Transport Scotland
Còmhdhail Alba

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Zero Emission Energy for Transport Project Report

Regional Case Study: Highland Council Area

Contents

1. Introduction

1.1 Study Area

[*The Highland Council*](#) area in Scotland covers over 26,000 square kilometres making it the largest local government area in the UK. This is 33% of the land area of Scotland and 11.4% of Great Britain. Despite being sparsely populated, it is the 7th most populous area in Scotland. It shares borders with council areas of Aberdeenshire, Argyll and Bute, Moray and Perth and Kinross. The Highland Council area covers most of the mainland and inner-Hebridean parts of the historic counties of Inverness-shire, Ross and Cromarty, Caithness, Nairnshire, and Sutherland, as well as small parts of Argyll and Moray.

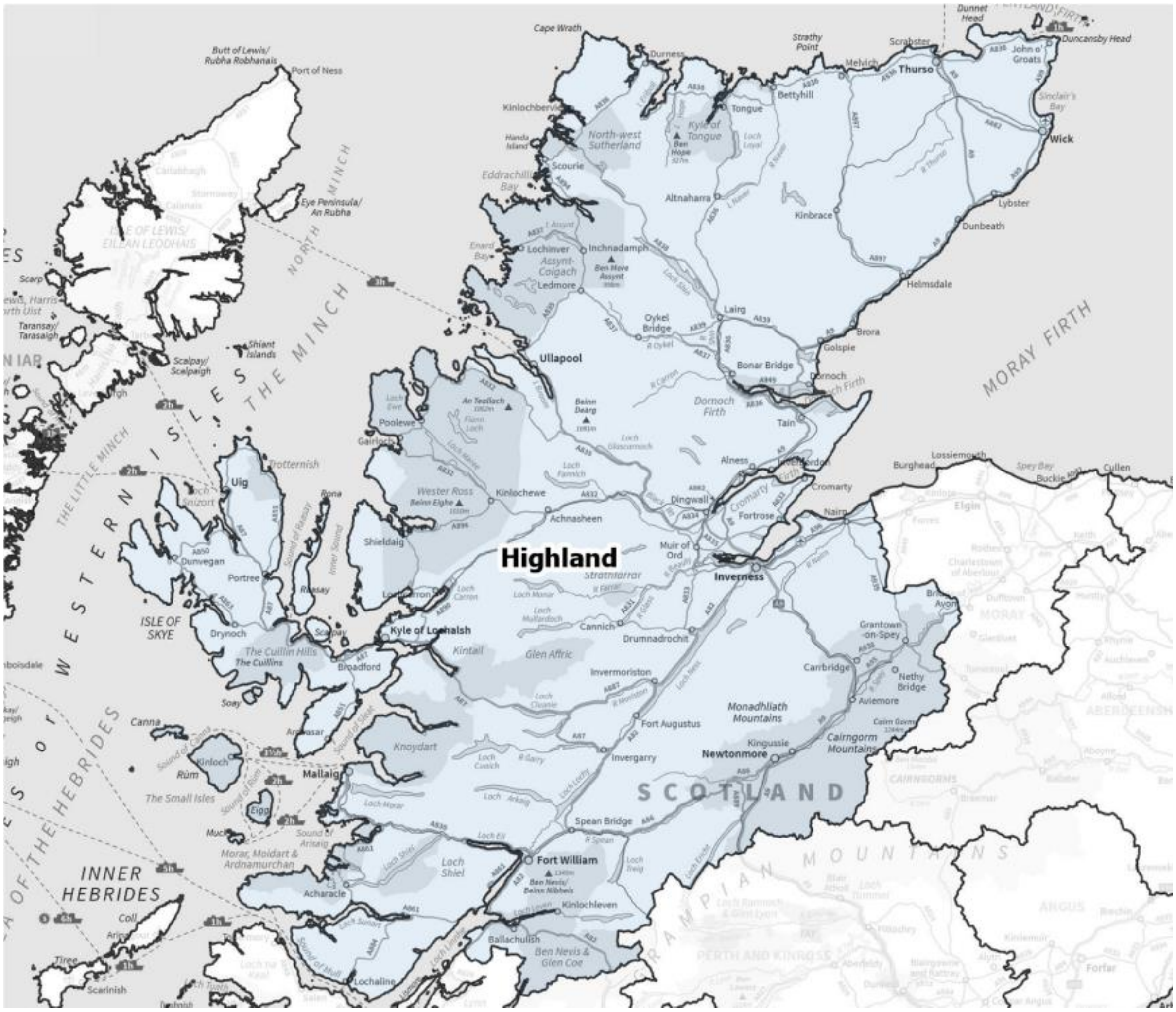


Figure 1 – Highland Council area, adapted from [Local Authority Maps of Scotland.](#)

Despite its name, it does not cover the entire Scottish Highlands. In terms of natural assets, the region is home to many lochs – some of which contain nearly twice as much water as all of the lakes of England and Wales combined. Additionally, it is home to numerous onshore and offshore windfarms – making it a high potential area for green hydrogen production within Scotland in the future.

1.2 Overarching Approach

Transport Scotland commissioned Jacobs to develop regional demand forecasts for the Highland Council area for three potential Low (Scenario A), Medium (Scenario B) and High (Scenario C) hydrogen uptake scenarios across all transport modes as part of its commitment to decarbonise the transport sector. This three-scenario approach was adopted for simplicity and flexibility to compare different scenarios easily.

The details of this study for the Highland Council area are outlined in the following report and estimate annual hydrogen demand for domestic or intra-Scotland transport including road, rail, maritime and aviation annually between 2022 and 2030, and for 2035, 2040 and 2045.

A three-part approach was adopted for forecasting hydrogen demand for transport consistent with the accompanying ***Zero Emission Energy for Transport: National Demand Forecasts for Electricity and Hydrogen*** as follows:

1. Transport Demand Baseline and Forecasting
2. Hydrogen Transition Scenario Development and Modelling
3. Hydrogen Demand Calculations and Analysis

While the overarching process was consistent across all transport modes (1-3 above), the individual methods for forecasting transport demand varied according to data availability, which is discussed in the following sections.

The study's results are a series of hydrogen demand forecasts for transport in each forecast year for the three scenarios. These results are then broken down into further categories by transport mode and individual types of vehicles as relevant.

This report is accompanied by a Microsoft Excel Results Tool (Tool) detailing the results for all three regional areas studied: Highland, Dumfries and Galloway, as well as Fife Council areas. The Tool enables the exploration and comparison between scenarios and regions in greater detail than that which is included within this report.

Overall, this study has been designed with the intention to inform the market of three possible hydrogen demand scenarios for transport purposes in the Highland Council area. While supply side considerations are important, such as capacity of existing or future infrastructure to produce and distribute hydrogen, they have not constrained the modelling process. This is because the key objective of the study is to indicate potential maximum demand scenarios for transport and thereby stimulate investment for infrastructure and supply.

2. Methodology

2.1 Transport Demand

The Highland Council area is multi-modal, being serviced by all transport modes including road, rail, maritime and aviation. The following sections describe characteristics of the existing transport demand across the study area and the methods used to quantify transport demand for each mode within the Highland Council area.

Unless specified below, the assumptions are consistent with the national technology transition scenarios the accompanying ***Zero Emission Energy for Transport: National Demand Forecasts for Electricity and Hydrogen*** report:

2.1.1 Road Transport Demand

Cars and Vans

Car and van use within the Highlands Council area is distributed across the population and employment centres, rather than at specific points of interest. This is due to cars and vans being a fundamental transport mode across all sectors of the population. For this reason, it is necessary to approach and view transport demand, and the potential hydrogen demand for cars and vans as an overall function of the vehicle fleet, rather than a series of discrete geographic areas of demand.

The accompanying ***Zero Emission Energy for Transport: National Demand Forecasts for Electricity and Hydrogen*** report outlines the bottom-up approach adopted to calculate hydrogen demand at a national level using transport demand projections from TMfS18.To establish the demand for the Highland Council area, it was necessary to disaggregate the national demand down to the local authority level.

The disaggregation process utilised the zonal system from the TMfS18 strategic transport model. The TMfS:18 model follows the standard demand model pattern of assigning origin-destination (OD) pairs to a road network to generate flows of traffic along the network. The origin totals for each zone were used to disaggregate the national demand. This process works under the assumption that most of the demand for hydrogen will be occurring at the point of origin for each journey rather than on route. The equation is as follows:

$$H_2Demand_{Zone1,Y,S} = H_2Demand_{Y,S}\frac{\sum Origin_{Zone1,Y,S}}{\sum_{Zone=All\ Zones} Origin_{Zone,Y,S}}$$

Where H_2Demand is the hydrogen demand for a specific year, Y, and for a specific scenario, S. $Origin_{Zone,Y,S}$ is the origin total for a specific zone, year and scenario.

By utilising this equation and the results of the accompanying ***Zero Emission Energy for Transport: National Demand Forecasts for Electricity and Hydrogen*** report it was therefore possible to disaggregates transport demand for hydrogen a lower level to represent the Highland Council area specifically.

HGVs and HDVs

The same approach to establish transport demand for cars and vans, was also used for HGVs and HDVs. However, HGV demand within the Highlands Council area is expected to be distributed across the major employment centres, with some concentration at freight depots. This is because HGV demand characteristically being more heterogenous than for cars or vans. However, demand is still dispersed across many different local areas and for this reason, it is necessary to approach and view demand for HGVs as an overall function of the vehicle fleet, rather than a series of discrete geographic areas.

Buses and Coaches

Bus and coach transport in the Highlands Council area consists of a mixture of buses which perform timetabled public services on several routes, as well as coaches largely used for private hire or excursions across the region. Each type of service is dominated by a few large operators, but smaller firms also operate in each category on a much smaller scale.

The largest bus and coach operator in the region is *Stagecoach*, which has depots based in Aviemore, Inverness, Portree, Thurso and Tain. Most of the vehicles owned by Stagecoach are buses which run local scheduled bus services, but there are also a small number of coaches at each of their depots.

Other mid-sized operators are *D&E Coaches*, based in Inverness, which provides contract and private hire vehicles, business transport and transfers for ports and airports; and *Shiel buses*, based at Fort William, who run school and service contracts and well as private bus and coach hire. Several small operators with less than 10 buses and coaches also operate throughout the region, from Durness in the northwest, to Aviemore in the southeast.

In terms of methods to establish transport demand for bus and coach services in the Highland region, this has been established using two complementary approaches:

- First national demand figures provided through TMfS:18 data were disaggregated for each of the six national technology transition scenarios for the Highland council area specifically. Since the TMfS:18 data only included local data for service buses, secondary sources of bus and coach data were located within the local region (such as council information) and cross-checked to establish reliability

- Additionally, bus and coach fleet operators were contacted directly where possible, to understand and verify the details of their specific fleets
- Importantly, the distance travelled buses and coaches in Highland Council is assumed to be constant through to 2045 aligned with TMfS:18.

This process established the TMfS:18 data only varied slightly from the locally available data. Figure 2 below shows the difference between the number of buses in the disaggregated national model for the Highland Council Area and the number of vehicles identified through the verification process. As shown, 283 buses and coaches were identified, of which 178 are buses (130 single decker, 48 double decker) and 105 are coaches (all single decker).

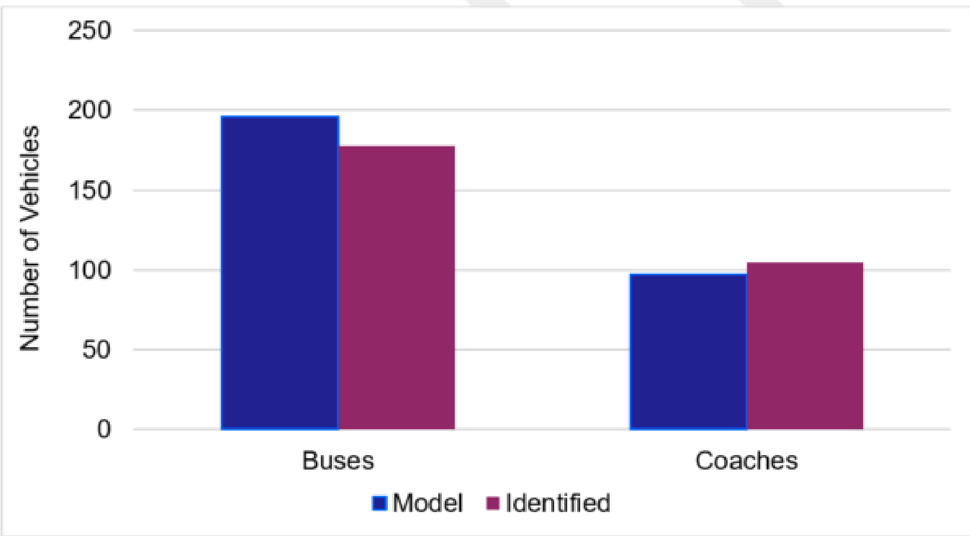


Figure 2 - Numbers of buses and coaches modelled versus identified through verification in the Highland region.

