EXECUTIVE SUMMARY

Scottish Offshore Wind To Green Hydrogen Opportunity Assessment

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Summary of Key Findings

01 Abundant Offshore Wind Resources

Scotland has an abundant offshore wind resource that has the potential to be a vital component in our net zero transition. If used to produce green hydrogen, offshore wind can help abate the emissions of historically challenging sectors such as heating, transport and industry.

02 Overcome Grid Constraints

The production of green hydrogen from offshore wind can help overcome Scotland's grid constraints and unlock a massive clean power generation resource, creating a clean fuel for Scottish industry and households and a highly valuable commodity to supply rapidly growing UK and European markets.

03 Primary Export Markets

The primary export markets for Scottish green hydrogen are expected to be in Northern Europe (Germany, Netherlands & Belgium). Strong competition to supply these markets is expected to come from green hydrogen produced from solar energy in Southern Europe and North Africa.

04 Falling Wind & Electrolyser Costs

Falling wind and electrolyser costs will enable green hydrogen production to be cost-competitive in the key transport and heat sectors by 2032. Strategic investment in hydrogen transportation and storage is essential to unlocking the economic opportunity for Scotland.

05 Long-term Outlook of LCoH

Xodus' analysis supports a long-term outlook of LCoH falling towards £2/kg, with an estimated reference cost of £2.3/kg in 2032 for hydrogen delivered to shore.

06 Extensive Port & Pipeline Infrastructure

Scotland has extensive port and pipeline infrastructure that can be repurposed for hydrogen export to the rest of UK and to Europe. Pipelines from the '90s are optimal for this purpose as they are likely to retain acceptable mechanical integrity and have a metallurgy better suited to hydrogen service. A more detailed assessment of export options should be performed to provide a firm foundation for early commercial green hydrogen projects.

07 Supply Chain Overlap

There is considerable hydrogen supply chain overlap with elements of parallel sectors, most notably, the oil and gas, offshore wind and subsea engineering sectors. Scotland already has a mature hydrocarbon supply chain which is engaged in supporting green hydrogen. However, a steady pipeline of early projects, supported by a clear, financeable route to market, will be needed to secure this supply chain capability through to widescale commercial deployment.

08 Gaps in Scottish Supply Chain

There are gaps in the Scottish supply chain in the areas of design, manufacture and maintenance of hydrogen production, storage and transportation systems. Support, including apprenticeships, will be needed to develop indigenous skills and capabilities in these areas.

09 Potential to Create High Value Jobs

The development of green hydrogen from offshore wind has the potential to create high value jobs, a significant proportion which are likely to be in remote, rural/coastal communities located close to offshore wind resources. These can serve as an avenue for workers to redeploy and develop skills learned from oil and gas, in line with Just Transition principles.

