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Scotland's capabilities in producing hydrogen products and derivatives

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Research completed: April 2025

DOI: http://dx.doi.org/10.7488/era/6397

1 Executive summary

1.1 Aims

The Scottish Government is committed to achieving net zero emissions by 2045, five years ahead of the UK's target. Scotland also aims to become a major exporter of low carbon hydrogen derivatives and products (HDPs) and has access to the abundant renewable energy necessary for their production. Hydrogen derivatives are chemicals produced from hydrogen that can more easily be stored and transported and then converted back to hydrogen for later use. Examples include ammonia and methanol. Hydrogen products, such as sustainable aviation fuels (SAFs), do not need a further conversion process and are used for a range of applications.

Hydrogen can be produced using electrolysis, a process which involves splitting water into hydrogen and oxygen. When this process is performed using only renewable sources of electricity, the hydrogen produced can be deemed as green hydrogen.

As green hydrogen supply is crucial for the development of HDP production, this study explores Scotland's strengths and weaknesses in developing both the green hydrogen and HDP sectors. Throughout this study, the term *"hydrogen and HDP sector"* is used to include green hydrogen and HDPs produced using that green hydrogen.

This study analyses Scotland's supply chain capabilities in producing HDPs and identifies opportunities and barriers it may face in scaling up the hydrogen and HDP sectors. It also aims to understand the role different regions of Scotland can play in enabling the growth of these sectors.

1.2 Findings

Scotland's abundant access to renewable energy, geographic proximity to the EU, skilled workforce and a favourable external policy landscape are major strengths that can enable growth in the hydrogen and HDP sectors. However, there are potential weaknesses and barriers too. Producing renewable electricity, a major cost source for producing green hydrogen, is currently relatively expensive in Scotland, with prices around 70% higher than the average of EU and G7 countries.

1.2.1 Supply chain capabilities

The Scottish Government's *Hydrogen Action Plan* identified 14 hydrogen hubs. This report systematically compared the supply chain capabilities of each for producing HDPs. Hubs were assessed on:

- Availability of feedstock (i.e., production source material)
- Economic factors from co-located industries
- Workforce and skills
- Infrastructure,
- Local policy and planning support, and
- Co-location with innovation institutions

For comparison, the Duisburg region of Germany was assessed against the same metrics, as a potential competitor to Scottish hubs.

Aberdeen ranked the highest in many metrics, followed by Cromarty and Ayrshire. The Duisburg hub also scored highly on several metrics. The aim was not to find a *single* best hub. Aberdeen's high score suggests that it is currently relatively well-developed against the supply chain metrics, it does not suggest that this is the sole hub suitable for developing Scotland's hydrogen and HDP sectors.

1.2.2 Addressable market demand

The report estimated the addressable market demand for HDPs in each hub. The HDPs considered were ammonia and e-methanol for the maritime sector, ammonia-based fertiliser for the agriculture sector, e-methanol feedstock for the chemical sector, and SAF for aviation.

The addressable demand for all HDPs in all the sectors is around 35 TWh. Roughly 97% of this comes from just the aviation and maritime sectors. Grangemouth is estimated to have the biggest market for HDPs in both sectors.

1.2.3 Co-locating demand and supply

Co-locating demand and supply will enable the early scaling of Scotland's hydrogen and HDP sectors as national network infrastructure is developed. Aberdeen and Grangemouth both stand out as key hubs for the development of Scotland's HDP economy. Analysis of supply and demand found that with the presence of a large chemicals industry and a major airport, Grangemouth outperforms all other hubs.

Despite relative strengths in supply chain capability, Aberdeen is not the optimal region for co-locating supply with demand opportunities because the maximum demand potential is higher in Grangemouth.

There are significant hazards associated with HDPs bringing associated regulatory requirements. Analysis of current Control of Major Accidents and Hazards (COMAH) site locations provides insight into the infrastructure and the expertise needed to handle HDPs safely. Fife, Glasgow, Moray and Grangemouth hubs have the most COMAH sites, bringing relatively strong experience in this regulatory environment.

1.2.4 Policy gaps

Analysis of the policy landscape in the UK, the EU and Scotland suggests a number of potential approaches to help develop the hydrogen and HDP sectors. Scotland's abundant access to renewable energy, strong workforce capabilities and demand potential can facilitate a vibrant hydrogen and HDP sectors. However, Scotland will need to address issues such as:

- the high cost of electricity generation;
- a more sophisticated planning regime that considers both site demand and supply in order to optimise co-location strategies.

Working with the UK and foreign governments to capitalise on export opportunities will allow Scotland to expand its potential market size.

1.2.5 Conclusions

Hub development requires both a cross-hub approach and strategic co-location of regional supply and demand. Individual hubs should not be considered in isolation. Particular hubs score relatively highly but this does not preclude a very significant role for other hubs within the overall hydrogen and HDP sectors.

Aberdeen and Grangemouth stand out as having relative strengths in relation to co-location of supply chain capabilities with demand. Cromarty and Ayrshire offer strong supply chain capabilities. Glasgow and Fife present significant demand opportunities. The Western Isles and Argyll and Islands may require targeted support to enhance their supply chain capabilities. The Scottish Borders may need support in developing greater regulatory experience.

By balancing cross-hub collaboration with localised development, Scotland can maximise the potential of its hydrogen economy, driving the sector's long-term growth and resilience.

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2 Glossary / Abbreviations

2.1 Abbreviations

COMAH	Control of Major Accident Hazards
FEED	Front-End Engineering Design
FTE	Full-Time Equivalent
GHS	Globally Harmonized System of Classification and Labelling of Chemicals
GSMR	Gas Safety (Management) Regulations 1996
GVA	Gross Value Added
HPBM	Hydrogen Production Business Model
HSBM	Hydrogen Storage Business Model
HSE	Health and Safety Executive
HTBM	Hydrogen Transport Business Model
IMO	International Maritime Organization
IPCEI	Important Projects of Common European Interest
IRENA	International Renewable Energy Agency
LOHC	Liquid Organic Hydrogen Carrier
MCH	Methylcyclohexane
MoU	Memorandum of Understanding
NSIP	Nationally Significant Infrastructure Project
NSTA	North Sea Transition Authority
NZHF	Net Zero Hydrogen Fund
REPD	Renewable Energy Planning Database
RFNBO	Renewable fuels of non-biological origin
SAF	Sustainable Aviation Fuel
SEPA	Scottish Environment Protection Agency
SIC	Standard Industrial Classification

2.2 Glossary of units

gCO_2e/MJ	Grams of CO_2 equivalent per megajoule
J	Joule
kg CO_2-eq/kg	Kilograms of CO_2 equivalent per kilogram
Wh	Watt-hour
m	Metre
%	Percentage
t	Tonne
W	Watt

3 Introduction

Scotland has set an ambitious target to reach net zero by 2045. To be able to achieve its targets, Scotland will have to rapidly decarbonise its economy. The Scottish Government is exploring options to use hydrogen to decarbonise certain sectors and to develop current HDP capabilities in support of climate goals. Scotland ultimately aims to produce 5 GW of low-carbon hydrogen by 2030 and 25 GW by 2045. In addition to reaching its net zero goals, the Scottish Government also aims to utilise these resources to capitalise on export and other economic opportunities. Green hydrogen is expected to be the dominant low carbon production method in Scotland. This study focuses solely on HDPs produced from green hydrogen, which are referred to as "HDPs" throughout this report.

In this study we aim to explore Scotland's supply chain capabilities. To situate the need for this research, we conducted a review of existing literature (see Appendix A: Current state of play). Our review of the literature analyses the strengths that Scotland possesses to scale up its hydrogen and HDP sectors. It also details some of the biggest barriers that Scotland is likely to face. The review then focusses briefly on specific HDPs and their potential role in enabling Scotland's transition to net zero.

We also analyse Scotland's strengths and weaknesses in developing its capabilities. We focus on assessing the opportunities and challenges associated with exporting HDPs to the rest of the UK and the EU. Moreover, we aim to understand the role that different regions of Scotland can play in enabling the development of HDP production. We have identified 14 regional hydrogen hubs in Scotland from the Scottish Government's *Hydrogen Action Plan* (2022), shown in Table 1. In addition to the Scottish hubs, the study also considers the Ruhr region of Germany as an alternative hub. Scotland is expected to export a significant amount of its green hydrogen produce to the EU. Therefore, the Ruhr region of Germany was considered as a potential alternative source of green hydrogen for the EU.

For each metric, we rank the hubs to analyse their relative strengths, before combining these rankings into a final capability score for each hub in Section 4.8. In this manner, we provide a balanced and quantitative assessment of the relative supply chain capabilities of Scotland's hydrogen hubs. It is important to note that the purpose of this analysis is not to find the absolute "best" hydrogen hub in Scotland. By ranking the hubs in each metric, we have assessed their **relative** strengths and weaknesses.

In an international market, Scotland's hubs will be competing with various other green hydrogen and HDP production areas. As Scotland aims to export to Europe, in particular Germany, it will have to compete with local European production (Scottish Government, 2024). Germany's Ruhr region aspires to be the first model hydrogen region to accelerate the hydrogen sector in Europe (Hydrogen Metropole Ruhr, 2023). Hydrogen is already playing a role in developing HDP production in the region (Metropole Ruhr Business, 2025). One example is the Greenlyte's project in Marl which is producing e-methanol from CO_2 and green hydrogen. In August 2025, this project secured a 7-figure e-methanol offtake agreement with Germany-based MB Energy, indicating substantial market interest for HDPs produced in the Ruhr region (Greenlyte, 2025). Given Ruhr's strong ambitions, to evaluate Scotland's competitiveness at the international level, we will compare the Scottish hubs with the hydrogen hub of Duisburg, situated in the Ruhr region.

In subsequent chapters, we analyse the supply chain capabilities of each hub in Scotland, addressable demand for various HDPs in different sectors, and the regulatory environment related to safety. The final chapter focusses on the wider policy landscape, analysing gaps and providing recommendations to policymakers.

Table 1: List of Scottish hubs and their corresponding local authorities.

Hub	Corresponding local authorities
Aberdeen	Aberdeenshire and Aberdeen City
Argyll and Islands	Argyll and Bute
Ayrshire	East Ayrshire, North Ayrshire, and South Ayrshire
Cromarty	Highlands
Moray	Moray
Dumfries and Galloway	Dumfries and Galloway
Dundee	Dundee and Angus
Fife	Fife
Glasgow	East Dunbartonshire, East Renfrewshire, Glasgow City, North Lanarkshire, Renfrewshire, South Lanarkshire and West Dunbartonshire
Grangemouth	Clackmannanshire, Falkirk and Stirling
Orkney	Orkney Islands
Scottish Borders	Scottish Borders
Shetland	Shetland Islands
Western Isles	Western Isles

4 Supply chain capabilities of Scotland’s hydrogen hubs

In this chapter, we investigate the **relative** supply chain capabilities of Scotland’s hydrogen hubs to produce HDPs. We have selected six capability groups for evaluation (shown in Table 2). These groups are broadly based on the six key advantages for hydrogen production identified in the Scottish Government’s *Hydrogen Action Plan* (2024). Certain capability groups, such as pipeline infrastructure, are highly dependent on future developments at a national and international level. The results from analysing all these capability groups will allow us to **assess each hub’s intrinsic and long-term supply chain strengths** that will enable the fast growth of the hydrogen and HDP sectors.

We have then broken down these groups further into assessment metrics in order to accurately evaluate the capability groups against available data. This analysis produces detailed hub differentiation to support actionable conclusions for policymakers. Table 2 shows each capability group and their associated metrics. Further information on metric methodology, sources and data is found in Appendix B.

Table 2: Capability groups and assessment metrics for evaluating the supply chain capabilities.

Capability group	Assessment metric
Feedstock and inputs	Maximum potential renewable power generation
	Water availability
Economic output from relevant co-located industries	Gross Value Added of the energy sector
Workforce and skills	Full time equivalent workers in energy and engineering
	Future workforce requirements
Infrastructure	Large-scale storage capacity
	Pipeline network infrastructure
	Ports
Local policy and planning support	Processing time for industrial planning applications
	Success rate of industrial planning applications
Co-location with innovation institutions	Innovation institutions with facilities for pilot-scale testing

4.1 Feedstock and inputs

Renewable electricity and water are the two fundamental feedstocks for green hydrogen production. The availability of both can be seen to vary, by region. This is in contrast to the supply of nitrogen for e-ammonia or carbon dioxide for e-methanol, where both feedstocks are derived from air, via direct air capture and can therefore be assumed to be equally available to all hubs.

4.1.1 Maximum potential renewable power generation

Scotland's abundant renewable energy resources are key to its net zero transition. In particular, the Scottish Government has identified Scotland's extensive offshore wind resource as a considerable opportunity for green hydrogen production (Scottish Government, 2020). Under a business-as-usual scenario, installed offshore wind capacity is expected to rise from 3.4 GW in 2025 to 27 GW in 2045 (Scottish Government, 2020). Green Hydrogen production can support this growth by helping to overcome Scotland's grid constraints.

The co-location of renewable energy generation and HDP production takes advantage of existing infrastructure, reduced electricity transmission costs and improved project economics. An example of co-location is Scottish Power's planned 20 MW Whitelee Green Hydrogen Project near Glasgow (Scottish Power, 2024). The facility will be co-located with a 70 MW combined Solar and Battery Energy Storage Scheme. Adjacent is the 539 MW Whitelee Windfarm and substation.

We have analysed the maximum potential renewable power generation for each hub, based on the total current, planned and announced installed capacity of solar and wind power projects (DESNEZ, 2024; Offshore Wind Scotland, 2024). We scaled the resulting capacities by the appropriate load factor to determine the maximum potential renewable power generation (see Appendix B for load factors). For offshore wind, we assigned each project to the hub associated with its current or forecasted onshore landing point.

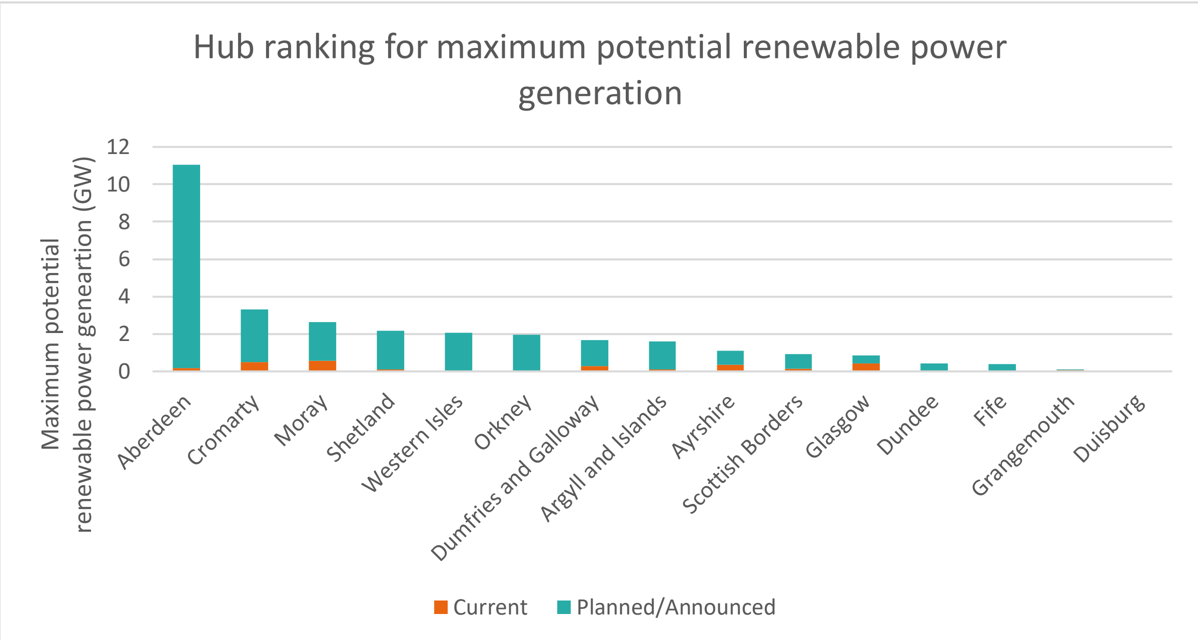

Figure 1: Maximum potential renewable power generation split by current and future (planned and announced) projects.

The order of hubs by maximum potential renewable power generation is shown in Figure 1. As shown from left to right, Aberdeen is ranked first and Duisburg, Germany is ranked last.

We can take several key insights from Figure 1:

- Access to future wind projects, particularly offshore wind, broadly determines which hubs have the most renewable power capability. Aberdeen, ranked first, accounts for around 50% of planned and announced offshore wind capacity among the Scottish hubs.
- Hubs with large future offshore wind projects – such as the announced ScotWind projects – lead the rankings (Offshore Wind Scotland, 2024). These hubs include Aberdeen, Cromarty and Moray.
- Grangemouth, with no current or future offshore wind capacity, ranks lowest among the Scottish hubs.
- As a densely populated hub, with no offshore wind, Duisburg ranks lowest overall.

4.1.2 Water availability

Sustainable water management is vital to balancing our water demand with environmental and ecological needs. Therefore, it is important to identify the water supply for hydrogen production early in the development process to ensure sufficient availability.

The electrolysis process requires large volumes of treated water, which is split to form hydrogen and oxygen. Reviewing the commercial electrolyser technologies, an estimated 10 litres of water is required per kilogram of green hydrogen produced (Ramboll, 2022). Water for green hydrogen production can be obtained from several sources, shown in Table 3:

Table 3: Sources of water for green hydrogen production (Ramboll, 2022).

Type of water	Definition for the purpose of this study
Effluent	Treated effluent from Scottish Water's Wastewater Treatment Works
Surface water	Freshwater abstracted from rivers, lochs and reservoirs
Groundwater	Freshwater abstracted from bedrock
Potable water	Drinking water
Sea water	Saltwater which is abstracted and desalinated

Where possible a local water supply should be used for green hydrogen production, due to the cost of transporting water over long distances (Ramboll, 2022). Ramboll proposes that effluent should be the first water source considered as it does not compete with other sectors such as agriculture. Surface water, groundwater and potable water may be sourced from the mains water supply dependant on capacity and infrastructure availability. However, the use of potable water should be avoided where possible (Ramboll, 2022). While desalination has not been established for water supply in Scotland, the use of seawater may be an interesting option for the future hub development, particularly for island hubs which have less connectivity to mains infrastructure. However, for this analysis, we have focused on Scotland's current water infrastructure capabilities from mains water supply and regional Scottish Water Wastewater Treatment Works.

In 2022, Ramboll, on behalf of SGN, investigated the water availability for green hydrogen production across Scotland (Ramboll, 2022). Drawing on Ramboll's work, Table 4 shows the maximum green hydrogen production potential, based on water availability and the forecasted installed green hydrogen production capacity in 2045. We used these figures to assess water availability for the forecasted installed capacity in 2045. For Duisburg, we applied the same assumptions used for the Scottish hubs (Ramboll, 2022, pp. 26-27).

Table 4: Water availability ranking by hub

Hub	Forecasted installed green hydrogen capacity in 2045 (GW)	Maximum potential installed green hydrogen production based on water availability (GW)	Water availability ranking
Glasgow	2.50	239.2	1
Grangemouth	2.00	145.9	2
Dundee	0.25	73.0	3
Fife	0.25	67.8	4
Cromarty	5.00	61.2	5
Ayrshire	0.50	47.5	6
Aberdeen	0.50	44.5	7
Dumfries and Galloway	0.50	26.7	8
Moray	2.00	26.6	9
Scottish Borders	0.00	22.9	10
Duisburg	1.00	14.0	11
Argyll and Islands	0.13	11.4	12
Western Isles	0.12	9.1	13
Orkney	0.05	1.5	14
Shetland	6.30	2.0	15

The relative water availability for hubs is shown in Table 4, from which we can take several key insights:

- Overall, water availability is unlikely to limit the deployment of forecasted green hydrogen installed capacity. However, future water abstraction may be limited by regulatory changes, land use restrictions, and competing demand.
- Shetland is ranked in last place as it is the only hub where forecasted green hydrogen production requires more water than is currently deliverable. This issue could be mitigated if desalination infrastructure is made available.
- Populous areas are more favourable for expanding green hydrogen production capacity based on water availability. These areas have greater effluent wastewater availability, which does not compete directly with other use cases. For example, Glasgow could potentially produce up to 203 GW of green hydrogen from effluent water. Orkney, in comparison, could only produce up to 0.03 GW.
- The island hubs (Western Isles, Orkney and Shetland) rank lowest. This is due to their limited freshwater supply and small population.