Since the figures are comparable, the disaggregated national model from TMfS:18 has been used to generate the hydrogen scenarios. This approach was adopted to ensure consistency across the road-based modes of transport.

2.1.2 Rail Transport Demand

There are five railway lines that are wholly or partly within the Highland Council area and none have been electrified to date, as shown in Figure 3 below - the highland routes include:

- The northern part of the West Highland line from near Rannoch to Fort William and Mallaig
- The northern part of the Highland Mainline from near Dalwhinnie to Inverness
- The western part of the Aberdeen to Inverness Railway line from between Forres and Nairn to Inverness
- Far North lines from Inverness to Wick / Thurso and to Kyle of Lochalsh.

The West Highland line services within the Highland Council area equates to approximately 23% of all service mileage. Approximately 18% of the Aberdeen to Inverness railway line lies within the Highland Council area.

In 2019/20, ScotRail Diesel Multiple Units operated 1.273 million vehicle miles on the Far North Line to Wick / Thurso, 0.434 million vehicle miles on the route from Inverness to Kyle of Lochalsh and 1.786 million vehicle miles on the West Highland Line services to Oban, Fort William and Mallaig.

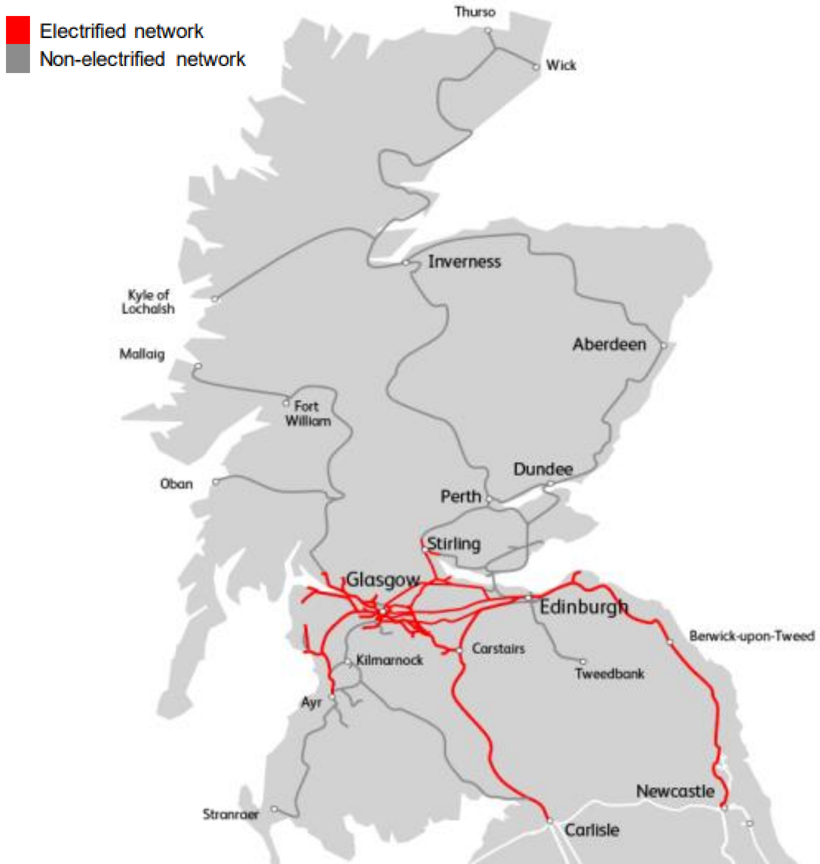


Figure 3 - Map showing railway electrification in Scotland, 2020, adapted from [Rail Services Decarbonisation Action Plan](), page 39.

To determine the rail transport demand for the Highland council area, the accompanying ***Zero Emission Energy for Transport: National Demand Forecasts for Electricity and Hydrogen*** outlines the bottom-up approach adopted. This process relied on route-based data provided by rail operators (including ScotRail) and outlines that rail service demand is expected to remain constant from 2030 in the Highland Council area.

This regional study builds on this national approach, taking the existing route data and estimating the proportion (expressed as a percentage) of annual rail trip kilometres that traverses the Highland Council area. A summary of the services operating on each railway line are detailed below:

Aberdeen to Inverness

The current ScotRail timetable for the Aberdeen to Inverness Railway provides for 11 trains per day in each direction between Aberdeen and Inverness. In addition, there are five trains per day in each direction that operate between Inverness and Elgin, 26 trains per day in each direction between Aberdeen and Inverurie along with one train per day between Aberdeen and Huntly, and one train per day between Aberdeen and Dyce.

North Highlands

The current ScotRail timetable for the North Highlands, provides for four trains per day in each direction between Inverness and Kyle of Lochalsh and four trains per day in each direction between Inverness and Wick / Thurso. There are a further four trains per day in each direction that only operate on the southern part of this route and these trains from Inverness terminate at Dingwall, Invergordon, Tain and Ardgay. These trains provide additional opportunities for travel to and from Inverness.

West Highlands Line

The current ScotRail timetable for the West Highland Line provides for six trains per day between Glasgow and Oban in each direction and three trains per day between Glasgow, Fort William and Mallaig in each direction with the Mallaig bound trains coupled to the rear of the Oban services as far as Crianlarich. There is one additional return service between Fort William and Mallaig, which leaves Fort William in the morning and returns to Fort William from Mallaig in the evening. A late afternoon service also operates in each direction between Oban and Dalmally to cater for local demand.

Highland Mainline

The current timetable for the Highland Mainline provides nine services in each direction between Inverness and Perth, Glasgow or Edinburgh. Eight of these services are operated by ScotRail with one service operated by London North Eastern Railway (LNER).

2.1.3 Maritime Transport Demand

Shipping

The UK Department for Transport: Maritime and Shipping provides data on tonnes of cargo handled at each port in Scotland. In total, Highland Council area represents circa 4% of all tonnes handled at Scottish ports in 2019 and 11% of all domestic tonnes. Cromarty Firth is the major cargo port within the Highland Council area. It handled 926,000 tonnes of cargo in 2019, including 383,000 classified as international - representing 40% of the cargo traded in the region.

There are also seven other cargo ports within the region which represent significant percentages of traded cargo, including: Corpach (9%), Gill's Bay Scotland (3%), Inverness (28%), Kyle of Lochalsh (1%), Scrabster (5%), Ullapool (13%) and Wick (1%). Additionally, there are six main fishing areas, including Kinlochbervie (15%), Lochinver (23%), Mallaig (5%), Portree (3%), Scrabster (16%) and Ullapool (23%).

According to the 2019 Scottish Sea Fisheries Statistics, transport demand from fishing activities within the Highland Council area were responsible for approximately 19% of the total fish tonnage handled at Scottish ports This fishing tonnage within the Highland region has shown a relatively flat trend between 2015 and 2019, going from 55,732 tonnes to 55,975 tonnes.

Figure 4 below shows ports in the Highland region have experienced growing demand between 2015 and 2019, albeit with a reduction of circa 30% in 2020 due to the global economic repercussions of the Covid-19 pandemic. Nevertheless, oil and gas continue to represent a significant part of the total cargo volumes at some of the ports (Inverness, Kyle of Lochalsh and Wick).

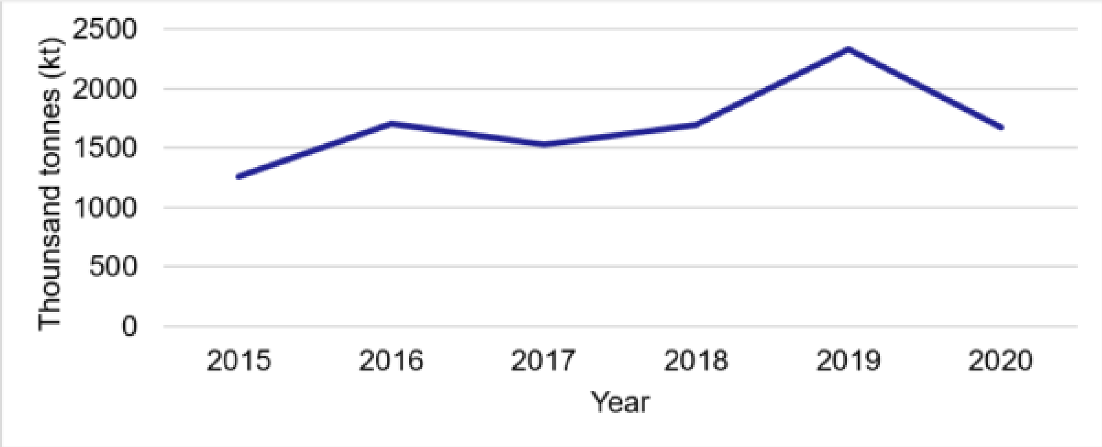


Figure 4 - Thousand tonnes handled at cargo ports in the Highland Council area (2015-2020)

In terms of methodology to establish transport demand for shipping, the same approach as for the accompanying ***Zero Emission Energy for Transport: National Demand Forecasts for Electricity and Hydrogen*** report with some adjustments of assumptions to make them applicable at a regional level. For example, the national 2019 CO2e from the maritime sector has been disaggregated down to the percentage of tonnes to represent each port in the Highland Council area proportionally, using the below equation:

$$Port\ A\ CO2e = Total\ CO2e * \frac{Tonnes\ Port\ A}{Tonnes\ all\ Scotland}$$

In addition, the total emissions by port for the region have been split between domestic and international to understand the different categories of potential demand for hydrogen in both domestic and international shipping markets in the future.

Finally, the future growth of transport demand at each port has been forecast based on the specific type of cargo that is being handled at each port within the Highland Council area. Data sources for these forecasts were obtained from DfT for major ports, while UK Ports and Harbours information was used to ascertain projected demand for minor ports. Aligned with these sources, oil and gas cargo, which represents the greatest proportion of transport demand for shipping in the region is assumed to decline at a rate of approximately 2% annually to 2045.

Despite this, oil and gas related transport demand is still expected to continue at some ports (Cromarty Firth, Inverness, Kyle of Lochalsh, Scrabster and Wick) in the period before 2045. Due to the uncertainty regarding changes to this industry’s transport demand over time, it has been considered out of the scope for this study to alter this transport demand forecast.

For the fishing ports, the forecast of tonnage has been based on the historical tonnage growth observed during the last 5 years and the same trend has been assumed to continue.

Ferries

For the purposes of this study, it is assumed that a ferry service is only operational if there is sufficient demand for the service and, therefore, transport demand can be inferred based on the existing timetabled ferry services.

The accompanying ***Zero Emission Energy for Transport: National Demand Forecasts for Electricity and Hydrogen*** report details the methodology Jacobs used to construct a dataset including information on the 150 ferry routes currently operational in Scotland. This dataset included individual journey length, journey times and journey frequency, along with the characteristics of the primary vessel operating the route. This dataset has been relied upon for this regional study of the Highland Council area.

Of the 150 ferry routes identified for the dataset, 33 have at least one port located in the Highlands Council area. These ports are primarily located along the West or North-West coasts of Scotland. Mallaig is the most regularly frequented port for ferries, with six of the 33 routes docking at the port, while three of the 33 ferry routes identified dock in Mull (Tobermory). Of the routes located in the Highlands Council area, 16 are operated by CalMac ferries – making it the largest operator. No other ferry operator runs more than four services within the region

To validate the datasets constructed in the accompanying ***Zero Emission Energy for Transport: National Demand Forecasts for Electricity and Hydrogen*** report for the local region, operators were contacted to confirm the publicly sourced information. These information requests asked for details on ferry timetables, plans for vessel replacement and the likely powertrain type of these replacements. Information requests were sent to the operators listed in Table 1, with responses received from Western Isles Cruises and Skye Ferry. The responses confirmed the validity of the constructed datasets for these smaller fleets; however, they did not include details on the current plans for vessel replacement.