Introduction

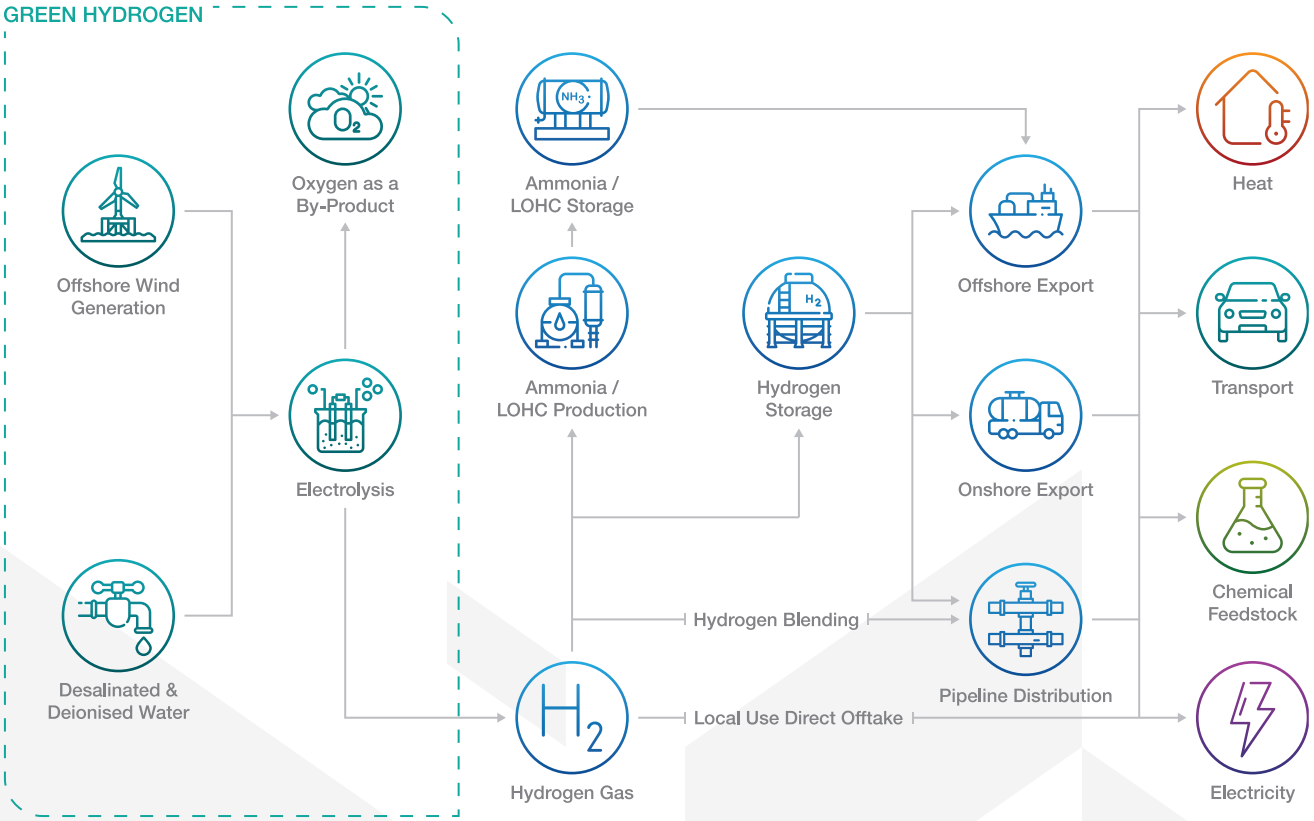
The Scottish Government's newly published Offshore Wind Policy Statement sets out a vision for up to 11GW of Scottish offshore wind capacity by 2030.

Scotland's extensive offshore wind resource offers considerable potential to support decarbonisation of many facets of the energy system via increased electrification and/or the displacement of existing fossil fuel-based systems with green hydrogen alternatives. Offshore wind coupled with green hydrogen production could not only unlock significant Scottish offshore wind resource in regions with constrained electricity grids, but also significantly contribute towards national and international net-zero targets by decarbonising 'hard-to-abate' sectors such as heat, industry and transport, as well as providing surplus green hydrogen to continental Europe.

The route to market for offshore wind projects supplying electricity to the grid is already well established. However, there is growing interest from industry and policymakers in exploring and enabling routes to market for the large-scale production of hydrogen from offshore wind, including for potential export. This opportunity was highlighted in the recent Offshore Renewable Energy Catapult (OREC) 'Offshore Wind and Hydrogen: Solving the Integration Challenge' report, which estimated that up to 240GW of offshore wind could be deployed in the UK by 2050 for the purpose of producing green hydrogen for export to Europe.

Xodus Group ('Xodus') was commissioned by Scottish Government, Scottish Enterprise, Highlands and Islands Enterprise and a consortium of industrial partners led by EMEC to provide an initial assessment of Scotland's opportunity to produce green hydrogen from offshore wind. This study complements the Scottish Government's Hydrogen Assessment (SHA), which takes a broader view of hydrogen's role as an energy vector and its potential contribution to Scotland's energy transition.

In the course of the study, Xodus conducted a supply chain survey and developed a database of Scottish companies active in the green hydrogen sector, or with aspirations to become so. Xodus would like to acknowledge the support kindly provided by Scottish Enterprise, Highlands and Islands Enterprise, SHFCA, DeepWind and many others in undertaking this survey.



