Lowering your emissions through innovation in transport and energy infrastructure

PROJECT

REPORT

North East Scotland Fleet Review (Hydrogen Demand)

ABERDEEN CITY COUNCIL

OPPORTUNITY NORTH EAST

Scottish Enterprise

SMART HY AWARE
Interreg Europe

European Union
European Regional Development Fund

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Document Revisions

No.	Details	Date
1	Internal draft	11/01/2021
2	First draft to client	13/01/2021
3	Reissued with minor corrections	14/01/2021
4	Final version with client feedback	09/03/2021

Introduction to Cenex

Cenex was established in 2005 as the UK's first Centre of Excellence for Low Carbon and Fuel Cell technologies.

Today, Cenex operates as an independent, not-for-profit consultancy specialising in the delivery of projects, supporting innovation and market development, focused on low carbon vehicles and associated energy infrastructure.

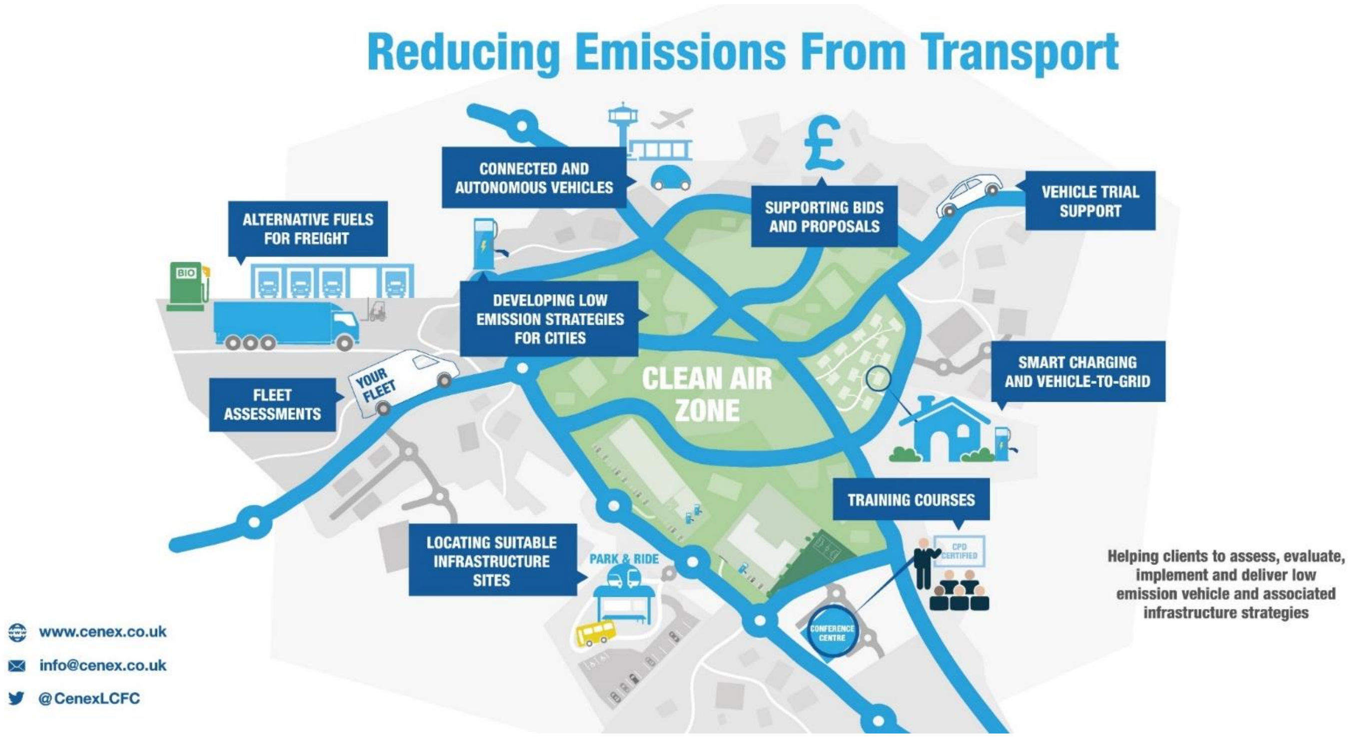
We highly value our independence as it allows us to provide impartial advice and helps us build trust with our customers.

Being a not-for-profit, Cenex isn't driven by doing the work which pays the most or builds our order book, but by what is right for our customers and for the industry. This is reflected in everything we do, from the work we do and the advice we give, even to the prices we charge.