Of the routes identified in Table 1 below, the two longest routes are Mallaig - South Uist (93.1km) and Ullapool - Lewis (82.2km). All other routes are under 50km in length. In consultation with Transport Scotland, it has been assumed that the distance travelled per annum by each of the vessels remains constant between 2019-2045.

Operator	Number of routes operated	Number of Vessels	Estimated annual distance travelled (km)
CalMac	16	7	734,423
Pentland Ferries	1	1	70,457
Northlink Ferries	1	1	51,915
Knoydart Seabridge	4	1	37,987
John O'Groats	1	1	18,246
Highland Ferries	2	2	13,899
Highland Council	1	1	9,815
Ardnamurchan	2	2	7,440
Skye Ferry	1	1	6,116
Handa Ferry	1	1	4,089
Arisaig Marine	1	1	3,979
Scoraig Ferry	1	1	1,187
Cape Wrath Ferry	1	1	151

Table 1 - Characteristics of ferry operators in the Highlands Council area

2.1.4 Aviation Transport Demand

The transport demand for the Highland Council area is based on the number of scheduled commercial aircraft movements. These movements have been split between international, UK domestic and Scottish domestic, which has been the key difference between the regional forecasting and the method used in the accompanying ***Zero Emission Energy for Transport: National Demand Forecasts for Electricity and Hydrogen*** report.

In the Highland area, there are two airports with reported data on scheduled commercial movements: Inverness (Figure 5) and Wick John O'Groats (Figure 6) airports. Demand for 2019 and 2020 is based on data from the CAA, while the demand for 2021 and 2022 is based on scheduled services from OAG - as there is no data available from the CAA. Demand coming from non-commercial flights (e.g., military movements or aero-club movements) has not been considered within this study.

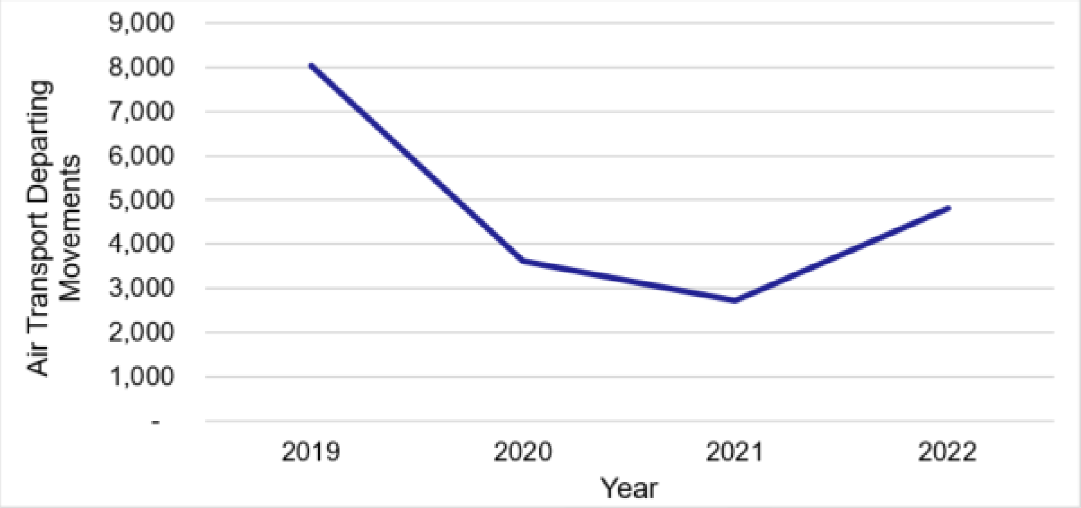


Figure 5 - Air Transport Departing Movements - Inverness Airport (2019 - 2022)

Inverness Airport

Inverness is the fourth busiest airport in Scotland in terms of scheduled commercial movements. In 2019, the airport handled 16,065 air transport movements. From 2020 to 2021, due to the impact of Covid-19, movements were reduced by 55% in 2020 and a further 25% in 2021. The first signs of recovery are shown in the scheduled movements for 2022.

Inverness airport has a range of scheduled services throughout the United Kingdom as well as scheduled services to Europe. Approximately 50% of the traffic in 2019 was international, 45% to the UK and approximately 5% within Scotland. Narrow body and regional aircraft account for approximately 70% of all the fleet operating at Inverness Airport, with the remaining 30% being large turboprops.

Wick John O'Groats Airport

Wick John O'Groats is a regional airport that used to provide connection for Caithness, with scheduled services to Aberdeen Airport and Edinburgh Airport. Loganair and Eastern Airways were the two airlines operating on these routes, however, in 2020 both revoked its services, leaving the airport with no scheduled services.

The Scottish Government announced on February 2021 that they would provide funding to the Highland Council to reinstate flights to and from Wick Airport. From April 11th 2022, Eastern Airways will resume services from Wick to Aberdeen. The service will operate up to twice daily each way on weekdays and Sundays. This is reflected on the data for 2022, which shows an increase on the demand from 2021.

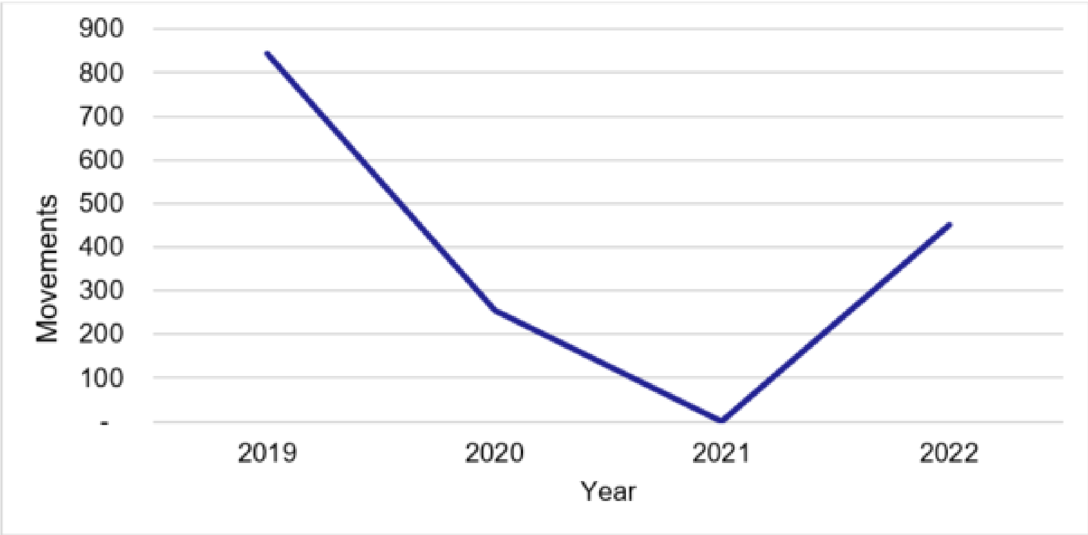


Figure 6 - Air Transport Departing Movements - Wick John O'Groats Airport (2019 - 2022)

Demand at Wick Airport is purely Scottish domestic and served by turboprops, a 60% of them being small turboprops and the remaining 40% large turboprops.

2.2 Hydrogen Transition Scenarios

Three technology transition scenarios have been developed for the purposes of forecasting future hydrogen energy demand for transport in the Highland Council area specifically, they include:

- A (Low) transition to hydrogen transport
- B (Medium) transition to hydrogen transport
- C (High) transition to hydrogen transport

Although there are plans for hydrogen hubs to become operational in Cromarty Firth (2024), Stornoway (2024), Orkney (2027), Fife as well as Ayrshire the impact of localised hydrogen hubs has not been considered within the hydrogen transition scenarios of this study. This is because the purpose of this study is to model potential demand, rather than consider potential limitations or availability of hydrogen-related infrastructure.

The following sections describe the key assumptions for each of the three scenarios for each transport mode. Unless specified below, the scenarios are consistent with the national technology transition scenarios the accompanying ***Zero Emission Energy for Transport: National Demand Forecasts for Electricity and Hydrogen*** report:

2.2.1 Road Transition

Cars and Vans

The methodology for cars and vans hydrogen transition assumes no regional specific transition drivers, with instead, the impetus for transition occurring at a national aligned to the accompanying ***Zero Emission Energy for Transport: National Demand Forecasts for Electricity and Hydrogen*** report – with legislated zero emission vehicle requirements driving the uptake of both electric and hydrogen.

As such, the transition to hydrogen and the subsequent demand for hydrogen will be driven in large part by market forces. This will be analogous to the current situation in Electric Vehicle (EV) uptake - where the general purchase of EVs is not driven by specific regional mechanisms of transition, but rather a broader desire to switch to hydrogen.

It should be noted that hydrogen for cars and vans is currently a very uncertain market, with the distinct possibility that Scenario A (low hydrogen) will represent a zero uptake. This is because transition to hydrogen is currently lagging behind EV uptake by at least 10 years and will face a different marketplace in the future - with no environmental benefits over EV driving uptake. However, for the purposes of the study, the trajectory of hydrogen vehicle uptake for cars and vans is assumed to follow TMfS:18 demand figures, leading to a peak in the total number of hydrogen vehicles purchased as a proportion of all ULEV vehicles by approximately 2035.

Due to the uncertainties around the use of hydrogen technology for cars and vans, the hydrogen uptake figures in the accompanying ***Zero Emission Energy for Transport: National Demand Forecasts for Electricity and Hydrogen*** report have been taken as the upper end of potential hydrogen transition scenarios.

- A (Low) transition to hydrogen transport: Cars and vans transition at 1/3 of the national rate of uptake.
- B (Medium) transition to hydrogen transport: Cars and vans transition at 2/3 of the national rate of uptake.
- C (High) transition to hydrogen transport: Cars and vans transition at the national rate of uptake.

These specific rates of uptake are shown in Table 2 to 6 below:

Vehicle Type	2022	2025	2030	2035	2040	2045
ICE	76.0%	60.4%	0.0%	0.0%	0.0%	0.0%
BEV	16.1%	34.0%	96.8%	94.8%	95.0%	99.3%
Hydrogen	0.1%	0.1%	1.1%	1.7%	1.7%	0.2%

Table 2 - Predicted new vehicle purchase rates for cars based on the TMfS:18 uptake for Scenario A (Low)

Vehicle Type	2022	2025	2030	2035	2040	2045
ICE	76.0%	60.4%	0.0%	0.0%	0.0%	0.0%
BEV	11.9%	24.0%	70.2%	94.8%	95.0%	99.3%
Hydrogen	0.1%	0.2%	2.1%	3.4%	3.3%	0.5%

Table 3 - Predicted new vehicle purchase rates for cars based on the TMfS:18 uptake for Scenario B (Medium)

Vehicle Type	2022	2025	2030	2035	2040	2045
ICE	76.0%	60.4%	0.0%	0.0%	0.0%	0.0%
BEV	7.6%	14.0%	43.5%	94.8%	95.0%	99.3%
Hydrogen	0.2%	0.3%	3.2%	5.2%	5.0%	0.7%

Table 4 - Predicted new vehicle purchase rates for cars based on the TMfS:18 uptake for Scenario C (High)

Vehicle Type	2022	2025	2030	2035	2040	2045
ICE	87.6%	73.3%	0.0%	0.0%	0.0%	0.0%
BEV	3.0%	6.5%	21.8%	99.0%	99.1%	99.7%
Hydrogen	0.1%	0.0%	0.9%	1.0%	0.9%	0.3%

Table 5 - Predicted new vehicle purchase rates for vans based on the TMfS18 uptake for Scenario A (Low)

Vehicle Type	2022	2025	2030	2035	2040	2045
ICE	87.6%	73.3%	0.0%	0.0%	0.0%	0.0%
BEV	6.2%	13.1%	48.6%	97.9%	98.2%	99.5%
Hydrogen	0.1%	0.1%	1.7%	2.1%	1.8%	0.5%

Table 6 - Predicted new vehicle purchase rates for vans based on the TMfS18 uptake for Scenario B (Medium)

Vehicle Type	2022	2025	2030	2035	2040	2045
ICE	87.6%	73.3%	0.0%	0.0%	0.0%	0.0%
BEV	9.3%	19.6%	75.4%	96.9%	97.3%	99.2%
Hydrogen	0.2%	0.1%	2.6%	3.1%	2.7%	0.8%

Table 7 - Predicted new vehicle purchase rates for vans based on the TMfS18 uptake for Scenario C (High)

Buses and Coaches

The accompanying ***Zero Emission Energy for Transport: National Demand Forecasts for Electricity and Hydrogen*** report developed six technology transition scenarios. However, for the purposes of modelling future hydrogen demand in the Highland Council area a simplified three scenarios for hydrogen technology uptake have been selected for buses and coaches (as outlined in Section 1.1).

