency (from local resources).** • **Influencing and developing policy and access to energy markets.** • **A secure transition to renewable and carbon energy systems.** • **Smart, Supportive Infrastructure Investment.**

Various regions worldwide are looking at the of reducing carbon emissions associated with hydrogen production at steam methane reformation sites as an 'interim' decarbonisation step on the way to a green hydrogen economy. The strategy for Orkney will however focus on the development of green hydrogen production in Orkney, where hydrogen production is sourced from renewable energy sources.

There may be potential to use hydrogen to partially decarbonise the existing oil and gas infrastructure in Orkney, for example on Flotta, or capture and decarbonise outputs from potential waste plant solutions. As such as we transition to a low carbon future it may be necessary to consider a small percentage of brown/blue hydrogen as we make the transition to fully green hydrogen. Cases as such would need to be weighed up carefully and considered only as a clear transitionary step towards green hydrogen production.

Focusing on green hydrogen production plays strongly into Orkney's knowledge, resources, natural resources and expertise and outputs are highly replicable in many remote and rural locations both nationally and internationally in other 'islanded' regions.

The UK and Scotland are considering decarbonisation of the entire gas grid, in which case mobility and power become secondary to heat provision being generated from hydrogen. Hydrogen production in this case is likely to come from centralised steam methane reformation (SMR) which require symbioses with carbon capture and storage to be less carbon polluting than the natural gas used at present. **Carbon Intensity of hydrogen produced via SMR without Carbon Capture and Storage is similar to that of natural gas (Royal Society, 2018)**.

At present there are no public plans published to establish a gas grid within Orkney and as such micro combined heat and power projects should be explored with the opportunity to co-locate electrolysis with microscale generation.

Energy Security, System Flexibility and Self-Sufficiency

Contributes towards the following Orkney Sustainable Energy Strategic Action Themes
• **Maximising local value and efficiency (from local resources).**   • **Influencing and developing policy and access to energy markets.**   • **A secure transition to renewable and carbon energy systems.**

At present Orkney has a moratorium on any new connections as the local electricity grid is operating at capacity. Actions are being taken in an attempt to develop satisfactory terms for a new subsea interconnector between Orkney and the Scottish mainland. If the subsea interconnector does get commissioned it is likely to be completed in 2023 at the earliest and will not solve all of the issues of curtailment that the Islands experience at present.

Legislation surrounding accessing the electricity grid for both generation and demand purpose and the complexity of local renewable generators acutely managed by the Active Network Management scheme make connection of additional electrolysers, a load drawing asset, challenging. In the short to medium term the electricity grid in Orkney could be managed using strategically placed electrolysers which could alleviate curtailment on the local electricity grid. It would also be possible to generate electricity back to the grid using fuel cell technology which would negate the use of fossil fuels.

Managing the grid using hydrogen could potentially allow further renewable generation connections. Access to the electricity grid is one of a number of regulatory barriers that have the potential to be detrimental to the further integration of hydrogen projects in Orkney. These include the complexities surrounding connection to the electricity grid due to the volume of renewable connections. Orkney partners should continue to inform the transition from Distribution Network Operator (DNO) to Distribution System Operator (DSO) which should have an impact on how generators are able to access the grid and allow consumer access to a greater range of services (SSE, 2018).

Just Transition

Contributes towards the following Orkney Sustainable Energy Strategic Action Themes
• Maximising local value and efficiency (from local resources). • Smart, Low Carbon Transport and Heat.

Shifting the economy away from fossil fuels is an opportunity to build fairer and more equal society throughout Orkney and Scotland. Orkney Islands Council Fuel Poverty strategy (2017) indicates that Orkney has the highest rates of fuel poverty in the UK with around 57% of households being classed as being in fuel poverty. Fuel poverty in Orkney is attributed to a number of factors, including older housing stock, lower than average income, the climate and higher cost of heating. Low carbon hydrogen technologies carry the risk of increasing costs for householders and the cost per kilowatt hour of hydrogen is higher than most alternatives at present.

It is important to establish that there will be a transitionary period where traditional oil and gas industries decline and skills need to be established to bring workers with the low carbon change (Friends of the Earth, 2018). A skills-based approach should be developed to provide a range of hydrogen training to provide job roles across a range of technical levels.

Promoting Innovative Development Using a Collaborative Approach

Contributes towards the following Orkney Sustainable Energy Strategic Action Themes
• Maximising local value and efficiency (from local resources). • Smart, Low Carbon Transport and Heat. • A secure transition to renewable and carbon energy systems. • Smart, Supportive Infrastructure Investment. • Influencing and developing policy and access to energy markets.

The hydrogen projects at present have demonstrated that stakeholders in Orkney are able to collaborate and share learning across projects to achieve aims. Learning is an active approach and sharing outcomes and differing perspectives can lead to quicker problem solving.

It is essential for the successful integration of hydrogen into the local energy system that stakeholders form the community, private enterprise, public bodies and education continue to work together to identify the correct opportunities to support the development of hydrogen supply and integration of technologies.

Barriers to Implementation

There are a number of barriers, perceived or otherwise, to the implementation of hydrogen into energy systems, some of which are outlined in Table 3. Many of these have been experienced though engagement in hydrogen demonstration projects such as Surf ‘n’ Turf and BIG HIT. Barriers have a negative impact on the budget and timescales of projects and carry the risk of preventing or delaying progress to timescales as required, creating additional costs and reducing viability. It is necessary to continue to evaluate and monitor these potential risks as they evolve and as hydrogen systems develop. Great potential benefits can also realised by addressing these barriers as early as possible within a project.