Scotland's Potential

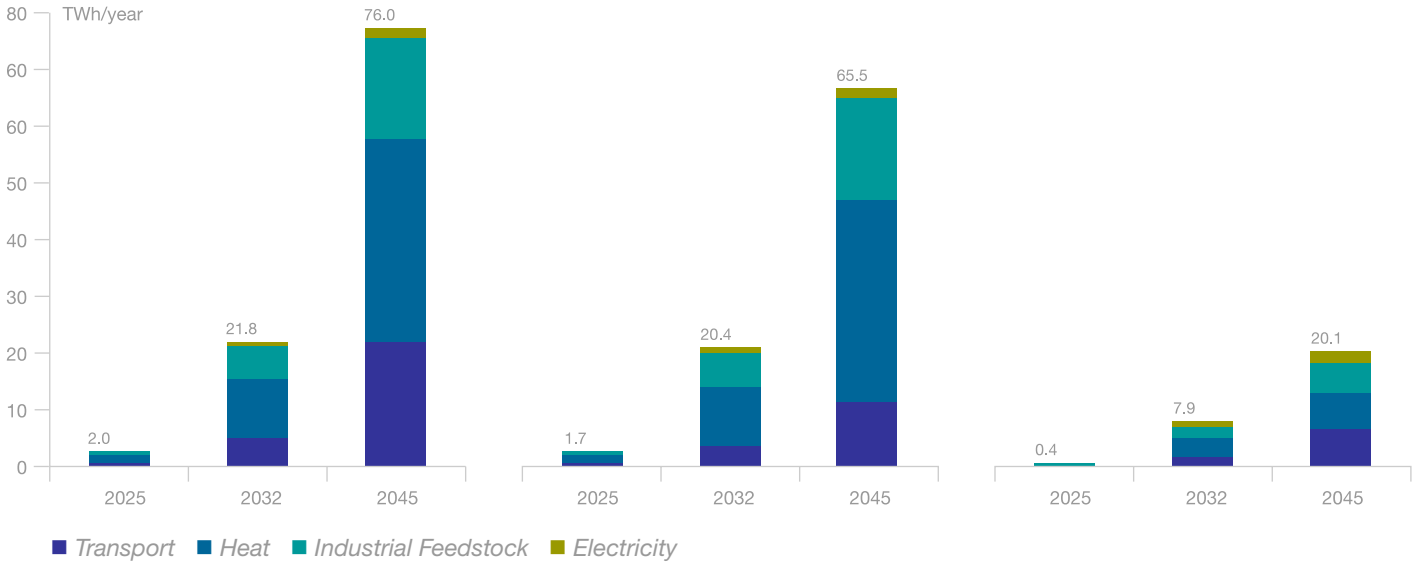
The current forecast from the UK Committee on Climate Change for global low-carbon hydrogen demand varies between 35-1,100 TWh/year in 2030, scaling up to 300-19,000 TWh/year by 2050.

Considering that more than 95% of global hydrogen supply is currently produced from fossil fuels, the opportunity for zero-carbon hydrogen produced by large-scale electrolyser systems is enormous.

Scotland is one of the leading nations in green hydrogen, having developed the world's first hydrogen production system from tidal energy (Surf'n'Turf, 2017), and incorporated anaerobic digestion (AD), combined heat and power (CHP) and electrolysis to produce and utilise hydrogen and oxygen as part of the Outer Hebrides Local Energy Hub (OHLEH). These are examples of multiple pioneering Scottish hydrogen projects, which also include the world's first hydrogen-powered double decker bus fleet in Aberdeen. With increasing domestic and international demand for hydrogen, offshore wind coupled with electrolysis presents a green solution with potential to address large scale demand. Scotland has a growing offshore wind sector, but with increased requirements for grid infrastructure upgrades and curtailment risk, hydrogen production could act as an alternative revenue stream to electricity supply to support continued offshore wind development, whilst serving to decarbonise 'difficult-to-abate' sectors.

Hydrogen Demand Projections

Three scenarios were created to explore the development of hydrogen demand in Scotland.