4.2 Economic output from relevant co-located industries

4.2.1 Gross Value Added of the energy sector

To evaluate the economic output from relevant co-located industries, we have compared the gross value added (GVA) of the energy sector in each hub. A high GVA signals that a region has a strong existing industrial base, infrastructure and workforce for the energy sector. This makes GVA a useful indicator of the investment attractiveness of establishing local hydrogen and HDP sectors.

Using the Scottish Government's Industry Statistics, we have calculated the approximate gross value added of the energy industry for each hub in 2022 (Scottish Government, 2024). The definition of energy sector is based on Standard Industrial Classification (SIC) Codes 2007 and is outlined further in Appendix B. Generally, these SIC codes cover the following industries:

- Fossil fuel extraction and mining
- Manufacturing of petroleum products and other organic chemicals
- Energy supply e.g. electricity
- Water processing and supply
- Waste treatment and disposal
- Engineering and environmental consultancy

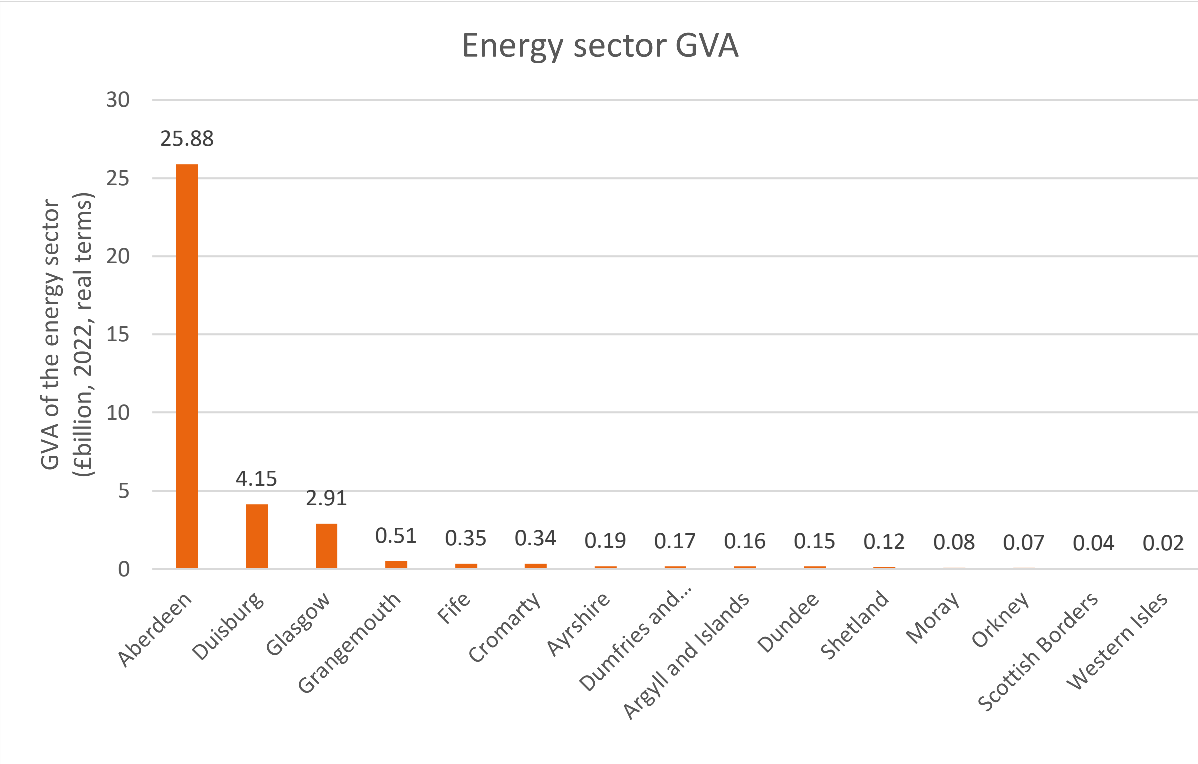

Figure 2: Estimated balanced GVA of the energy sector (2022).

The order of hubs by energy sector GVA is shown in Figure 2 from left to right. Aberdeen's energy sector has the highest GVA at £25.9 billion in 2022; the Western Isles has the lowest, with a GVA of £16.8 million. Aberdeen, as the primary base of operations for the UK's offshore oil and gas industry, is by far the major contributor to Scotland's energy sector GVA (Port of Aberdeen, 2025).

For Duisburg, we conducted a separate analysis to allow comparison on a like-for-like basis using available data. Considering the Production Sector, as defined by SIC Codes 2007, Duisburg is ranked second after Aberdeen with a GVA of £4.15 billion (Länder, 2024; Office for National Statistics, 2024).

4.3 Workforce and skills

For this capability group, we have assessed the current workforce and the future workforce metrics for each hub. The expanding hydrogen and HDP sectors will demand a skilled and educated workforce. Scotland’s existing energy and engineering professionals are best positioned to make this transition, although not all will do so. To account for this unknown, we have evaluated future workforce requirements as well as the current transferable workforce.

4.3.1 Full time equivalent workers in energy and engineering

We have analysed the number of full-time equivalent (FTE) workers in these sectors (Skills Development Scotland, 2024). This will provide us with an indication of the **relative** workforce availability between the hubs.

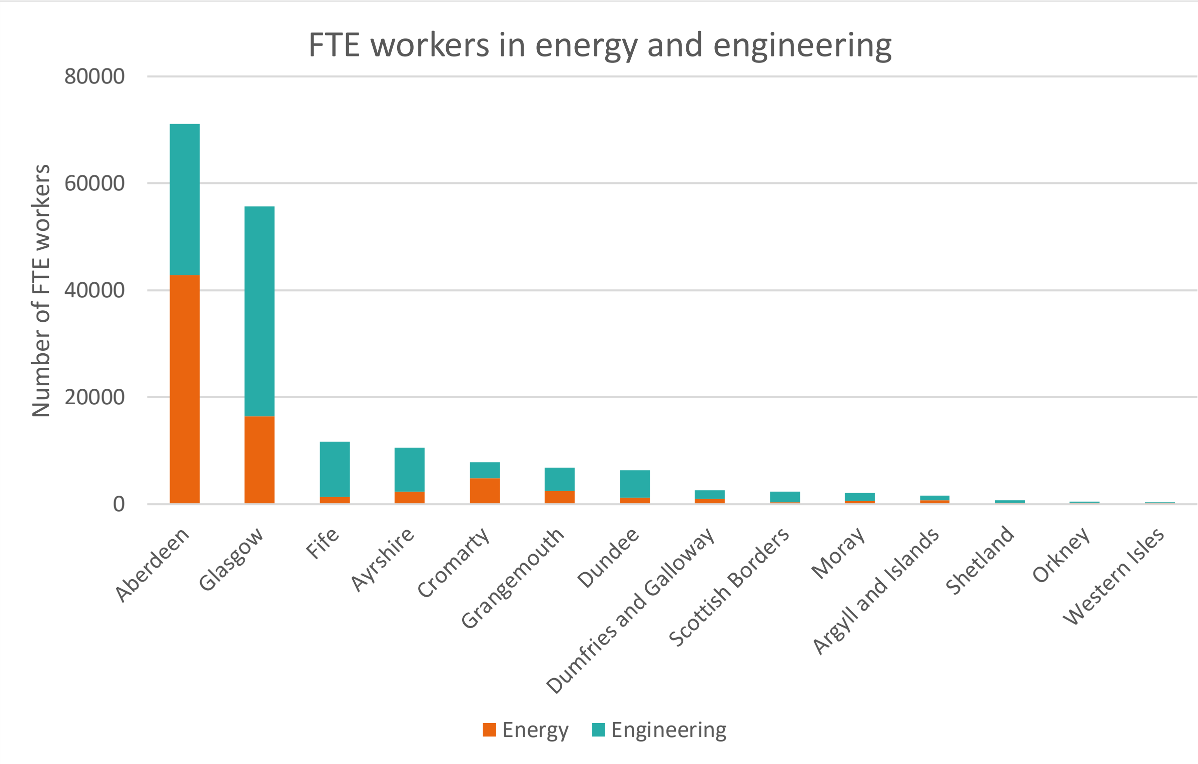

Figure 3: Number of FTE workers in the energy and engineering sectors by hub

Figure 3 shows that Aberdeen has the most workers in energy and engineering with 71,100 FTEs; the Western Isles ranks lowest with only 400 FTEs. We can take several key insights from Figure 3:

- Aberdeen and Glasgow are the hubs with the largest transferable workforce. Among all the hubs, Aberdeen and Glasgow contain 70% of all FTE workers in energy and engineering.

- Skilled workforce availability may be a challenge for island hubs. There are only 1600 FTEs in energy and engineering across Shetland, Orkney and the Western Isles combined.

4.3.2 Future workforce requirements

We evaluated the hubs in terms of their future workforce requirements, analysing estimated demand for Scottish workers in the energy and engineering sectors. Labour forecasts can be divided into two categories: replacement demand and expansion demand. For this study, we have only considered expansion demand[1].

Positive expansion demand represents increasing labour demand due to sector growth. Negative expansion demand suggests shrinking sectors, demanding less labour. The time period considered for this analysis was 2027-2034.

Hubs with higher expansion demand will see more competitive labour market conditions. Growing hydrogen and HDP sectors in such hubs can be expected to increase labour competition further. Hubs with negative expansion demand are expected to have less competitive labour market conditions in the future. Growing the HDP sector in such hubs will not exacerbate competition for skilled workers, as the number of jobs is likely to exceed the number of available workers.

[1] There are two types of estimated demand: replacement and expansion. Replacement demand refers to workers that will be needed to replace the current workforce. Expansion demand represents demand that will arise due to the growth in an industry.

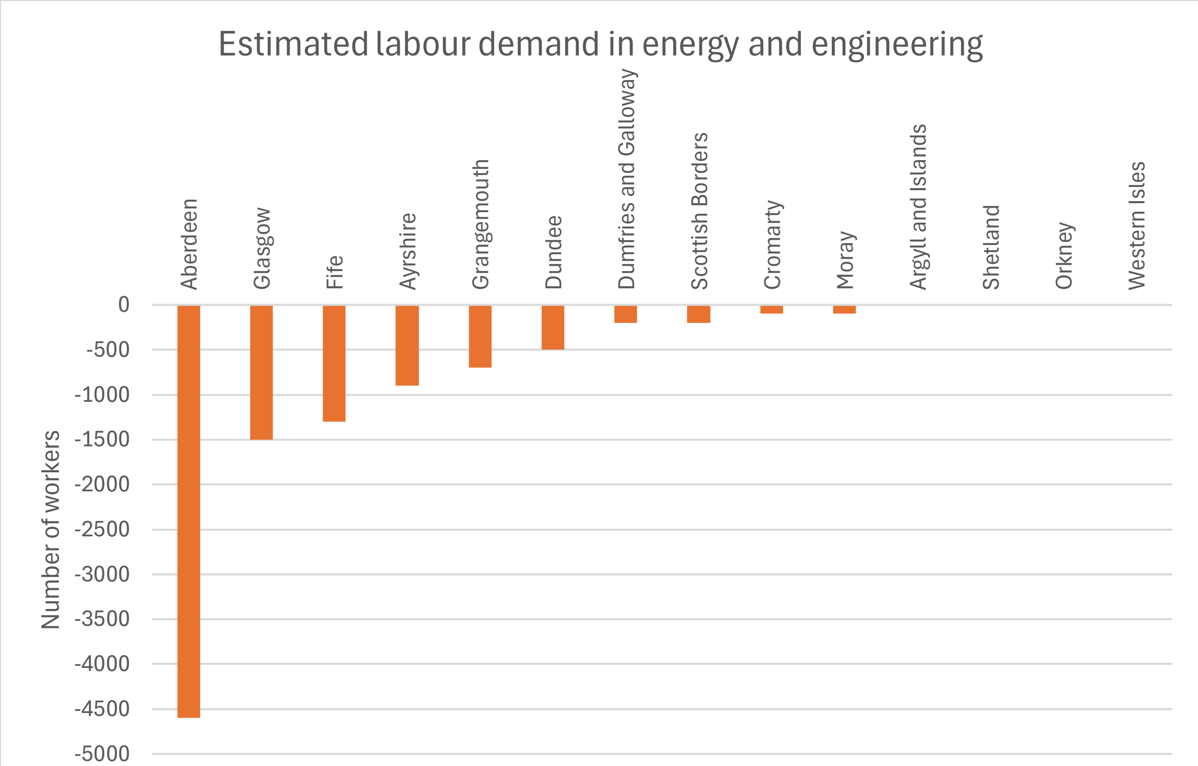

Figure 4: Estimated expansion labour demand in energy and engineering sectors.

Figure 4 shows Aberdeen with the lowest expansion demand of -4,600 people. This means the engineering and energy sectors in Aberdeen will require 4,600 fewer workers in the period 2027-2034 compared to today. Glasgow, Fife, Ayrshire and Grangemouth follow with expansion demands between around -1,500 (Glasgow) and -700 (Grangemouth). These hubs are likely to have the least competitive labour market conditions in the future, implying less competition for workers in the growing hydrogen and HDP sectors. As Figure 4 shows, none of the hubs is forecast to have positive expansion demand: more *additional* workers are not expected to be needed in any hub. The labour market environment for engineering and energy jobs, within each of the hubs, appears to be favourable for growing Scotland's hydrogen and HDP sectors.

It is worth reiterating that replacement demand has not been considered in this analysis. Therefore, it is important to understand that this analysis does not provide a full image of the future labour market for the hubs in these two sectors.

4.4 Infrastructure

Regional infrastructure is key for facilitating the storage, distribution and trade of green hydrogen to supply HDP production. In *A Trading Nation - Realising Scotland's Hydrogen Potential - A Plan for Exports*, the Scottish Government identified ports, pipelines and large-scale storage as the three connectivity pillars required to enable the hydrogen and HDP sector's growth (2024). Here, we investigate each hub's relative strengths.

4.4.1 Large-scale storage capacity

Large-scale storage will be required to scale up hydrogen production and balance supply and demand. This scale of storage will likely be provided by underground geological storage, rather than aboveground storage which is constrained by land availability. There are several types of geological storage, which are described in Table 5.

Table 5: Types of geological storage for hydrogen and their technology readiness levels (ClimateXChange, 2023).

Geological storage technology	Description	Technology readiness level (1 = lowest, 9 = highest)
Salt caverns	Most mature hydrogen storage technology, formed of an underground cavity in a rock salt layer.	9
Saline aquifers	Deep, porous rock formations filled with salty water. Previously used for commercial town gas (~50% hydrogen) storage.	2-3
Depleted oil and gas fields	Former fields can be repurposed for storage. This technology already provides the majority of global gas storage capacity.	3-4

There are currently no projects to develop commercial geological hydrogen storage in Scotland. Moreover, apart from salt caverns, these technologies are still immature. So, we have assessed the **technical** geological storage capacity for each hub. For this, we have used available estimates from scientific literature. We assigned storage capacities to each hub based on their location or, if offshore, their likely terminal. The locations and total technical capacity for each storage technology is shown in Table 6.

Table 6: Technical capacity and locations for geological storage types in Scotland.

Type of storage	Locations in Scotland	Technical capacity in Scotland (TWh)
Onshore salt caverns	• There are no onshore salt caverns in Scotland.	0 TWh (ClimateXChange, 2023)
Offshore salt caverns	• There are high prospectivity offshore salt caverns in the Central North Sea and North Channel (Edlmann, et al., 2024). • These are mapped in the UK Hydrogen Storage Database (Edlmann, et al., 2024).	Unknown
Saline aquifers	• Offshore aquifers would likely be in the Aberdeen (1849 TWh), Moray (118 TWh) and Shetland (82 TWh) hubs (Safidi, et al., 2021). • Onshore aquifer storage capacity is unknown.	~2048 TWh of offshore storage capacity (Safidi, et al., 2021).
Depleted oil and gas fields	• North Sea fields mostly terminate in the Aberdeen hub at St Fergus (1082 TWh). • Some capacity in Shetland (32 TWh).	~1115 TWh maximum potential capacity including producing fields (Peecock, et al., 2022)

We scored the hubs based on their total geological storage capacity for hydrogen. We then adjusted these scores to account for the possibility of developing offshore salt caverns and planned pipeline connections to English salt caverns.

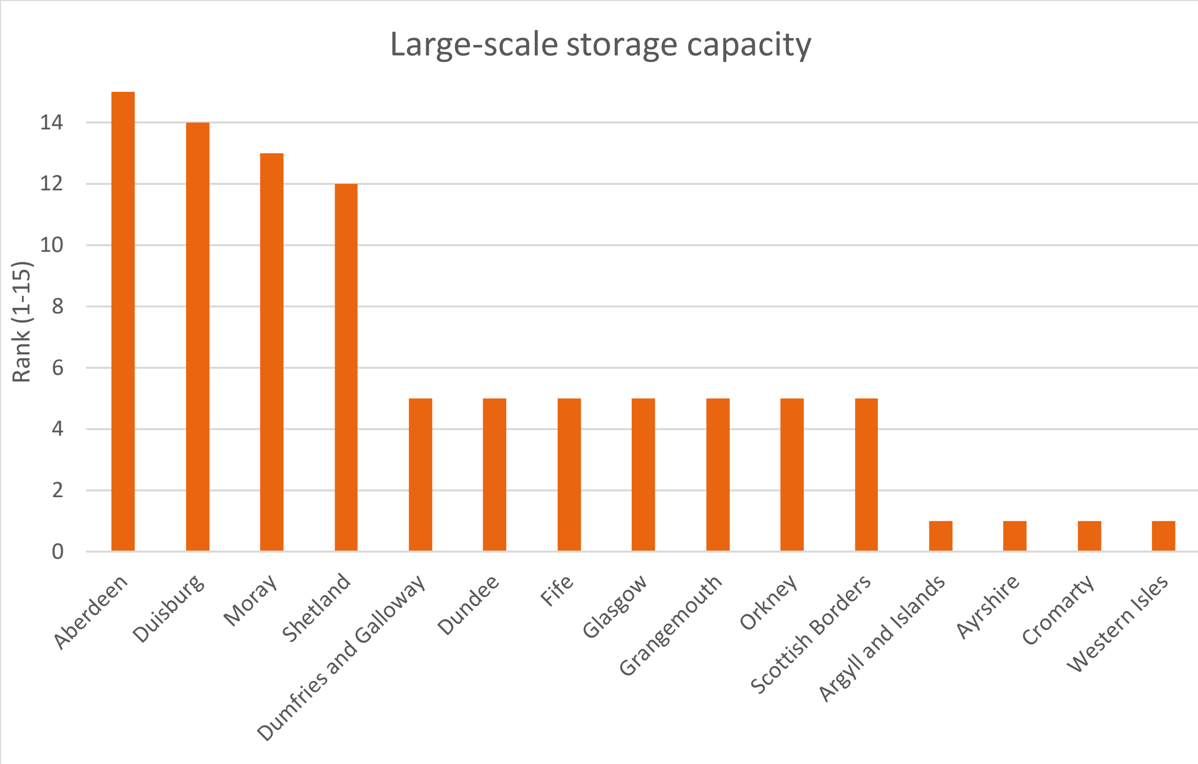

Figure 5: Large-scale storage capacity by hub.

Figure 5 shows the relative strength of hubs in terms of geological storage capacity. As shown from left to right, Aberdeen is ranked highest, and the Western Isles is ranked lowest. We can take several key insights from our analysis and the rankings in Figure 5:

- The most attractive hubs – Aberdeen, Moray, Shetland – are those with terminals for potential offshore geological storage infrastructure.
- There is a vast opportunity, particularly in Aberdeen, for repurposing depleted oil and gas fields as production tails off. This would extend the fields' economic value and build on Scotland's oil and gas expertise.
- With the construction of a national hydrogen pipeline infrastructure, connected hubs with a lack of geological storage may be able to pipe hydrogen to other storage facilities.
- Duisburg is advantaged by the fact that nearby hydrogen storage projects are under development (e.g. the RWE Gas Storage West project in Epe) (Hornby, 2023). These projects will be connected to Duisburg by the approved German core hydrogen network.