The selection of three scenarios for buses and coaches has been informed by the validation exercised conducted as described in Section 2.1.1 which identified current trends in the Highland Council area (allowing more precision than the average national forecast of technology transition scenarios). These trends included:

- 5 fully electric single decker buses already operating in Inverness
- No existing hydrogen buses or coaches have been identified in the region

- Stagecoach have been awarded ScotZEB funding for a further 25 electric buses
- No hydrogen buses have been funded in this round.

The scenarios which have been carried forward are those which are consistent with these observations.

Scenario	Description	No. of buses	No. of coaches
A (Low)	High take-up of electric vehicles leaves little market for hydrogen	0	0
B (Medium)	Moderate take-up of electric vehicles occurs with a high price for fuel cells	0	0
C (High)	Moderate take-up of electric vehicles occurs with a lower price for fuel cells	2	1

Table 8 - Hydrogen bus and coach numbers 2023

Based on the same modelling technique as the national model these three scenarios indicate no hydrogen vehicles in 2023 in the low and medium hydrogen scenarios and only one or two of each in the high scenario. These results take into account that no hydrogen vehicles are known to have been ordered so far in the Highland Council area.

HGVs and HDVs

Similar to cars and vans, the hydrogen transition for HGVs assumes no regional specific transition drivers, with instead, the impetus for transition occurring at a national level with the zero emission vehicle requirements pushing an overall change to both electric and hydrogen.

However, unlike the cars and vans transition, it is possible that the transition to hydrogen will be driven by potential inability of electric to meet the HGV needs in either an ergonomic or economic sense. EV HGVs would require exceptionally large batteries plus an infrastructure with greater than 350kW charge points. This an order of magnitude more than cars or vans requirements.

The predicted uptake rates for HGVs have been specified within the report for the Climate Change Committee: *Analysis to provide costs, efficiencies, and roll-out trajectories for zero emission HGVs, buses and coaches*.

Vehicle Type	2022	2025	2030	2035	2040	2045
ICE	100%	100%	80%	9%	0%	0%
BEV	0%	0%	17%	77%	82%	82%
Hydrogen	0%	0%	3%	14%	18%	18%

Table 9 - purchase rates of HGV vehicle types for Scenario A (Low)

Vehicle Type	2022	2025	2030	2035	2040	2045
ICE	100%	100%	80%	9%	0%	0%
BEV	0%	0%	12%	46%	62%	71%
Hydrogen	0%	0%	7%	46%	38%	29%

Table 10 - purchase rates of HGV vehicle types for Scenario B (Medium)

Vehicle Type	2022	2025	2030	2035	2040	2045
ICE	100%	100%	80%	9%	0%	0%
BEV	0%	0%	13%	47%	57%	54%
Hydrogen	0%	0%	7%	45%	43%	46%

Table 11 - purchase rates of HGV vehicle types for Scenario C (High)

In all scenarios, we can see the rapid drop off in the purchase rates of ICE HGVs from 2030, with the subsequent replacement by either BEV or ICE.

2.2.2 Rail Transition

The *Rail Services Decarbonisation Action Plan* *(RDAP)* sets out the Scottish Government's intention to decarbonise the rail network by 2045, as shown in Figure 7 below. The RDAP has been relied upon exclusively in this study to determine the hydrogen transition scenarios for rail in the Highland Council area, which include different combinations of electrification and alternative traction solutions for the region.

To align with the RDAP, all hydrogen technology transition scenarios assume overhead electrification of the Highland Mainline to facilitate freight trains to Inverness by 2035. Additionally, the timing of rolling stock introductions and future fuel assumptions on each Highland Council area route align with the scenarios already outlined in the accompanying ***Zero Emission Energy for Transport: National Demand Forecasts for Electricity and Hydrogen*** report.

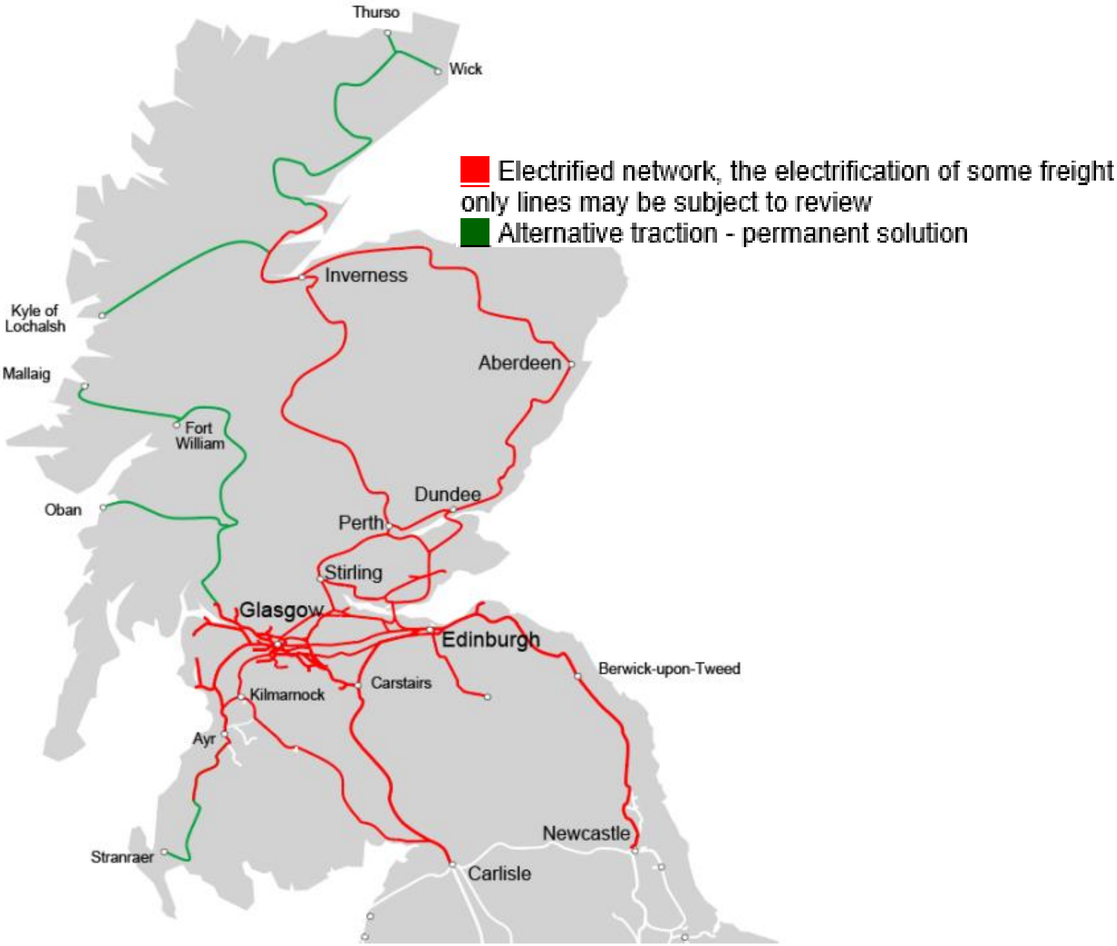


Figure 7 - Map showing decarbonised rail network in Scotland, 2045, modified from [Rail Services Decarbonisation Action Plan](), page 41

Whilst there are three hydrogen technology transition scenarios A (Low), B (Medium) and C (High) for this study, there are only two scenarios which are able to be differentiated for rail in the Highland Council area, which is determined by the technology transition on the Aberdeen to Inverness line. The North Highland and West Highland lines are assumed to transition to hydrogen under all scenarios, as shown in Table 12 below:

Hydrogen Scenario	Assumptions
A (Low)	• Hydrogen trains introduced on the Far North (2028 to Wick and 2029 to Kyle of Lochalsh • Hydrogen trains introduced on the West Highland (2030)
B (Medium)	• Hydrogen trains introduced on the Far North (2028 to Wick and 2029 to Kyle of Lochalsh • Hydrogen trains introduced on the West Highland (2030) • Hydrogen trains introduced between Aberdeen and Inverness (2035)

Hydrogen Scenario	Assumptions
C (High)	• Hydrogen trains introduced on the Far North (2028 to Wick and 2029 to Kyle of Lochalsh • Hydrogen trains introduced on the West Highland (2030) • Hydrogen trains introduced between Aberdeen and Inverness (2035)

Table 12 - Forecast transition to hydrogen for rail services

Aberdeen to Inverness

Although the Scottish Government aspires to electrify the route between Aberdeen and Inverness by 2045 (as shown in Figure 7) it is possible that alternative traction on this route will be required to meet the 2035 deadline for decarbonisation of Scotland's passenger rail services. On that note, the *RDAP* acknowledges that other options include both partial electrification and/or the use of alternative technology. Hydrogen is therefore considered as the preferred traction fuel under the medium and high technology transition scenarios modelled.

North Highland and West Highland

According to the *RDAP*, hydrogen is considered to the most likely permanent traction power source on both the Far North Lines to Wick / Thurso and Kyle of Lochalsh and on the West Highland Lines from Glasgow Queen Street to Oban, Fort William and Mallaig. This is because a hydrogen fuel cell train can typically operate over longer non-electrified routes than a train with battery traction. This is assumed for all future scenarios: low, medium, and high.

2.2.3 Maritime Transition

Shipping

The hydrogen transition scenarios are based on the accompanying ***Zero Emission Energy for Transport: National Demand Forecasts for Electricity and Hydrogen*** scenarios but adjusted based on the specific ambitions for the Highland Council area for hydrogen production and demand.

Cromarty Firth is a planned future hydrogen hub within the Highland Council area. The North of Scotland masterplan programme aims to develop a state-of-the-art hub in Cromarty Firth to produce, store and distribute green hydrogen at scale to the region, Scotland, other parts of the UK and Europe.

Through the programme, Scottish Power would build a 35MW electrolyser capable of producing up to 14 tonnes of green hydrogen a day by 2024 to meet local and distillery demands. But could also be expanded to meet growing demand, both at home and abroad. The port also has plans to develop hydrogen refuelling infrastructure, which will be available to ships and landside operations.

Cromarty Firth has potential access to a large amount of offshore wind energy supply, which is a key factor for green hydrogen production. Therefore, to reflect both the intention and potential of the Highland Council area to become a hydrogen hub, the potential uptake has been assumed to be higher than the national average:

	High (% by 2045)	Medium (% by 2045)	Low (% by 2045)
National Hydrogen Uptake - Domestic	71%	38%	19%
National Hydrogen Uptake - International	50%	30%	8%
Regional Hydrogen Uptake - Domestic	100%	71%	38%
Regional Hydrogen Uptake - International	80 – 100%*	50%	30%

Table 13 - Comparison of the hydrogen penetration rates by 2045 for the high, low and medium scenarios

* From literature review, the following ports are assumed to be 100% hydrogen by 2045 in the high scenario: Cromarty Firth, Wick, Scrabster and Inverness.

Ferries

Although there are no hydrogen ferries currently in service, projects around the world are designing and testing hydrogen vessels including HYSEAS III in Scotland, MF Hydra in Norway, and Sea Change in California. Regardless, it can be assumed the technology is not currently available to many ferry operators in the Highlands Council area. By contrast, battery electric ferries have already become operational across the world most notably in Scandinavia where Norway has been growing its electric fleet since 2015. The world's largest electric ferry, the 143 metre-long Bastø Electric, is now commercially operational. However, there are range limitations of battery technology, due to the size and weight of batteries required. As a result, alternative fuels such as hydrogen will need to be used for longer routes.

The hydrogen scenarios developed for the Highland Council area built on the route-based dataset and methodology developed for the accompanying ***Zero Emission Energy for Transport: National Demand Forecasts for Electricity and Hydrogen*** report. Like these national forecasts, a transition profile was developed for each ferry route in the Highland Council area. This profile estimated the year of vessel replacement and likely replacement fuel-type for each route. The modelled rate of uptake of hydrogen ferries is dependent on the maturity of hydrogen powertrains in the expected year of replacement.