Ambitious

Full transition towards a hydrogen economy in Scotland. This scenario is based on a combination of the most ambitious projections for each sector from the SHA.

Planned Development

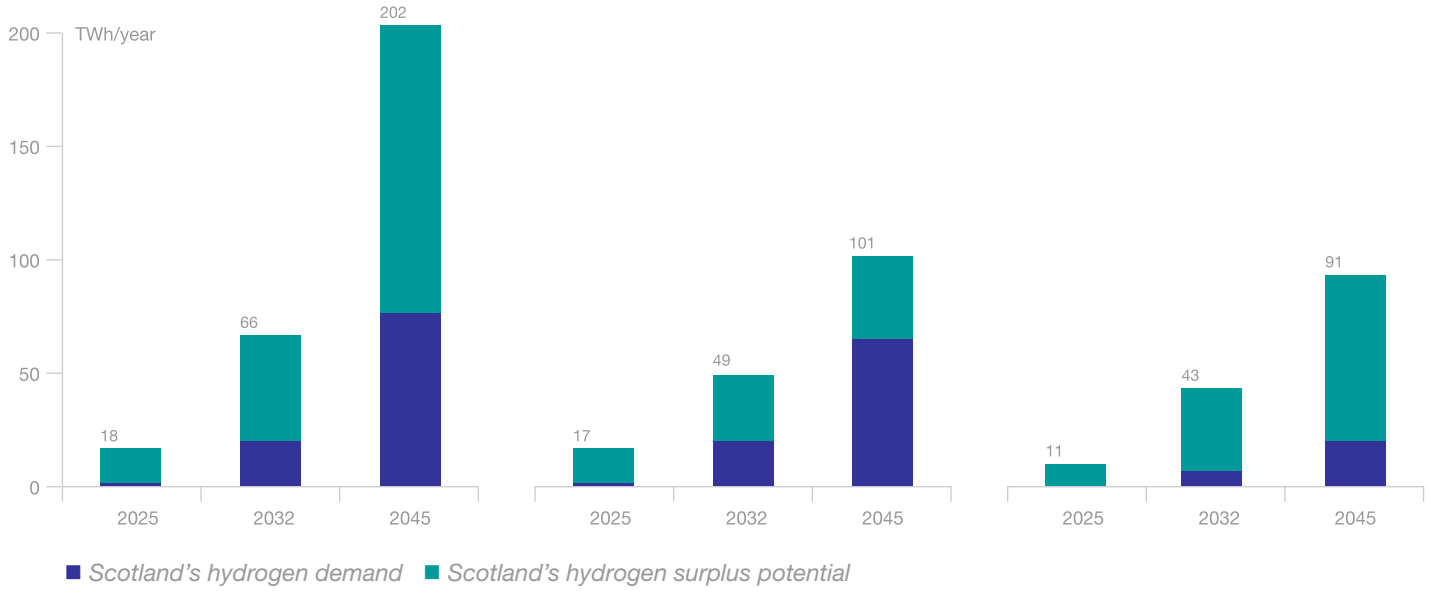
Scenario based on wide-ranging hydrogen technology deployment and use across various sectors. This scenario was aligned with Scenario A: 'Hydrogen Economy' from the SHA.

Business as Usual

Conservative scenario with modest hydrogen use and extensive electrification across all sectors. This scenario was aligned with Scenario C: 'Focused Hydrogen' from the SHA.

Hydrogen Production Projections

Corresponding scenarios were developed for the potential supply of green hydrogen from offshore wind in Scotland in the period up to 2045.



Ambitious / 60GW

Estimated capacity that could be achieved with multiple ScotWind rounds and by going beyond current net-zero targets. This represents around 1/3 of the total practical developable Scottish offshore wind resource as estimated in 2010 by the Offshore Valuation Group.

Planned Development / 30GW

Aligned with Scotland delivering 40% of the 75GW UK offshore wind deployment target recommended by the Committee on Climate Change.