Perceived Barrier	Effect
Regulation / Legislation	Electricity market regulation: Inability to implement decentralised local energy system due to regulatory barriers connecting to the grid.
Moratorium on connection of additional generation capacity in Orkney	Cannot expand hydrogen production through new generation or connect fuel cells to grid.
Energy provision issues due to market failure in rural areas	More expensive energy tariffs and a higher cost to the consumer.
Per capita model to measure economic activity	Service provision more expensive in and often less fit for purpose in less densely populated areas
Uncertainty of viability of hydrogen as a future fuel	Reticence to commit to investing in hydrogen for future energy needs, there are other energy carriers such as electricity and other transitionary fuels and technologies that may be given precedence.
Innovation risk	Many organisations (public/private) are risk averse which can delay the development of new technologies and systems.
Technological readiness	Hydrogen produced through renewably powered electrolysis is the only way to produce ‘green hydrogen’, other forms of green hydrogen production rely on unproven Carbon Capture and storage methodologies which would lower carbon emissions but not negate them. Green standards for hydrogen are yet to be finalised. Although pressurised hydrogen is the most common storage method, projects utilising liquid hydrogen and other chemical carriers exist.

Drive to reduce fuel poverty	Without careful management of energy systems, the low carbon transition has a real likelihood of Increasing bills for the consumer in the short to medium term.
Cost competitiveness	Innovative energy solutions are often required to be economically equal to fossil fuel alternatives despite fewer operational years. Although there are mechanisms in place for monitoring social and environmental benefit/harm, in practice (in the UK) these measures are often principles based and do not carry any significant weighting and economic parity of low carbon and fossil fuel is expected. Considering only financial impacts can lead to decision making weighted towards fossil fuel solutions.
Perceived Safety Concerns	The safety case for the use of hydrogen is different depending on application and significantly different from standard fuels in similar applications. Stringent processes are required to demonstrate safety.
Efficiency Losses	The efficiency trail of hydrogen utilisation is different from current patterns of energy consumption. Well to wheel should be considered for comparisons. Hydrogen at 700pa has a similar volumetric and gravimetric energy as existing fossil fuels and greater than that of li-on batteries (Zuttel, 2010).
Logistics	Road infrastructure can be a challenge in rural areas creating limitations in the type of vehicles for haulage. Transporting hydrogen by sea requires dangerous goods exemption which limits the availability of transport routes adding complexity and costs.
Subsidy	At present hydrogen produced for road transport is eligible for subsidy through the Renewable Transport Fuel Obligation (RTFO) (DfT, 2018). This should be extended into the maritime and heating sectors to ensure hydrogen is an attractive alternative in these areas.
Potable water supply	There are a number of areas in Orkney with limited potable water supply. Care should be taken that future electrolysis projects are developed in areas where there is an abundance of potable water until such time that recycled water projects or electrolysis from sea water become viable.

Table 3. Perceived barriers to hydrogen development.

Potential Hydrogen Pathways

Hydrogen can disrupt present energy systems at various integration levels and across a number of different applications (see Figure 6). Each application can use hydrogen via direct combustion or can utilise the more efficient Fuel Cell technology which will broadly reduce the amount of hydrogen required to reach the same output. The most relevant potential hydrogen applications routes that are relevant to Orkney are explored below.