In addition to hydrogen powertrain maturity, the range and performance of the predominant competing technology (battery electric vessels), would also influence future hydrogen ferry uptake. For this reason, and considering the elements above, the replacement fuel type was dependent not only on the route length, but also projected battery energy density, estimated year of replacement, and technological readiness of hydrogen in that year. This is a development from the national scenarios, where only route length was considered when assigning replacement fuel type. Due to the uncertainty around the future maturity of hydrogen powertrains, three possible hydrogen transition scenarios have been modelled, as described in Table 14 below:

Hydrogen Scenario	Lifetime (years)	Year of Hydrogen Readiness	Hybrid	Hydrogen Characteristics
A (Low)	25 + 5	2030	Yes (2022-2029)	Replacements occur up to 30 years after commissioning. Hydrogen is not viable until 2030. Replacements before 2030 are battery electric or hybrid.
B (Medium)	25	2025	Yes (2022-2025)	Replacements occur 25 years after commissioning. Hydrogen not viable until 2025. Replacements before 2025 will be battery electric or hybrid.
C (High)	25	2022	No	Replacements occur 25 years after commissioning. Hydrogen is ready to be utilised now (no technological readiness or supply side restrictions). No hybrid ferries.

Table 14 - Characteristics of the three modelled uptake scenarios

Key notes on the scenarios outlined above:

- All three scenarios assume a 'medium' battery electric range. During model development, it became apparent that varying the battery electric range by up to 50% scarcely affected the energy demand forecasts
- The location of specific hydrogen hubs has not been considered for any scenario.
- Vessel replacements are assumed to be either battery electric, hydrogen, or electric-diesel hybrid. Hybrid vessels are assigned in situations where battery electric technology is not viable (e.g. the route length is too great), and the year of hydrogen viability is deemed to be after the necessary replacement year.
- The replacement year of each vessel is based on its year of construction and the assumed operational lifespan of ferries. For scenarios B and C, it is assumed that ferries have a lifespan of 25 years and must be replaced in their 26th year. It is assumed that each vessel is replaced midway through the 26th year, so hydrogen demand is halved for the year of introduction (assuming six-months of operation).
- For Scenario A, it is assumed that a vessels lifespan can be extended for up to an additional 5 years (to 30 years) if it enables a direct transition to hydrogen (rather than the use of a hybrid powertrain). For example, if a vessel is due to be replaced in 2028, but hydrogen technology is not assumed to be viable until 2030, the replacement date can be extended by two years to ensure the vessel can transition to hydrogen rather than the hybrid diesel-electric powertrain that would otherwise be assumed.
- A 25–30 year lifespan is a conservative estimate of the actual operational lifespan of Scottish ferries. Ferries can operate for longer than 40 years. However, a 25–30 year lifespan has been assumed as this rate of replacement will be necessary to achieve the emission targets set by the Scottish Government.

Besides the methodology used to estimate the year of vessel replacement and assign an appropriate low emission replacement fuel type (as described above), the methodology is consistent with the accompanying ***Zero Emission Energy for Transport: National Demand Forecasts for Electricity and Hydrogen*** report, as described in Section 2.1.3.

2.2.4 Aviation Transition

There are no hydrogen aircraft currently in service, however, there are multiple projects around the world, including the UK, researching and designing hydrogen aircraft including FlyZero in UK, Project NAPKIN in UK, Zero Emission from Airbus or ZeroAvia.

Because the hydrogen scenarios developed for the accompanying ***Zero Emission Energy for Transport: National Demand Forecasts for Electricity and Hydrogen*** report were based on aircraft type and technology readiness, the same hydrogen scenarios have been considered for the Highland Council area.

Like these national forecasts, the key considerations to forecast hydrogen uptake were suitability of hydrogen compared to other replacement technologies and/or fuel types, readiness of hydrogen in that year compared to other technologies and/or fuel types and estimated life cycle of aircraft.

It should be noted that by 2045, the model does not make aviation Net Zero, as the use of Sustainable Aviation Fuels, which is expected to be one of the main fuels for long-range aircraft, is out of the scope of the study.

Additionally, Inverness Airport Master Plan 2020 does not contemplate a strategy to develop hydrogen infrastructure and the HIAL environmental strategy considers the usage of hydrogen for surface access only. Therefore, there was no solid evidence to support a higher hydrogen uptake for Inverness Airport than the uptake considered when building the national forecasts.

In addition, hydrogen uptake does not solely rely on the airport's strategy but on a series of factors, including but not limited to:

- Aircraft scrap rate adopted by the airlines
- Technology readiness
- Level of hydrogen infrastructure at airports at a national level

On the last point, it is important to highlight that a holistic approach for the development of hydrogen infrastructure at airports is required at a national level, as aircraft will need to be able to refuel at both ends (departure and arrival airports).

Due to the uncertainty around the future maturity of hydrogen powered aircraft, three possible hydrogen transition scenarios have been modelled, as described in the sections below.

Scenario A (Low)

Life cycle (years)

18: Regional and Turboprops

22: Narrow Body and Wide Body

Entry-into-Service (Year)

2035: Regional and Turboprops

2038: Narrow Body

2040: Wide Body

Hydrogen Characteristics

Retirement after 18 years for smaller aircraft and 22 years for Narrow Body and Wide Body aircraft. Hydrogen not viable until 2035 for smaller aircraft and 2038-2040 for long-range aircraft.

Scenario B (Medium)

Life Cycle (years)

15: Regional and Turboprops

20: Narrow Body and Wide Body

Entry-into-service (Year)

2032: Regional and Turboprops

2035: Narrow Body

2037: Wide Body

Hydrogen characteristics

Retirement after 15 years for smaller aircraft and 20 years for Narrow Body and Wide Body aircraft. Hydrogen not viable until 2032 for smaller aircraft and 2035-2037 for long-range aircraft.

Scenario C (High)

Life cycle (years)

15: Regional and Turboprops

20: Narrow Body and Wide Body

Entry-into-service (Year)

2030: Regional and Turboprops

2033: Narrow Body

2035: Wide Body

Hydrogen characteristics

Retirement after 15 years for smaller aircraft and 20 years for Narrow Body and Wide Body aircraft. Hydrogen not viable until 2030 for smaller aircraft and 2033-2035 for long-range aircraft.

3. Hydrogen Demand Forecasts

The following section describes the results of modelling of hydrogen demand forecasts for the Highland Council area. The forecasts have been calculated using localised transport demand and the hydrogen transition scenarios described in the preceding sections.

Additionally, the energy demand calculations for each transport mode are consistent with the calculations and assumptions described in the accompanying ***Zero Emission Energy for Transport: National Demand Forecasts for Electricity and Hydrogen*** report.

3.1 Road Results

3.1.1 Cars and Vans

Across the results for cars and vans, there is expected to be a limited take up of hydrogen technology for cars and vans until 2035. Compared to the national results of accompanying ***Zero Emission Energy for Transport: National Demand Forecasts for Electricity and Hydrogen*** report – cars represent 19% of the regional hydrogen demand, compared to 7.6% of the national hydrogen demand. While for vans, it is 1.9%, compared to 1.4% in the national hydrogen demand, indicating that a greater proportion of the hydrogen demand in the Highland Council area will be driven by cars. This is likely due to the large, scattered population (excluding Inverness) with relatively few concentrated centres of employment which typically drive van and LGV uptake.

Scenario A (Low)

Vehicle Type	2022	2025	2030	2035	2040	2045
Cars	0.2	0.3	1.1	5.2	10.9	13.6
Vans	0.0	0.0	0.1	0.5	0.8	0.9

Table 15 - Hydrogen demand for cars and vans for low hydrogen scenario

In Scenario A, cars will require 13.6 GWh by 2045, with vans requiring 0.9 GWh.

Scenario B (Medium)

Vehicle Type	2022	2025	2030	2035	2040	2045
Cars	0.2	0.5	2.0	10.1	21.2	26.5
Vans	0.0	0.0	0.2	1.0	1.5	1.9

Table 16 - Hydrogen demand for cars and vans for medium hydrogen scenario

In Scenario B, cars will require 26.5 GWh by 2045, with vans requiring 1.9 GWh.

Scenario C (High)

Vehicle Type	2022	2025	2030	2035	2040	2045
Cars	0.3	0.7	2.9	14.9	31.3	38.9
Vans	0.0	0.1	0.4	1.4	2.3	2.8

Table 17 - Hydrogen demand for cars and vans for high hydrogen scenario

In Scenario C, cars will require 38.9 GWh by 2045, with vans requiring 2.8 GWh.

The spatial distribution of hydrogen demand for cars and vans is shown in Section 6.

3.1.2 Buses and Coaches

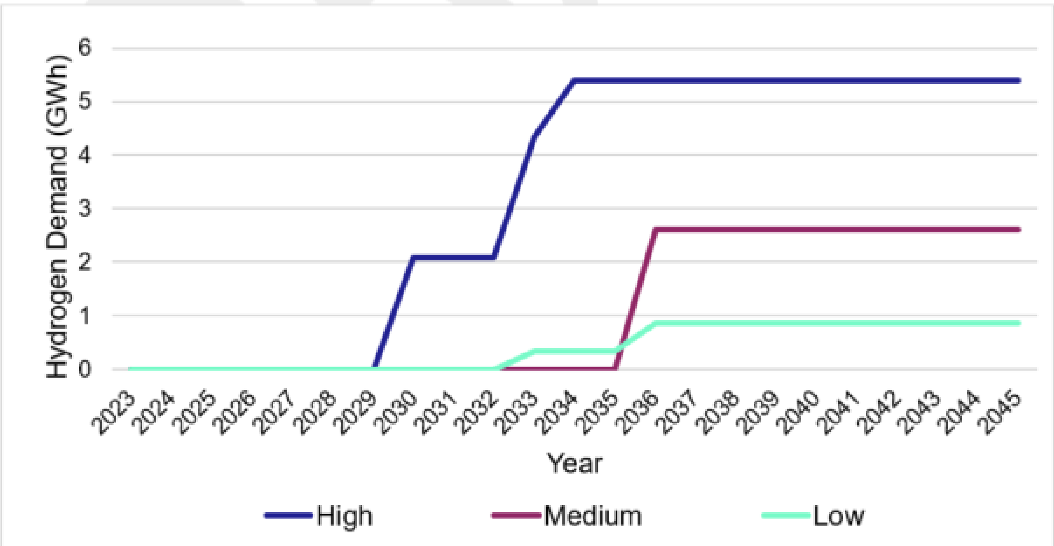


Figure 8 - Forecast hydrogen demand for buses

Figure 8 shows the high, medium and low scenarios for the demand for hydrogen over time, based on approximating the rate of growth in the model with a series of step changes representing small fleets of hydrogen vehicles being introduced. The numbers of buses and coaches making up this demand is presented in the Appendix Table 25.

Scenario A (Low)

High take-up of electric vehicles leaves little market available for hydrogen. The low scenario indicates 2 hydrogen buses and 3 coaches at the peak. Introduction of buses has been shown in 2033, earlier than coaches which are shown in 2036, although in practice one operator might introduce a small fleet of both at the same time.

Scenario B (Medium)

Moderate take-up of electric vehicles occurs with a high price for hydrogen vehicles. The medium scenario indicates 9 buses and 6 coaches at the peak. Both are shown introduced from 2036.

Scenario C (High)

Moderate take-up of electric vehicles occurs with a lower price for hydrogen vehicles. The high scenario indicates 18 buses and 13 coaches at the peak. The buses are shown being introduced in two stages, with 12 in 2030 and another 6 in 2034. The 13 coaches are introduced in 2033.

Implications for hydrogen usage

A hydrogen hub is planned at Cromarty Firth which is within 20 miles of buses and coaches at Tain. Hydrogen for buses and coaches based in Fort William could be produced from the Lochaber hydroelectric plant.

3.1.3 HGVs and HDVs

The Highland forecasts for HGVs are shown in the following tables. Unlike cars and vans, there is no take up of hydrogen at all until 2030. This is a consequence of the technology transition scenarios. However, past 2030 there is an increasingly rapid take up of hydrogen in all scenarios, and particularly in the High and Medium hydrogen scenario. Hydrogen energy demand in these two scenarios is comparable to the total energy demand for electric HGVs.

Scenario A (Low)

Assumed to follow the low uptake rates for hydrogen, as specified within the report for the Climate Change Committee: *Analysis to provide costs, efficiencies, and roll-out trajectories for zero emission HGVs, buses and coaches*.

Scenario	Vehicle Type	2022	2025	2030	2035	2040	2045
A (Low)	HGV	0.0	0.0	3.5	8.9	15.6	20.8

Table 18 - Hydrogen demand for HGVs for low hydrogen scenario

In Scenario A, HGVs will require 20.8 GWh by 2045.