Business as usual / 27GW

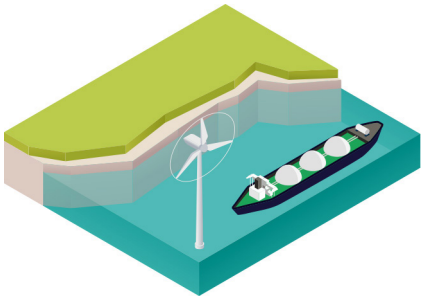
Continuing, but more conservative, deployment of offshore wind.

Due to anticipated future grid constraints it was assumed, for purposes of this initial simplified analysis, that in all scenarios, the entire offshore wind would, or could, be used for hydrogen production. When then compared with the corresponding demand scenario, it can be seen that a considerable excess of green hydrogen is produced in all scenarios. This represents a valuable supply opportunity to the rest of UK and export opportunity to Europe where demand for hydrogen from the heating, transport and chemical feedstock sectors is growing. Indeed, due to grid constraints, green hydrogen may represent the best means to commercially develop the rich Scottish offshore wind resource in the longer term.

The primary export markets for Scottish green hydrogen are expected to be in Northern Europe (Germany, Netherlands & Belgium) which can be accessed by pipeline. Competition to supply these markets is expected come from hydrogen produced from solar energy in Southern Europe (notably Portugal) and North Africa.

Cost of Green Hydrogen Production

Levelised cost of hydrogen (LCoH) has been estimated for three base case production scenarios.

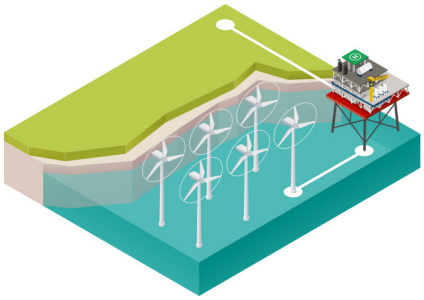


Scenario 1 – Small-scale pilot project for green hydrogen production from offshore wind.

- *Hydrogen production offshore from one 14MW wind turbine*
- *Hydrogen transport to shore*

Scenario 2 – Commercial scale offshore wind farm coupled with onshore hydrogen production.

- *500MW offshore wind farm*
- *Export cable to shore*
- *Electrolysis onshore*



Scenario 3 – Commercial scale offshore wind farm coupled with offshore hydrogen production.

- *1000MW offshore wind farm*
- *Hydrogen production offshore*
- *Subsea pipeline to shore*

RESULT	UNIT	SCENARIO 1	SCENARIO 2	SCENARIO 3
Year	–	2025	2028	2032
Wind Farm Capacity	MW	14	500	1000
Hydrogen Production	Te/day	3	119	276
LCoH	£/kg	6.2	2.9	2.3

- As expected, the results of the modelling show the cost of hydrogen production decreasing with reducing technology cost and increased scale. Xodus' analysis supports a long term outlook of LCoH falling towards £2/kg for fixed bottom offshore wind turbines.
- Floating wind and any additional costs for transportation significantly increase the LCoH. The cost of hydrogen at the point of use must therefore take these logistics components into account on a case by case basis.
- Desalination cost and distance to shore do not significantly influence LCoH.