4.4.2 Pipeline network infrastructure

Scotland is actively pursuing several large-scale hydrogen pipeline projects to maximise the potential of our hydrogen and HDP sector (Scottish Government, 2024). Several key projects include the National Gas Project Union and an offshore pipeline from Scotland to Germany:

- National Gas Project Union will repurpose sections of the UK National Transmission System to carry 100% hydrogen (National Gas, 2025). These transmission pipelines will stretch from St Fergus in Aberdeenshire, down Scotland's east coast and throughout the UK.
- The H2 Caledonia project plans to construct new hydrogen transmission pipeline to support the creation of Scotland's hydrogen ecosystem (SGN, 2023). This project

combines pre-FEED projects in Scotland's Central Belt, Fife's East coast and the Aberdeen Vision study.
- The Scottish Government is in Phase 2 of a project which is considering the development of an offshore pipeline from northeast Scotland to Germany. This would connect Scotland to the European Hydrogen Backbone pipelines (2024).

To score each hub's potential pipeline infrastructure, we used the following scale from 1-6:
1. There is no pipeline infrastructure suitable for hydrogen and no proposed or planned new hydrogen pipelines.
2. There are existing gas pipelines which can be repurposed. There are no planned new hydrogen pipelines but there may be some projects proposed.
3. There is a small-scale (e.g. distribution/spur pipelines) hydrogen pipeline project at any phase of development.
4. There is a large-scale (e.g. trunkline pipelines) hydrogen pipeline project at any phase of development.
5. The hub is a potential international export or import site for hydrogen and HDPs. However, the planned pipeline infrastructure is insufficient and/or the site is not well-established for international trade.
6. The hub is a potential international export or import site for hydrogen and HDPs. There is sufficient planned pipeline infrastructure, and the site is well-established for international trade.

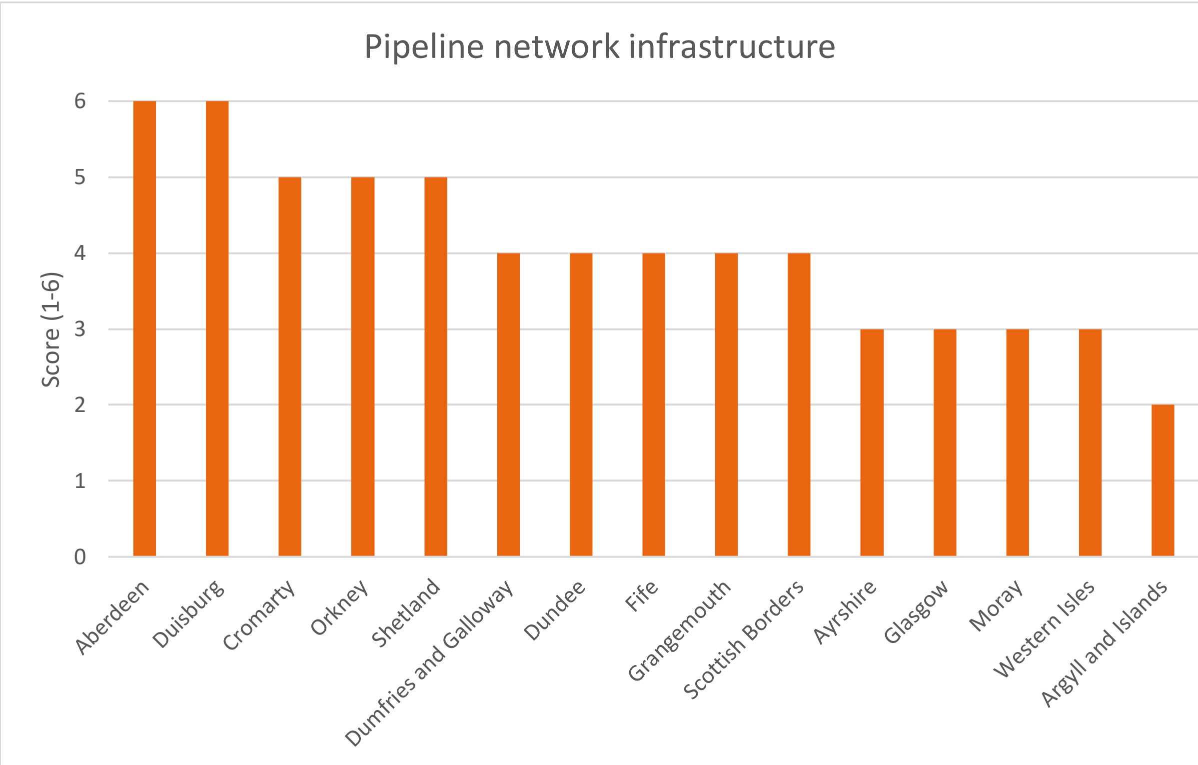

Figure 6: Hydrogen pipeline network infrastructure by hub.

Figure 6 shows the final hub scores for hydrogen pipeline infrastructure. As shown from left to right, Aberdeen is ranked highest, and the Argyll and Islands is ranked lowest.

We can take several key insights from our analysis and the hub rankings in Figure 6:

- In Scotland, Aberdeen, Cromarty, Orkney and Shetland are all hubs which could support export activity. They are all being considered as export locations for the Scotland to Germany pipeline project (Net Zero Technology Centre, 2023).
- Aberdeen and Duisburg rank highest with a score of 6/6.
- In the Aberdeen hub, St Fergus Gas Terminal is recognised as a well-established export route. St Fergus will be connected to the rest of the UK by the Project Union Hydrogen backbone pipeline project.
    - With the largest inland container port in the world, Duisburg is planning to be a major import hub for hydrogen and HDPs (Gasunie, 2023). The approved 9,040 km German hydrogen core network should connect Duisburg sufficiently (Bundesnetzagentur, 2024).
- Hubs on the east coast of Scotland will benefit most from national and international trading opportunities. This is due to their relative proximity to mainland Europe and their planned connection to the Project Union and H2 Caledonia pipelines.

4.4.3 Ports

Access to ports is crucial for hydrogen hubs for several reasons:

- To engage in the trading and export of hydrogen (as a liquid, gas or LOHC) and HDPs by ship.
- To capitalise on the growing demand for HDPs to be used as shipping fuels, such as ammonia and e-methanol.

We have investigated which hubs are most suitable for meeting maritime shipping fuel demand and for trading hydrogen and HDPs by ship. To evaluate the scale of each hub's maritime industry, we first scored the hubs based on the total freight traffic through their ports. This analysis was based on the Department for Transport's Port Freight Statistics Publication (Maritime Statistics, 2024). We adjusted these initial scores based on several criteria, including:

1. Does the hub have a port with existing or planned infrastructure for the storage, production or maritime fuelling of hydrogen/HDPs?
2. Does the hub have a port with dimensions suitable for a typical small carrier vessel for transporting gas or ammonia? The Scottish Government defines these dimensions as a 100m length, 25m beam and a 12m draft (2020, p. 63).
3. Does the hub have a port which is suitable for hydrogen/HDP exports to mainland Europe, as considered by the Scottish Government? Or, for Duisburg, is the hub a key port for hydrogen imports into Europe?

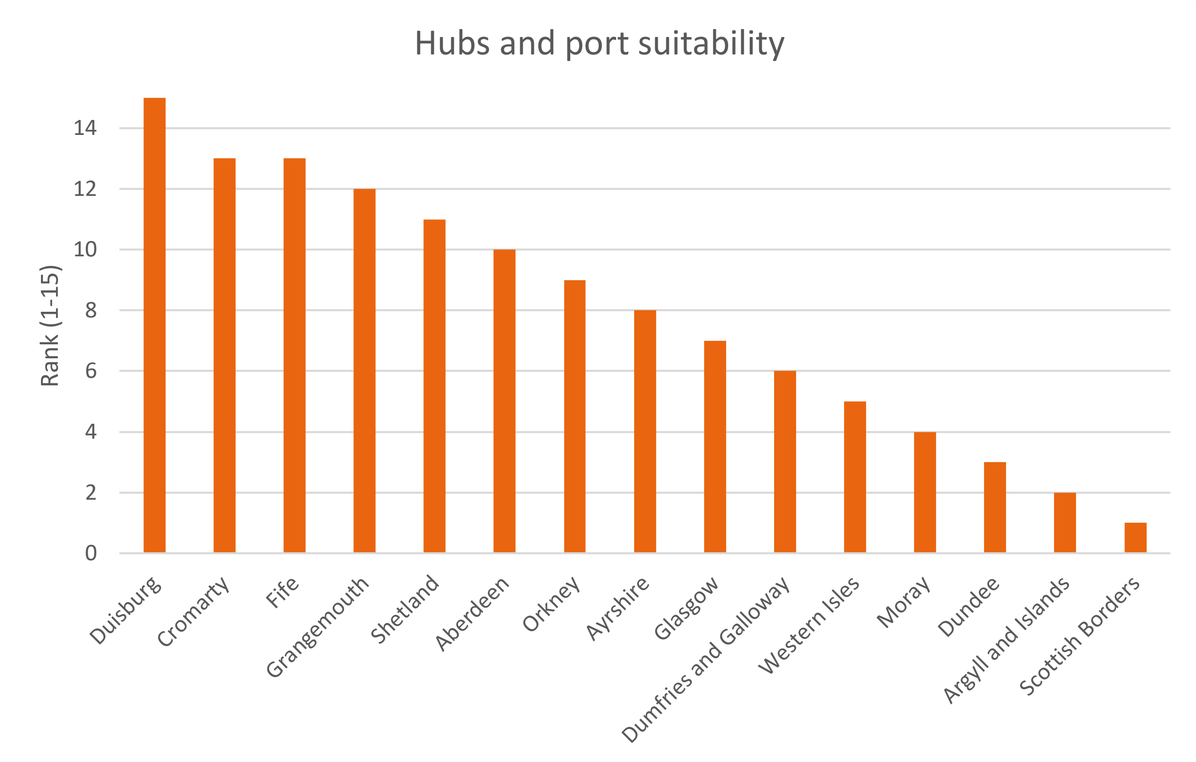

Figure 7: Port suitability for the hydrogen sector (higher score = more suitable).

Figure 7 shows the final hub scores and ranking for ports. As shown from left to right, Duisburg is ranked highest, and the Scottish Borders is ranked lowest. Several key insights can be made based on our analysis:

- Duisburg ranks highest with regards to port suitability for the hydrogen and HDP sector. As the largest inland container port in the world, Duisburg has by far the largest potential maritime fuel demand (Duisburger Hafen HG, 2025).
- Considering all of Scotland's ports, Forth Ports in Grangemouth and Fife have the most freight traffic at around 19 million tonnes in 2023. Although, this figure only represents around half of Duisburg's total freight traffic.
- The Scottish Government considers that the Aberdeen, Fife, Grangemouth, Shetland, Cromarty and Orkney hubs are most attractive for exports to Europe (2020). These hubs also have existing or planned port infrastructure for hydrogen.
- Without port redevelopment, most hubs do not have ports with suitable dimensions for the trade of ammonia by a typical carrier vessel. Those that do include Cromarty, Shetland, Aberdeen and Orkney.
- The Scottish Borders ranks lowest as it has no major or minor freight traffic in the region, and it scored negatively for all additional criteria.

4.5 Local policy and planning support

In Scotland, most industrial planning applications must be approved at the local council level. Local policy and planning support are crucial in sanctioning the construction of hydrogen hubs in Scotland. Streamlined planning processes and supportive local policy will help expedite the development of a robust infrastructure network. To investigate this capability group, we evaluated the industrial planning process duration and success rate for each hub. Hubs with shorter processing times and higher success rates for planning applications indicate that they are more supportive of industry and can support new infrastructure more efficiently.

4.5.1 Processing time for industrial planning applications

To assess hub processing time for industrial planning applications, we have taken an average of the relevant council areas. For Duisburg, the average processing time for construction permits in Germany is used (World Bank, 2024).

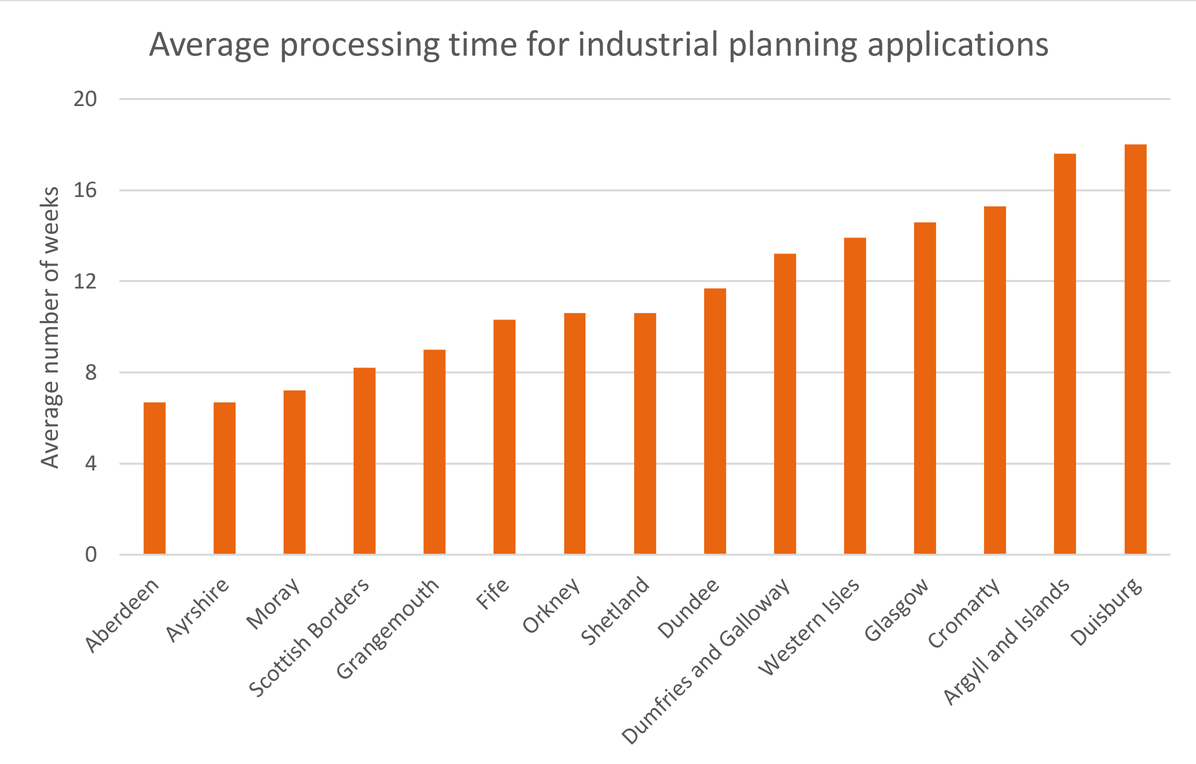

Figure 8: Average industrial planning process duration

Figure 8 shows the average number of weeks taken to process an industrial planning application in each hub. Ayrshire and Aberdeen are ranked highest with an average of 6.7 weeks of processing time, while Duisburg has an average 18-week processing time. Several insights can be taken from this analysis:

- Among the Scottish hubs, the range in average processing time is 10.9 weeks. The range of number of weeks taken is from 6.7 weeks to 18 weeks. This indicates disparity in local planning efficiency.
- On average, Scottish hubs process planning applications seven weeks faster than German industrial planning applications.

4.5.2 Success rate of industrial planning applications

To calculate the hub success rate for industrial planning applications, we have taken an average of the relevant council areas (Planning Application Statistics, 2024). No data was found for Duisburg, Argyll and Islands, Dumfries and Galloway, Moray, Orkney, Shetland or the Western Isles.

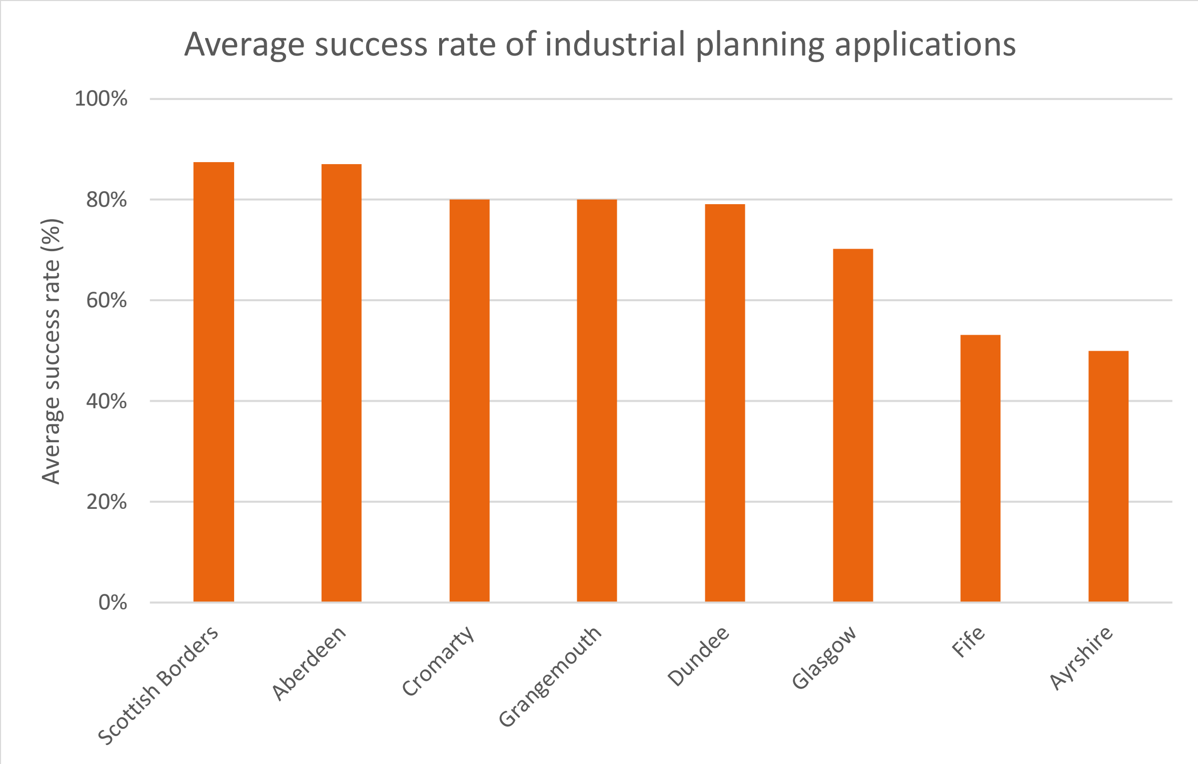

Figure 9: Hubs by average success rate of industrial planning applications.

Figure 9 shows the average success rate of industrial planning applications in each hub. The Scottish Borders is ranked highest with an average of 88%, while Ayrshire ranks lowest with an average of 50%.

When considering the average success rate and processing times for industrial planning applications together, Aberdeen is the most favourable hub for local planning and policy support. However, these two metrics do not always go hand-in-hand. While Ayrshire has the shortest processing duration for planning applications, these applications are also the least successful on average.

4.6 Co-location with innovation institutions

4.6.1 Innovation institutions with facilities for pilot-scale testing

Formed by Scottish Enterprise, the Scottish Hydrogen Innovation Network (SHINe) aims to support Scotland's hydrogen and HDP sectors and accelerate innovation. SHINe innovation institutes can streamline access to the necessary infrastructure and expertise required to develop a successful hydrogen and HDP sectors. To assess this metric, we ranked the hubs by the number of SHINe institutions present. Innovation institutions include a range of projects like pilot-scale manufacturing capabilities of hydrogen related components, green hydrogen production, research centres, etc (Table 7). For Duisburg, we have assessed the number of comparable innovation institutions in the area (Scottish Enterprise, 2025).

Table 7: Innovation institutions and their capability for pilot-scale manufacturing by hub. Hub ranking is shown descending from the top (highest) to bottom (lowest) of the table.

Rank	Hub	Innovation institutions	Pilot-scale manufacturing
1	Duisburg	NH3toH2	Yes
		H2BF	Yes
		ELECKTRA II	Yes
1	Aberdeen	Energy Transition Zero	Yes
		HyOne	Yes
		Net Zero Technology Centre	Yes
2	Glasgow	Glasgow Hydrogen Innovation Centre	Yes
		Energy Technology Partnership	Yes
		Power Networks Demonstration Centre	No
3	Dundee	Michelin Scotland Innovation Parc	Yes
3	Orkney	European Marine Energy Centre	Yes
4	Cromarty	Powerhouse	No
5	All other hubs	There are no SHINe innovation institutions.	No

From Table 7, we can take away several key insights:

- Aberdeen and Duisburg have the highest number of innovation institutions with pilot-scale manufacturing capabilities.
- SHINe innovation institutions are mostly concentrated in Scotland's major cities – Aberdeen, Glasgow, Dundee and Edinburgh. One exception, with pilot-scale manufacturing capabilities, is the European Marine Energy Centre in Orkney.
- The majority of hubs have no local SHINe innovation institutions.