Finally, as consultants our aim is to be trusted advisors with expert knowledge – the 'go-to' source of help and support for public and private sector organisations. We want to be people you can trust to help where and when it is most needed as our customers progress along their journey to a zero-carbon future.

To find out more about us and the work that we do, visit our website:

www.cenex.co.uk



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Abbreviations

ACC	Aberdeen City Council
AQ	Air Quality
BEV	Battery Electric Vehicle
CAZ	Clean Air Zone
CO_2	Carbon Dioxide, which in this report includes other greenhouse gases on a CO_2 equivalence basis (CO_2e)
EV	Electric Vehicle
FC	Fuel Cell (Vehicle)
FCH	Fuel Cells and Hydrogen
FCH JU	Fuel Cell and Hydrogen Joint Undertaking
FC REEV	Fuel Cell Range Extended Electric Vehicle
FCEV	Fuel Cell Electric Vehicle
GHG	Greenhouse Gas
H_2	Hydrogen
H2ICE	Hydrogen-Diesel Dual Fuel Internal Combustion Engine
HDV	Heavy Duty Vehicle
HFC	Hydrogen and Fuel Cell Vehicle
HGV	Heavy Goods Vehicle
HRS	Hydrogen Refuelling Station
ITQ	Invitation to Quote
km	Kilometre
kW	Kilowatt
kWh	Kilowatt Hour
LCA	Life Cycle Assessment
LCV	Light Commercial Vehicle
LDV	Light Duty Vehicle
LHV	Lower Heating Value
MPG	Miles per Gallon
MW	Megawatt
NES	North East Scotland
NOx	Nitrogen Oxides
OEM	Original Equipment Manufacturer
PHEV	Plug-in Hybrid Electric Vehicle
PM	Particulate Matter
RAG	Red Amber Green
RCV	Refuse Collection Vehicle
RHD	Right Hand Drive
SD	Standard Deviation
SG	Scottish Government
SMR	Steam Methane Reforming
SSEN	Scottish and Southern Energy Networks
SUV	Sports Utility Vehicle
TCO	Total Cost of Ownership
TTW	Tank-to-Wheel (tailpipe emissions from burning fuel in a vehicle)
WLC	Whole Life Cost
WP	Work Package
WTW	Well-to-Wheel (emissions including fuel production, transportation, and usage)
ZEV	Zero Emission Vehicle
ZEZ	Zero Emission Zone

Executive Summary

In its national plan to end Scotland's contribution to climate change, the Scottish Government has pledged to phase out the purchase of new petrol and diesel light commercial vehicles by the public sector by 2025 and to eliminate the need for all new petrol and diesel vehicles in their fleets by 2030[1].

In parallel with these national goals, Aberdeen City Council (ACC) and its partners Opportunity North East (ONE) and Scottish Enterprise (SE) are working with public and private sector partners in North East Scotland (NES) to exploit the potential for hydrogen to decarbonise road transport and establish Aberdeen as a *hydrogen hub*. As part of these efforts, ACC has commissioned Cenex to carry out a review of potential hydrogen demand from 12 NES fleets (Aberdeenshire Council, ACC, Angus Council, Highland Council, Moray Council, NatureScot, North East Scotland College, NHS Grampian, Robert Gordon University, Royal Mail, Scottish Water and Scottish Environmental Protection Agency) in order to assess their collective potential for the introduction of hydrogen vehicles and associated refuelling infrastructure to 2023 and 2025.

This study has been partly funded by Interreg Europe project Smart HyAware, which aims to promote hydrogen-electric mobility by tackling main infrastructural, technological and market uptake barriers.

Hydrogen Vehicle Availability

In order to understand the potential for hydrogen and fuel cell (HFC) vehicle uptake in the region, Cenex held meetings with suppliers to establish their ability to supply vehicles in the project timeframes. The discussions established that:

- The 2023 and 2025 project timescales are a significant challenge to obtaining HFC vehicles from mainstream original equipment manufacturers (OEMs). OEM pure fuel cell vehicle models of acceptable maturity in all non-car segments are only likely to appear after 2025.
- UK right hand drive (RHD) preference adds an additional challenge to obtaining early market releases of vehicles.
- Low volume hydrogen vehicle system integrators and converters that have already supplied HFC vehicles to NES fleet are keen to supply further vehicles, particularly if order volumes can be guaranteed through large-scale project activity and/or aggregated deployment.
- Hydrogen vehicles will remain considerably more expensive than diesel or battery equivalents in the project timescales and beyond. However, vehicle order volumes of 100s of units will reduce prices by around 20%.

