Towards Zero Emission HGV Infrastructure in Scotland

Centre for Sustainable Road Freight
Heriot-Watt University

for

Transport Scotland

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About the Project

This project provides a proof of concept for a data-driven assessment of critical locations for charging and refuelling infrastructure for zero-emission Heavy Goods Vehicles (HGVs) across Scotland. The project employed advanced analytics on real-world data from fleet operators' Scottish activities, utilising an in-house modelling and simulation suite developed by the Centre for Sustainable Road Freight (CSRF) at Heriot-Watt University.

This report was commissioned and funded by Transport Scotland to fulfil a commitment within the HGV Decarbonisation Pathway for Scotland. It was delivered by the Centre for Sustainable Road Freight (CSRF). This is a summary report of a larger technical report that will be available on Heriot-Watt University's Centre for Logistics and Sustainability (CLS) website below.

CLS Website:
https://www.hw.ac.uk/ebs/research/logistics-sustanability/charging-refuelling-needs-trucks-scotland.htm

Transport Scotland

Transport Scotland is the national transport agency of Scotland, responsible for delivering the Scottish Government's vision for transport.

Centre for Sustainable Road Freight (CSRF)

The Centre for Sustainable Road Freight (CSRF) is a leading research centre with expertise in modelling and policy development for decarbonising freight transportation. The CSRF is a collaboration between Heriot-Watt University, Cambridge University, and Westminster University.

Aim

The project's aim is to aid government and other relevant stakeholders to facilitate a smooth transition to zero-emission freight fleets by offering an evidence-based analysis of the most likely critical en route, shared-use charging and hydrogen refuelling infrastructure needs across Scotland to support freight operations.

Scope

The scope of the project was freight transportation by Heavy Goods Vehicles (HGVs) within Scotland, for journeys ranging from the relatively short (2-4 hours) to more than 8 hours, including tramping operations.

Outcomes

a. Suggest where shared en route charging or refuelling facilities should be developed to allow efficient operation of battery electric (BEV) and hydrogen fuel cell electric (FCEV) HGVs. Provide an estimation of the demand at each corresponding location.

b. Provide recommendations on which locations should be prioritised and phased based on utilisation.

In addition, the project provides a proof of concept for evidence-based identification of critical locations for shared en route charging and refuelling infrastructure for BEVs and FCEVs.

As more data is added, the model will uncover further locations and will provide additional insight into resource usage. This will lead to more accurate recommendations for how locations should be prioritised and phased.

Key Messages

1. Whole fleet Battery Electric HGV (BEV) operation is possible for current routes, provided depot and en route charging infrastructure is developed in key locations across Scotland.

2. Based on data included to date, prioritising shared charging on the A9, A90, and M74 corridors maximises the impact for these BEV operations.

3. Most modelled routes can be completed with no additional stops for charging and, in the worst case, travel an average of 15 km more than the existing diesel HGVs.

4. Even when considering only a small proportion of Scotland's HGV fleet, considerable mitigation for increased peak grid demand, such as reinforcement of grid connections, will likely be required.

5. The mapping of locations for hydrogen refuelling is more uncertain than for charging due to an earlier stage of technology maturity and the potential need to site fuelling alongside hydrogen production. Hydrogen refuelling distributors indicate that hydrogen in individual depots will not be commercially viable and shared fuelling sites are required.

! *Data from more operators will validate the proof of concept, ensuring identified charging or fuelling locations support all operations across Scotland, and creating confidence for investment.*

Contact the team at cls-info@hw.ac.uk to have your fleet data included in future iterations of the model.

Methodology

1	Identify and engage with relevant stakeholders
2	Obtain telematics and scheduling data of existing diesel HGV routes
3	Analyse fleet routes using CSRF modelling for electric and hydrogen vehicles
4	Feedback preliminary findings to stakeholders
5	Use stakeholder feedback to validate and refine model and assumptions
6	Engage with Electricity Distribution Network Operators (DNOs), obtain network data
7	Report findings and continue engagement with Industry and DNOs

CSRF Modelling Approach

This study takes the existing diesel HGV routes currently in operation and analyses them to understand how these routes can be serviced using electric and hydrogen vehicles and where recharging or refuelling will be required. The CSRF modelling in step 3 of the methodology is further outlined below:

Detail for Step 3: CSRF Modelling

3a. *Create a network of HGV charging or refuelling locations based on existing suitable potential host infrastructure. These are locations such as truck stops, which have the required facilities like toilets and cafes.*

3b. *The existing diesel truck routes are overlayed over this network. A route "starts" when the truck leaves the home depot, and "finishes" when it returns there.*

3c. *A simulation is created to investigate how electric or hydrogen HGVs would complete each route. Each vehicle chooses from the given network list where the optimal location is to recharge or refuel.*

3d. *Truck routes are analysed for changes to accommodate charging or refuelling.*

3e. *Charging or refuelling locations are analysed to determine utilisation.*

Findings Overview

Note on Scope of Findings

The data covers a small number of fleets in operation in Scotland, representing about 1% of all registered trucks, and accounting for 80,000 individual journeys. The plan, over the next year, is to improve the **quantity** of data (see below) to reflect a wider variety of HGV routes, including tramping and 24/7 logistics operations, strengthening the case for investment in specific locations. This data is of interest to fleet CPOs, DNOs and all HGV fleets looking to understand what en route energy infrastructure needs to be in place to support their vehicles.

As technology progresses, increased range or charging speed may be achieved, but it is not anticipated to happen so rapidly as to change the broad conclusions of the results which will enable a smooth transition towards zero-emission targets. Repeated analysis will be needed in future years as technology continues to evolve.

Data Request to Operators

The project should be considered a **proof of concept** that can be improved with more data. We encourage fleet operators to share their telematics data with the CSRF.

Contact our team at cls-info@hw.ac.uk for data sharing. Details of data sharing arrangements are available on Heriot-Watt University's Centre for Logistics and Sustainability website at: [Charging or refuelling needs for trucks in Scotland - Edinburgh Business School (hw.ac.uk)]

The study found that all routes* are feasible if both depot and en route charging are available. If only depot charging is provided with no access to shared charging, only 66% of routes modelled could be completed.

The analysis of the available data identified several key freight corridors experiencing high HGV traffic volumes. These corridors primarily connect major population centres, industrial zones, and ports across Scotland. Of particular importance for the available fleets in the dataset are the existing established critical corridors for freight movement within Scotland (Figure 1).

**some remote routes require further analysis. See Future Work.*

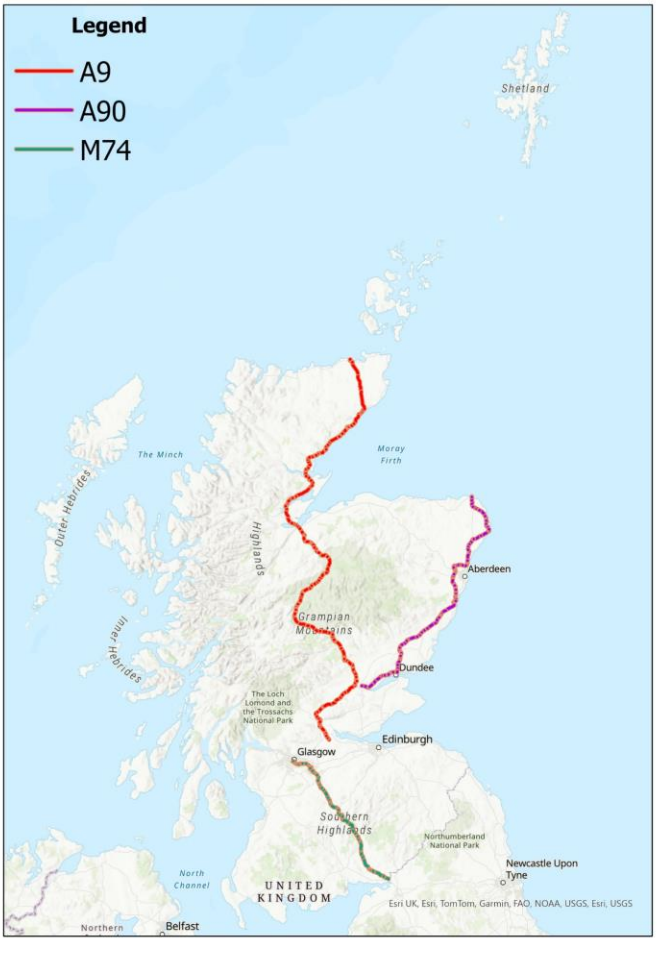


Figure 1. Critical routes for fleets in data set (1% of HGVs in Scotland)

The model, combined with stakeholder feedback, has suggested specific locations as a priority for en route chargers (see Figure 2). These are based, where possible, on existing locations such as truck stops, lorry parks, intermodal hubs and ports. Land within or adjacent to these host charger locations, for example ports, will be required to allow installation of rapid chargers and space for HGVs to park and charge. The charging network has only been modelled across Scotland; locations in England have not been included.