4.7 Financial aspects

While not included in the scope of this project, we recognise that financial aspects can impact hydrogen hub supply chain development. According to the UK Government, the UK's industrial electricity prices were 25.85 pence per kWh in 2023 including taxes (Energy Prices Statistics Team, 2024). This price is 70% higher than the average of the EU and G7 countries. As electricity costs account for some 70% of the total cost of green hydrogen, these high prices could hamper grid-connected project economics (Renewable UK & Hydrogen UK, 2025). Regional hubs with higher electricity prices could be impacted more. Notably, North Scotland has some of the highest electricity distribution costs in the UK (Gallizzi, 2025). Additionally, rural hubs may experience greater transportation costs to procure goods, services, and labour. For island-based hubs, reliance on a rotational workforce from the mainland could further impact their competitiveness by driving up labour costs.

4.8 Overall supply chain capabilities

To assess overall supply chain capabilities, we have calculated a total score for each hub from the metrics discussed above. Each metric has been assigned a specific weight, based on their importance to producing HDPs and the confidence in the quality of available data. Table 8 shows the final weightings we applied to each metric. For each hub, we scaled each metric by the relevant weighting. We then summed the resulting metric scores to give a final score out of 100. The overall hub ranking for supply chain capability is shown in Figure 10.

It is important to note that the purpose of this analysis is not to find the absolute "best" hydrogen hub in Scotland. By ranking the hubs in each metric, we have assessed their **relative** strengths and weaknesses. This detailed analysis provides the nuance required to understand each hub's overall supply chain capabilities. The metric weightings selected provide **an expert-based view on the supply chain capabilities of each hub**. However, as shown by sensitivity analysis (detailed in Appendix B), hub rankings can vary when metric weightings are altered. The conclusions drawn from the final hub scores detailed below should be viewed in this context.

Table 8: Metric weightings for final hub scoring.

Priority ranking	Group weighting	Capability group	Metric	Metric weighting
1	25%	Feedstock and inputs	Maximum potential renewable power generation	15%
			Water scarcity	10%
2	23%	Workforce and skills	Full time equivalent workers in energy and engineering	13%
			Future workforce requirements	10%
3	22%	Infrastructure	Large-scale storage capacity	3%
			Pipeline network infrastructure	7%
			Ports	12%
4	15%	Local policy and planning support	Processing time for industrial planning applications	12%
			Success rate of industrial planning applications	3%
5	10%	Economic productivity of the energy sector	Gross Value Added of the energy sector	10%
6	5%	Co-location with innovation	Innovation institutions with facilities for pilot-scale testing	5%

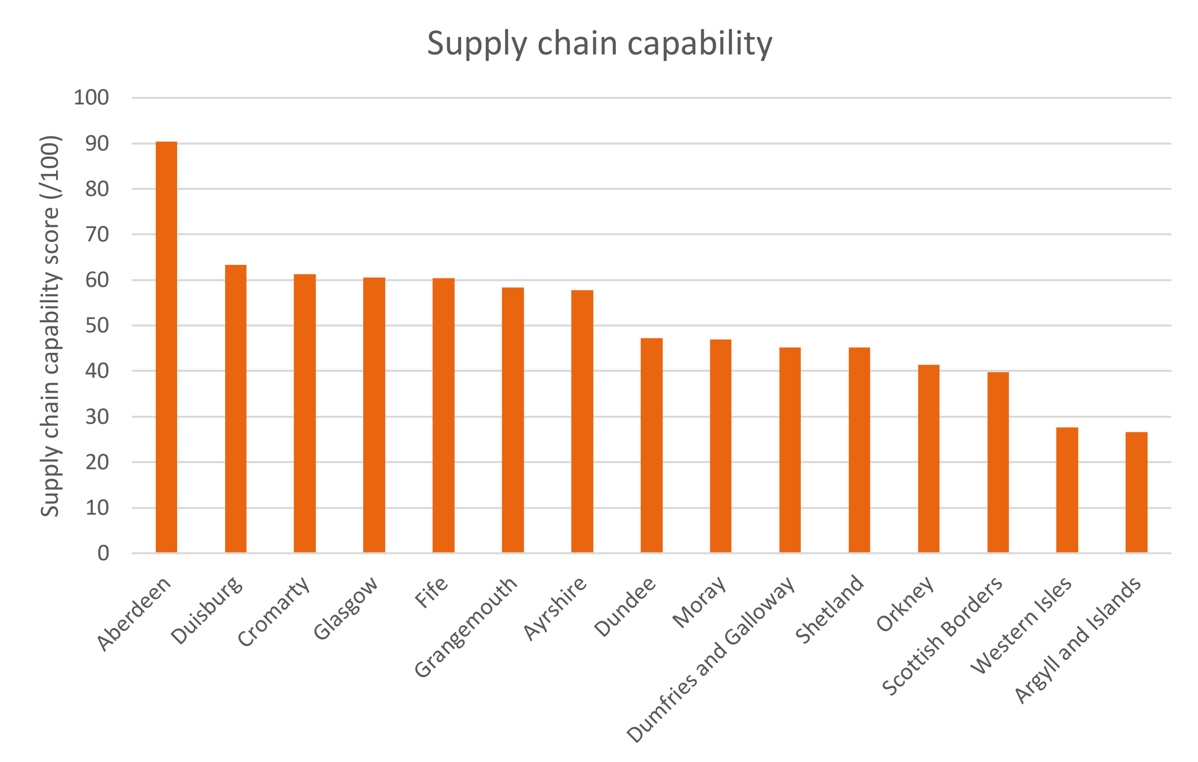

Figure 10: Final scores for hub supply chain capability.

From Figure 10, our analysis suggests that the Aberdeen hub has the greatest relative supply chain capability (90/100), while Argyll and Islands has the lowest (27/100). There are several conclusions that we can take from these final scores:

- Aberdeen stands out as being particularly capable to support the hydrogen and HDP sector. The hub ranked highest for 7 metrics out of 11, including:
    - Maximum renewable power generation
    - GVA of the energy industry
    - Full-time equivalent workers in energy and engineering
    - Large-scale storage capacity
    - Pipeline network infrastructure
    - Processing time for industrial planning applications
    - Innovation institutions with facilities for pilot-scale testing
- Cromarty and Glasgow are also identified as attractive hubs.
    - The Cromarty hub benefits from excellent access to offshore wind developments, a strong current workforce and major port infrastructure at Cromarty Firth with identified export opportunities.
    - The Glasgow hub benefits from a particularly strong workforce capability and plentiful access to effluent water as well as support from innovation institutions and major port infrastructure from the Clydeport network.
- While specific strengths vary between hubs, the majority of Scotland's hydrogen hubs can be broadly grouped by overall supply chain capability.
    - Cromarty, Glasgow, Fife, Grangemouth and Ayrshire fall into an "upper category" with scores ranging only three points (58-61).
    - Dundee, Moray, Dumfries and Galloway, Shetland Orkney and the Scottish Borders broadly fall into the "lower category" with scores ranging from 40-47.

- The Aberdeen hydrogen hub offers a promising opportunity to compete with local Duisburg supply in the Ruhr region. However, considering their similarly high scores, any of the Scottish hubs in the "upper category" may also be considered to be well placed. As the Ruhr area aims to be a model hydrogen region, this result indicates Scotland's potential competitiveness in the European market.
- On the other hand, Western Isles and Argyll & Islands have promising renewable power generation potential. Development of green hydrogen production may therefore help address grid curtailment issues and address local, isolated demand. However, their supply chain capabilities are hindered by a lower workforce capability and fewer connections to suitable ports, large-scale storage and pipelines.

Overall, Scotland's hydrogen hubs are relatively well balanced in their supply chain capabilities and have the potential to contribute significantly to both the national and international hydrogen market. The Aberdeen and Cromarty hubs particularly excel, while the Western Isles and Argyll and Islands may face resource limitations. By enhancing the strengths of higher-scoring hubs while addressing others' limitations, Scotland will ultimately improve its competitive position in the global market.

5 HDP demand in Scotland's hydrogen hubs

The Scottish Government's *Hydrogen Action Plan* identifies that low-cost green hydrogen production is key to the net-zero transition (2022). To minimise the additional cost of transportation and other supporting infrastructure, the Scottish Government plans to encourage the "aggregation of cross-sectoral demand and co-location of the whole hydrogen value chain". Thus, the efficiency of co-locating supply with high local demand will support the rapid scaling of Scotland's hydrogen and HDP sectors. This rationale underpins the hydrogen hub model.

In this chapter, we analyse and estimate the addressable market or demand for each HDP in each hub. This analysis will initially provide a view on which hubs are most suited to supporting the development of local HDP demand in Scotland (Section 5.1.5). In Chapter 6, we bring together our supply chain capability and demand analysis to identify co-location opportunities for HDPs.

We assess the hubs based on current demand opportunities, which will initially support rapid market scaling. Therefore, we define HDP demand as the **addressable market** that HDPs could supply in a complete fuel-switching scenario. This enables us to differentiate hubs and provide a **relative** view on HDP demand opportunities. We assess four key sectors which could support the aggregation of cross-sectoral HDP demand within Scotland's hydrogen hubs:

- Ammonia and e-methanol fuel for the maritime sector.
- Ammonia-based fertilisers for the agriculture sector.
- E-methanol feedstock for the chemical sector.
- SAF for the aviation sector.

To differentiate HDP demand by end use, our analysis considers HDPs used for direct consumption, excluding HDPs used as a hydrogen carrier (e.g. LOHCs).

Please refer to Appendix C for further information on this section's methodology, sources and raw data.

5.1.1 HDP fuel for maritime shipping

In 2021, UK shipping used over seven million tonnes of fossil marine fuel oils, accounting for 18% of UK transport emissions (Transport & Environment, 2023). As the global regulatory body for shipping, the International Maritime Organisation (IMO) has set a 2050 net zero target for international shipping (IMO, 2023). In conjunction with Scotland's net zero target, this means that the Scottish maritime industry will seek to replace fossil-based shipping fuels. The UK shipping industry can be decarbonised with HDPs, such as ammonia and e-methanol.

To evaluate the addressable market for these HDPs, we have analysed the current shipping fuel demand for each hub. There are uncertainties on which HDP shipping fuel – ammonia or e-methanol – will predominately address the market. Therefore, we have based our calculation on total energy demand in TWh.

Based on the UK's 2021 marine fuel consumption, we calculated the annual energy demand for shipping. We then assigned this demand proportionally to each hub according to its total shipping traffic (Maritime Statistics, 2024).

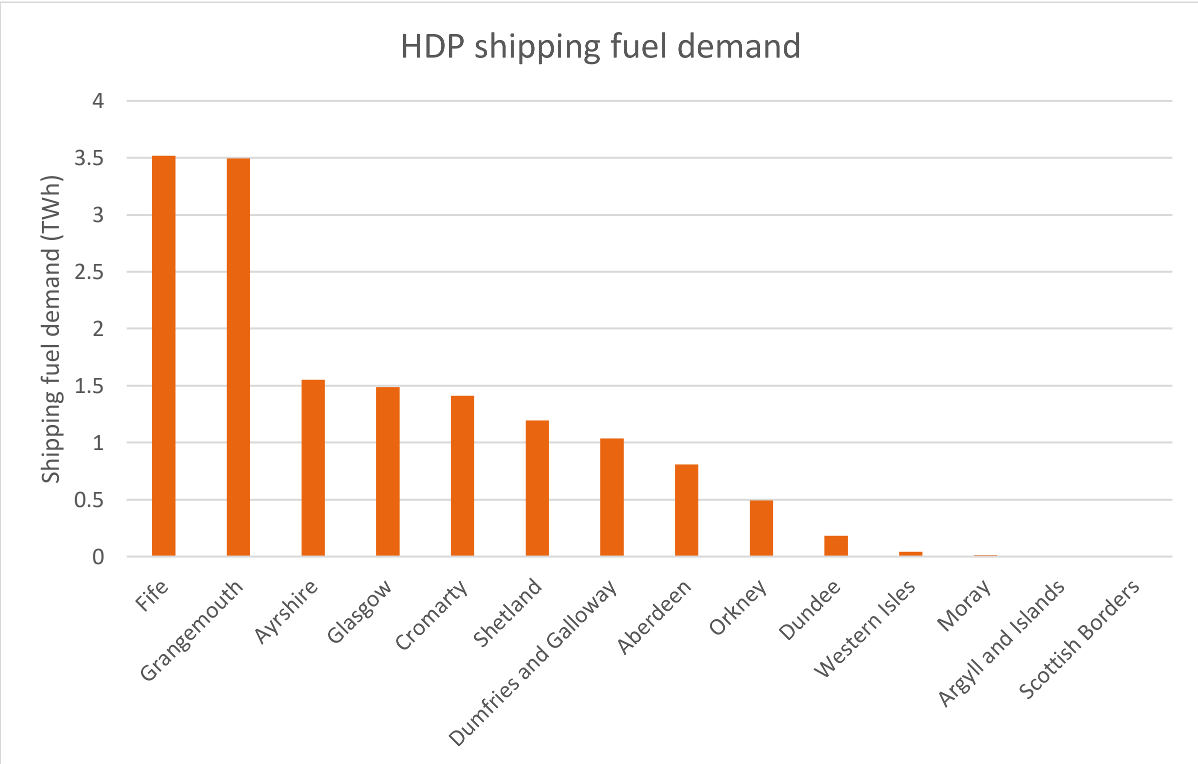

Figure 11: Ranking of hubs by HDP shipping fuel demand.

Figure 11 shows the addressable market for HDP shipping fuel in each hub. Fife and Grangemouth rank highest with ~3.5 TWh of demand, while the Scottish Borders ranks lowest with no current demand. From Figure 11 and our analysis, there are several key insights to address:

- Forth ports in Fife and Grangemouth is likely to be the largest addressable market for HDP maritime fuels, followed by the Clydeport network in Glasgow and Ayrshire.
- Forth ports and the Inverness and Cromarty Firth port network are Green Freeports (Inverness & Cromarty Firth Green Freeport, 2025; Forth Ports, 2025). These ports have varied tax and custom rules which could incentivise the development of HDPs for maritime fuel.
- While we have covered shipping demand, there may be other smaller sources of maritime demand for HDP fuels that were out of scope for this project. These sources include fishing vessels, ferries, service vessels and tugs.

5.1.2 Ammonia-based fertilisers for agriculture

The International Energy Agency estimates that around 70% of ammonia produced is used to make nitrogen-based fertilisers (2021). Ammonia production, by the Haber-Bosch process, is fossil-fuel based and highly energy intensive. The process accounts for 2% of the world's total final energy consumption and 1.3% of carbon dioxide emissions from the energy system (International Energy Agency, 2021). As a sustainable alternative, green ammonia is gaining attention to decarbonise fertiliser production.

We have estimated green ammonia's addressable market for fertilisers in each hub. First, we estimated total nitrogen-based fertiliser demand in Scotland for cropland and grassland. For this, we used average fertiliser application rates from UK Government data (UK Government, 2023). We also assumed that the nitrogen-based fertilisers were urea and ammonium nitrate, applied in equal proportions. From this assumption, we estimated the ammonia required to produce these fertilisers. Finally, we allocated this ammonia demand across the hubs based on their share of agricultural GVA in Scotland.

It is important to note here that we have only considered nitrogen-based fertiliser in our analysis, and not any other type of fertilisers. Therefore, our demand analysis only represents a subset of demand for fertilisers and not the total demand for fertilisers in Scotland.

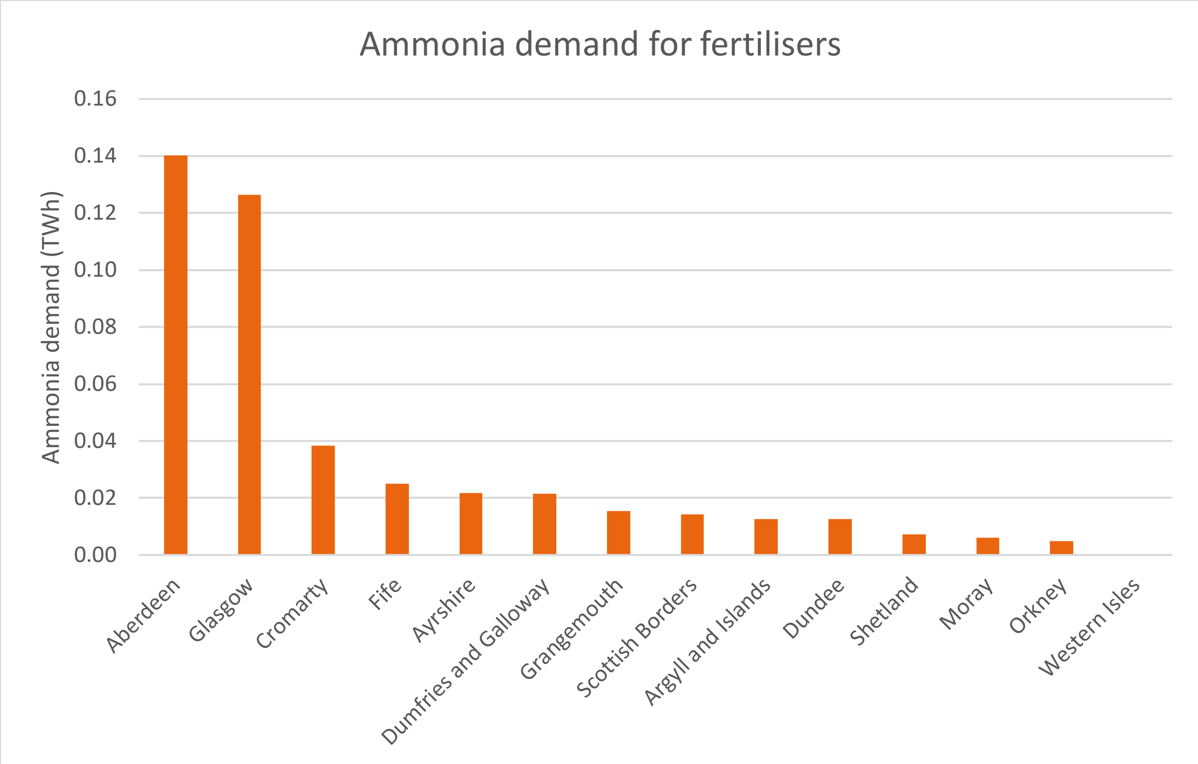

Figure 12: Ranking of hubs by demand for green ammonia fertilisers. The ranking is shown from left (highest rank) to right (lowest rank).

Figure 12 shows green ammonia's addressable market for fertilisers in each hub. Aberdeen ranks highest with ~0.14 TWh of demand – around 31% of Scotland's total demand. Moray and the island hubs rank lowest. Green ammonia's addressable market will likely be greater on Scotland's east coast where there is more agriculture.

5.1.3 E-methanol feedstock for chemical production

The International Renewable Energy Agency (IRENA) estimates that around 98 million tonnes of methanol is produced globally each year (IRENA and Methanol Institute, 2021). It is mostly used as a feedstock – a starting material – to produce formaldehyde, acetic acid and plastics. Currently, we produce most methanol from fossil fuels – such as synthetic gas (syngas). Methanol emissions represent around 10% of the chemical sector's carbon dioxide emissions, and addressing these will be key for decarbonising the sector. E-methanol, produced with green hydrogen and captured carbon dioxide, could address methanol's current market.

In Scotland, we assume that Grangemouth Chemical Science Park is the only large-scale user of methanol as a chemical feedstock. It is one of only four major chemical parks in the UK, and the only one in Scotland (Scottish Development International, 2023). With the closure of the refinery, Grangemouth's industrial future is uncertain. However, INEOS's Olefins and Polymers business will continue running as usual (INEOS, 2024). Their two onsite ethane cracker plants have the capacity to produce 1 million tonnes of ethylene per year (Endeavor Business Media, 2016). Fossil-based hydrogen and methane are produced as a by-product from an ethane cracker and can be used as syngas (Brooks, 2013).

To evaluate the maximum potential addressable market, we assume that this syngas is used to produce methanol. From this, we estimate that e-methanol could address a maximum demand of 100,000 tonnes per year (0.56 TWh).