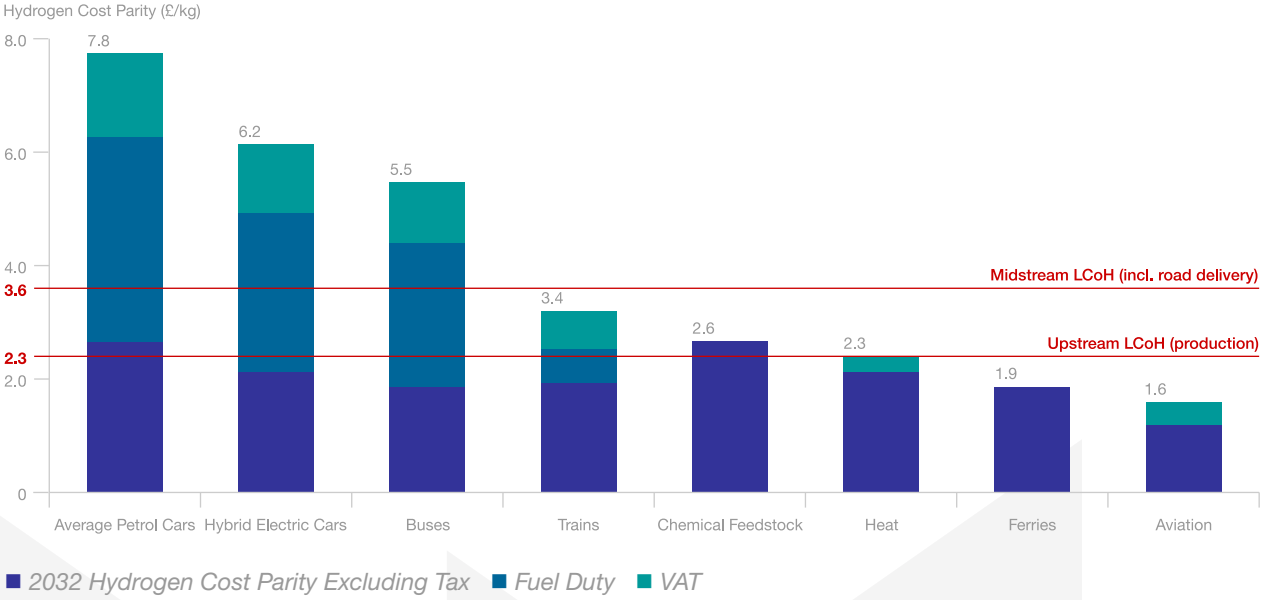
Cost Parity

The levelised cost of green hydrogen (LCoH) in 2032 has been compared with the parity price of equivalent hydrocarbon fuels both at the point of production of hydrogen and after including logistics cost for delivery.

Further, where appropriate, fuel duty and VAT effects are shown. The analysis excluded any consideration of additional end user costs required for infrastructure (hydrogen fuelling stations, gas network upgrades), appliance retrofits or fuel cell vehicles, and therefore directly compares only fuel cost. There are currently still barriers to the widespread uptake of hydrogen solutions due to lack of conveniently available supply and limited or costly (particularly in the case of vehicles) consumer choices at this emergent stage of market adoption.

- Due to the existing taxation effects of fuel duty and VAT, untaxed hydrogen is shown to be cost-competitive with hydrocarbon fuel for cars and buses at the pump, without subsidy, where logistics costs (fuelling station, storage and transport cost) can be kept reasonably low (e.g. a centralised bus fleet).
- Projected green hydrogen production at £2/kg is equivalent to £50.8/MWh, higher than the £16.4/MWh natural gas commodity price equivalent. Direct substitution of natural gas by green hydrogen would therefore need to be supported by market intervention.
- In Scotland, the largest demand for hydrogen is expected to be for heat, replacing or (by blending) supplementing natural gas, where hydrogen can be delivered without substantial additional cost by using the existing natural gas network. The required support thus contrasts with minimal infrastructure investment needs.
- By contrast, significant investment would be required in offshore seasonal storage to enable hydrogen to replace natural gas as fuel for back-up electricity generation. Green hydrogen is not considered competitive in this sector, though the parity price assessment is more complex and not directly comparable with the other sectors illustrated.