Scenario B (Medium)

Assumed to follow the medium uptake rates for hydrogen, as specified within the report for the Climate Change Committee: *Analysis to provide costs, efficiencies, and roll-out trajectories for zero emission HGVs, buses and coaches*.

Scenario	Vehicle Type	2022	2025	2030	2035	2040	2045
B (Medium)	HGV	0.0	0.0	7.6	26.1	41.5	47.7

Table 19 - Hydrogen demand for HGVs for medium hydrogen scenario

In Scenario B, HGVs will require 47.7 GWh by 2045.

Scenario C (High)

Assumed to follow the high uptake rates for hydrogen, as specified within the report for the Climate Change Committee: *Analysis to provide costs, efficiencies, and roll-out trajectories for zero emission HGVs, buses and coaches*.

Scenario	Vehicle Type	2022	2025	2030	2035	2040	2045
C (High)	HGV	0.0	0.0	7.7	25.5	42.2	53.7

Table 20 - Hydrogen demand for HGVs for high hydrogen scenario

In Scenario A, HGVs will require 53.7 GWh by 2045.

From comparison to the results of the accompanying ***Zero Emission Energy for Transport: National Demand Forecasts for Electricity and Hydrogen*** report, it can be seen that the regional forecasts for hydrogen broadly follow the national forecasts. However, the difference observed between vans and cars may also be observed here. The percentage of hydrogen within the Highland region is even lower than for vans. With the proportion of hydrogen at 78% of the regional totals, compared to 90% of the national totals. Similarly, to the result for vans, this is potentially due to limited large centres of employment or commerce, which drives the HGV origin totals under the TMfS18.

The spatial distribution of hydrogen demand for HGVs is shown in Section 6.

3.2 Rail Results

Scenario A (Low)

The Low scenario assumes Hydrogen trains running on the North Highland and West Highland lines by 2030, with no further Hydrogen trains introduced.

Scenario	2022	2025	2030	2035	2040	2045
A (Low)	0	0	27	27	27	27

Table 21 - Hydrogen demand for rail for low hydrogen scenario

In Scenario A, North and West Highland Services will require 27 GWh of hydrogen by 2030. Approximately 16 GWh would be required when the line from Inverness to Wick / Thurso converts (assumed in 2028) and this would increase to 22 GWh when the line from Inverness to Kyle of Lochalsh is assumed to convert to hydrogen. The Introduction of hydrogen to West Highland Line services in 2030 would then increase Hydrogen demand within the Highland Council area to 27 GWh.

Scenario B (Medium) and C (High)

The Medium and High scenarios assume Hydrogen trains running on the North Highland and West Highland lines by 2030, as with the Low Scenario, but that Hydrogen trains would also operate between Aberdeen and Inverness, which would increase the regional demand to 35 GWh.

Scenario	2022	2025	2030	2035	2040	2045
B (Medium)	0	0	27	35	35	35
C (High)	0	0	27	35	35	35

Table 22 - Hydrogen demand for rail for medium and high hydrogen scenarios

In Scenarios B and C, North and West Highland Services will require 27 GWh by 2030, as with Scenario A, but demand for hydrogen would increase to 35 GWh if Aberdeen to Inverness services switch to hydrogen fuel by 2035.

Implications for Hydrogen Usage for Rail

These estimates are based on route miles, but Network Rail's Traction Decarbonisation Network Strategy Interim Programme Business Case highlights that hydrogen powered trains have a predicted range of around 1,000 km and that it is expected trains would need to be refuelled roughly once every twenty-four hours, such as during overnight stabling.

As all multiple units operating on the Inverness to Wick / Thurso, Inverness to Kyle of Lochalsh and Inverness to Aberdeen routes all serve Inverness, Inverness is likely to be the main refuelling location. However, although all units are based at Inverness, units on the Far North Lines are stabled overnight at Kyle of Lochalsh, Ardgay, Tain and Wick to form the first services into Inverness each morning. For operational reasons, the ability to refuel multiple units at these stations may be desirable.

On the West Highland Line, it is perhaps likely that all multiple units are refuelled at a depot in Glasgow, in which case there would be no need for hydrogen supply for the West Highland line within the Highland Region. However, units on the West Highland Line are stabled at Oban and Mallaig, to form the first trains towards Glasgow and at Fort William to form the first train towards Mallaig each morning. For operational reasons, the ability to refuel multiple units at these stations may be desirable.

For scenarios B (Medium) and C (High) where Aberdeen to Inverness services are assumed to switch to hydrogen powered trains in 2035, the most logical locations for fuelling points would be the depots at Aberdeen and Inverness. However, although most of the units serving this route are based at Inverness, two units are stabled overnight at Elgin to form the first services towards Inverness, and two units are stabled overnight at Inverurie to form the first services towards Aberdeen. For operational reasons, the ability to refuel multiple units at these stations may also be desirable.

3.3 Maritime Results

3.3.1 Shipping

Shipping tonnes handled at Highland ports represent ca. 4% of the total tonnes handled at Scotland and therefore, hydrogen demand at these ports would be expected to be relatively low compared to other ports within Scotland. However, given that the Highland region is expected to be a hydrogen hub driven by its high offshore wind potential and proximity to Northern Europe, it has been considered that the hydrogen penetration rates are likely to be higher than the national average and consequently, the demand for hydrogen is likely to increase.

Figure 9 presents the hydrogen demand from the shipping sector for the high, medium and low scenarios. By 2045, the hydrogen demand from the Highland region is expected to represent between 13% to 19% of the national hydrogen demand depending on the scenario.

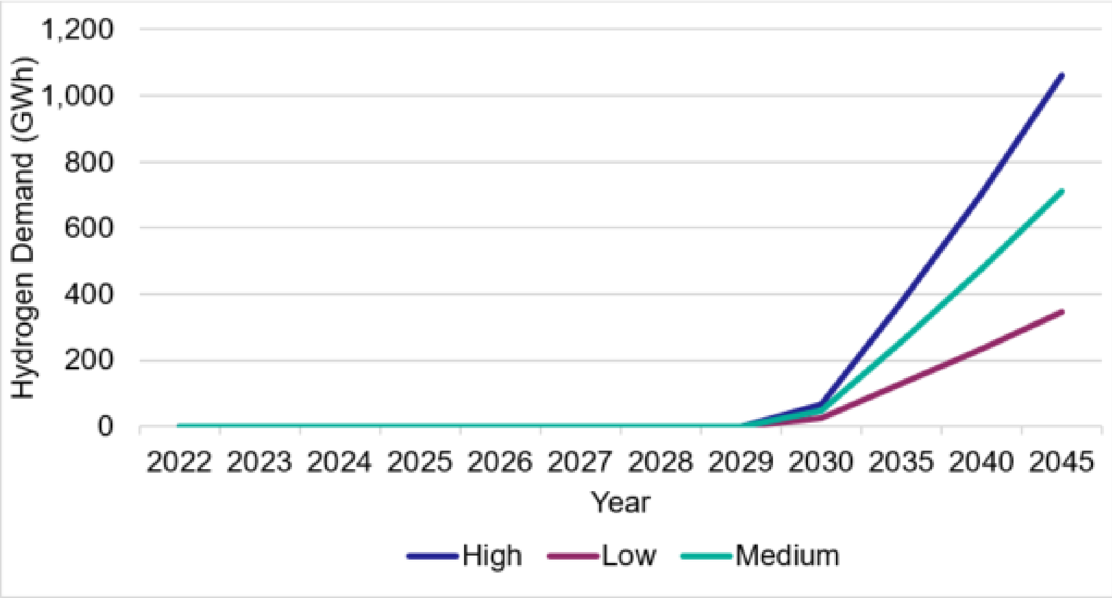


Figure 9 - Forecast hydrogen demand in the Highland Council Area

Although Cromarty Firth is currently the largest port within the Highland Council area, approximately 60% of its cargo is classified as '*Other General Cargo'* and, as per the tonnage forecasts published by the DfT, this category shows a downtrend at a rate of ca. 2% annually. This means that the total tonnage handled at Cromarty Firth is forecasted to decline at a rate of between 0.5% - 1% annually.

In addition, around 40% of the tonnage traded at Cromarty Firth is international and, due to the longer distances of international routes, it has been assumed that hydrogen penetration rates for international shipping will be lower than for domestic shipping.

On the other hand, Ullapool is a 100% Ro-Ro port. The forecasts for Ro-Ro cargo present an annual tonnage increase of between 2% - 3% up to 2045, which has driven the increase on the hydrogen demand for this port. In addition, Ullapool is an important fishing port, which has also increased the hydrogen demand for this port.

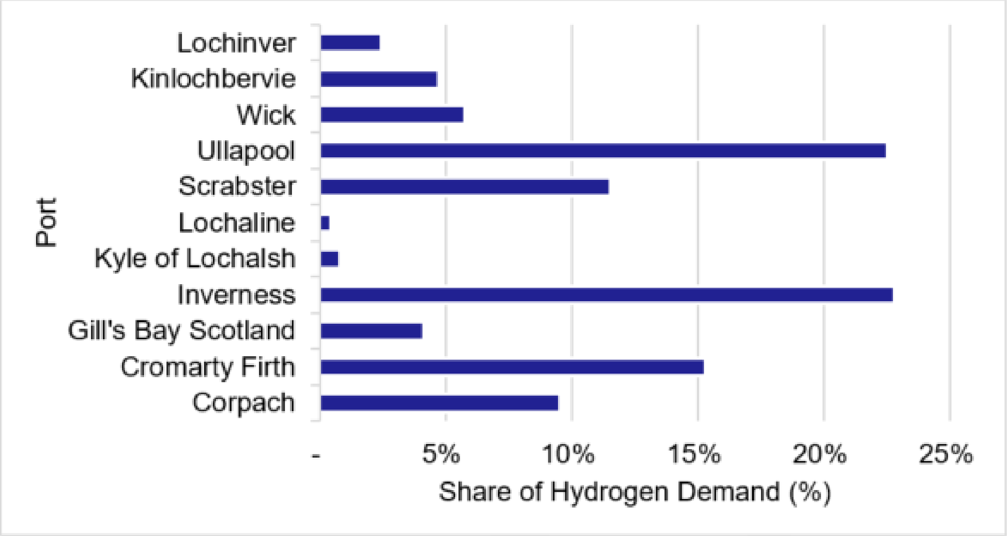


Figure 10 - Share of hydrogen demand by port (2045)

3.3.2 Ferries

The hydrogen demand forecasts for the Highland Council area vary significantly across the high, medium, and low uptake scenarios as a result of the different transition assumptions. Figure 11 illustrates the rate of conversion to hydrogen technology for each scenario, based on the cumulative number of vessels that have transitioned in each year.

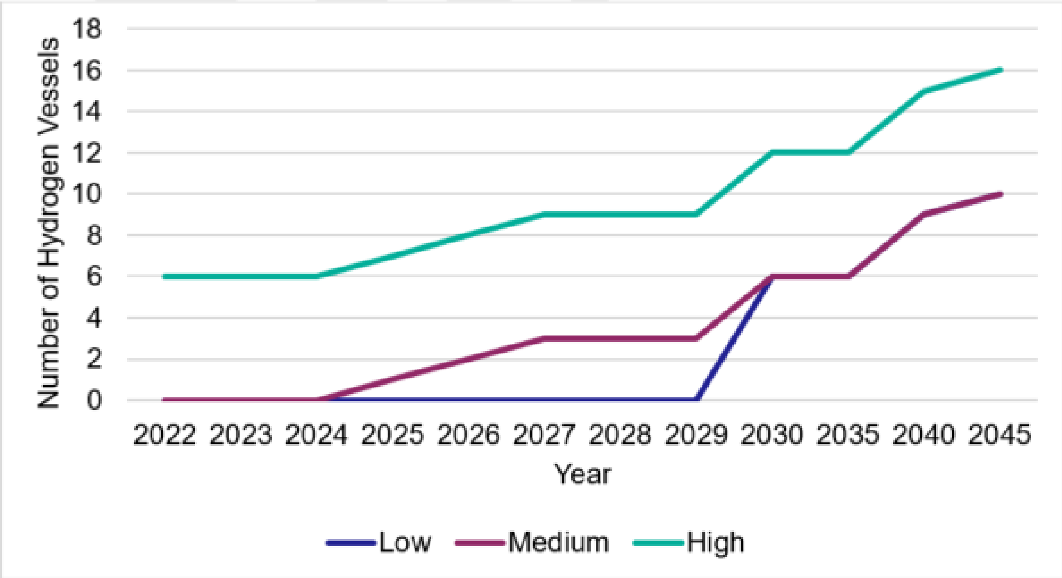


Figure 11 - Number of hydrogen vessels by year and scenario

While the year of transition differs in each scenario, it is assumed that MV Lochnevis, MV Hebrides, and MV Hamnavoe will be the earliest adopters of hydrogen in the Highlands region. These three ferries operate between Canna – Eigg – Mallaig – Rum, Skye – Harris – North Uist, and Scrabster – Stromness respectively.