5.1.4 SAF for aviation

The UK SAF mandate determines the share of SAF in total UK jet fuel demand (UK Government, 2024). It sets key SAF targets of 2% by 2025, 10% by 2030 and 22% by 2040. In securing demand, this mandate incentivises SAF production and supply across the UK.

To evaluate the addressable market for SAF, we analysed the current aviation fuel demand for each hub. To achieve this, we assigned the UK's aviation fuel consumption in 2022 proportionally to each hub according to its total aircraft movement. To capture Edinburgh airport's fuel demand, we have assigned it to the nearby Grangemouth hub.

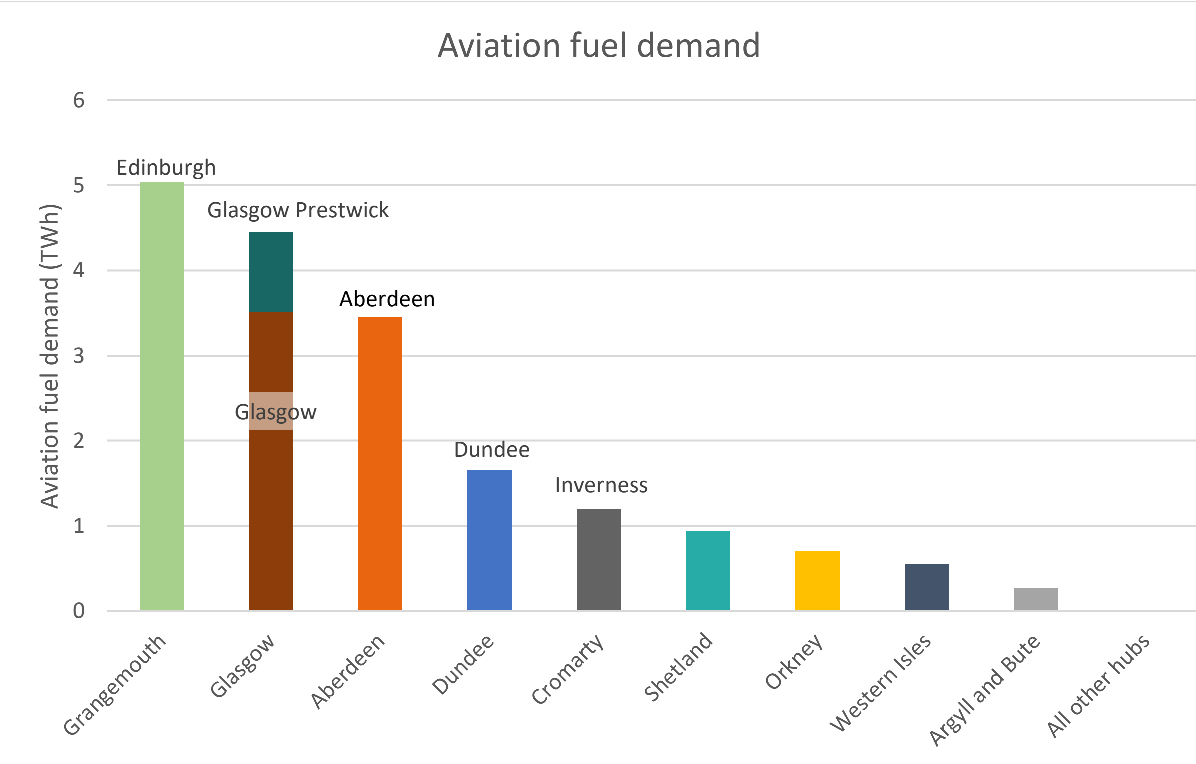

Figure 13: Ranking of hubs by aviation fuel demand.

Figure 13 shows the addressable market for SAF in each hub. The airports in each island hub are shown combined: Shetland includes Lerwick (Tingwall), Scatsta and Sumburgh; Orkney includes Kirkwall and Wick John O'Groats; Western Isles includes Barra, Benbecula and Stornoway; Argyll and Bute includes Cambeltown, Islay and Tiree.

Grangemouth ranks highest with ~5 TWh of demand, while hubs with no airports rank lowest. Regionally, about a third of SAF demand would arise from Edinburgh Airport and around a quarter from Glasgow Airport and Glasgow Prestwick. From Figure 13, we can see that locating SAF production around Scotland's major airports would maximise co-location synergies. Progress has already begun in this area:

- In 2021, Edinburgh Airport signed a Memorandum of Understanding with Ørsted (Edinburgh Airport, 2021). The partnership recognises the importance of HDPs to accelerate the shift to sustainable air travel.
- In 2022, AGS Airports which own and operate Aberdeen and Glasgow airports, signed an agreement with ZeroAvia (Glasgow Airport, 2022). This partnership is exploring the development of hydrogen fuel infrastructure for zero-emission flights.
- In 2024, the Glasgow Airport Hydrogen Innovation Hub consortium delivered a feasibility study for a hydrogen hub at the airport (Glasgow Airport, 2024).

5.1.5 Overall HDP demand opportunities

The maritime and aviation sectors will be the main sources of HDP demand as Scotland scales its hydrogen and HDP sectors. These sectors account for 97% of the roughly 35 TWh addressable market analysed in this report. Due to this scale, our analysis suggests that hubs with major ports and airports would be best suited to develop HDP demand opportunities. In this regard, the hubs that stand out are Grangemouth (with 9.1 TWh of demand opportunity), Glasgow (with 6.1 TWh) and Aberdeen (with 4.4 TWh). Grangemouth's advantage arises from several factors:

- An established and experienced chemical industry.
- Developed port infrastructure within the major Forth Ports network.
- Proximity to major airports, like Edinburgh Airport.

The Scottish Borders notably have the lowest demand opportunity overall. It is disadvantaged by the lack of shipping, aircraft traffic and chemical industry as well as a relatively small agricultural sector.

The potential demand opportunity for HDPs is greatest for SAF with a total addressable market of approximately 18 TWh. In comparison, e-methanol and green ammonia have a combined total of around 17 TWh.

Overall, our demand analysis has identified that focus should be placed on developing major offtake opportunities from the maritime and aviation sectors. This focus would best facilitate the large-scale and rapid scaling of the Scotland's domestic HDP market. As the Scottish Government identified in the *Hydrogen Action Plan*, aggregating multiple end-use applications for production streams would improve the economic benefit of Scotland's hydrogen hubs. Therefore, while SAF does have the greatest demand opportunity, it is worth noting that green ammonia and e-methanol have more diverse end uses and so would be better suited for demand aggregation. As such, each HDP has a distinct potential role in accelerating Scotland's hydrogen and HDP sectors.

6 Co-location of HDP supply chain capabilities and demand opportunities

The Scottish Government recognises that co-location of supply and demand will help develop a sustainable domestic hydrogen and HDP sectors (2022). This development is required to establish Scotland in the wider global market (2022). In this chapter, we bring together our insights from the supply chain capabilities in Chapter 4 and the demand analysis in Chapter 5. This enables us to identify co-location opportunities for HDPs within Scotland's hydrogen hubs.

Figure 14 summarises the co-location opportunity in each hub. The x-axis shows the overall supply chain capability score; the y-axis and bubble size show the aggregated demand opportunity. The top right quadrant broadly indicates which hubs may be best suited for co-location.

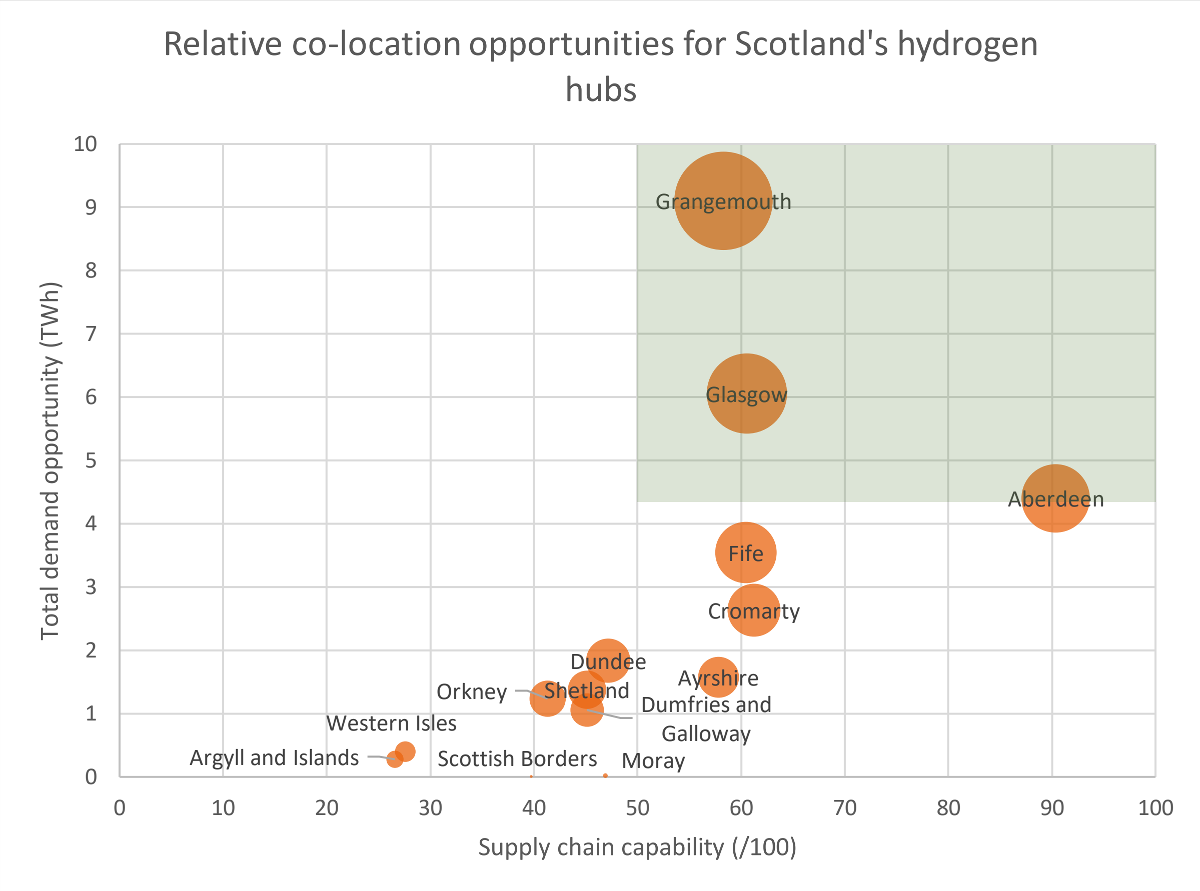

Figure 14: Overall co-location analysis showing the relative supply chain capability on the x-axis and the demand opportunity on the y-axis and as the relative bubble size.

From Figure 14, it is interesting to note that the top hydrogen hub for supply chain capability is not the one with the greatest demand opportunity. Aberdeen has the greatest supply chain capability score (93/100) while, with Edinburgh Airport and Forth Ports, Grangemouth has the greatest HDP demand opportunity (9.1 TWh). This supports the idea that these analyses should not be looked at in isolation. Rather, differing hub strengths can favour the development of different sections of the HDP economy.

Looking at the top right quadrant, we note that Aberdeen, Glasgow and Grangemouth are most aligned to facilitate the development of a regional, co-located HDP economy. In general, the hubs identified as strongest in supply chain capability – including Grangemouth, Aberdeen, Glasgow, Fife and Cromarty – are also those with greater demand opportunity.

We identify the Western Isles and Argyll and Islands as hubs which may need further support to develop their supply chain capabilities. On the other hand, the Scottish Borders and Moray may need to identify other, smaller offtake sectors to capitalise on co-location efficiencies.

The balancing of supply and demand opportunities will require careful consideration, particularly in the early stages of Scotland's hydrogen and HDP sector development. Favouring supply opportunities could increase the cost and logistical complexity of transportation and storage to address more distant demand. Conversely, locating supply based on demand opportunities could limit the capacity and the economics of supply.

Overall, the diversity of Scotland's hydrogen hub strengths points to the importance of a cross-hub approach, in addition to co-locating demand with supply. Hubs with greater connectivity to pipeline and port infrastructure, such as Aberdeen, will be more able to take advantage of this approach. As suitable pipeline and port infrastructure develops, supply and demand opportunities will be unlocked that are not possible by co-location. For example, piped green hydrogen from Fife could support HDP production in the adjacent Grangemouth hubs. For hubs with lower connectivity, such as the Western Isles, further development of suitable infrastructure is required to access cross-hub opportunities. Overall, the growth of HDP production will require both cross-hub and co-located approaches. Balancing these will help maximise each hub's potential and, ultimately, that of the hydrogen sector itself.

7 Regulatory considerations for the HDP sector

Each HDP has different health, safety and planning requirements due to differing chemical properties. These requirements are stipulated by UK regulations. Higher hazard HDPs may face more severe limitations in how, where, and in what quantities they can be handled, for example for production or storage. This section explores the UK regulatory environment and its potential impact on the development of the HDP economy in Scotland.

7.1 Hazards associated with HDPs

Table 9 shows the physical, health and environmental hazards of hydrogen and HDPs. These hazards were identified from the standardised safety data sheet for each substance. The LOHC that we analysed was methylcyclohexane (MCH), the most common LOHC. The rating from 1-4 indicates the highest hazard severity category for each hazard type. According to the Globally Harmonised System classifications, a Category 1 hazard is the most severe while a Category 4 hazard is the least severe (United Nations, 2019).

Table 9: Hazards of hydrogen and HDPs from 1 (most severe) to 4 (least severe).

Substance	Physical hazard	Health hazard	Environmental hazard
Hydrogen	1	4	4
Ammonia	2	1	1
E-methanol	2	1	4
LOHC (MCH)	2	1	2
SAF	3	1	2

From Table 9, we can see that ammonia is the most hazardous substance overall. Handlers must monitor it closely to mitigate its Category 1 health hazard and environmental hazards. LOHCs, E-methanol and SAF are less hazardous overall, although all also have Category 1 health hazards. This means that handling these HDPs is generally less inhibitive than for ammonia. As a feedstock, hydrogen's severe flammability and explosion hazards should also be considered carefully for any HDP production development.

7.2 Review of key UK regulations affecting HDP handling

Due to these physical, health and environmental hazards, HDP production is strictly controlled by UK regulations and regulatory authorities. With the exception of LOHCs, HDPs like ammonia, methanol and aviation fuel are already produced and handled on a large-scale globally. Therefore, there are relatively few new regulatory issues concerning these HDPs. We have reviewed several key regulations that site handling HDPs must adhere to. These are detailed in Table 10.

Table 10: Key regulations and regulatory bodies and their implications for HDP production.

Regulation/Regulatory Body	Implications for a HDP production site
The Control of Major Accident Hazards (COMAH) Regulations	• Operators should submit an environmental risk assessment. All measures necessary must be taken to prevent major accidents. • The site must register as a COMAH site based on the quantity of hazardous substances stored or processed. There are two tiers of sites: Lower and Upper. • Operators should identify sensitive environmental receptors within 10 km.
UK registration, evaluation, authorisation and restriction (UK REACH) of chemicals	• The development is subject to UK REACH regardless of company size. • If manufacturing or importing one tonne per year or more of any substance, the company must register the substance with the Health and Safety Executive. • The development must comply with both UK REACH and EU REACH regulations where necessary.
Town and Country Planning (Environmental Impact Assessment) (Scotland) Regulations 2017	• The development must obtain planning permission from the relevant planning authority. • Hazardous Substances Consent is required if more than two tonnes of hydrogen are onsite or if hydrogen is present with other chemicals. • An Environmental Impact Assessment is required for certain developments.
Health and Safety Executive (HSE) and Scottish Environment	• These regulatory bodies enforce the compliance of COMAH, as well as other environmental and safety regulations.

Regulation/Regulatory Body	Implications for a HDP production site
Protection Agency (SEPA)	• They are consulted for many planning applications.

It is important to note that, under COMAH, each HDP is subject to different regulatory requirements based on their hazards, classified by the Globally Harmonized System (GHS). Based on the COMAH Lower Tier threshold quantity for each HDP, we have broadly ranked the HDPs by the regulatory stringency required to manage its hazards.

Table 11: Rank of HDPs by their COMAH Lower Tier threshold. The associated energy content of LOHC assumes the theoretical hydrogen storage content of MCH (6.22 wt%). Energy content of the HDPs was sourced from (Ozkan, et al., 2024).

HDP	Lower Tier threshold (tonnes)	Energy content (MJ/kg)	Associated energy content (TJ)	Rank (1 = most stringent, 4 = least stringent)
LOHC (MCH)	50	120 (for H_2)	0.4	1
Ammonia	50	18.8	0.9	2
E-Methanol	500	19.9	10.0	3
SAF	2500	45.7	114.3	4

From Table 11, we can see that LOHC and ammonia are the most stringently regulated by COMAH with the same Lower Tier threshold of 50 tonnes. However, as an energy carrier of hydrogen, LOHC handling is more limited by the threshold. The associated energy content of LOHC is 0.5×10^{12} J lower than that of ammonia. In comparison, e-methanol and SAF are less stringently regulated by COMAH. By energy content, a Lower Tier COMAH site would be able to handle 25x more e-methanol or over 250x more SAF than LOHC. Therefore, based on the stringency of COMAH regulations, the simplest HDP to handle is SAF, followed by e-methanol, ammonia and LOHC.

7.3 Hub-level regulatory capabilities

Considering the hazards associated with hydrogen and HDPs, hubs with more regulatory experience are likely to be better suited to handling these substances safely. For HDP production, existing COMAH sites may be expanded or new COMAH sites developed. As a broad measure of **current** and relative regulatory experience at a hub level, we will evaluate the number and tier level of COMAH sites present in each hub. The presence of COMAH sites, with their **existing infrastructure and workforce**, indicates that a hub may be more capable at handling hazardous HDPs safely according to regulation. Identifying these sites can also provide insights into potential offtakers as well as production, storage and distribution sites for HDPs.

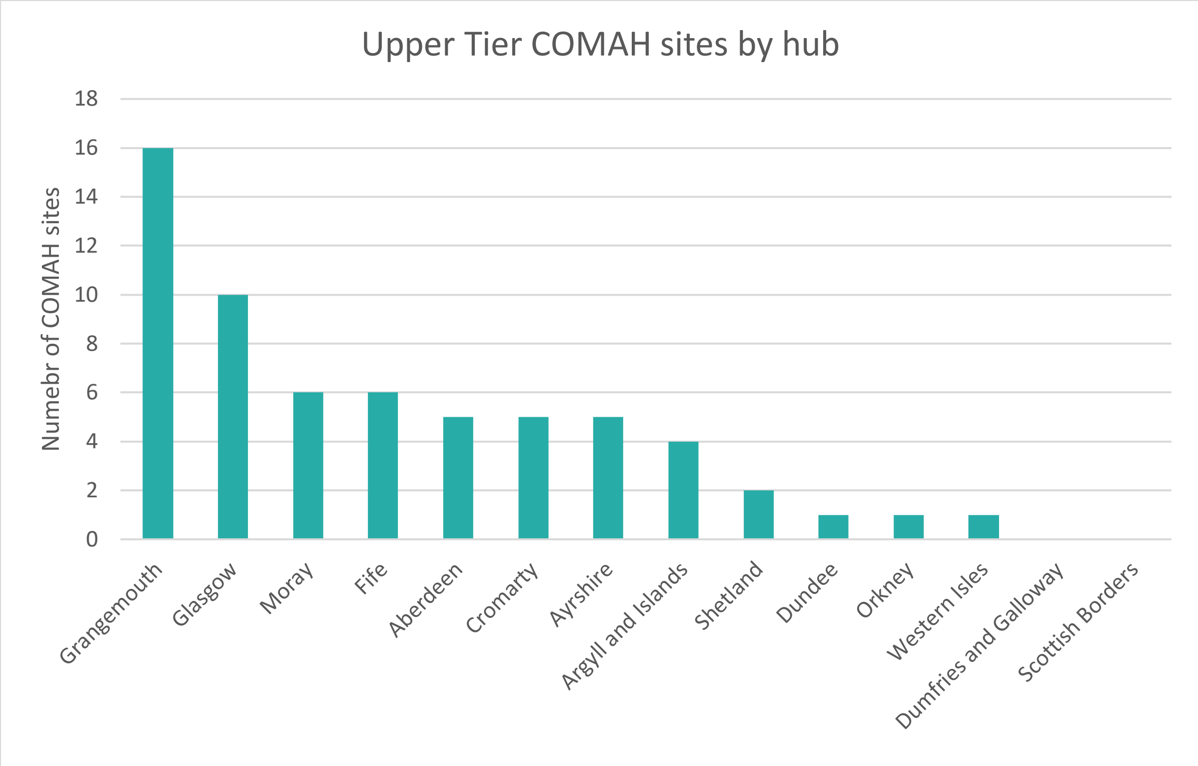

Figure 15: Number of Upper Tier COMAH sites present in each hub.