All routes were similarly modelled for hydrogen vehicles (see page 10). However, these findings should be considered in the context of evidence in the supply chain that battery electric HGVs are dominating due to better maturity and lower cost than hydrogen HGVs. The cost differential between electricity and hydrogen is likely to remain in the future for zero emission HGVs as the production of green hydrogen is less energy efficient than the production of electricity.[1-5]

Adding new en route chargers in strategic locations (see Figure 2) will unlock the full potential of electric fleets. More data is required to ensure all locations have been identified.

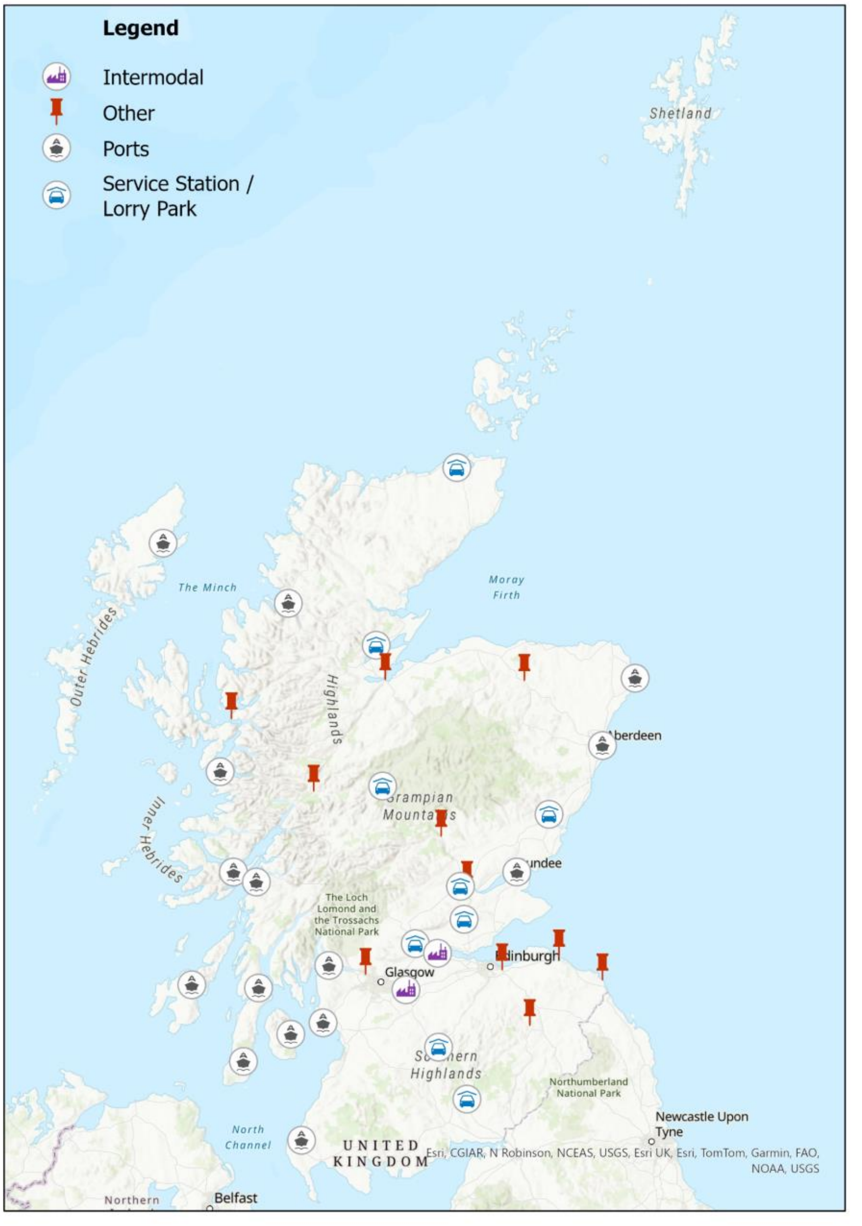


Figure 2. Suggested locations of en route infrastructure from available data

1. Zixian Wang, S. Acha, Max H. Bird, Nixon Sunny, M. Stettler, Billy Wu, Nilay Shah (2023). A total cost of ownership analysis of zero emission powertrain solutions for the heavy goods vehicle sector. Journal of Cleaner Production
2. Howey, D., Contestabile, M., Clague, R. D., & Brandon, N. P. (2009). Comparative analysis of battery electric, hydrogen fuel cell and hybrid vehicles in a future sustainable road transport system. Energy Policy
3. Gray, N., O'Shea, R., Wall, D., Smyth, B., Lens, P., & Murphy, J. (2022). Batteries, fuel cells, or engines? A probabilistic economic and environmental assessment of electricity and electrofuels for heavy goods vehicles. Advances in Applied Energy
4. Cunanan, C., Tran, M. K., Lee, Y., Kwok, S., Leung, V., & Fowler, M. (2021). A Review of Heavy-Duty Vehicle Powertrain Technologies: Diesel Engine Vehicles, Battery Electric Vehicles, and Hydrogen Fuel Cell Electric Vehicles. Clean Technology
5. Hydrogen section, p10

Battery Electric Vehicles (BEVs)

This section explores the key findings for Battery Electric HGV Vehicles (BEVs), assuming all HGV fleets to be electric. There is no clear evidence on future intentions of fleets which would enable an alternative ratio to be used. It gives a suggested network of en route charging locations, and describes the viability of the routes given in the data under three scenarios:

A. Home depot charging only.

B. En route charging only.

C. Home depot and en route charging.

The results from each scenario, including any additional stops compared to current diesel HGV journeys, are summarised in Table 1. The best scenario is C, where both depot and en route charging are available – all routes* can be completed, although some may require additional stops for charging.

Scenario A, with depot charging only, has 33% of routes incurring a flat battery event with no opportunity to recharge. *Of the 65% routes that complete, some violate the 20% minimum battery charge threshold.