MV Hebrides is expected to require the greatest quantity of hydrogen, with 22GWh of hydrogen per annum between 2027-2045 in the high and medium hydrogen scenarios. This route is not located near any of the proposed hydrogen hubs identified, but hydrogen supply is not considered to be a barrier.

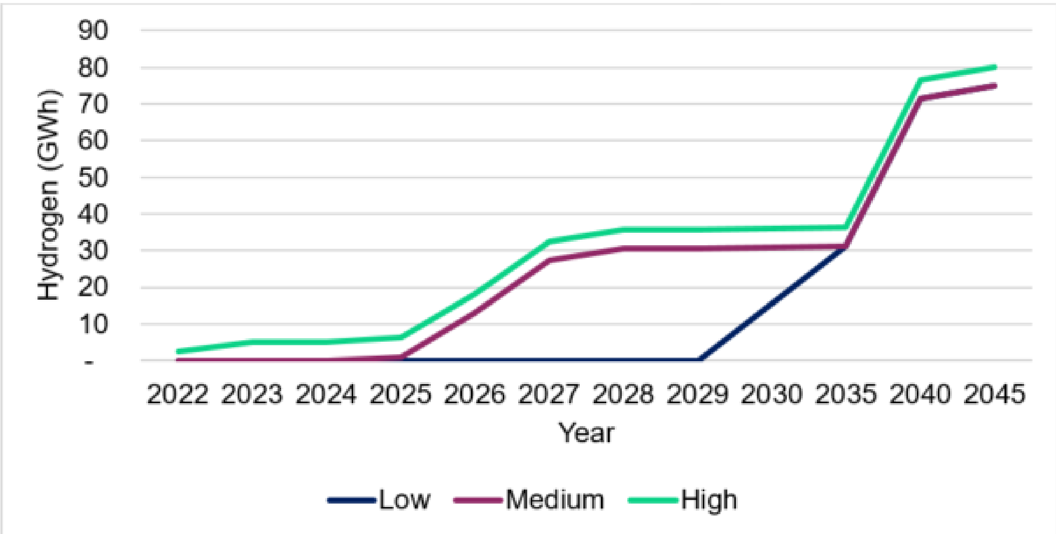


Figure 12 - Forecast hydrogen demand for the Highland Council Area

Figure 12 shows the estimated hydrogen demand for each scenario. Full data tables are included in Table 27 in the Appendix.

As with all regions in the study, replacement vessels are assumed to be introduced halfway through their introductory year (e.g. July), meaning hydrogen demand during the first year of operation is only 50%. Hydrogen demand is assumed to be 100% in the second year.

Scenario A (Low)

In the lowest hydrogen scenario, hydrogen vessels are first introduced in 2030, meaning hydrogen demand is zero between 2022 and 2029. Between 2030 and 2035 there is a rapid influx of 6 hydrogen vessels, resulting in an annual hydrogen demand of approximately 31 GWh by 2035. From 2035 to 2045 there are four more vessel replacements, which increases the fleet to 10 vessels and results in annual hydrogen demand increasing to approximately 75 GWh by 2045.

Scenario B (Medium)

In the medium hydrogen scenario, hydrogen vessels are introduced from 2025. From 2025 to 2027, there is one new hydrogen vessel introduced each year, resulting in a hydrogen demand increase from 1 GWh in 2025 to 31 GWh by 2028. This remains constant until 2030. Three more vessels are introduced in 2030 but these operate on small routes and therefore hydrogen demand increases by less than 1 GWh. From 2035, the medium scenario follows the same trajectory of the low scenario, culminating in 10 vessels and a demand of 75 GWh by 2045.

Scenario C (High)

The high scenario sees an instant introduction of six hydrogen vessels in 2022. Following this, the vessels added follow the same trajectory as the medium scenario; three vessels are added between 2025 and 2027, three more vessels are added in 2030, and the final four vessels are added between 2035 and 2045. By 2045 there are 16 hydrogen vessels total, which is six more than either the low or medium scenario in 2045. By 2045 there are 16 hydrogen vessels total, which is six more than either the low or medium scenario. In this scenario, hydrogen demand is approximately 6 GWh in 2025, 36 GWh in 2030, and 80 GWh in 2045.

3.4 Aviation Results

The accompanying ***Zero Emission Energy for Transport: National Demand Forecasts for Electricity and Hydrogen*** assumes that hydrogen is the most likely fuel for regional and narrow body aircraft and less relevant for turboprop aircraft as these are assumed to transition towards electrical aircraft.

Narrow body and regional aircraft account for approximately 70% of all the fleet operating at Inverness Airport and therefore, hydrogen demand at this airport is likely to be significant. For Wick Airport however, half of the movements are done by small turboprops, and therefore, hydrogen demand is expected to be low.

Hydrogen demand for Inverness and Wick airports is shown in Tables 23 and 24. These figures represent circa 4% of the national hydrogen demand by 2045.

Scenario	2030 [GWh]	2035 [GWh]	2040 [GWh]	2045 [GWh]
High	0.61	12.92	35.45	67.63
Medium	0.00	4.73	22.96	48.85
Low	0.00	0.35	8.96	26.45

Table 23 - Hydrogen demand for Inverness airport (GWh)

Scenario	2030 [GWh]	2035 [GWh]	2040 [GWh]	2045 [GWh]
High	0.01	0.08	0.16	0.28
Medium	0.00	0.04	0.10	0.18
Low	0.00	0.01	0.04	0.08

Table 24 - Hydrogen demand for Wick airport (GWh)

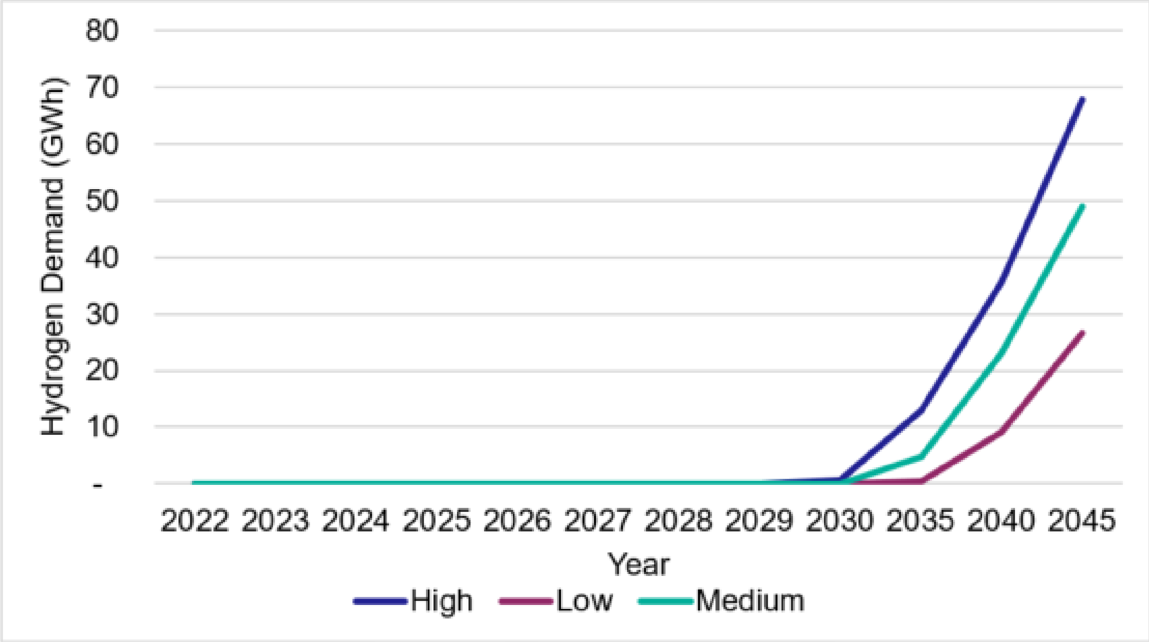


Figure 13 - Forecast hydrogen demand for the Highland Council area

Demand from international aviation represents 51% of the total hydrogen demand from the Highlands. UK Domestic represents 44% while the Scottish domestic demand only represents the 5% of the total demand. This is because routes between Scotland are usually operated by small turboprops, and these are assumed to move towards electric aircraft rather than hydrogen.

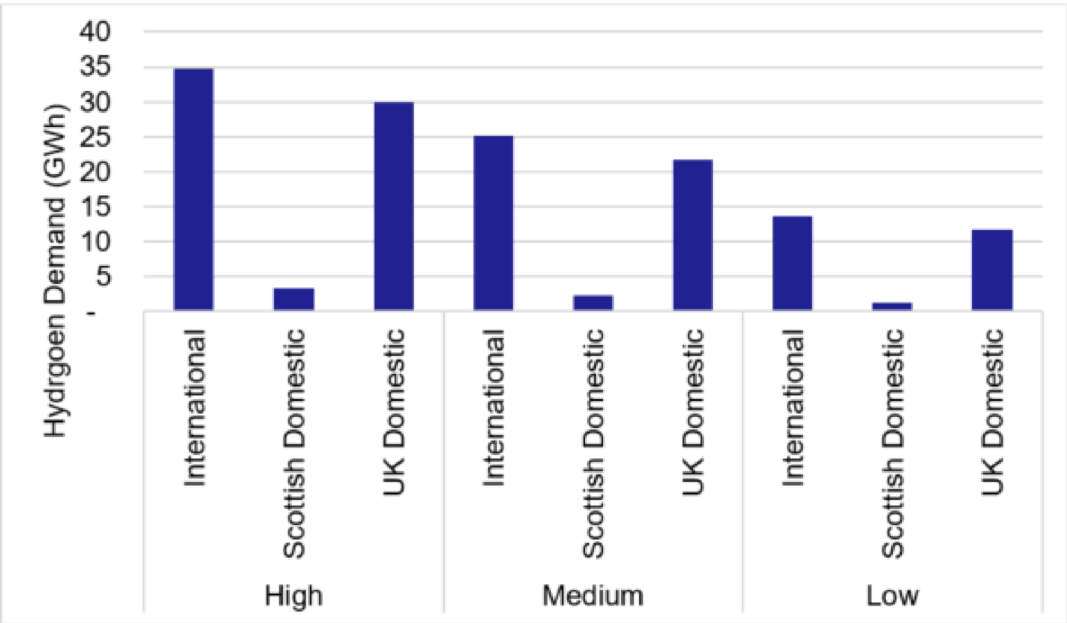
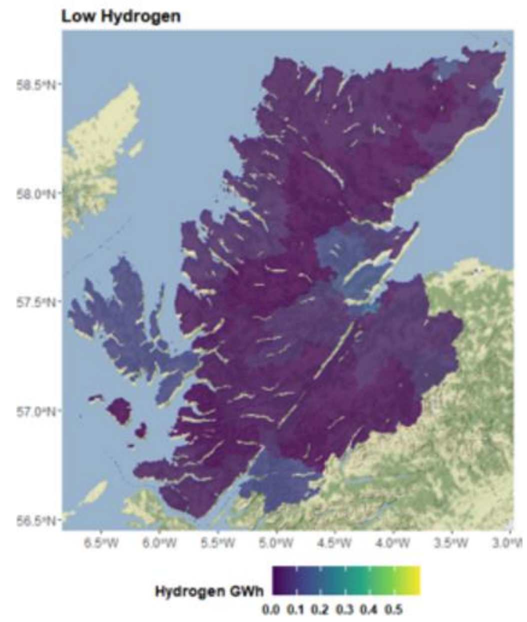