We have assessed the number of registered COMAH sites in each hub as of June 2023 (Health and Safety Executive, 2023). There are two tiers of COMAH site: a Lower Tier and an Upper Tier. Upper Tier sites are more stringently regulated since they handle greater quantities of hazardous substances. Figure 15 shows the number of Upper Tier COMAH sites in each hub. Grangemouth has the most (16), including the Grangemouth Terminal and INEOS chemical sites. This indicates that the Grangemouth hub, and its associated workforce, may have the most regulatory experience for the large-scale handling of hazardous chemicals. The terminal, for instance, already facilitates the supply of Scotland's aviation fuel (Forth Ports , 2025).

Key COMAH Upper Tier sites include:

- The St. Fergus Gas Terminal in the Aberdeen hub. This site receives, processes and compresses North Sea gas for the National Transmission System as well as stores and distributes other chemicals and fuels (North Sea Midstream Partners, 2025).
- The Clydebank Terminal operated by Exolum in the Glasgow hub. This site has a storage capacity of 56,257 m^3 and a jetty to receive and storage liquid products, including fuels (Exolum, 2025).
- Moray's sites are predominately distilleries which are engaged offtakers for the hydrogen sector. In March 2025, Storegga submitted a planning application to Moray Council to construct a 25 tonne per day green hydrogen facility to decarbonise local distilleries (Storegga, 2025). The UK Government has also found LOHCs to be a viable option for supplying hydrogen to distilleries, and could be explored further for the decarbonisation of Scotland's distilleries (BEIS, 2021).

These hubs are likely to have a lower safety risk for handling HDPs. This is due to their existing regulatory experience and infrastructure. These insights are supported by the fact that the number of COMAH sites in each hub generally aligns with its overall supply chain capability score: the “upper” and “lower” hub groupings are broadly preserved. In comparison, the Scottish Borders has only one Lower Tier COMAH site, a fuel storage and distribution site operated by Flogas Britain. This relatively limited experience could indicate that there is greater need for local workforce training, community engagement and risk communication and investment into infrastructure to support the safe development of a local HDP sector.

Overall, this broad hub-level analysis has provided an indication of hubs’ regulatory capabilities. While out of scope for this project, individual assessment of existing and potential COMAH sites would add value to the analysis. This would provide greater detail into the specific capabilities of each hub to handle, produce and distribute HDPs safely, in accordance with regulations.

8 Policy gap analysis

In the previous chapters, we identified the strengths and barriers for Scotland to scale up its HDP market. To maximise opportunities a favourable and clear policy landscape is needed. This landscape must consider policy at a devolved, national and regional level. This will ensure that Scotland’s HDP related policies work with UK and EU specific policies in a harmonious manner.

To that end, we analysed relevant policies in the UK, Scotland or the EU. We considered policies in the following categories:

- Subsidies and obligations
- Supply chain/infrastructure development
- Technical and safety regulations
- Licensing
- Planning and consenting

8.1 Scottish policy gaps

Here we describe the main policy gaps, and the resultant risks, faced by the Scottish HDP industry. The Scottish Government has already taken some positive steps. However, plugging some gaps will significantly improve the standing of the industry.

8.1.1 Supply chain incentives/development for HDPs

The Scottish Government recently published plans to realise export opportunities for green hydrogen (International Trade and Investment Directorate, 2024). Although this a very important step in furthering the interest of Scottish exports to nearby regions, there are still some gaps remaining. The government’s plan identifies the various investment opportunities and barriers. However, there is a need for more clarity on how the Scottish Government will collaborate with the UK Government or build relationships with international export partners. Timely publication of such plans will provide investors with more certainty.

8.1.2 Clarity in planning and consenting

The Scottish Government has made substantial progress in improving the planning regime for hydrogen projects. The government is committed to preparing and training its planning authorities to expedite hydrogen planning applications. Additionally, it also aims to provide planning authorities with access to specialist expertise and staff upskilling. The government aims to do this this by introducing the planning hub. As a first step towards achieving their goal of improving the planning regime, the Scottish government conducted stakeholder engagement (Improvement Service, 2025), which attempted to understand concerns of both the planning authorities and industry.

The Improvement Services report focussed on five areas: understanding of hydrogen within planning applications, regulatory regime, more clarity on planning process, impact and risk of hydrogen manufacturing, and spatial factors. Some of the key concerns raised by the planning authorities were about lack of clarity on roles when multiple bodies are involved in a planning/consenting process. Additionally, resource constraints faced by the authorities and lack of awareness about hydrogen applications are some of the other concerns raised. For industry, some of the major points raised concerned uncertainty regarding water availability and Hydrogen Allocation Round (HAR) timelines. Industry also proposed conducting wider public engagement to spread awareness about how hydrogen can safely play a role in Scotland's net zero transition.

All this effort has been crucial in shining some light on the challenges faced by industries and policymakers. To fully capitalise on this initiative, the government should now focus on implementing the findings and recommendations from their engagement.

8.2 UK policy gaps

The UK government has implemented many policies that have boosted green hydrogen development in the national economy. Our analysis concludes that the success of such policies should be replicated to similarly develop the HDP space.

8.2.1 Lack of HDP considering in subsidies and obligations

The Hydrogen Storage Business Model (HSBM) does not currently include HDPs in its scope. There are a number of benefits to including HDPs in HSBM. It would increase the avenues available for storing hydrogen. It would also allow for small scale storage of hydrogen in the form of hydrogen derivatives (HSBM currently focusses on large-scale hydrogen storage). Additionally, inclusion of HDPs in scope may mitigate some of the challenges associated with storing hydrogen, such as safety concerns. For example, as ammonia contains hydrogen, including it in HSBM could act as an alternative way of storing hydrogen.

8.2.2 Supply chain incentives for industry and innovation

We identified a policy gap in relation to encouraging links between industrial clusters, which are well suited to producing HDPs. Chapter 5 showed how there are multiple hubs which are optimal for producing HDPs. Collaboration between the different clusters in these hubs would allow for sharing knowledge and potentially products as well.

There also needs to be a focus on conducting trial and demonstration projects. Many hydrogen projects will use innovative technology which will need to be proven and demonstrated in real-life settings. Trials will go a long way in assessing whether investing in such technologies is worthwhile.

8.2.3 Updating technical and safety regulations

Regulations regarding hydrogen need to be updated in the UK. Onshore hydrogen projects are regulated under the Gas Act 1986 and Planning Act 2008, and hydrogen is generally referred to as a 'gas'. The Gas Safety Management Regulation (GSMR) prohibits injecting more than 0.1% of hydrogen into gas networks. Although there are discussions ongoing to exempt hydrogen from this rule, there needs to be more clarity here (Pinsent Masons, 2023). Repurposing the gas network to enable hydrogen transport is essential to grow the HDP sector. Green hydrogen is an important input for HDPs. Hence, a developed transport system will remove supply bottlenecks for HDP producers.

8.2.4 Clarity in offshore licensing

The industry seeks more clarity on the timeline and details of future offshore hydrogen regime. These projects will be critical in developing HDP production.

8.2.5 Delays in planning and consenting

Green hydrogen and HDP projects require various regulatory approvals, environmental permits, etc. Many investments are subject to approval of such plans. Delays associated with the planning and consenting regime may extend the lead time of green hydrogen projects. Streamlining the regime will mitigate some of these issues.

8.3 International policy gaps

8.3.1 Lack of clarity on emissions factors

There is an urgent need to standardise the emission factors for many fuels, such as ammonia or methanol. Sectors that use such fuels will need a standard emission factor as it eases carbon accounting and adhering to different regulations.

8.3.2 Lack of a standard framework for low-carbon hydrogen

There is a misalignment between low-carbon hydrogen standards in different countries. To foster international trade, a uniform definition of low-carbon hydrogen is needed.

8.4 Recommendations

Chapter 8 outlines relevant current policies that can enable development of the hydrogen and HDP sectors in Scotland. While introducing such policies is a significant step towards building the hydrogen space in the UK, some gaps remain. In addition, there is policy action required at an international level. Addressing these issues will significantly improve the prospects of Scotland's hydrogen and HDP sectors.

A summary of our recommendations is as follows:

- The Hydrogen Sector Export Plan showcases the Scottish Government's commitment to building hydrogen export capabilities. However, there is a need for more information on how the Scottish and the UK governments will work together with potential trade partners.
- Scottish Government should continue the progress on building a hydrogen planning regime. This will build on the introduction of the planning hub and the subsequent stakeholder engagement. This momentum should be continued by addressing the main findings of the Improvement Services report.
- The UK Government should include HDPs in the scope of subsidies like HSBM. HDP projects face similar risks as hydrogen projects. Therefore, providing similar subsidies to HDPs projects will mitigate risks and provide more certainty.
- Due to many hydrogen projects using innovative technology, there is a need for increasing the number of trials and demonstration projects.
- Another important issue is the potential misalignment of many standards and definitions. For instance, different governments should collaborate and decide on a common definition for low-carbon hydrogen. These misalignments will hinder growth opportunities as they increase the risk for potential traders.

There needs to be a more detailed plan for prioritising hub development. Our analysis highlighted the strengths and weaknesses of each hub. These results should be used to organise collaboration between production and demand hubs. Additionally, as shown in the co-location analysis, the ideal production hubs aren't necessarily the same as the key demand hubs. Sorting this misalignment might require government intervention and support.

9 Conclusions

In our examination of Scotland's industrial capabilities to produce hydrogen derivatives and products, we looked at supply chain capabilities, demand opportunities, regulatory and policy analysis.

Our assessment of co-location of supply chain capabilities with demand suggests Aberdeen and Grangemouth stand out as key hubs for the development of HDP production. Additionally, Cromarty and Ayrshire offer strong supply chain capabilities and Glasgow and Fife present significant demand opportunities. Meanwhile, the Western Isles and Argyll and Islands may require targeted support to enhance their supply chain capabilities. The Scottish Borders may need support in developing greater regulatory experience to facilitate HDP development.

Many of the Scottish hubs scored highly on the metric of renewable power generation capacity. This is evidence of Scotland's biggest strength: access to renewable energy. Regions like Aberdeen, Cromarty, Moray, Shetland and Western Isles were the highest scores. Regarding local policy and planning support, Aberdeen, Ayrshire and Scottish Borders were among the top performers.

Given the nascency of HDP production, a favourable policy environment is needed to ensure rapid adoption of these fuels. In Scotland a more nuanced planning regime would help to support the growth of HDP adoption. Scotland would benefit from a planning regime that accounts for its specific geographic factors.

At the UK level, HDPs should be included in the scope of policies like HSBM. Health and safety regulations should be updated to account for the increasing role of hydrogen and HDPs in the economy of the future.

Our analysis shows that for Scotland to meet its aims of becoming a major exporter of HDPs, it will need a holistic approach to evaluating the strengths of Scotland’s potential hydrogen hubs.

Overall, by balancing cross-hub collaboration with localised development, Scotland can maximise the potential of HDP production from green hydrogen, driving the sector’s long-term growth and resilience.

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11 Appendices

Appendix A Current state of play

To understand the role that Scotland can play in the hydrogen and HDP sectors of the future, a thorough review of literature was undertaken. The current state of the hydrogen and HDP sectors in Scotland will very much dictate its future prospects. For the purposes of this study, the literature review focussed on many factors associated with the production and export of hydrogen by Scotland. The review allowed us to identify certain common themes related to Scotland's ambition for net zero and revealed hydrogen's role in achieving those goals.

We explored the potential key drivers and enablers of the hydrogen and HDP sectors. Then, we analysed barriers Scotland is likely to face in growing its hydrogen supply chain capabilities. Apart from studying strengths and weaknesses specific to Scotland, we also analysed factors specifically relevant to the HDPs in scope of our study.

11.1.1 **Scotland specific factors**

Most of the literature reviewed concludes that Scotland is very well-placed to be able to produce green hydrogen in the future. There are many factors that work in Scotland's favour. First and foremost, Scotland's access to abundant levels of renewable energy, especially offshore wind, is a major strength (ClimateXChange, 2023). Production of green hydrogen will require renewable electricity as the major component. Scotland's wind resources make it very suitable for producing green hydrogen.

Another major key driver for Scotland's hydrogen and HDP sectors is the ambitious policies in the EU. These policies are likely to spur hydrogen demand in the next few decades. According to the RePowerEU Strategy, the EU aims to import 10 million tonnes of hydrogen by the year 2030. This provides Scotland with a significant opportunity to be a major exporter of low-carbon hydrogen to the EU (Scottish Government, 2022). Since the Russia-Ukraine conflict, the EU also aims to stop importing natural gas and rely on its domestic capabilities (Scottish Power, 2022). This will also likely further the usage and demand for hydrogen in the continent.

Scotland is also likely to benefit significantly from its geographical proximity to the EU. Hence, Scotland may transport hydrogen and HDPs to the EU at costs lower than faraway regions like North America, the Middle East or Asia (ClimateXChange, 2023).

In addition, there are other factors working in Scotland's favour. For example, Scotland has a vast oil and gas industry with a highly skilled workforce. These skills can be transferred to the hydrogen and HDP sectors (Scottish Enterprise, 2024).

On the other hand, the literature reviewed also highlighted areas which need further development and focus to enable green hydrogen production. One of the biggest weaknesses identified in the literature is the high costs associated with electricity generation. Electricity cost is one of the biggest components of green hydrogen production.

Currently, cost of electricity generation is much higher in Scotland compared to other competitor regions like the USA or the Middle East (ClimateXChange, 2023). This makes green hydrogen production in Scotland more expensive than regions like the US or the Middle East. This could reduce Scotland's competitive edge to export to the EU.

Past studies also point out the lack of electrolyser manufacturing capabilities in Scotland as a potential bottleneck (ClimateXChange, 2024). Another major challenge faced by Scotland is regarding transporting and storing hydrogen or HDPs (Optimat and Scottish Enterprise, 2023). Scotland lacks a dedicated pipeline infrastructure that could be used to transport hydrogen to the EU. However, many studies point out the possibility to repurpose existing gas pipelines and use them for hydrogen transport. Scotland also lacks onshore deposits for salt caverns. However, this can be mitigated by the existence of depleted gas fields and lined rock caverns (ClimateXChange, 2024).

Some of the studies also mention the lack of projected demand for hydrogen in Scotland as a potential issue. Scotland is not expected to demand very high levels of hydrogen, meaning hydrogen supply capabilities will be built to service external demand. Increasing demand will be contingent on the policies that will be enacted in the future.

Similarly, studies have pointed out the need for more clarity from the government on possible policy actions (Scottish Enterprise and Optimat, 2023). The sector will also benefit from a coordinated response to tackle supply chain issues and more visibility into existing opportunities. Databases similar to the Offshore Energy UK's Supply Chain Visibility Tool and the North Sea Transition Authority's (NSTA) Energy Pathfinder will increase awareness and information regarding opportunities and enable potential investors to make informed decisions (Aberdeen City Council, n.d.).

The lack of clarity and uncertainty regarding future policy making explain why hydrogen demand projections by different studies vary significantly. Latest demand projections for Scotland for hydrogen expect demand to be in the range of 0.6-2.7 TWh for 2030 and 2.7-24.7 TWh for 2050 (Morton, et al., 2025). Some studies project the economic impact of exporting hydrogen products to the EU. According to the ambitious scenario of the Hydrogen Action Plan, 2022 report, exporting hydrogen to the EU could create roughly a total of 300,000 jobs in Scotland by 2045. It could also add roughly £25 billion every year to the Scottish economy by 2045 (Scottish Government, 2022).

The findings from these studies show that Scotland has inherent strengths that can be harnessed to build and grow strong hydrogen and HDP sectors. Scotland's access to renewable energy and the skills possessed by existing workforce puts it in a very robust position. However, building supply chain capabilities in Scotland will also come with its own challenges. The biggest challenge faced by Scotland is the high cost of generating renewable electricity. Lack of storage and transport infrastructure is also a big issue. Many studies have pointed out the need for government support to mitigate such challenges.

11.1.2 **HDPs specific literature review**

The literature review conducted also focussed specifically on the current state of HDPs production in Scotland and the UK. In some cases, it makes more economic sense to use a hydrogen product than hydrogen itself to achieve decarbonisation. This is specifically true for two hard-to-abate sectors: aviation and shipping. Two of the most mentioned hydrogen products in our literature review were sustainable aviation fuels (SAFs) and ammonia.

SAFs are expected to play a major role in decarbonising aviation. Currently, very little SAF is supplied to Scottish airports. Nevertheless, in the long-term, SAFs will be key to replacing high-carbon jet fuels. According to the SAF Mandate, roughly 2% of the UK's jet fuel demand in 2025 will be from SAFs. The share of SAFs in final jet fuel demand will increase to 10% by 2030 and to 22% by 2040. The global SAF demand is expected to reach 22.7-32.8 million tonnes by 2030 (Scottish Enterprise and Optimat, 2023).

In addition to SAFs, using hydrogen directly as a fuel is also a solution that can be deployed to decarbonise aviation. Direct use of hydrogen in aviation is not expected to be used as much as SAFs (Scottish Enterprise and Optimat, 2023). This is partly because of hydrogen not being a drop-in fuel, whereas SAFs are. Drop-in fuels are fuels that can be used in an airplane without making any modifications to the engine. This increases cost for air carriers to use it as an alternative to high-carbon fuels currently used. Another major concern is the safety issues that using hydrogen will pose. In addition, due to hydrogen being a lighter fuel, its volumetric density is lower. This means that a lot more hydrogen will be required to operate an airplane, increasing storage requirements and also increasing the weight of the plane. However, even if hydrogen is not used as a fuel itself, it will still play a big role in decarbonising aviation as it is an important input in the production of many SAFs. One such example is Power-to-Liquid (PtL) fuel. PtL fuels are formed by combining carbon and hydrogen together. Renewable electricity is used to remove carbon from CO_2 and H from water, making the whole process zero-carbon. The PtL technology is also at a mature technological readiness level (German Environment Agency, 2016).

Similar to SAFs in aviation, low-carbon fuels will play an important role in decarbonising shipping. The hydrogen products mentioned in literature as potentials fuels to decarbonize marine transport are ammonia and methanol. The biggest concern regarding these products is the relatively weak supply chain capabilities in Scotland when compared to the EU. An example of this is the weak shipbuilding supply chain and fewer active commercial shipbuilders of scale. Scotland is unlikely to be able to meet the demand for these fuels for even a small number of cargo vessels (Optimat and Scottish Enterprise, 2023). Security factors could be another possible concern with ammonia. Ammonia is a very toxic fuel, which should only be handled by qualified personnel. Despite their importance in decarbonising certain sectors, the current production of these products is limited. Therefore, more focus needs to be placed on increasing their supply.

11.1.3 **Need for further research**

Many studies have focussed extensively on analysing both demand- and supply-side factors of Scotland's hydrogen and HDP sectors. However, our research found that there is not enough information about different geographical hubs in Scotland and the role they can play. The lack of individual focus on different hubs has motivated this study.

Appendix B Supply chain capabilities of Scotland’s hydrogen hubs

11.1.4 Maximum potential renewable power generation

The maximum potential renewable power generation is defined as the total current, planned and announced installed capacity of solar PV and wind power projects in each hub region. Data was provided by council authority, so data was aggregated according to the defined council authority groupings for each hub. 2023 installed capacities were obtained from the DESNEZ Regional Renewable Statistics (2024). To obtain current capacity, this data was supplemented by projects that came online in 2024, as reported by the DESNEZ Renewable Energy Planning Database (REPD) and desk-based research (2024). Offshore wind projects were assigned to hubs based on their onshore landing points. The resulting current capacities were scaled by the 2023 average load factor for Scotland, appropriate to each technology (DESNEZ, 2024).

The REPD was also used to calculate planned installed capacity. From this database, development statuses encompassed under “planned” included:

- “Under Construction”.
- “Awaiting Construction”.
- “No Application Required”.
- “Application Submitted”.
- “Revised”.