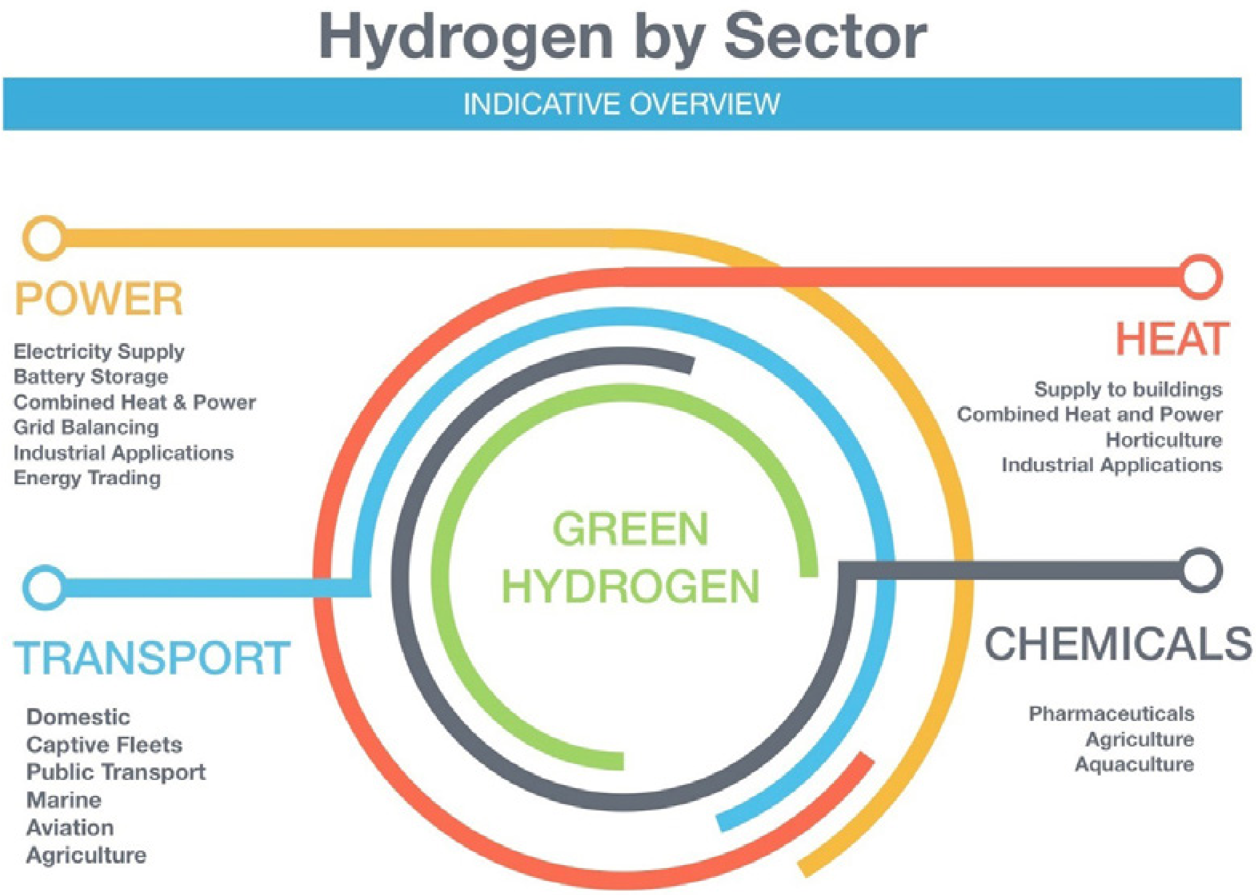


Figure 6. Potential end uses for Hydrogen.

Transport

The UK H2 mobility project predicts that there could be over 1.6 million Fuel Cell Electric Vehicle (FCEV) in the UK by 2030 and a number of transport applications as well as propulsion methodologies are explored below. It is worth noting that there are no plans within the H2 mobility project to develop further hydrogen infrastructure in Orkney which indicates the importance of developing a local energy system that is suitable for Orkney as opposed to waiting for more centralised initiatives (H2 mobility, 2017).

Although Orkney already hosts a 350bar refuelling station and five hydrogen powered Renault Kangoo vans, it would be beneficial for Orkney to add a second hydrogen refuelling station to refuel at 700 bar pressure to service a wider variety of vehicle types as well as reduce the potential for periods of unavailability of hydrogen. There are other local authority areas in Scotland such as Aberdeen and Fife that are currently demonstrating a wide range of hydrogen transport applications including buses, public refuse lorries, street sweepers and passenger vehicles which serves as an indicator of the types of hydrogen vehicles that could potentially be operated in Orkney.

There are two realistic routes to implementing hydrogen for mobility. The first converts hydrogen into mechanical energy utilising an internal combustion engine (ICE). Modifications can be made to existing engines to accept hydrogen for combustion (H2-ICE). Hydrogen can be blended, co-injected or used as a complete fossil fuel replacement (Marigreen, 2018). H2-ICE is suitable for high propulsion power and low energy consumption application for auxiliaries such as ship auxiliary power loads or heating systems onboard electric vehicles or buses (Marigreen, 2018). H2-ICE can be designed and applied to new vehicles or it can be applied retrospectively to convert plant or other vehicles near the start of their operating life. Carbon and other particulate emissions will depend on the percentage of hydrogen used but are unlikely to be net zero unless hydrogen is implemented at 100% intervention rate.

As well as H2-ICE hydrogen can also be converted into electrical energy for propulsion using a fuel cell. Fuel cells require combination with an electric battery for propulsion. Fuel cells tend to be more efficient for many transport applications than the H2-ICE but also tend to be more expensive. Fuel Cells also require a much higher purity of hydrogen than H2-ICE, with only electrolysis providing the purity required. Capital costs for H2-ICE tend to be lower than that of Fuel cell equivalents but running costs tend to be higher due to the larger number of moving parts (H2FC Supergen, 2017b).

In terms of market opportunity in Orkney marine transport is the largest user of energy, with road transport next. It is worth noting that carbon intensities of the ferry routes to mainland Scotland significantly impact on localised carbon emissions as seen in Figure 7 below and aviation fuel is omitted.

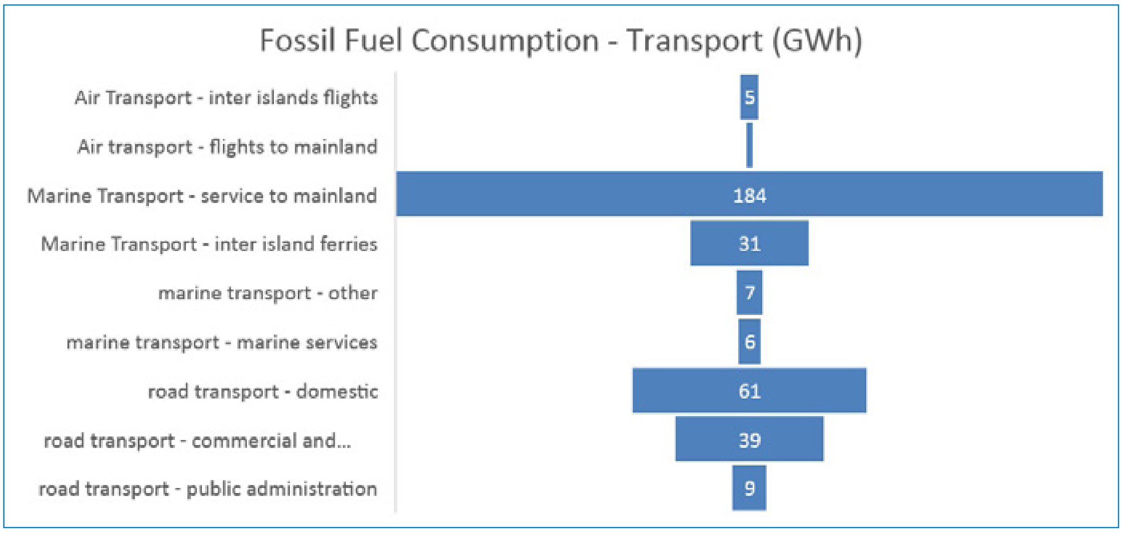
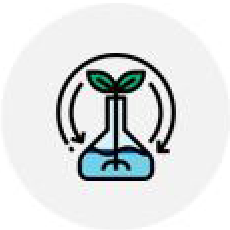


Figure 7: Consumption of fossil fuels, Transport in Orkney (GWh), OREF, 2014.
*Aviation fuel is omitted as data was unavailable at time of publishing.