Scenario B, with en route charging only, supports almost all routes. Over longer routes, the number of stops does not vary significantly from Scenario C, as vehicles may just charge sooner. However, for shorter routes, 2% remain unable to be completed; and over a larger sample, this can represent a significant number of journeys.

Having both en route and depot charging, as in Scenario C, is the best option for all operations included in the dataset. The locations for non-depot charging infrastructure are discussed on page 8.

In Scenario C, 61% of modelled journeys can be completed without any charging stops while between the depot, destination and return (see Table 1). This occurs without any vehicles violating the 20% minimum battery charge threshold. 12% require one stop en route and 27% require more than one stop. In this scenario, BEVs trucks would only travel an average of 15 km more than the diesel equivalent for charging diversions.

**some remote routes require further analysis. See Future Work.*

Charging Hot Spots

Analysis of journey data revealed heavy usage of specific routes, particularly along **the A9 (Stirling-Perth-Inverness), A90 (Perth-Aberdeen), and M74 (Glasgow-Carlisle) corridors. These critical corridors for freight movement within Scotland would benefit significantly from strategically placed en route charging stations to support BEV journeys.**

The high utilisation hot spots are marked in Figure 3 and outlined in Table 2. The longest distance on the mainland between these potential charging locations is 106 km to Cairnryan. The median distance between charge points is 43km. Further investigation to ensure sufficient coverage for remote and critical routes is planned in the future.

	Scenario A (depot charging only)	Scenario B (en route charging only)	Scenario C (both)
% routes unable to complete	33%	2%	~0%
% complete with no extra stop	65%*	59%	61%
% complete with +1 stop	2%	12%	12%
% complete with +2-3 stops	0%	20%	20%
% complete with 4+ stops	0%	7%	7%

Table 1. Complete or incomplete routes and additional stops under each scenario

Real World Trials & Pathway

Switching to BEVs is demonstrated here to be feasible and more than half of journeys can be done without an extra charging stop. As with any model, real-world trials to validate the assumptions and unforeseen challenges regarding vehicle movements are critical. Current and future planned trials consider both the soft (behaviour, opinion) and hard (technology related) challenges with implementing BEVs into existing operations. These trials can also help understand ways to mitigate any impact of additional stops.