For announced installed capacity, we included the 27.6 GW of ScotWind leasing round projects (Offshore Wind Scotland, 2024). The likely onshore landing point (and so corresponding hub) was identified from individual project websites. If this information was not available, the closest hub was allocated the offshore capacity. We included additional announced wind and solar projects from the Global Energy Monitor tracker (2025). To scale the resulting planned and announced capacities, we used load factors reported by DESNZ for UK new build projects (for delivery years 2026-2029) (2024).

To obtain the maximum potential renewable energy power generation for each hub, we then summed the current, planned and announced solar PV and wind power generation. We ranked the hubs from 1 (least generation) to 15 (highest), as shown in Table 13.

Table 12: Summary of data used for the calculation of maximum potential renewable power generation.

Data category	Unit	Value/Data used	Source	Confidence rating
Installed capacity - 2024	MW	Installed capacity of solar PV and wind projects by council authority	(DESNEZ, 2024) (DESNEZ, 2024)	3
Installed capacity – planned	MW	Planned installed capacity of solar PV and wind projects.	(DESNEZ, 2024)	3

Data category	Unit	Value/Data used	Source	Confidence rating
Installed capacity – announced	MW	Capacity of announced solar PV and wind projects	(Offshore Wind Scotland, 2024) (Global Energy Monitor, 2025)	2
Current load factors for Scotland	%	PV: 9.5% Onshore wind: 23.6% Offshore wind: 29.5%	(DESNEZ, 2024)	3
Load factors for UK new build projects	%	PV: 10.8% Onshore wind: 44.8% Offshore wind: 62.3%	(Department for Energy Security & Net Zero, 2024)	2

Table 13: maximum potential renewable power generation by hub.

Hub	Current maximum potential renewable power generation (GW)	Planned/announced maximum potential renewable power generation (GW)	Rank (1 = lowest to 15 = highest)
Aberdeen	0.18	10.87	15
Argyll and Islands	0.10	1.50	8
Ayrshire	0.34	0.75	7
Cromarty	0.49	2.83	14
Duisburg	0.01	0.00	1
Dumfries and Galloway	0.27	1.41	9
Dundee	0.01	0.40	4
Fife	0.03	0.34	3
Glasgow	0.44	0.41	5
Grangemouth	0.06	0.05	2
Moray	0.57	2.08	13
Orkney	0.01	1.95	10
Scottish Borders	0.15	0.78	6
Shetland	0.11	2.07	12
Western Isles	0.01	2.05	11

11.1.5 Water availability

In 2022, Ramboll, on behalf of SGN, investigated water availability for green hydrogen production across Scotland (Ramboll, 2022). This estimated hubs' maximum green hydrogen production potential based on current water availability and forecasted hydrogen production capacity for 2045.

Water availability was defined as the total volume of effluent water and fresh water, including groundwater, surface water and potable water. Sea water was excluded from the analysis as its availability is effectively unlimited and it is accessible to all Scottish hubs. To evaluate potential water availability, we took the difference between Ramboll's forecasted green hydrogen production capacity and the maximum production potential for each hub.

To ensure a fair comparison, we used the same methodology and assumptions for Duisburg as for the Scottish hubs. Ramboll outlines this approach on pages 26–27 of their report (2022). According to the Jülich research centre, Duisburg could have a maximum installed hydrogen capacity of 1 GW by 2050 (Cerniauskas, et al., 2021, p. 79). Since no specific data was available for 2045, we assumed that the installed capacity would be the same as in 2050.

The total water availability for hydrogen production in Duisburg is approximately 18,697,000 cubic metres. This includes:

- 2,697,000 cubic metres of non-used fresh water (Statistische Ämter des Bundes und der Länder, 2025).
- 16,000,000 cubic metres of effluent water from central waste treatment plants (Wirtschaftsbetriebe Duisburg, 2025).

Based on Ramboll's assumptions, green hydrogen production requires 10 kg water per kg hydrogen. Additionally, we should account for a 20% water loss. Using 2,697,000 cubic metres of fresh water, the maximum hydrogen production potential is approximately 1.5 million tonnes. This result was converted to kilowatt-hours (kWh) using the lower heating value for hydrogen (33.3 kWh). We estimated that Duisburg's maximum hydrogen production potential is 14 GW using the following equation:

$$(\text{Maximum production potential} \div \text{Average operating load} \div \text{Annual operating hours} \div \text{Electricity to hydrogen conversion effiency}) \div 1{,}000{,}000$$

The assumptions for this calculation are detailed in Table 14. Finally, we calculated Duisburg's water availability by taking the difference between its forecasted hydrogen production capacity and its maximum production potential.

The final rankings from 1 to 15 (with 1 representing the hub with the least water availability) are shown in Table 15.

Table 14: Summary of data used for the calculation of water scarcity.

Data category	Unit	Value/Data used	Source	Confidence rating
Forecasted green hydrogen capacity in Scotland	GW	• Maximum green production capacity for each hub in 2045. • The value for SW Scotland was distributed to the Dumfries and Galloway and Ayrshire hubs equally.	(Ramboll, 2022, p. 3)	2
Surface water availability in Scotland	GW	• Maximum green hydrogen production capacity for each hub based on surface water availability.	(Ramboll, 2022, pp. 3, 34)	2

Data category	Unit	Value/Data used	Source	Confidence rating
		• The value for SW Scotland was distributed to the Dumfries and Galloway and Ayrshire hubs in a 3:1 ratio. This ratio, and the value for the Scottish borders, was estimated roughly from Figure 15 of the source report.		
Groundwater availability in Scotland	GW	• Maximum green hydrogen production capacity for each hub based on groundwater availability. • The value for SW Scotland was distributed to the Dumfries and Galloway and Ayrshire hubs in a 1:8 ratio. This ratio, and the value for the Scottish borders, was estimated roughly from Figure 16 of the source report.	(Ramboll, 2022, pp. 3, 35)	2
Effluent water availability in Scotland	GW	• Maximum green hydrogen production capacity for each hub based on effluent water availability. • The value for SW Scotland was distributed to Ayrshire which had the Wastewater Treatment Works. The value for the Scottish borders, was estimated roughly from Figure 18 of the source report.	(Ramboll, 2022, pp. 3, 37)	2
Forecasted green hydrogen capacity in Duisburg	GW	Estimated installed green hydrogen capacity in 2050. Based on Figure 73 of the source report.	(Cerniauskas, et al., 2021, p. 79)	2
Electricity to hydrogen conversion efficiency	%	69%	(Ramboll, 2022, p. 20)	2
Annual operating hours	hrs	7350	(Ramboll, 2022, p. 20)	2
Average operating load	%	70%	(Ramboll, 2022, p. 20)	2
Lower heating	kWh	33.3	(U.S. Department of Energy, 2025)	3

Data category	Unit	Value/Data used	Source	Confidence rating
value of hydrogen				
Water loss allowance	%	20	(Ramboll, 2022, p. 27)	2
Freshwater availability in Duisburg	Cubic metres	Non-public fresh water discharged unused/water given to third parties in 2019.	(Statistische Ämter des Bundes und der Länder, 2025)	3
Effluent water availability in Duisburg	Cubic metres	Total annual wastewater treated in the three municipal wastewater treatment plants.	(Wirtschaftsbetriebe Duisburg, n.d.)	3

Table 15: Raw data and rank for water availability by hub.

Hub	Forecasted green hydrogen capacity in 2045 (GW)	Maximum green hydrogen potential based on total water availability (GW)	Rank (15 = most available to 1 = least available)
Aberdeen	0.50	44.5	9
Argyll and Islands	0.13	11.4	4
Ayrshire	0.50	47.5	10
Cromarty	5.00	61.2	11
Duisburg	1.00	14.0	5
Dumfries and Galloway	0.50	26.7	8
Dundee	0.25	73.0	13
Fife	0.25	67.8	12
Glasgow	2.50	239.2	15
Grangemouth	2.00	145.9	14
Moray	2.00	26.6	7
Orkney	0.05	1.5	2
Scottish Borders	0.00	22.9	6
Shetland	6.30	2.0	1
Western Isles	0.12	9.1	3

11.1.6 Gross Value Added of the energy sector

The Office of National Statistics (ONS) supplied data on the gross value added of the energy and the production sectors (2024). The ONS defined the production sector as SIC07 A-E. For the energy sector (including renewables), the ONS included the following SIC codes:

- SIC 05: Mining of coal and lignite
- SIC 06: Extraction of crude petroleum and natural gas
- SIC 09: Mining support service activities
- SIC 19: Manufacture of coke and refined petroleum products
- SIC 20.14: Manufacture of other organic based chemicals

- SIC 35: Electricity, gas, steam and air conditioning supply
- SIC 36: Water collection, treatment and supply
- SIC 38.22: Treatment and disposal of hazardous waste
- SIC 71.12/2 Engineering related scientific and technical consulting activities
- SIC 74.90/1 Environmental consulting activities

The GVA data by council area was aggregated to provide a hub-level view. Table 16 provides the data for GVA for each hub in the energy and the production sectors.

Table 16: Raw data and rank for GVA of the energy sector by hub.

Hub	Energy sector GVA (2022; £millions)	Production sector GVA (2022, £millions)	Rank (15 = highest to 1 = lowest)
Aberdeen	25878.9	4480	15
Argyll and Islands	162.1	422	7
Ayrshire	185.3	1762	9
Cromarty	342.8	1426	10
Duisburg	—	4147	13
Dumfries and Galloway	167.8	980	8
Dundee	146.9	1322	6
Fife	351.4	2232	11
Glasgow	2910.0	7447	14
Grangemouth	512.1	1522	12
Moray	78.7	875	4
Orkney	69.4	130	3
Scottish Borders	43.7	547	2
Shetland	119.4	184	5
Western Isles	16.8	83	1

Table 17: Summary of data used for the calculation of GVA of the energy sector.

Data category	Unit	Value/Data used	Source	Confidence rating
Energy sector GVA in Scotland	£million	• Approximate GVA for Energy (including Renewables) at basic prices by local authority area in 2022. • Where data was non-disclosed for 2022, the value for 2021 was used.	(Scottish Government, 2024)	3
Production sector GVA in Scotland	£million	Regional GVA (balanced) by local authority for the Production Sector in 2022.	(Office for National Statistics, 2024)	3
Production sector GVA in Duisburg	€million	Duisburg GVA at basic prices for the Production Sector in 2022.	(Volkswirtschaftliche Gesamtrechnungen der Länder, 2024)	3

Data category	Unit	Value/Data used	Source	Confidence rating
Euro to pound conversion rate	£	12-month average for 2022: £0.8489	(HMRC, 2022)	3

11.1.7 Full time equivalent workers

The data for the current size of workforce in different hubs was taken from Skills Development Scotland. The data was broken down into 32 local authorities. We took the current workforce figures for the Energy and Engineering sectors. The numbers from relevant local authorities were then added to derive the final number for each of our hubs. Table 18 shows the current workforce stats for each hub.

Table 18: Size of workforce in the engineering and energy sectors of Scotland.

Hub	Energy	Engineering	Total
Aberdeen	42900	28200	71100
Argyll and Islands	800	800	1600
Ayrshire	2400	8200	10600
Cromarty	4900	3000	7900
Dumfries and Galloway	1000	1600	2600
Dundee	1300	5100	6400
Fife	1400	10300	11700
Glasgow	16400	39300	55700
Grangemouth	2500	4400	6900
Moray	600	1500	2100
Orkney	300	200	500
Scottish Borders	400	2000	2400
Shetland	300	400	700
Western Isles	200	200	400

11.1.8 Future workforce requirement

The data for the future workforce requirement was taken from Skills Development Scotland's database. This data was also disaggregated into 32 local authorities. The figures for all relevant local authorities were added to calculate final figures for our hubs. Table 19 shows the final estimates for future expansion demand.

Table 19: Estimated future expansion demand for each hub in Scotland.

Hub	Total Expansion Demand
Aberdeen	-4600
Argyll and Islands	0
Ayrshire	-900
Cromarty	-100
Dumfries and Galloway	-200
Dundee	-500
Fife	-1300
Glasgow	-1500
Grangemouth	-700
Moray	-100
Orkney	0
Scottish Borders	-200
Shetland	0
Western Isles	0

11.1.9 Large-scale storage capacity

Currently, there are no commercial geological hydrogen storage projects in Scotland. So, we have assessed the **technical** geological storage capacity for each hub. For this, we have used estimates from scientific literature. The sources for each storage technology are detailed in Table 21. We assigned the storage capacities to each hub based on the site's location or, if offshore, their likely terminal.

We normalised the total large-scale storage capacity for each hub to provide a score from 1-10 (highest capacity). We adjusted the scores of the following hubs by +0.25. This adjustment accounted for the possibility of developing offshore salt caverns and the planned Project Union pipeline that could connect hubs to English salt caverns.

- Aberdeen
- Dumfries and Galloway
- Dundee
- Fife
- Glasgow
- Grangemouth
- Moray
- Orkney
- Scottish Borders

The adjustment helped differentiate low-scoring hubs while maintaining the ranking integrity of those with confirmed storage capacity. Finally, we ranked the hubs from 1-15, where 15 represents the hub with the highest capacity (Table 20).

For Duisburg, we were unable to assess its specific technical storage capacity from scientific literature. However, compared to Scotland, Germany has hydrogen storage projects in the planning phase (Hornby, 2023). Due to the approved German core pipeline network, Duisburg will be connected to these projects. Therefore, due to higher confidence in hydrogen storage availability, we qualitatively assigned Duisburg a score of 3/10. This places Duisburg second to Aberdeen in the final ranking.

Table 20: Large-scale storage capacity by hub.

Hub	Hydrogen storage capacity (TWh) by technology				Rank (1-15)
	Onshore salt caverns	Saline aquifers	Offshore oil/gas	Total	
Aberdeen	0	1849	1082	2931	15
Argyll and Islands	0	0	0	0	1
Ayrshire	0	0	0	0	1
Cromarty	0	0	0	0	1
Duisburg	0	0	0	0	14
Dumfries and Galloway	0	0	0	0	5
Dundee	0	0	0	0	5
Fife	0	0	0	0	5
Glasgow	0	0	0	0	5
Grangemouth	0	0	0	0	5
Moray	0	118	0	118	13
Orkney	0	0	0	0	5
Scottish Borders	0	0	0	0	5
Shetland	0	82	32	114	12
Western Isles	0	0	0	0	1

Table 21: Summary of data used for the calculation of large-scale storage capacity.

Data category	Unit	Value/Data used	Source	Confidence rating
Hydrogen storage capacity – onshore salt caverns	TWh	0 TWh	(ClimateXChange, 2023)	3
Hydrogen storage capacity – saline aquifers	TWh	Location and technical working hydrogen gas capacity by site	(Safidi, et al., 2021)	2
Hydrogen storage capacity –	TWh	Location and technical working hydrogen gas capacity by field	(Peecock, et al., 2022)	2

offshore oil/gas fields				
Offshore salt cavern locations	N/A	-	(Edlmann, et al., 2024)	3
Potential hydrogen pipeline locations	N/A	-	(Edlmann, et al., 2024)	3
Planned hydrogen storage in Ruhr area	N/A	-	(Hornby, 2023)	3

11.1.10 Pipeline network infrastructure

To score each hub's potential pipeline infrastructure, we used the following scale from 1-6:

1. There is no pipeline infrastructure suitable for hydrogen and no proposed or planned new hydrogen pipelines.
2. There are existing gas pipelines which can be repurposed. There are no planned new hydrogen pipelines but there may be some proposed.
3. There is a small-scale (e.g. distribution/spur pipelines) hydrogen pipeline project at any phase of development.
4. There is a large-scale (e.g. trunkline pipelines) hydrogen pipeline project at any phase of development.
5. The hub is a potential international export or import site for hydrogen and HDPs. However, planned pipeline infrastructure is insufficient and/or the site is not well-established for international trade.
6. The hub is a potential international export or import site for hydrogen and HDPs. There is sufficient planned pipeline infrastructure, and the site is well-established for international trade.

We have detailed the justification and sources for each hub's rating in Table 22. Using these ratings, the hubs were ranked from 1 to 15 (Table 23). 15 represents the hub with the most suitable pipeline network infrastructure.

Table 22: Scoring method for pipeline network infrastructure.

Hub	Rating (1-6)	Justification	Source
Aberdeen	6	• Identified as potential export route via St Fergus - a well-established export route with existing gas network which can be repurposed. • Project Union Hydrogen Backbone project to directly connect. • Project Acorn (FEED) plans for 100% conversion of local network at Moray and Aberdeen.	(Net Zero Technology Centre, 2023)

Hub	Rating (1-6)	Justification	Source
Argyll and Islands	2	• No known new pipeline infrastructure planned. • Not connected to main gas transmission network or planned Hydrogen Backbone. • Some smaller gas pipelines may be available for conversion.	(Net Zero Technology Centre, 2023)
Ayrshire	3	• Transmission Gas Network does not cross the hub. • Pre-FEED announced spur line by SGN connected to Hydrogen Backbone.	(Scottish Enterprise, n.d.; SGN, 2021),
Cromarty	5	• Transmission Gas Network does not cross the hub. • Identified as potential export route by NZTC. • Hydrogen Backbone link could connect to Cromarty Firth.	(Net Zero Technology Centre, 2023; Scottish Enterprise, n.d.)
Duisburg	6	• Planned major hydrogen import hub. • Will be connected. • to approved German core pipeline network.	(Bundesnetz agentur, 2024; Gasunie, 2023)
Dumfries and Galloway	4	• Existing gas transmissions pipelines, including Scotland to Northern Ireland Pipeline. • Announced Project Union and European Backbone transmission infrastructure to run through hub.	(Net Zero Technology Centre, 2023; Scottish Enterprise, n.d.)
Dundee	4	• Announced Pre-FEED spur lines by SGN connected to Hydrogen Backbone. • Announced Project Union to run through region.	(SGN, 2021)
Fife	4	• Under construction H100 pipeline • Announced pre-FEED spur lines by SGN connected to Hydrogen Backbone • Project Union projected to run through region.	(SGN, 2021)
Glasgow	3	• National Grid Gas Transmission Network pipelines cross through South Lanarkshire. Potential for hydrogen blending. • Pre-FEED projected spur lines by SGN connected to Hydrogen Backbone.	(SGN, 2021; Scottish Enterprise, n.d.)

Hub	Rating (1-6)	Justification	Source
Grangemouth	4	• Project Union Hydrogen Backbone project has a particular focus on connecting directly to Grangemouth. • Approved SGN project plans to trial 30 km hydrogen pipeline to Edinburgh.	(SGN, 2021; SGN, 2023)
Moray	3	• SGN plans to repurpose spur pipeline to connect to Project Union pipeline. • Project Acorn (FEED) plans for 100% conversion to hydrogen of local pipeline network at Moray and Aberdeen.	(SGN, 2021; Scottish Government, 2020)
Orkney	5	• Transmission Gas Network does not cross through the Cluster. • However, identified as a potential export site from Flotta. NZTE identified opportunity for new pipeline to connect to SIRGE and UK mainland.	(SGN, 2021; Net Zero Technology Centre, 2023)

Table 23: Hub ranking for pipeline network infrastructure.

Hub	Rank (1 = least suitable to 15 = most suitable)
Aberdeen	14
Argyll and Islands	1
Ayrshire	2
Cromarty	11
Duisburg	14
Dumfries and Galloway	6
Dundee	6
Fife	6
Glasgow	2
Grangemouth	6
Moray	2
Orkney	11
Scottish Borders	6
Shetland	11
Western Isles	2

11.1.11 Ports

We have investigated which hubs are most suitable for meeting maritime shipping fuel demand and for trading hydrogen and HDPs by ship. To evaluate the scale of each hub's maritime industry, we ranked the hubs based on their total port freight traffic in 2023. This analysis was based on the Department for Transport's Port Freight Statistics Publication (Maritime Statistics, 2024). The *Port0101* dataset breaks down freight traffic by port and council authority. Traffic included domestic and international freight traffic in both directions and we included all ports - major and minor. For Duisburg, we used State Office for Information and Technology NWR data for freight traffic in both directions for 2023 (2024).

We adjusted these initial ranked scores based on several criteria, shown in Table 24. For the port dimensions criterion, if online information was conflicting, we selected the greatest dimension for further scoring. This multi-factor scoring method reflects the diverse functions that ports serve. Based on these final scores, we ranked the hubs from 1 to 15 (Table 25). 15 represents the hub with the most suitable port infrastructure.

Table 24: Score adjustment criteria for scoring port metric.