Potential transport conversions to hydrogen include:

- Ferries.
- Buses.
- Planes.
- Local Authority Fleet.
- Other captive fleets (SME's and large enterprises).
- Passenger Vehicles.
- Agricultural Vehicles.
- Medium and Heavy Plant.

Chemicals



Green hydrogen could serve as a raw material or feedstock to produce chemicals that are currently imported for various purposes in Orkney. Today chemicals make up 62% of the industrial demand for hydrogen in Europe (Hydrogen Europe, 2017).

Chemicals that required hydrogen for production include: Methanol, ammonia, urea, chlorine and a number of synthetic fuels such as bioethanol and synthetic diesel. At present these chemicals are generated from feedstocks from heavily polluting industrial processes (Dechema, 2017).

In 2014 it was estimated that 30,000 tonnes of fertiliser were imported to Orkney each year including over 7,000 tonnes of ammonia (OREF, 2014). Developing chemical production locally may introduce a primary industry increasing job opportunities and reducing reliance upon import.

Heat

There is potential to replace traditional fossil fuel heating systems with hydrogen boilers such as catalytic boilers or microscale combined heat and power units. Fuel Cells convert hydrogen back to electricity and generate excess heat in the process, both the 'waste' heat and the electricity can be used for heating for domestic purpose.

The committee for climate change has suggested that the UK government should explore a low-carbon heat strategy to encourage commercial investment in hydrogen production (2019). Efficient heat pump technology can be powered by low carbon sources like hydrogen.

Power

Orkney has one 75kW Fuel Cell which provides auxiliary power to two vessels while they are docked at Kirkwall harbour. The ReFlex Orkney project is looking to add another fuel cell to provide heat and power to the local sports centre.

There is an opportunity for Orkney to demonstrate the potential of hydrogen fuel cells to balance the local electricity grid.

How can we deliver this?

In order to streamline the actions necessary to develop a specialist centre that is responsible for managing not only the supply and demand of hydrogen but the continued development of hydrogen solutions towards the development of a stand alone hydrogen economy (see Quick Glimpse – Hydrogen management hub).

Supply and demand should continue to be developed alongside one another at an appropriate pace and scale. It is important for Orkney to deliver hydrogen solutions that address the needs of the local populations which is why it is important that projects are relevant to Orkney but also consider that there may be an export opportunity (see figure 9 overleaf).

Quick Glimpse – Hydrogen management hub

Figure 8: Example of a hydrogen hub to manage the relationship between hydrogen supply and demand, manage hydrogen delivery, maintenance of equipment and general administration of hydrogen activities.

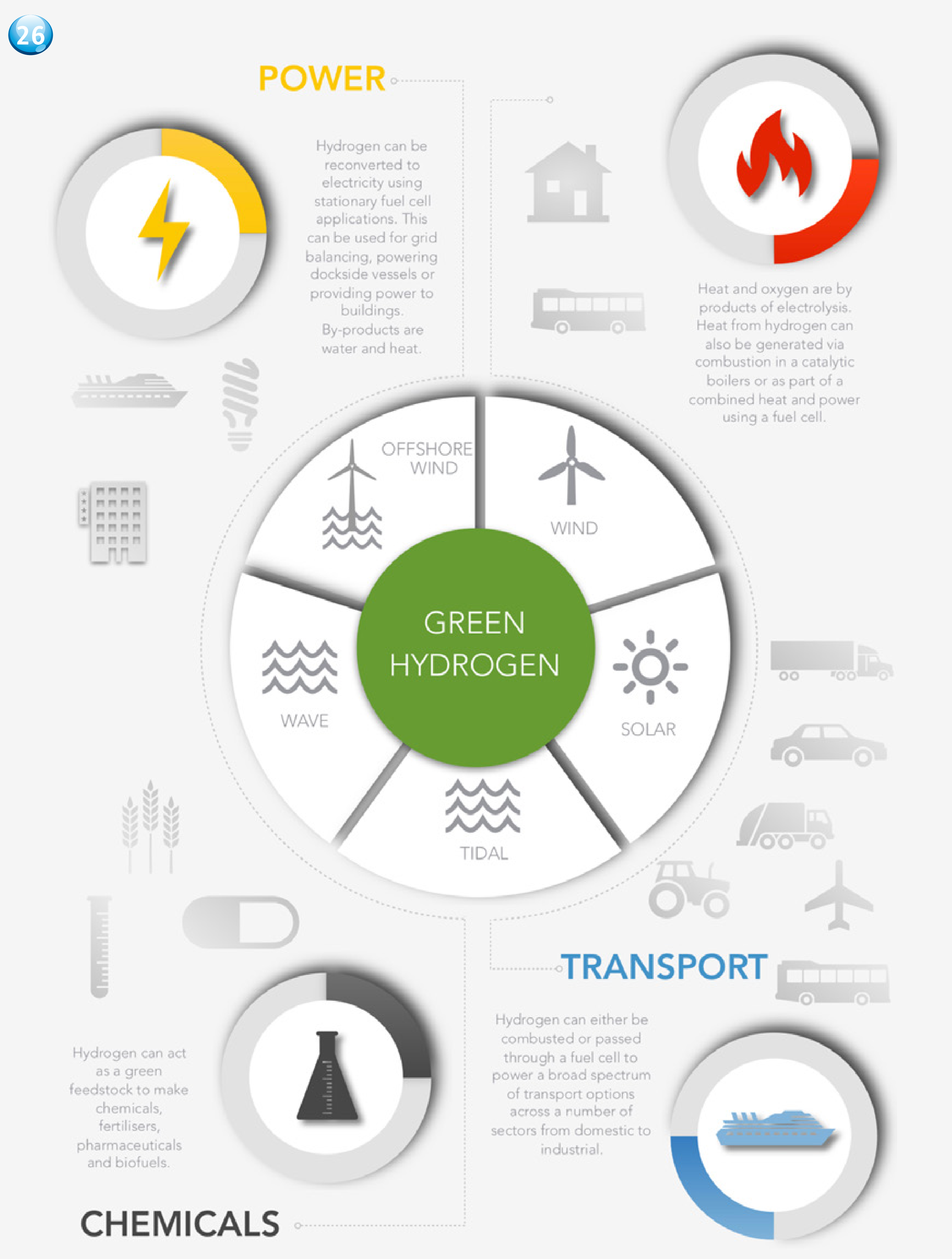


Figure 9: Potential supply and demand pathways for Green Hydrogen in Orkney.