Battery electric HGVs are already in use on UK roads and the HGV Decarbonisation Pathway for Scotland states that where the technology is proven and commercially viable, haulage, energy and finance businesses should be transitioning now.

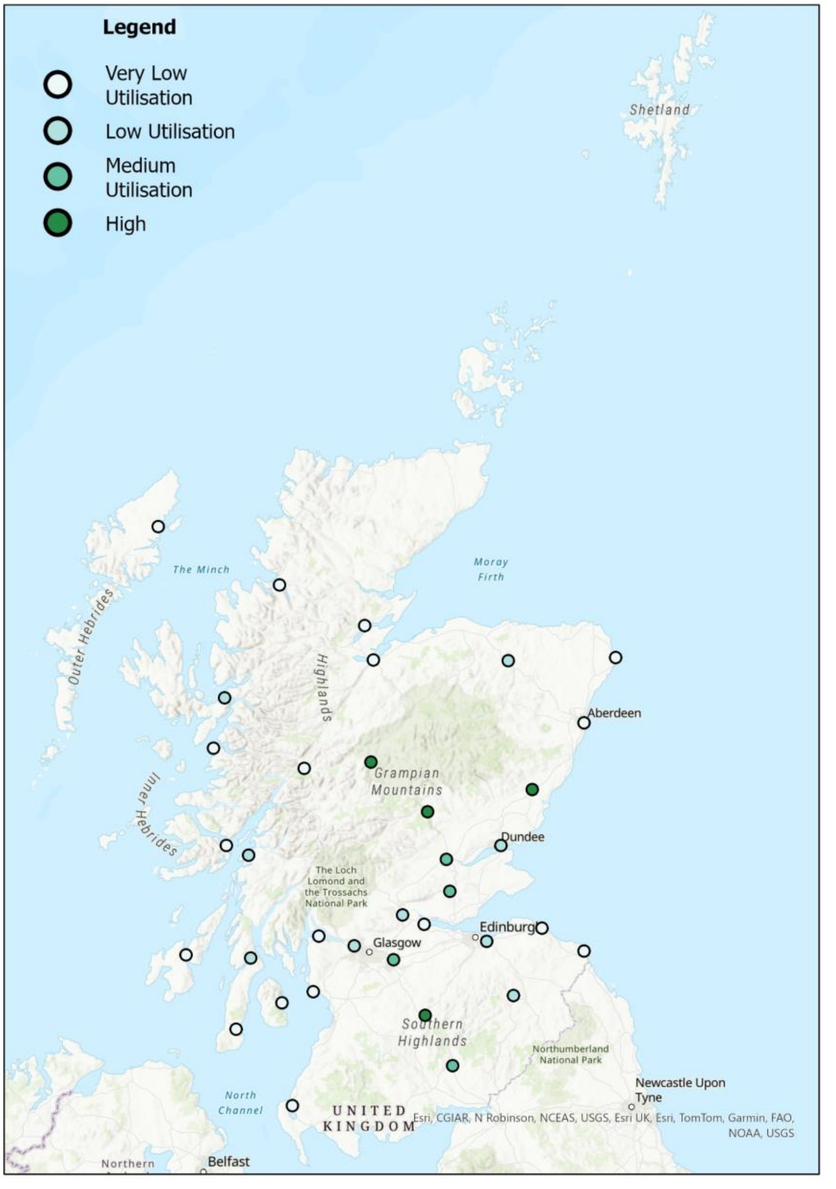


Figure 3. Medium to high utilisation en route charging locations for fleets in data set (dark = more visits)

Table 2. Top locations for chargers

Location	Number of uses (annual)	Total charge delivered (MWh)
Dalwhinnie	11,180	2,357
Ballinluig	8,801	1,409
Stracathro	8,490	2,045
Abington	6,950	1,571
Kinross	4,662	945
Annandale Water	3,835	937
Broxden	3,625	822
Mossend	2,890	658
Clydebank	2,538	576
Dundee	2,152	476

Grid Infrastructure

To determine whether there is sufficient energy infrastructure to support the identified optimal charging locations for the current fleet data set, several primary substations were identified close to each proposed charging location. Data from Distribution Network Operators (DNOs) was used to understand expected headroom (unutilised grid capacity) at each of these primary substations. Our analysis here is based on the DNO forecasts for the 2025/26 horizon.