Potential for the Introduction of Hydrogen Vehicles

The project analysed data on 3,766 vehicles from the 12 fleets, covering a wide range of types and operating patterns from small cars to refuse collection vehicles (RCVs). The baseline energy consumption (from reported annual mileage and annual fuel usage or estimated in the absence of provided data) of each vehicle was translated to that of a zero (tailpipe) emission vehicle (ZEV) equivalent – i.e., a battery electric vehicle (BEV), fuel cell electric vehicle (FCEV), or fuel cell range extended electric vehicle (FC REEV, a vehicle with a battery which can be charged with electricity from a chargepoint, as well as a fuel cell which runs on hydrogen). Based on its energy consumption, a vehicle was then defined as ZEV compatible if a ZEV equivalent was capable of driving its estimated maximum day of operation without needing to refuel (a relatively conservative assumption).

Due to the lower price and wider availability of BEV vehicles over FC equivalents, a combined BEV/FC scenario for ZEV adoption in the NES fleets was chosen. This means that:

- In vehicle segments where a BEV was compatible, the BEV was taken as the preferred choice.
- In vehicle segments where a BEV was not compatible, the FCEV/FC REEV option was chosen if operationally compatible.

[1] https://www.gov.scot/publications/protecting-scotlands-future-governments-programme-scotland-2019-20/

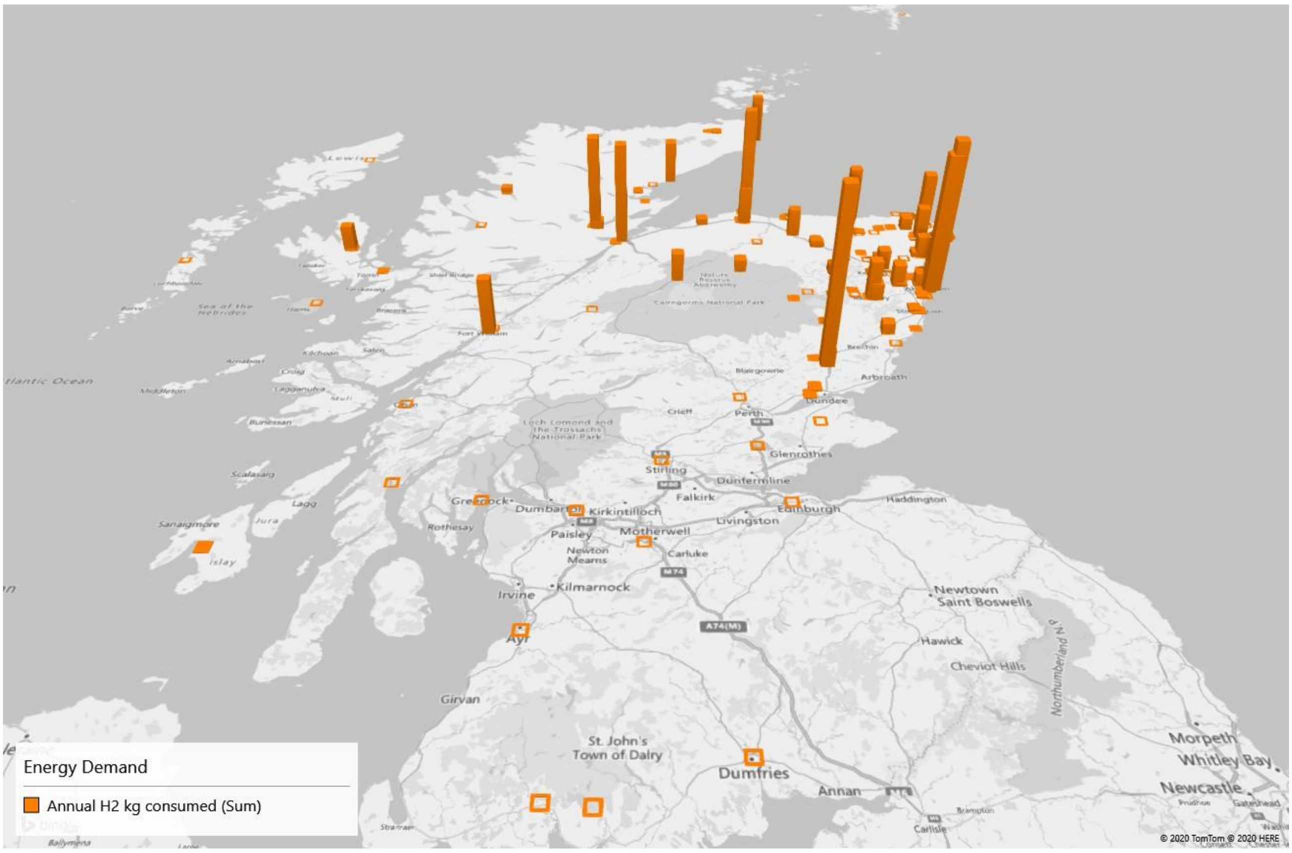
- Compatibility means that a BEV or FCEV if available could perform the daily duty cycle of the vehicle that it is replacing, it does not mean that one is available.