Dissemination

Existing hydrogen projects in Orkney have been successful in their communication thus far by presenting to a wide range of stakeholders across a breadth of age groups and attracting additional opportunities for the local area. While project partners have been invited to present at conferences and events across the world, hydrogen demonstrations have been brought into the local schools and community engagements across Orkney. Notable achievements to date include:

- The hydrogen story in Orkney has been publicised by numerous media agencies including the BBC, the Herald and Forbes
- The hydrogen thread was raised on social media by the DiCaprio foundation
- The ReFLEX energy systems project made it onto national news
- The BIG HIT project won a UK wide local authority award
- Hundreds of visitors from across the world have visited the hydrogen infrastructure on Orkney
- The HySeas III hydrogen ferry project was awarded the 'innovation of the year' award at the 2019 Greentech Festival's Green Awards

As well as continuing to progress with wider dissemination activity effort to promote projects in the local area should also be continued, including local information events, coverage in the local press and educational events in collaboration with local schools and colleges.

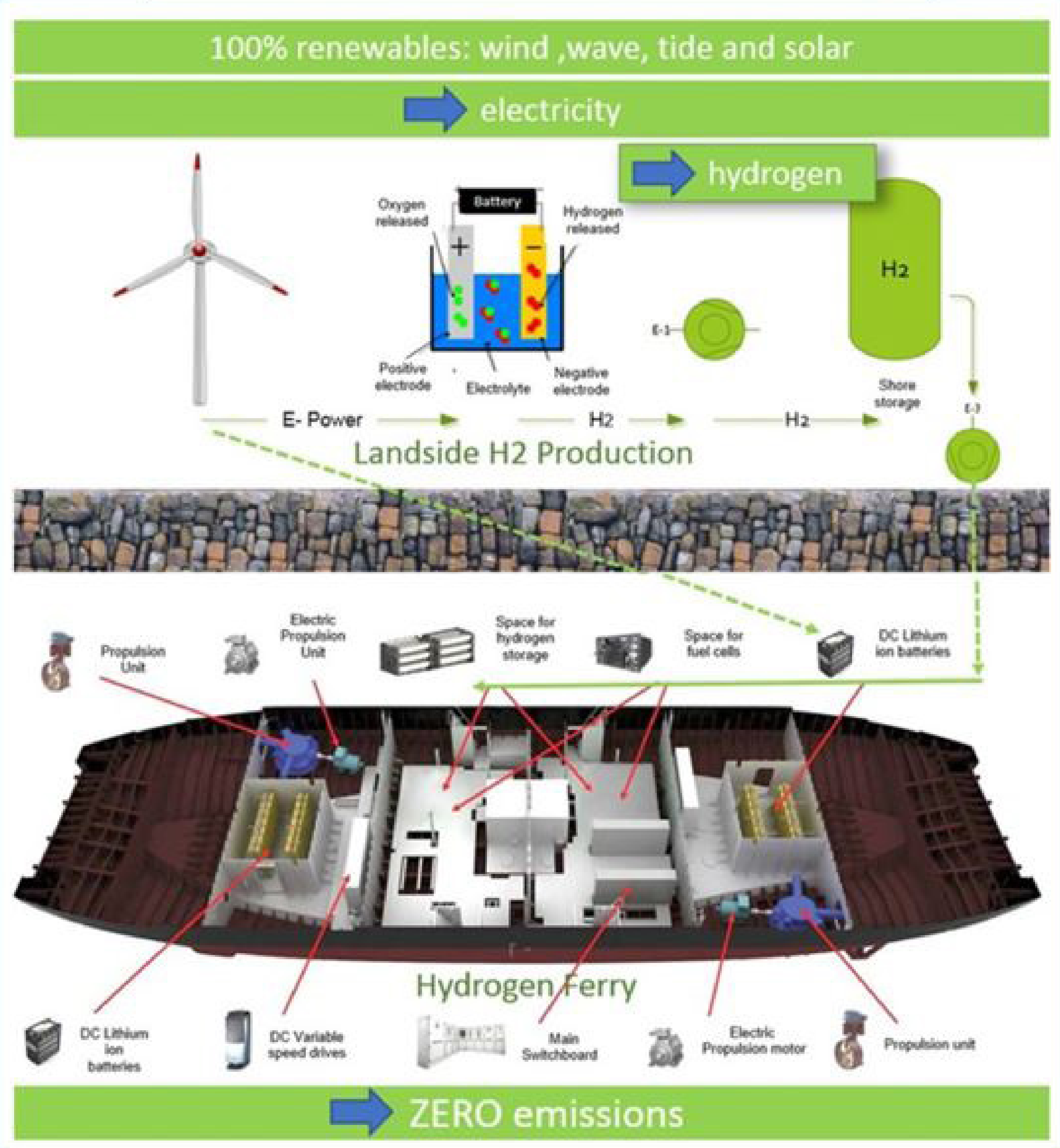
Continuing to reach out to the community allows projects to be tailored to specific needs and including communities in developments from the very beginning allows for concerns to be addressed appropriately. It will also help develop the next step appropriate for integration of hydrogen technologies at the community level.