The model predicts the maximum number of charging events per day at each charging location for the current small data set. Two scenarios were considered. A high intensity scenario where trucks arrive for charging in two concentrated peak periods and a low intensity scenario where truck arrivals are spread out across four charging periods over the day.

For each scenario, the expected total power draw at the primary substation was calculated. The calculated power demand in each scenario was compared to the primary substation's existing headroom to identify locations where there may currently be a shortage of capacity.

Substations are colour-coded based on their current headroom availability (Figure 4):

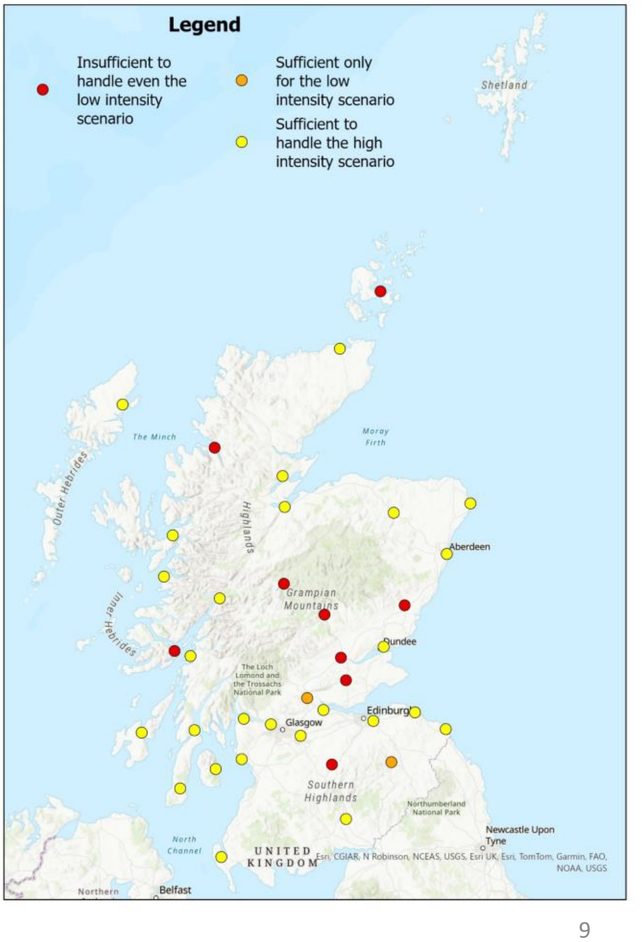
- **Yellow:** Sufficient headroom to handle even the high intensity scenario (68% of all substations based on available data).
- **Amber:** Headroom is sufficient only for the low intensity scenario. Upgrades might be necessary depending on future demand projections (5.2% of all substations based on available data).
- **Red:** Insufficient headroom to handle even the low intensity scenario. Upgrades are likely required (26.4% of all substations based on available data).

The substations identified here are the most likely to require upgrade; many more substations may require upgrade once the full logistics industry fleet data is included in the model.

The critical substations identified are Milnathort, Inchbare, Symington, Kirkwall, Burghmuir, Ullapool, Lochdonhead, Dalwhinnie, and Pitlochry. Precise locations are given in the Technical Report.

There may be situations in which the DNO can still provide for rapid charging, e.g., using flexibility services, whilst minimising reinforcement, despite low capacity.

Figure 4. Charging locations coloured to highlight insufficient capacity headroom at primary substations for serving BEV routes included in the current data set



Hydrogen Vehicles (FCEV)

Refuelling Locations

All routes were similarly modelled as if all fleet vehicles were hydrogen (FCEV). There is no clear evidence on future intentions of fleets which would enable an alternative ratio to be used. As BEVs are already in use on UK roads, the volumes of hydrogen required will likely be much lower than reflected in the tables below.

Heavy Usage Corridors: Analysis revealed heavy usage of hydrogen refuelling stations along the A90 (Perth-Aberdeen) and M74 (Glasgow-Carlisle) corridors, which serve as major arteries for freight movement.