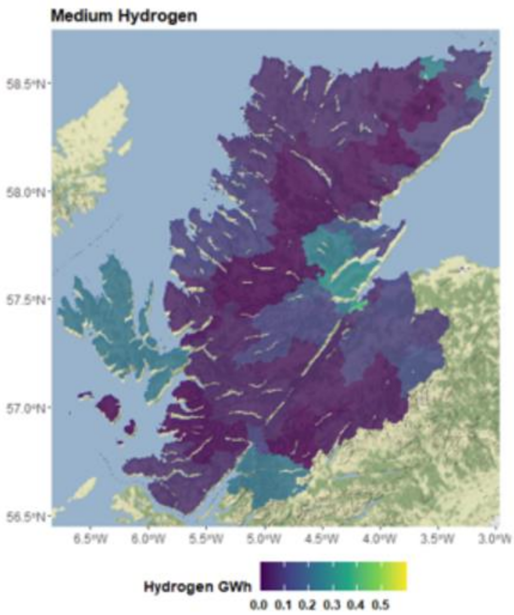
Figure 14 - Forecast hydrogen demand for the Highland Council area by flight type and scenario (2045)

6. Hydrogen Demand Mapping

6.1 Roads

Cars





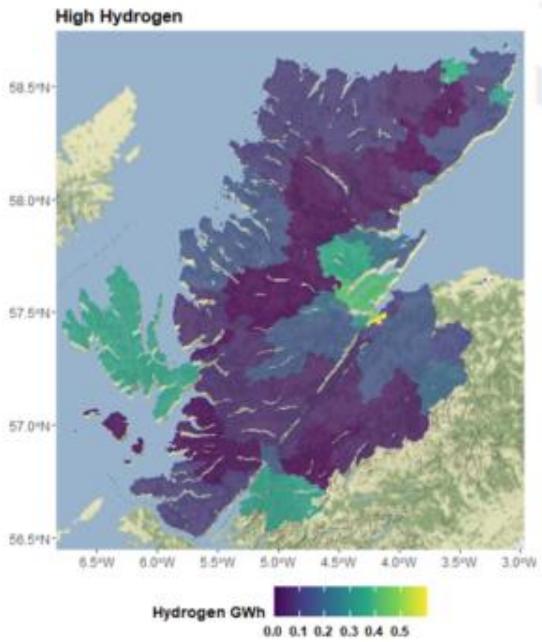
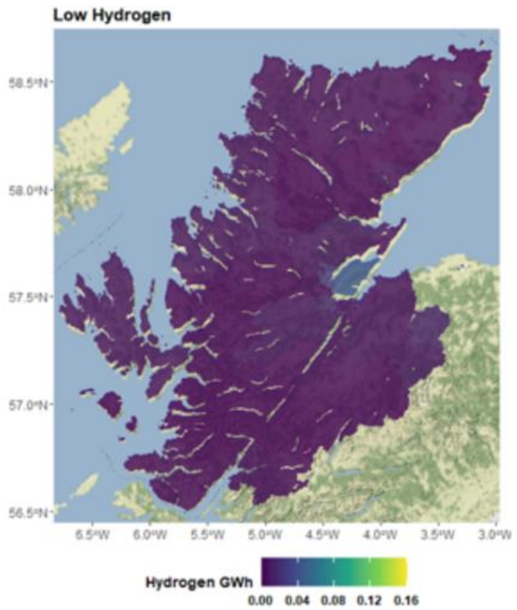
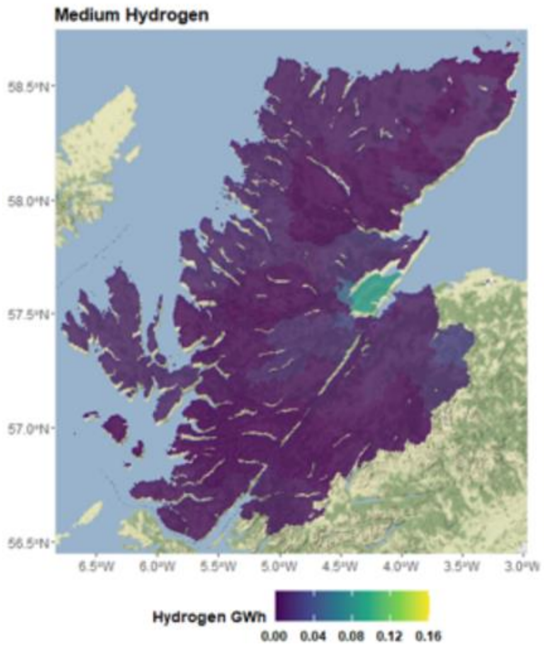


Figure 15 - Hydrogen demand for cars in Highland region for each scenario

Figure 15 shows the total hydrogen GWh demand for cars for all scenarios for 2035 within each separate area in the Highland region. The results shown here are total demand, rather than density of demand, hence the relatively large values shown in the less well populated regions of the Highlands. Although there are areas of concentration in demand, specifically Inverness, the demand is also quite widely distributed across the Highland region.

Vans


Low Hydrogen
58.5°N
58.0°N
57.5°N
57.0°N
56.5°N
6.5°W
6.0°W
5.5°W
5.0°W
4.5°W
4.0°W
3.5°W
3.0°W
Hydrogen GWh
0.00
0.04
0.08
0.12
0.16


Medium Hydrogen
58.5°N
58.0°N
57.5°N
57.0°N
56.5°N
6.5°W
6.0°W
5.5°W
5.0°W
4.5°W
4.0°W
3.5°W
3.0°W
Hydrogen GWh
0.00
0.04
0.08
0.12
0.16

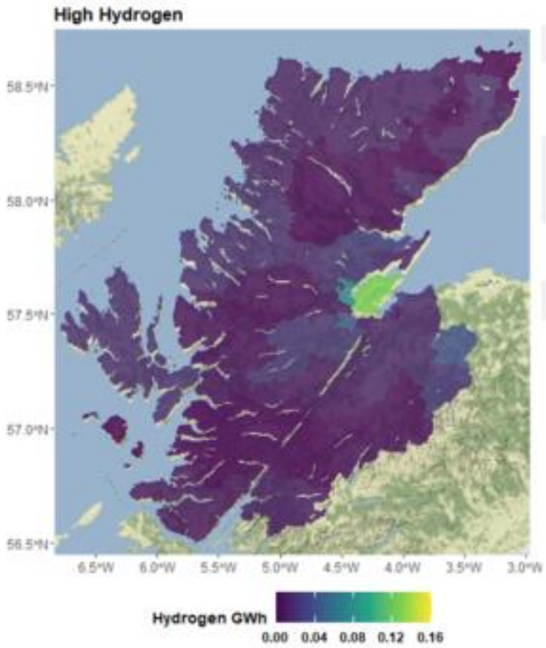
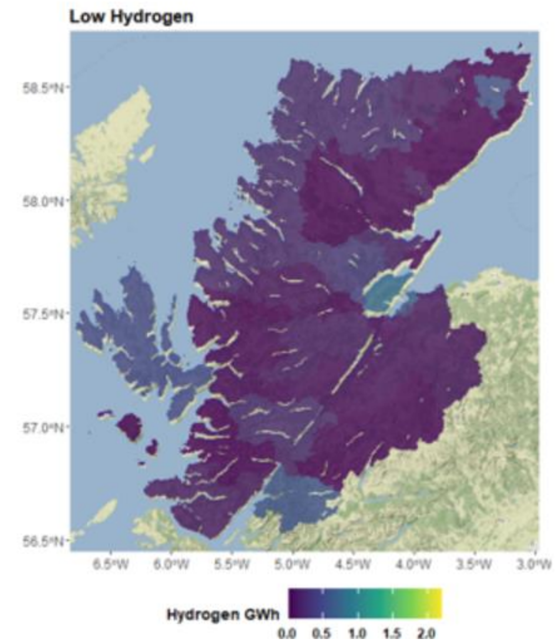
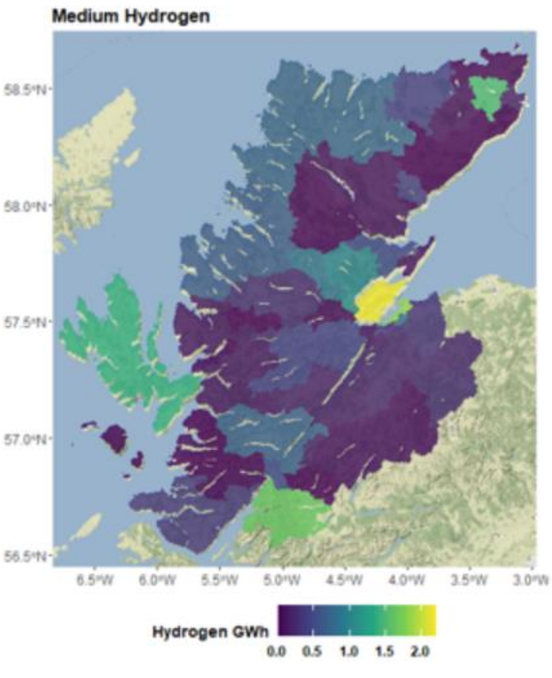


Figure 16 - Hydrogen demand for vans in the Highland region for each scenario

Figure 16 shows the total hydrogen GWh demand for vans for all scenarios for 2035 within each separate area in the Highland region. A major difference between car and van demand can be seen in the concentration of hydrogen demand around the Inverness area, with little to no demand in the more rural zones. This indicates that the demand for hydrogen refuelling for light commercial fleet is likely to be concentrated around urban areas.

HGVs


Low Hydrogen
58.5°N
58.0°N
57.5°N
57.0°N
56.5°N
6.5°W
6.0°W
5.5°W
5.0°W
4.5°W
4.0°W
3.5°W
3.0°W
Hydrogen GWh
0.0
0.5
1.0
1.5
2.0


Medium Hydrogen
58.5°N
58.0°N
57.5°N
57.0°N
56.5°N
6.5°W
6.0°W
5.5°W
5.0°W
4.5°W
4.0°W
3.5°W
3.0°W
Hydrogen GWh
0.0
0.5
1.0
1.5
2.0

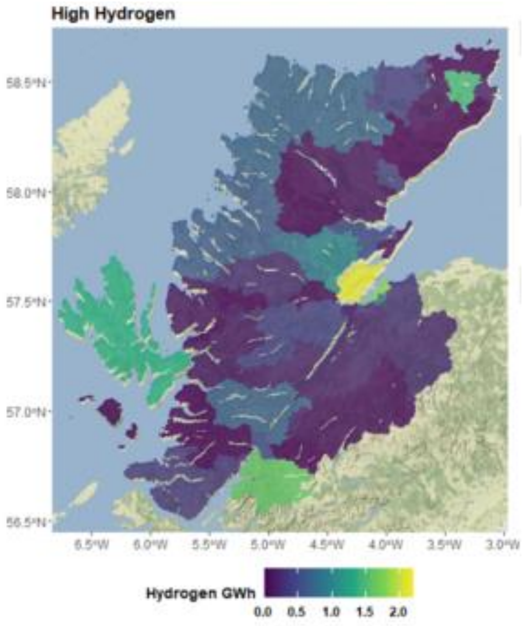


Figure 17 - Hydrogen demand for HGVs in Highland region for each scenario

Figure 17 shows the HGV hydrogen demand for the highland region. There are two points of interest when compared to the car/van hydrogen demand. The total demand within the individual areas is much higher than for car or van, indicating that, as would be inferred from the technology transition forecasts, it is HGV which will be the dominant hydrogen demand.

The second point of interest is that the demand is less concentrated than the van demand, and more closely resembles the car demand.

7.0 Appendices

7.1 Buses and Coaches

Year	High hydrogen Demand in GWh	High hydrogen fleet	Medium hydrogen Demand in GWh	Medium hydrogen fleet	Low hydrogen Demand in GWh	Low hydrogen fleet
2023	0	No H2FC vehicles	0	No H2FC vehicles	0	No H2FC vehicles
2030	2	12 buses	0	No H2FC vehicles	0	No H2FC vehicles
2033	4	12 buses, 13 coaches	0	No H2FC vehicles	0	2 buses
2034	5	18 buses, 13 coaches	0	No H2FC vehicles	0	2 buses
2036	5	18 buses, 13 coaches	3	9 buses, 6 coaches	1	2 buses, 3 coaches
2045	5	18 buses, 13 coaches	3	9 buses, 6 coaches	1	2 buses, 3 coaches

Table 25 - Hydrogen Demand for Buses and Coaches

7.2 Ferries

Year	Scenario A (Low Hydrogen)	Scenario B (Medium Hydrogen)	Scenario C (High Hydrogen)
2022	0	0	3
2023	0	0	5
2024	0	0	5
2025	0	1	6
2026	0	13	18
2027	0	27	33
2028	0	31	36
2029	0	31	36
2030	16	31	36
2035	31	31	36
2040	72	72	77
2045	75	75	80

Table 26 - Data for Hydrogen Demand (GWh) for each Transition Scenario

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