How can we expect a Hydrogen future to look in Orkney?

Energy decisions made now will play a large role in shaping the future landscape of energy in Orkney as technology replacements today will potentially last decades from now (see **Quick Glimpse: HySeas III: Orkney's zero carbon ferry**). Orkney has demonstrated that it is possible to produce well in excess of 100% of local electricity demand from renewable sources (OREF, 2014). The capital investment to fund these renewable sources has come from a variety of sources from public, private and community owned renewable business models.

At present fossil fuels are able to deliver almost instantaneous energy to the end consumer. Hydrogen storage solutions have potential to address this gap with the addition of being more mobile, with similar cost effectiveness (Supergen, 2015) and less reliant on specialist resources than battery storage.

Quick Glimpse: HySeas III – Orkney's zero carbon ferry



HySeas III is looking to design, test and build a hydrogen fuel cell ferry to service the Kirkwall to Shapinsay ferry route. According to preliminary results from the HySeas III project the Fuel Cell & Battery Kirkwall to Shapinsay ferry could enable a reduction up to 90% of the Global Warming Potential from cradle to the end of life with regards to a conventional Diesel ship when both hydrogen and electricity are produced by wind turbines.

At present fossil fuels are able to deliver almost instantaneous energy to the end consumer. Hydrogen storage solutions have potential to address this gap with the addition of being more mobile, with similar cost effectiveness (Supergen, 2015) and less reliant on mined natural resources required for battery storage.

While it is impossible to define today the future energy mix of tomorrow, this strategy seeks to lay out some potential scenarios for hydrogen within the Orkney energy system. These vary from 'Low' Integration to 'High' Integration which spans from soaking up excess power that is currently curtailed from current renewable production to seeing Orkney as a net hydrogen exporter (see Figure 10 below). Figures are indicative and have been estimated using existing knowledge and estimates of likely demand of varying end-use technologies. There could be an extension of the volume of hydrogen expected in the 'high' integration route if Orkney were to begin exporting hydrogen and hydrogen products and expertise in addition to using it locally. It is assumed that hydrogen transport and heat applications will become economically viable over time. More details are given in the sections below.

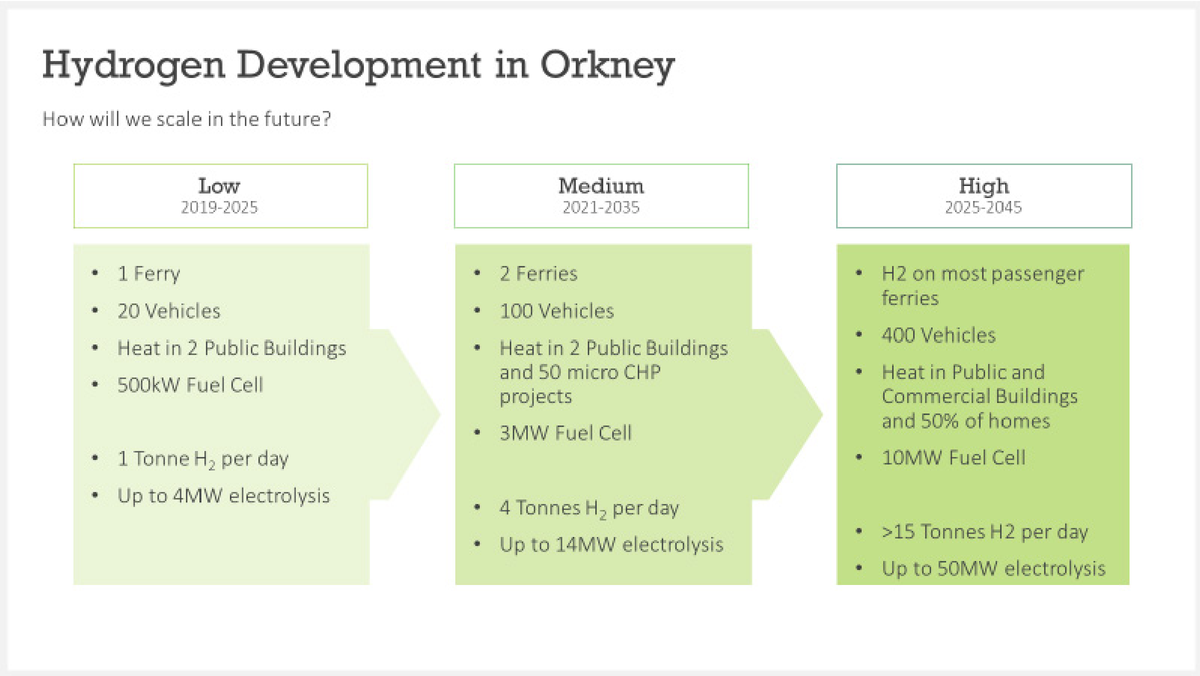


Figure 10: Potential Hydrogen pathways over time.

Low Integration Scenario

A low integration pathway would see hydrogen support the role of smart electrification in the region. The main bulk of energy provision across all energy streams will be electricity and hydrogen will support this role minimally. Many of the assets required to achieve the output below are already deployed or are in the process of being deployed at time of publication. Adoption of hydrogen at this lower integration scale can be expected by 2022/23. (see Table 4).

There will be limited job roles supported by this integration route growing from ~25 roles in 2019 to 40 in 2023. There may be a rise of up to 20 relevant studentships available in the region per annum. Focus will be on research and development of hydrogen with scope for around five technician or engineering roles for maintenance and repair.