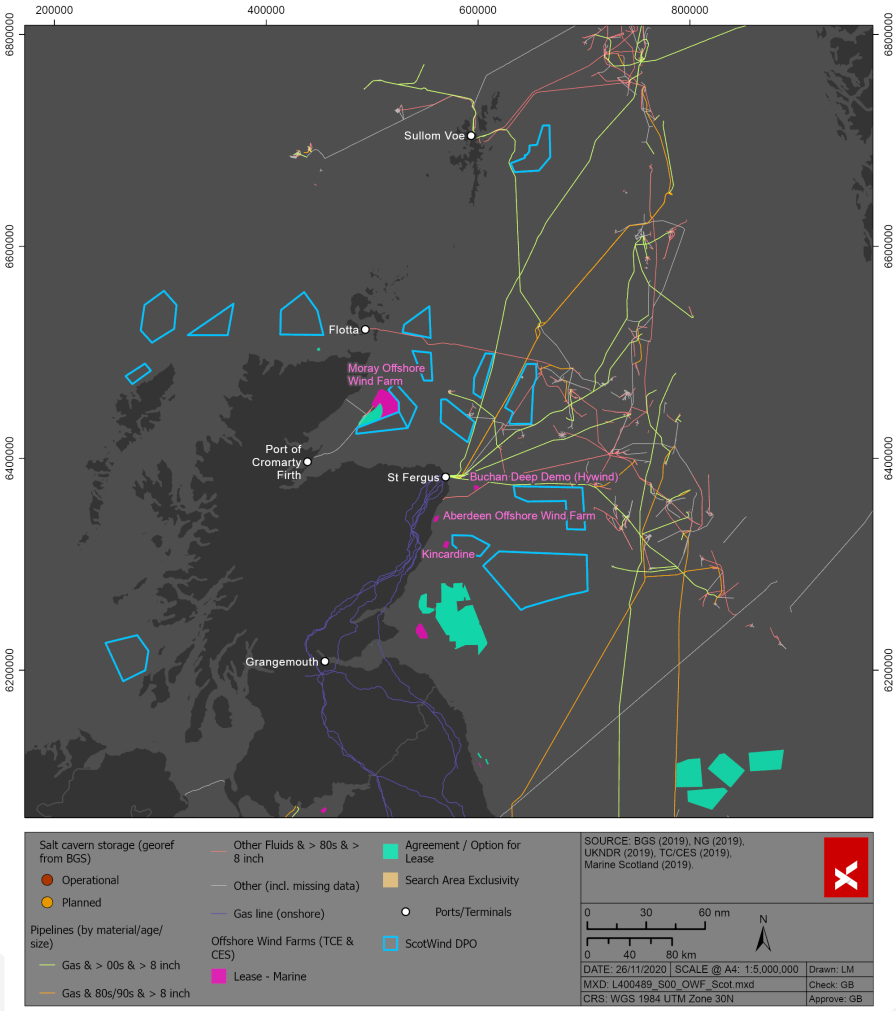
Despite the vastly different cost parities to the end user, the fiscal support gap for hydrogen as a fuel substituting natural gas for heat or hydrogen mobility is within the margin of error. Individual hydrogen mobility is likely to require additional subsidies for costlier hydrogen vehicle acquisition.



Scottish Infrastructure

Scotland has a range of existing oil and gas infrastructure that could be repurposed to develop a hydrogen economy. This includes:

- An extensive infrastructure of existing O&G pipelines, much of which overlays the 2020 Offshore Wind Plan Option areas in the Sectoral Marine Plan, and includes four pipelines that currently connect the UK to continental Europe. Examples of repurposing exist but key challenges include long term integrity of now-aging pipelines, especially for the additional challenges of transporting hydrogen, and a potentially extended period between cessation of hydrocarbon production and repurposing for hydrogen transport.
- Several Scottish ports and terminals are well-equipped for hydrogen export and are already actively considering repurposing for hydrogen export.
- Depleted fields and other subsurface structures that would allow for large scale storage of hydrogen. Research in this area however is still in its infancy.