The results obtained from this combined BEV/FC scenario revealed that:

- **89% (57% BEV, 32% FC) of the NES fleet is potentially ZEV compatible**. Since any vehicle that is BEV compatible is also FC compatible (assuming hydrogen fuel is available), therefore **89% of the fleet is potentially FC compatible**.
- Replacement of all ZEV compatible vehicles will yield **greenhouse gas emission savings** of between **31%** (non-renewable electricity and hydrogen used to fuel vehicles) and **70%** (renewable electricity and hydrogen used to fuel vehicles).
- The majority of emission savings are from the replacement of heavy duty vehicles (HDVs, i.e., vehicles 7.5t and larger) by zero emission equivalents.
- If all potentially compatible vehicles were replaced by ZEVs in the combined BEV/FC scenario (i.e., 89% replacement case), this would lead to a maximum **annual H_2 demand of 745 tonnes/year**, **92% of which is from HDVs**.
- Hydrogen/diesel dual fuel internal combustion engine (H2ICE) technology presents a non-ZEV option for the non ZEV-compatible vehicles (and indeed all vehicles, as a H2ICE equivalent, if available, will be able to perform the daily duties of a ZEV), particularly heavier vehicles.

Refuelling Infrastructure and the Aberdeen Hydrogen Hub

Large-scale growth of the number of ZEVs in the NES fleet will require expansion of the number and capacity of regional hydrogen refuelling stations (HRS) to serve an annual demand of up to 745 tonnes of hydrogen. The locations of this potential hydrogen demand are shown in the map below:



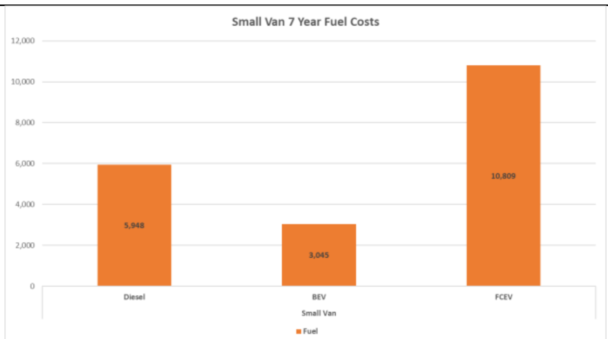
The map shows that siting additional HRS in Aberdeen supplied by a Hydrogen Hub will favour fleets that have depots in the city, such as ACC and Royal Mail. However, several fleets in the study – notably Aberdeenshire, Angus, Highland and Moray Councils – have depots that are not within practical reach of Aberdeen HRS (it was agreed with the study sponsors that the analysis would assume that the maximum distance that a vehicle might travel to a HRS to refuel would be 20 km), and therefore would require a distributed refuelling approach more suited to their local needs. Study analysis showed that a network of nine HRS – consisting of the two existing Aberdeen HRS at Cove and Kittybrewster; a further two potential locations in north and south Aberdeen; plus, five future sites in Elgin, Forfar, Inverness, Inverurie and Peterhead near fleet locations of high demand – could supply over 2 tonnes of hydrogen per working day to fleets located within 20 km of a refuelling station. These HRS would initially focus on NES fleets, but have the potential to expand to other vehicles that use the trunk road network around the locations to build usage. The potential daily hydrogen demand at each location from vehicles located within 20 km of each HRS is shown in the table below.

	Aberdeenshire	ACC	Angus	Highland	Moray	NatureScot	NESCol	NHS	RGU	Royal Mail	Scottish Water	SEPA	Total kg per working day
Aberdeen Cove	19	57	0	0	0	0	0	4	0	166	2	0	**248**
Aberdeen Kittybrewster	16	23	0	0	0	0	0	16	0	13	3	0	**71**
Potential Aberdeen AEP	12	16	0	0	0	0	0	5	0	9	3	0	**45**
Potential Aberdeen ETZ	14	285	0	0	0	0	0	4	0	31	2	0	**336**
Potential Elgin	0	0	0	0	257	0	0	1	0	0	4	0	**262**
Potential Forfar	0	0	347	0	0	0	0	0	0	0	14	0	**361**
Potential Inverness	0	0	0	259	0	2	0	0	0	0	59	0	**320**
Potential Inverurie	172	0	0	0	0	0	0	0	0	0	17	0	**189**
Potential Peterhead	281	0	0	0	0	0	0	0	0	0	0	0	**281**
Total kg per working day	**514**	**381**	**347**	**259**	**257**	**2**	**0**	**30**	**0**	**219**	**104**	**0**	**2,113**