Hydrogen supply Electrolysis	Hydrogen Demand	Volume of Hydrogen (+Gen/-Use) day (kg)
>4MW		+1,060
	First ferry	-270 (+ 1,500 stored)
	Up to 20 hydrogen vehicles (various)	-300
	Heat at 2 public buildings	-100
	500kW Fuel Cells combined	-400
	Total Demand	1,070

Table 4: Low Integration scenario for green hydrogen, assumed supply is electrolysis at 70% utilisation of input energy source.

Associated Actions for Success

- Keep current projects on target for deliver and maintain operation.
- Identify additional sources of electrolysis for green hydrogen production to satisfy demand.
- Increase the number of operational vehicles including heavy and passenger transport i.e. trucks and buses

Medium Integration Scenario

A medium integration scenario would see hydrogen support the role of electrification in the region and start to develop a commercial business case for hydrogen supply and production. The main bulk of energy provision across all energy streams will be electricity and hydrogen will support this role more fully than the low integration route. There will be some grid balancing using fuel cell and hydrogen storage technologies of multiple scales (mobile to stationary), this will ease pressure on the electricity grid and provide consumer options. To fully realise this scenario access to the electricity grid would be less prohibitive both economically and operationally than at present. This should be considered with the regulatory changes associated with the electricity markets move from Distribution Network Operator (DNO) to Distribution Service Operators (DSO).

The assets required to achieve the output below will require additional capital investment and consumers may have to be convinced to uptake technologies using subsidies or other appropriate cost parity measures. With relevant support adoption of hydrogen at this medium integration scale could be achieved by 2025/30.

If hydrogen was to be produced from renewable electricity generation, it would most likely require connection to a dedicated commercial scale marine energy or wind farm. Curtailed wind alone would struggle to cope with these production quantities. It would be possible to scale down the megawatts of electrolysis required if the electrolysers were connected to the electricity grid to increase utilisation rates to 100% and fuel cells help to balance the electricity grid balancing applications. Inputs to the grid should be wholly renewable.

Job roles would rise to between 50 and 60 including and include hydrogen transport and an increased function for research, development and replication and potential to develop some higher-level research roles (see Table 5).

Hydrogen supply Electrolysis	**Hydrogen Demand**	**Volume of Hydrogen (+Gen/-Use) day (kg)**
14MW		+3,920
	2 Ferries	-1,200 (+ 3,000 stored)
	100 hydrogen vehicles (various)	-1,500
	Heat at 2 public buildings and 50 micro CHP projects	-250
	3MW Fuel Cells Combined	-900
	Total Demand	3,850

Table 5: Medium Integration scenario for green hydrogen, assumed supply is electrolysis at 70% utilisation of input energy source.

Associated Actions for Success

- Dedicated renewable resource for production.
- Access to the electricity grid for generation.
- An additional ferry is added to the fleet and captive fleet and buses begin transition to hydrogen.
- General public utilise hydrogen for domestic heat and transport.

High Integration Scenario

A high integration scenario would see hydrogen support the role of smart electrification in the region and start to develop a larger scale commercial business case for hydrogen supply and production. The main bulk of energy provision across all energy streams will remain electricity and hydrogen will support this role more as well as becoming commercially attractive. There will be some grid balancing using fuel cell and hydrogen storage technologies of multiple scales (vehicles to Fuel Cells), this will ease pressure on the electricity grid and provide consumer options. Access to the grid would be less prohibitive both economically and operationally than at present.

The assets required to achieve the output below will require additional capital investment and consumers may have to be convinced to uptake technologies using subsidies or other appropriate cost parity measures. Adoption of hydrogen at this high integration scale could be achieved with appropriate resource investment, in-line with the Scotland's Net Carbon zero targets by 2045.

Hydrogen production would require a dedicated commercial scale marine energy or wind farm. Curtailed wind would not cope with these quantities. It would be possible to scale down the Megawatts of electrolysis required if the electrolysers were connected to the electricity grid to increase utilisation rates to 100%. The fuel cells may help with electricity grid balancing applications. Microscale wind generators (domestic, commercial and agricultural) can generate small volumes of hydrogen for domestic combined heat and power units and transport applications (see Table 6).

Job roles will be wide reaching and varied in the high integration routes including roles in ports, maintenance, compliance, logistics, administration and community development roles. The number of job roles that could be supported by this integration route could grow to ~200 by 2045. Orkney could develop itself to be considered a centre for excellence around hydrogen education across all educational levels (see **Quick Glimpse: Hydrogen Management Hub**).

Hydrogen supply Electrolysis	**Hydrogen Demand**	**Volume of Hydrogen (+Gen/-Use) day (kg)**
50MW		+14,000
	H2 on most passenger ferries	-5,000
	400 hydrogen vehicles	-6,000
	Heat in public, commercial and in 50% of homes	-2,000
	10MW Fuel Cell	-3,000
	Total Demand	15,400

Table 6: High Integration scenario for green hydrogen, assumed supply is electrolysis at 70% utilisation of input energy source as well as increasing utilisation by coupling with grid balancing applications. Does not include volumes for chemical applications.

Associated Actions for Success

- Ferry fleet switches to hydrogen.
- Captive fleets increase their transition to hydrogen vehicles and 10% of passenger vehicles are hydrogen powered.
- Low pressure hydrogen pipelines to deliver to source.
- Fuel Cells to manage grid balancing.
- Re-purposing existing oil and gas infrastructure.
- Potential to develop export chains.

Evaluation, Monitoring and Engagement

Evaluating and monitoring how real-world interactions affect the key priorities identified in this strategy is vital to achieving a vibrant hydrogen economy in Orkney. It is proposed that this could be achieved by producing a short **local energy statement** annually which defines the most recent energy statistics; progress towards regional targets; developments under key strategic themes; assessment of technological change and any other relevant changes to the energy system.