Central Belt Usage: The model also identified potential for hydrogen refuelling stations within the central belt, although to a lesser extent.

Lighter Usage on A9: the model currently predicts lighter usage along the A9. This difference is likely a result of the specific operations of the few fleets in our dataset and may change with additional fleet data.

There are practical complexities associated with identifying sites for hydrogen refuelling relating to the potential need to site refuelling stations close to hydrogen production.

There is no infrastructure currently available to move hydrogen at scale, for example pipelines which may shape refuelling locations. While there are many proposed hydrogen production projects, the majority are not yet under construction. Locations identified here must be seen as speculative (see Figure 5).

Location	Number of uses (annual)	Total hydrogen delivered (kg)
Dalwhinnie	6205	140,722
Annandale Water	6166	290,291
Kinross	1675	46,780
Clydebank	631	18,651
Broxden	197	9,034
Ballinluig	155	8,502
Abington	133	5,658
Stirling	98	2,972
Stracathro	79	2,504
Dundee Port	64	2,040

Table 3. Top locations for hydrogen

Research [6-8] indicates that there is also significant energy loss in the production of green hydrogen; it takes 2-3x more electricity to make hydrogen than using electricity directly to power vehicles. Infrastructure costs for the production, storage and transportation of hydrogen are currently 1.5-2x higher than BEV rapid charging stations. Hydrogen can be produced locally, piped (not considered here) or requires specialised tube trailers to transport and sophisticated equipment for compressing, storing and dispensing safely.