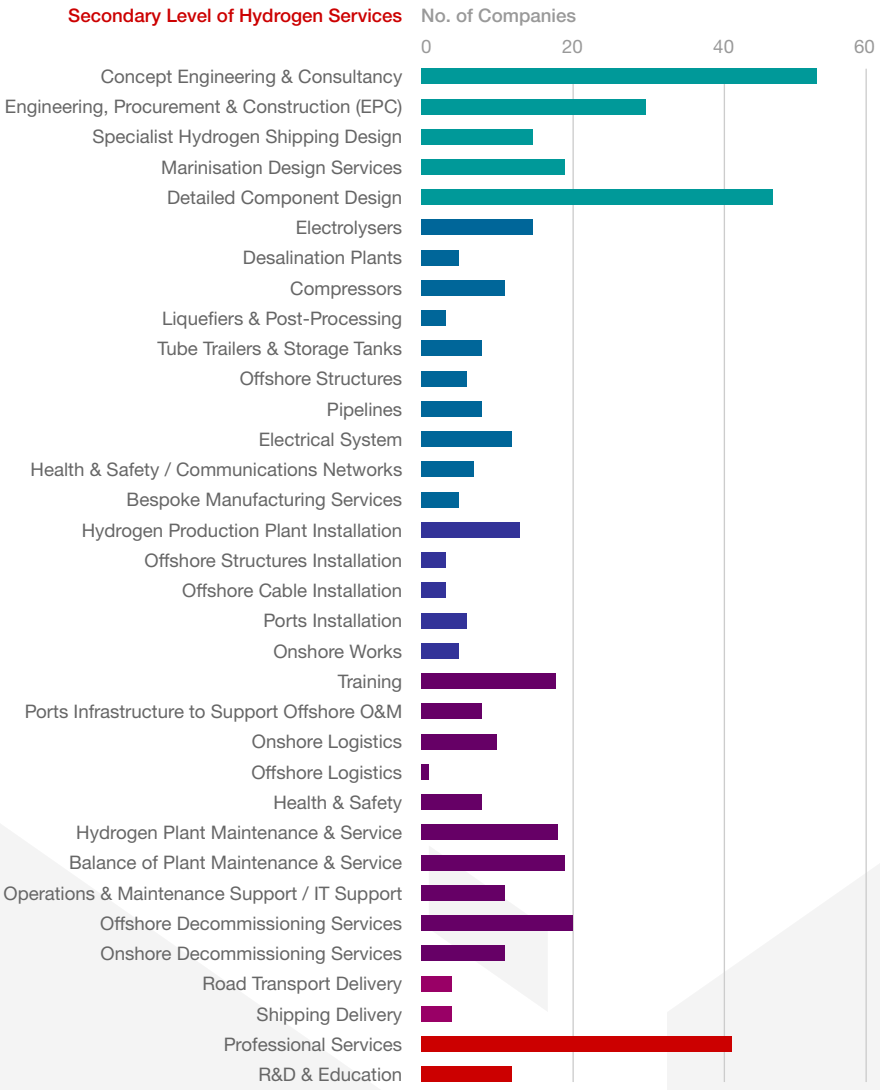


A co-ordinated strategy and plan for hydrogen transportation both within the UK and to Europe is required in order to maximise the efficient re-use of this existing infrastructure and to ensure optimum redevelopment of terminals and ports.

Supply Chain Assessment

A database has been established of around 100 Scottish companies active in, or with an expressed interest in entering the green hydrogen sector.

- There is considerable hydrogen supply chain overlap with elements of parallel sectors, most notably, the oil and gas, offshore wind and subsea engineering sectors.
- The current strengths of the Scottish hydrogen supply chain are in the areas of project development, installation, Operations & Maintenance and sector support where these capabilities can be transferred from Scottish companies with experience in similar industries.
- Gaps in the Scottish supply chain are predominantly in supply areas bespoke to the design, manufacture and maintenance of hydrogen generation plant.
- Transportation of hydrogen appears to be an area with limited Scottish capability.
- The prevailing threat to the Scottish supply opportunity may be in a low pipeline of hydrogen generation projects.
- Established supply chains in competing markets may take advantage of low barriers to supplying Scottish projects or have stronger experience and track record than Scottish suppliers.
- Further work requires to be undertaken to address the skills gap, including retraining from oil and gas as well as potential apprenticeship opportunities, ensuring the Scottish workforce are ready to move quickly when required later this decade.



The Scottish supply chain is well positioned to support, and ultimately to benefit from, the development of green hydrogen. However, a steady pipeline of hydrogen developments over the next decade will be essential to ensuring the development of an indigenous supply chain so that Scotland is ready to deliver and take advantage of full commercial deployment.

Commissioning Partners

Scottish Government
Riaghaltas na h-Alba
gov.scot

Scottish Enterprise

HIE
Highlands and Islands Enterprise
Iomairt na Gàidhealtachd 's nan Eilean

EMEC
THE EUROPEAN MARINE ENERGY CENTRE LTD