In addition to the monitoring and evaluation benefits a local energy statement would help:

- Raise awareness and improve the understanding of the choices and challenges facing Orkney community members as we move towards decarbonisation.
- Develop a Sense of Ownership and control amongst communities, consumer, producers and investors in the local energy system to provide the greatest benefits from a low carbon transition.
- Continued Collaboration to feed in sensible ideas to the energy system by having the ability to implement sensible design ideas via stakeholder's experience with the energy system.

What's Next?

Renewable energy is of strategic importance to future of the local, national and international energy mix. The UK and Scottish Governments have announced net zero carbon emissions targets for 2045 and 2050 respectively and Orkney Islands Council along with other local authorities have declared a climate emergency in order to provide political direction. The need to develop low carbon energy systems has never been greater,

This strategy has set out how hydrogen can be of importance in Orkney's future energy mix to people, communities, business and industry but will need continued action to move forward and make these future technologies every day realities.

An action plan should now be developed in collaboration with the relevant stakeholders to define achievable targets, define actions moving forward and identify who is best placed to undertake those actions.

References

Cision, 2018. Global Hydrogen Generation Market 2017-2018 and 2026: Market Accounted for $103.20 Billion in 2017 and is Expected to Reach $207.48 Billion by 2026. Accessed 9 May 2019. (online) Available at: <https://www.prnewswire.com/news-releases/global-hydrogen-generation-market-2017-2018--2026-market-accounted-for-103-20-billion-in-2017-and-is-expected-to-reach-207-48-billion-by-2026--300763535.html>. (Accessed 14 May 2019).

DECHEMA, 2017. Low carbon energy and feedstock for the European chemical industry (technology study). (pdf) available at:

https://dechema.de/dechema_media/Downloads/Positionspapiere/Technology_study_Low_carbon_energy_and_feedstock_for_the_European_chemical_industry-p-20002750.pdf. (Accessed 16 August 2019).

Department for Transport, 2018. Renewable Transport Fuel Obligation Guidance Part One Process Guidance. (Online). Available at:

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/694277/rtfo-guidance-part-1-process-guidance-year-11.pdf. (Accessed 19 August 2019).

Elexon, 2019. Balancing Mechanism Reporting Service (BMRS). (online) Available at: https://www.bmreports.com/bmrs/?q=help/about-us. (Accessed 14 May 2019).

Grand View Research, 2018. Automotive Battery Market Size Worth $95.57 Billion By 2025. (online). Available at: <https://www.grandviewresearch.com/press-release/global-automotive-battery-market>. (Accessed 14 May 2019).

H2FC Supergen, 2015. Hydrogen or batteries for grid Storage. (online) Available at: <http://www.h2fcsupergen.com/other/report-hydrogen-or-batteries-for-grid-storage-a-net-energy-analysis/>. (Accessed 7 May 2019).

H2FC Supergen, Extended Summary: Steinberg-Wilckens, R., Kurban, Z., Dodds, P.E. and Radcliffe, J., Velazquez Abad, A., 2017a The role of hydrogen fuel cells in delivering energy security for the UK. London: H2FC SUPERGEN.

H2FC Supergen, Staffel and P.E. Dodds. (Eds), 2017b. The role of hydrogen and fuel cells in future energy systems. London: H2FC SUPERGEN.

Hydrogen Europe, 2017. Decarbonise Industry. (Online) Available at: <https://hydrogeneurope.eu/index.php/decarbonise-industry>. (Accessed 16 August 2019).

International Energy Agency (IEA), 2011. The transition to a Low-Carbon Economy: Socio-Economic Considerations (Summary Report). (pdf) Available at: <http://www.ieadsm.org/wp/files/EGRD-transition-to-a-low-carbon-economy.pdf>. (Accessed 9 May 2019).

International Labour Organisation, 2018. Greener growth, just transition, and green jobs: There's a lot we don't know. (online) Available at: <https://www.ilo.org/employment/Whatwedo/Publications/research-briefs/WCMS_628605/lang--en/index.htm>. (Accessed 9 May 2019).

The Royal Society, 2018. Options for producing low carbon hydrogen, (pdf) Available at: <https://royalsociety.org/topics-policy/projects/low-carbon-energy-programme/hydrogen-production/>.(Accessed 14 May 2019).

Scottish Government, 2018a. Leading the way to a Low-Carbon future. (online) Available at: <https://news.gov.scot/news/leading-the-way-to-a-low-carbon-future>. (Accessed 14 May 2019).

Scottish Government, 2018b. The future of Energy in Scotland: Scottish energy strategy. (pdf) Available at: <https://www.gov.scot/publications/scottish-energy-strategy-future-energy-scotland-9781788515276/>. (Accessed on 14 May 2019).

Scottish and Southern Electricity Networks, 2016. Impact of Electrolysers on the Network: Part of the Aberdeen Project.(pdf) Available at: <https://www.ssen.co.uk/ImpactofElectrolysersontheDistributionNetwork.pdf>. (Accessed 14 May 2019).

Scottish and Southern Electricity Networks, 2014. Renewable generation exceeds demand in Orkney. (online) Available at: <https://sse.com/newsandviews/allarticles/2014/04/renewable-generation-exceeds-demand-in-orkney/>. (Accessed 9 May 2019).

Scottish and Southern Electricity Networks, 2018. Supporting a smarter Energy System. (online) Available at: <https://www.ssen.co.uk/smarterelectricity/>. (Accessed 14 May 2019).

UK Government, 2013. (online) Constraint Payments. (online) Available at: <https://www.gov.uk/government/publications/constraint-payments>. (Accessed 1 May 2019).

Zuttel, A., 2010. *Hydrogen: the future energy carrier.* Philosophical transactions of the Royal Society. International Journal of Hydrogen Energy A: Mathematical Physical and Engineering Sciences, 2010. **368** 1923): p3329-3342.

BIG HIT launch event. (photo credit: Colin Keldie).

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