#	Criteria	Score adjustment	
		If YES	If NO
1	Does the hub have a port with existing or planned infrastructure for the storage, production or maritime fuelling of hydrogen/HDPs?	+2	−2
2	Does the hub have a port with dimensions suitable for a typical small carrier vessel for transporting gas or ammonia? The Scottish Government defines these dimensions as a 100m length, 25m beam and a 12m draft (2020, p. 63).	+2	−2
3	Does the hub have a port which is considered suitable for hydrogen exports or imports by the government?	+3	−2

Table 25: Summary of data used for scoring the port metric.

Data category	Unit	Value/Data used	Source	Confidence rating
Port freight traffic - Scotland	Thousand tonnes	2023 freight traffic, both directions	(Maritime Statistics, 2024)	3
Port freight traffic - Duisburg	Thousand tonnes	2023 freight traffic, both directions	(Information und Technik Nordrhein-Westfalen, 2024)	3
Port dimensions	metres	Where available – the port’s maximum length, beam and draft	(SHIPNEXT BV, 2025; OneOcean Group Ltd, 2023; Port of Aberdeen, 2025; UKPORTS, 2025)	3
Hydrogen/HDP infrastructure - Duisburg	-	-	(Duisport, 2022)	3

Data category	Unit	Value/Data used	Source	Confidence rating
Hydrogen/HDP infrastructure - Scotland	-	-	(Scottish Government, 2020)	3
Import hub - Duisburg	-	-	(Tix, 2024)	3
Export hubs - Scotland	-	-	(Scottish Government, 2020)	3

Table 26: Raw data, analysis and rank for ports by hub.

Hub	Port freight traffic (thousand tonnes, 2023)	Criteria 1 (YES = ☒)	Criteria 2 (YES = ☒)	Criteria 3 (YES = ☒)	Rank (1 = least suitable to 15 = most suitable)
Duisburg	41333	☒	☐	☒	15
Cromarty	7376	☒	☒	☒	13
Fife	18681	☒	☐	☒	13
Grangemouth	18521	☒	☐	☒	12
Shetland	5975	☒	☒	☒	11
Aberdeen	4395	☒	☒	☒	10
Orkney	1689	☒	☒	☒	9
Ayrshire	8923	☐	☒	☐	8
Glasgow	8594	☐	☐	☐	7
Dumfries and Galloway	6511	☐	☐	☐	6
Western Isles	204	☒	☐	☐	5
Moray	108	☒	☐	☐	4
Dundee	996	☐	☐	☐	3
Argyll and Islands	46	☐	☐	☐	2
Scottish Borders	0	☐	☐	☐	1

11.1.12 **Local policy and planning support**

The data for the local policy and planning support metrics were taken from Scottish government's Planning Application Statistics database. The data was broken down into 24 local planning authorities. The data was taken from the relevant local authorities and averaged for all our hubs.

It was found that for the average success rate of applications, there was no data for 6 hubs. Table 27 shows the average success rate and average planning duration for each Scottish hub and Duisburg.

Table 27: Average success rate and duration for planning applications

Hub	Average success rate of planning applications	Average duration of planning applications (weeks)
Aberdeen	87%	6.7
Argyll and Islands	No Data	17.6
Ayrshire	50%	6.7
Cromarty	80%	15.3
Duisburg, Germany	No Data	18
Dumfries and Galloway	No Data	13.2
Dundee	79%	11.7
Fife	53%	10.3
Glasgow	70%	14.6
Grangemouth	80%	9
Moray	No Data	7.2
Orkney	No Data	10.6
Scottish Borders	88%	8.2
Shetland	No Data	10.6
Western Isles	No Data	13.9

11.1.13 **Sensitivity analysis**

For main report, we weighted capability groups according to the working group's priorities and adjusted these weightings based on data confidence. We normalised each metric ranking from 1-15 into a 1-10 scale. Then, according to the defined weightings, we scaled the metric score for each hub to provide a total score out of 100.

Here, we analyse the sensitivity of this **priority** scoring by considering two alternative scenarios:

1) The **balanced** scenario – all metrics are weighted equally at 9.1%.
2) The **absolute** scenario – Rather than scoring hubs relatively according to metric rankings, we used the absolute data for each metric. For example, for GVA of the energy sector, we normalised the absolute GVA values to give a score from 1-10. The same weightings are used as in the priority scenario.

Table 28: Hub rankings from priority, balanced and absolute scenario.

Rank (15 = highest score to 1 = lowest score)	Hub scoring method		
	Priority scenario	Balanced scenario	Absolute scenario
15	Aberdeen	Aberdeen	Aberdeen
1	Argyll and Islands	Argyll and Islands	Argyll and Islands
9	Ayrshire	Ayrshire	Ayrshire
13	Cromarty	Glasgow	Cromarty
14	Duisburg	Duisburg	Duisburg
6	Dumfries and Galloway	Moray	Dumfries and Galloway
8	Dundee	Dundee	Dundee
11	Fife	Grangemouth	Fife
12	Glasgow	Cromarty	Glasgow
10	Grangemouth	Fife	Grangemouth
7	Moray	Shetland	Moray
4	Orkney	Orkney	Orkney
3	Scottish Borders	Dumfries and Galloway	Scottish Borders
5	Shetland	Scottish Borders	Shetland
2	Western Isles	Western Isles	Western Isles

Table 28 shows the final ranking for supply chain capability according to all three scenarios. Several key insights can be taken from our sensitivity analysis:

- We can see that the hubs at the ranking extremes remain the same. Aberdeen remains the top hub for supply chain capability, while the Western Isles and Argyll and Islands are the bottom hubs.
- The hubs between these extremes vary according to the scenario. However, the general "upper" (Cromarty, Glasgow, Fife, Grangemouth, Ayrshire) and "lower" (Dundee, Moray, Dumfries and Galloway, Shetland, Orkney and Scottish Borders) groupings identified in the priority scenario are consistent in the balanced and absolute scenarios.

Appendix C HDP demand in Scotland's hydrogen hubs

11.1.14 **Demand mapping – e-methanol and ammonia for maritime**

It is estimated that the UK used roughly 7 million tonnes of fossil marine fuels in the year 2021 (Transport & Environment, 2023). We used the EU Commission's assumption of 40.5 MJ/kg as the energy content of marine fuel. Using this, we derived the addressable market for the whole of UK. Assuming that the fuel usage by Scottish ports will have the same share, we estimated the addressable market for Scotland's maritime sector. Using data from the Department for Transport, we calculated the share of freight activity of each hub's ports in the UK (Maritime Statistics, 2024).

Due to the uncertainties associated with estimating demand for individual HDPs in this sector, our analysis is technologically agnostic. We have not tried to estimate individual demand for each HDP. This analysis only estimated the addressable demand for all HDPs in the maritime sector of Scotland.

Table 29: Estimated shipping fuel demand by hub

Hub	Shipping fuel demand (TWh)
Aberdeen	0.8
Argyll and Islands	0.0
Ayrshire	1.6
Cromarty	1.4
Dumfries and Galloway	1.0
Dundee	0.2
Fife	3.5
Glasgow	1.5
Grangemouth	3.5
Moray	0.0
Orkney	0.5
Scottish Borders	0.0
Shetland	1.2
Western Isles	0.0

11.1.15 **Demand mapping – e-methanol for chemicals**

In Scotland, we assume that Grangemouth Chemical Science Park is the only large-scale user of methanol as a chemical feedstock. We based this analysis on the estimated syngas produced from two onsite ethane crackers which supply INEOS' polymer plants (INEOS Group, 2025). The ethane crackers have a production capacity of around 1 million tonnes of ethylene per year (Endeavor Business Media, 2016). From this value, we have reverse calculated the yield of syngas (hydrogen and methane from the crackers). Assuming an 80% yield of ethylene product, 1.25 million tonnes of ethane feedstock is required (Brooks, 2013). From literature, we can expect an estimated 13% yield of syngas (Brooks, 2013). This means 160,000 tonnes of syngas is produced from 1.25 million tonnes of ethane. In the production of petrochemicals, syngas is converted to methanol. Assuming 8600 hours/year of operation and a 62% yield, we can expect to produce around 100,000 tonnes of methanol

(Timsina, et al., 2021). We then multiplied this result by the lower calorific value of methanol (19.9 MJ/kg) and the conversion factor of $2.78x10^{-10}$ to give the energy demand in TWh.

11.1.16 **Demand mapping – SAF for aviation**

We estimated the addressable market for SAFs in the Scotland by estimating the potential demand for jet fuel in each public airport in Scotland. Due to lack of data on jet fuel consumption in each airport, we took some assumptions to calculate potential demand. It is estimated that the UK used 11 million tonnes of jet fuel in the year 2022. This figure is for all the airports in the UK. So, to determine jet fuel demand for Scotland, we calculated the percentage of aircraft activity in each airport against the total UK aircraft activity. It was then assumed that the proprtion of jet fuel used in an airport will be the same as their share in total aircaft activity.

The table below show the proportion of aircraft movement in each hub and airport.

Table 30: Estimated jet fuel demand in all Scottish airports.

Hub	Airport	Potential SAF Demand (TWh)	Total hub potential demand (TWh)
Aberdeen	Aberdeen	3.49	3.49
Argyll and Bute	Campbeltown	0.07	0.26
Argyll and Bute	Islay	0.12	0.26
Argyll and Bute	Tiree	0.07	0.26
Cromarty	Inverness	1.20	1.20
Dundee	Dundee	1.66	1.66
Glasgow	Glasgow	3.51	4.45
Glasgow	Glasgow Prestwick	0.94	4.45
Grangemouth	Edinburgh	5.03	5.03
Orkney	Kirkwall	0.54	0.70
Orkney	Wick John O' Groats	0.16	0.70
Shetland	Lerwick (Tingwall)	0.06	0.93
Shetland	Scatsta	0.19	0.93
Shetland	Sumburgh	0.68	0.93
Western Isles	Barra	0.05	0.55
Western Isles	Benbecula	0.13	0.55
Western Isles	Stornoway	0.37	0.55

11.1.17 Demand mapping – ammonia for fertilisers

To estimate ammonia demand from fertilisers, we first estimated the total demand for nitrogen based fertilsers in Scotland. For our analysis, we assumed that nitrogen-based fertilisers consist of just urea and ammonium nitrate fertilisers. The fertiliser use estimation was done for both cropland and grassland. The average nitrogen based fertiliser application rate was taken from the UK government's Fertiliser Use Database. The average application rate for nitorgen fertiliser in Scottish croplands is 120 kg/ha. And the average application rate for grassland is 83 kg/ha.

This average application rate was then multiplied by the total estimated crop and grass lands in Scotland. We then estimated the nitrogen content in these two fertilisers. After getting the nitrogen content in them, we estimated the demand for ammonia.

Once the final figure for ammonia was derived, we divided the total use of ammonia for all our hubs. This was done by assuming that each hub's share of use of ammonia will be the same as their share of total GVA in agriculture. The table below shows our demand estimates for ammonia in each Scottish hub.

Table 31: Estimated ammonia demand from fertilisers in Scotland

Hub	Ammonia fertiliser demand (thousand tonnes)	Ammonia fertiliser demand (TWh)
Aberdeen	27.1	0.140
Argyll and Islands	2.5	0.013
Ayrshire	4.2	0.022
Cromarty	7.4	0.038
Dumfries and Galloway	4.2	0.021
Dundee	2.5	0.013
Fife	4.8	0.025
Glasgow	24.5	0.126
Grangemouth	3.0	0.015
Moray	1.2	0.006
Orkney	0.9	0.005
Scottish Borders	2.8	0.014
Shetland	1.4	0.007
Western Isles	0.0	0.000

Appendix D Policy gap analysis

Table 32: Further information about all the policies and regulations we researched.

Region	Policy name	Description
European Union	Net Zero Target	The European Union aims to meet net zero emissions by 2050.
European Union	Hydrogen Strategy	The hydrogen strategy for a climate-neutral Europe was adopted in July 2020.
European Union	RePowerEU	The European Commission implemented the REPowerEU Plan to phase out reliance on Russian fossil fuel imports following the invasion of Ukraine.
European Union	REDIII Targets	Transport: RED III fuel suppliers must achieve a 14.5% reduction in GHG emissions associated with their fuels or achieve at least 29% renewables share in the fuel supply. In addition, at least 5.5% of the fuel mix must be composed of advanced biofuels and RFNBOs (combined binding target). Industry: The EUs CBAM Regulation (10th May 2023) will be transitioned in during the period of 2023-2026 and then full force from 2026 onwards. The EU's Fit for 55 proposals include a 50% renewable share for hydrogen used in industry. RED III - Industry must procure at least 42% of its hydrogen from renewable fuels of non-biological origin (RFNBOS) by 2030, though countries that can achieve a fossil-free hydrogen mix of at least 77% by 2030 can see that target reduced by 20%.
European Union	H2Global	H2Global is live (1st auction closed 2023) and formed through H2 purchase and sale agreements through a central body. Managed windows for funding applications through 10-year hydrogen purchase agreements, competition-based procurement process. As of 06/23, H2Global and the Hydrogen Investment Bank have been linked. Working on a European auction open to all EU countries.
European Union	Hydrogen Bank	Acts through an auction system, fixed price payment per kg. Fixed premium per kg hydrogen produced for a maximum of 10 years of operation. Auctions launched under the Innovation Fund in the autumn of 2023.
European Union	Innovation Fund	The innovation fund hydrogen focussed from Nov 2022. Acts through a competitive bidding process - max bid 4 Euro per kg* - and via waves of calls for proposals.
European Union	IPCEI	Important Project of Common European Interest (IPCEI) are live and provided in waves of grant funding. A requirement for projects must be for them to show they are financially viable without subsidies.
European Union	AFIR	AFIR passed March 2023, detailing one HRS to be deployed every 200km along Ten-T core.

Region	Policy name	Description
European Union	Fitfor55	Fit for 55: 2.6% target for renewable fuels of non-biological origin (RFNBO) in transport by 2030
European Union	EU ETS	The EU Emission Trading Scheme is a "cap and trade" system that limits the amount of greenhouse gases which can be emitted within the EU.
European Union	EU MoUs	The EU has signed MoUs with Japan, Egypt, Mauritania (and others) around hydrogen including export/imports.
European Union	RED Low Carbon Hydrogen Standard	3.38 kg CO2-eq/kg hydrogen (28 gCO2e per MJ) (70% lower compared to emissions from fossil fuels). Two delegated acts under Renewable Energy Directive published by the Commission in Feb-23 - (i) principle of additionality, (ii) methodology for calculating GGG emissions. Rules to apply to imports.
United Kingdom	Net Zero Target	Net zero by 2050. 78% emission reduction by 2035. Mandated in law. Net Zero power system by 2030.
United Kingdom	UK Hydrogen Strategy	Production target of 10 GW by 2030, with at least 6 GW of this coming from green production.
United Kingdom	HPBM	Hydrogen Production Business Model – a CFD funding mechanism bridging the difference between producing low-carbon hydrogen gas and the price of natural gas. Funding provided through allocation rounds.
United Kingdom	Hydrogen Transport Business Model (HTBM)	This is a policy for hydrogen transport projects that are expecting to connect to hydrogen network in the future. The policy aims to mitigate risks for hydrogen network developers. This is done by guaranteeing a fixed rate of return to the developers.
United Kingdom	Hydrogen Storage Business Model (HSBM)	Similar to HTBM, this policy aims to incentivise large scale hydrogen storage.
United Kingdom	Net Zero Hydrogen Fund (NZHF)	The NZHF provides support for a range of different costs such as development or capital expenditures.
United Kingdom	Health and Safety Executive (HSE)	HSE will play a role in determining the safety case for hydrogen in heating. More information from HSE will reduce the uncertainty with hydrogen's role in decarbonising heat.
United Kingdom	ADR Regulation	ADR regulation lays down specific regulations for transport of "dangerous goods". This regulation includes in its scope both hydrogen and various HDPs that meet the criteria of being dangerous.
United Kingdom	Gas Safety Management	GSMR prohibits injecting more than 0.1% hydrogen into the networks. This will need to be updated to expand the role of hydrogen blending into existing pipelines.

Region	Policy name	Description
	Regulation (GSMR)	
United Kingdom	Control of Major Accident Hazard (COMAH)	This applies to many of hydrogen derivatives and products due to their safety concerns.
United Kingdom	LCHS	The UK Low Carbon Hydrogen Standard sets a carbon intensity threshold for hydrogen production of 20 gCO2e/MJ (2.4 kg CO2-eq/kg hydrogen). If the hydrogen produced meets this standard, it can be deemed low-carbon and is eligible for government subsidy.
United Kingdom	UK ETS	The UK's own ETS scheme since leaving the EU.
United Kingdom	SAF Mandate	The UK has formed a SAF mandate stipulating set targets for percentage shares of SAF, and specific production pathways (such as PtL). Headline figure is that 10% of UK aviation fuel will be SAF by 2030.
United Kingdom	RTFO	The Renewable Transport Fuels Obligation
Germany	Net Zero Target	Net zero by 2045. Emissions shall move to net negative after 2050. Germany has set the preliminary targets of cutting emissions by at least 65 percent by 2030 compared to 1990 levels, and 88 percent by 2040 Mandated in law.
Germany	National Hydrogen Strategy	The German hydrogen national strategy was released in 2020 before being an update was released in 2023.
Germany	H2 Global	H2 Global - value €4 billion. Initial auction of 900mn euros launched in Dec 2022 for H2 derivatives. Government plans to make a further 3.5 billion euros available for new bidding rounds with durations up to 2036.
Germany	Carbon Tax	CO2 tax (introduced in 2023) for Avgas and Jet A-1.
Germany	Hydrogen Mobility Targets	Targets include fuel cell trucks, 20 HRS's and passenger cars, fuel cell buses for public transportation, and the operation of the first inland ship operating on hydrogen by 2025.
Germany	National MOUs	Several MoUs signed surrounding imports of hydrogen and ammonia into the country - Mauritania MoU could equate to 8 million tonnes/year.
The Netherlands	Net Zero Target	Net zero by 2050. 55% CO2 reduction by 2030. In law.
The Netherlands	National Hydrogen Strategy	The Netherlands hydrogen strategy was released in 2020.

Region	Policy name	Description
The Netherlands	National Climate Agreement	The national climate agreement contains set targets for fuel cell HDVs, passenger cars and hydrogen refuelling stations.
The Netherlands	Carbon Levy	In 2021, introduced carbon levy for industry - complementary to EU ETS - road mapped to 2030 currently.
The Netherlands	Guarantees of Origin Scheme	Green hydrogen Guarantees of Origin operational from Oct-22, following a Bill (May-22) and trial (summer-22).
The Netherlands	H2Global	300mn euro specific funding from H2Global, including funding for ammonia.
The Netherlands	National MoUs	In 2020, the US and the Netherlands signed a statement of intent to collaborate on hydrogen. The Minister of Energy of Chile and the State Secretary for Economic Affairs and Climate Policy signed a joint statement on collaboration in the field of green hydrogen import and export (July 2021). The UAE Ministry of Energy and Infrastructure and the Dutch Ministry for Foreign Trade and Development Cooperation have signed a Memorandum of Understanding on hydrogen energy. As part of their Joint Economic Committee, the UAE and the Netherlands have been in discussions to identify common interests and create a partnership for decarbonisation of the energy sector and increasing the use of clean hydrogen (March 2022).
Belgium	Net Zero Target	Net Zero by 2050, 55% emissions reductions target in place for 2030.
Belgium	National Hydrogen Strategy	Hydrogen strategy enacted firstly in 2021, with an update in 2022. Both strategies focussed on positioning Belgium as an import and transit location for low-carbon molecules into Europe. The country will remain dependent on energy imports in various forms to cover its domestic demand, estimating between 2 and 6 TWh of renewable hydrogen (or derivatives) in 2030 and between 100 and 165 TWh in 2050
Belgium	Energy Transition Fund	The Energy Transition Fund will fund until 2025, providing 20-30 million euros in support. The federal government has also earmarked 60 million euros (including 50 million euros from the national recovery and resilience plan) to invest and support projects to scale up innovative, low-carbon technologies.
Belgium	Hydrogen Act	The Hydrogen Act establishes a regulatory framework for the transport of hydrogen via pipelines. The act intends to foster the growth of the Belgian hydrogen market and the required hydrogen transport infrastructure.

How to cite this publication:
Yip, E., Nagpal, D., Wilson, J., Morton, H. (2025) Scotland's capabilities in producing hydrogen products and derivatives ', ClimateXChange. DOI: http://dx.doi.org/10.7488/era/6397

This work was supported by the Rural and Environment Science and Analytical Services Division of the Scottish Government (CoE – CXC).

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