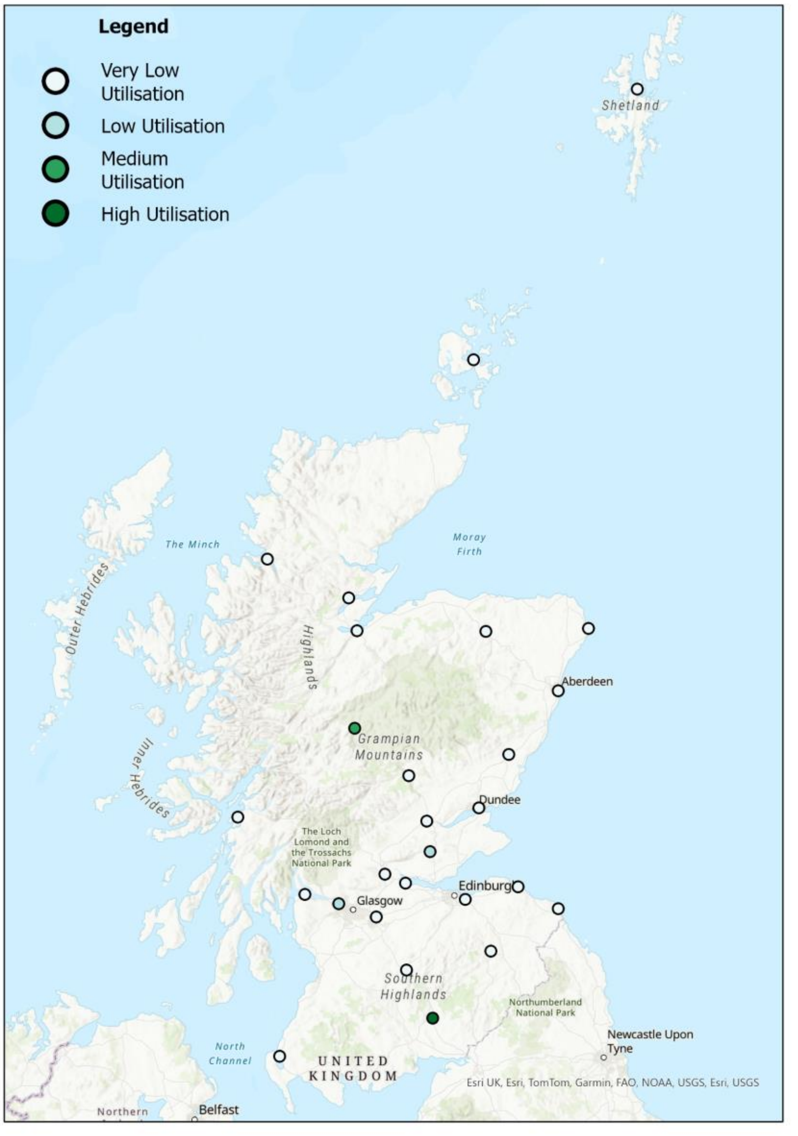


Figure 5. Mainland locations for hydrogen for fleets in data set

6. Pashchenko, D. (2024). Green hydrogen as a power plant fuel: What is energy efficiency from production to utilization?, Renewable Energy
7. Yaïci, W., & Michela, L. (2021). Hydrogen Gas Refuelling Infrastructure for Heavy-Duty Trucks: A Feasibility Analysis. Journal of energy resources technology
8. Yaïci, W., & Longo, M. (2022). Feasibility Investigation of Hydrogen Refuelling Infrastructure for Heavy-Duty Vehicles in Canada. Energies, 15(9), 2848.

Qualifications

Key Assumptions

Depot Usage: all vehicles are assumed to be able to charge at depots run by their operator. In Scenario A and C, vehicles starting each day at their own depot are considered 100% charged. Scenario B assumes vehicles leave the depot with the charge state they returned with and are charged after departing from the depot.

Due to the complexities of hydrogen refuelling stations only large-scale refuelling is considered here, refuelling locations are selected with this consideration. It is assumed that individual depots will not have hydrogen access on site.

Charging Assumptions: all charging points are assumed to be 500 kW to allow ultra rapid charging, and HGV batteries are assumed to have a usable capacity of 350kW. To remain conservative, all vehicles are modelled as 44 tonne with conservative estimates of load and energy consumption used. Range is based on energy consumption rates from previous CSRF publications.

Charging at destinations is assumed not to be possible. This is because many destinations such as small shops lack the infrastructure and space for HGV charging.

The charging network has been modelled across Scotland only; locations in England have not been included.

Data Quality and Quantity

The project considered fleet operations covering a mix of freight including retail, food, and general logistics.

The data sourced from stakeholders and used in this analysis is extremely high **quality**, being a mix of raw telematics data and scheduling data. It reflects a network of over 80,000 unique HGV journeys within a one-year period, covering much of mainland Scotland. The average travel distance per journey was 258 kilometres.

The **quantity** of operations covered by the study represents a small proportion of the logistics activity in Scotland, and, consequently, the results presented in this report illustrate the potential of the model and methodology.

More data will provide comprehensive coverage across the industry to inform discussions on infrastructure requirements for investment.

Future Work

Get Involved

It is intended that an updated version of this report will be published 2025.

The team welcomes additional journey data from HGV fleets. For more detail on the telematics data required and how data will be stored and anonymised, please contact **cls-info@hw.ac.uk**.

Transport Scotland is developing a forum for operators and fleet chargepoint operators, financiers and others interested in developing energy infrastructure projects for HGVs. If you are interested in joining this forum, please email FleetsandInfrastructure@transport.gov.scot The forum will enable hauliers to express interest in specific locations and understand the potential commitment asked of them. It may build sufficient interest for specific locations to move to development stage. There is already substantial interest from fleet chargepoint operators in this forum.

DNOs are already engaged with this project to improve their future modelling and evidence in order to strategically invest in the electricity network. Those considering installing charging infrastructure at some point in the future should contact their DNO at an early stage to understand what information is helpful in securing the power required.

Data for Modelling

More data will enable an increasingly accurate understanding of what will be required and will build the evidence base required for investment in HGV charging and fuelling.

Aggregated data, such as forestry data and traffic count data, may be used in future modelling. This data is low-quality by nature but could potentially make the modelling relevant to all heavy vehicle operations in Scotland.

More data will also allow for a deeper analysis of low/medium/high charging demand scenarios. The distribution network operators (DNOs) emphasise that detailed scenarios combined with times of charging are crucial for planning future energy infrastructure.

Outlying cases where there may still be insufficient existing host infrastructure (service stations, truck stops, etc) for charging were identified on the A9 north of Invergordon and in Shetland. Stakeholders also suggest the A82 and A83, important freight routes for timber, aquaculture and access to the Western Isles, as well as the A77 to Cairnryan are in remote areas where potential gaps in charging infrastructure require further modelling. Transportation by ferry to the islands also needs to be accounted for in modelling. Once more data becomes available, these situations will be further investigated.