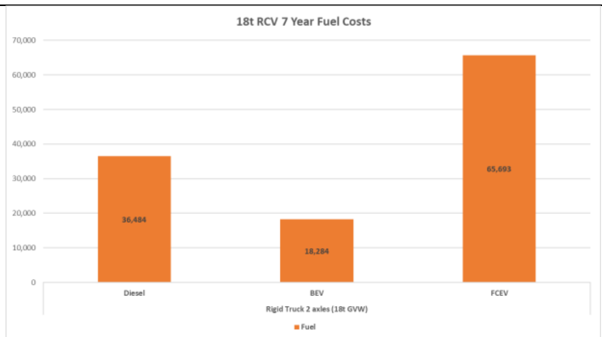
Expansion of the regional ZEV fleet under the combined BEV/FC scenario would also require additional electrical recharging at depots. A brief analysis of the headroom of primary substations near vehicle locations revealed that the electricity network is able to support electrical infrastructure for charging light duty vehicles in all locations, other than those fleets located in South Aberdeen, under the combined BEV/FC scenario. Further detailed investigation of the local low voltage network in each location to confirm the supply arrangements would be required before any implementation.

Running Costs of Hydrogen Vehicles

FC vehicles are more energy efficient than diesel equivalents. Nevertheless, based on the current hydrogen market price of £10/kg, this efficiency is offset by higher unit fuel costs resulting in higher running costs for potential hydrogen replacement vehicles. For example, for small vans and 18t refuse collection vehicles (RCVs) considered in this study hydrogen prices would need to fall by 44% to reach cost parity with a diesel equivalent over a seven year period (based on a diesel price of 95 pence per litre), as shown in the figures below.



Price of hydrogen required to reach fuel cost parity with diesel: £5.50/kg



Price of hydrogen required to reach fuel cost parity with diesel: £5.60/kg

Detailed whole life costs (WLC) of hydrogen vehicles, including vehicle costs based on supplier consultations carried out during the project, has been supplied to the project sponsors as a confidential appendix.

The study analysis suggests that hydrogen currently struggles to demonstrate cost-competitiveness against EVs on an individual basis and at small scale. In the short term this will likely require public sector subsidies to offset the cost differential which is predominantly due to the lack of technology maturity. Only by deploying at scale and in a wide range of use cases will hydrogen be able to compete with other options and realise its potential as a low carbon, and ultimately low cost, fuel.

Conclusions and Next Steps

Maximising the use of ZEVs – both BEV and FC variants – aligns with national, regional, and local strategies on hydrogen and low carbon transport. This study has revealed considerable local appetite for the uptake of ZEVs and that such vehicles, if available, could replace the vast majority of conventional vehicles in NES fleets. However, there are issues with the availability and high cost of FCEVs in the project timescales. Without further improvements in availability and delivery of both BEV and FC vehicle options many of the fleets cannot fully decarbonise in line with national, regional, and local policy, in particular by 2025. While a regional alignment of vehicle policy and an aggregated procurement approach as proposed by this study may encourage some European and international manufacturers to provide right hand drive hydrogen vehicles, the scale required to get OEM's attention and ability to reduce prices to the diesel equivalent warrants facilitation at a national level. If hydrogen vehicles were available the NES fleets would need to be serviced by a regional infrastructure of hydrogen refuelling stations, thus supporting the roll out of hydrogen hubs across Scotland. Suggested next steps to maximise the potential for hydrogen transport in the NES fleets include:

- **Continued North East Scotland dialogue between stakeholders** working as a NES consortium to take forward the actions of this study: collaborating on best practice, sharing training and learning, establishing funding opportunities, progress hydrogen vehicle procurement and hydrogen infrastructure rollout in the short to medium term until such time as a national Scottish-wide network and frameworks are available.
- **Liaison with the Scottish and UK Governments** to communicate difficulties in procuring FCEV's within the proposed timeframes (2025 in particular) without more direct intervention, including funding and active support for hydrogen vehicle manufacturers to facilitate entry to the UK market.
- **Continued engagement with vehicle suppliers** to improve the availability and affordability of right-hand drive vehicles based on an aggregated procurement approach – which study research has shown will reduce unit vehicle costs by 20% – and to exploit funding opportunities as they occur. Showing a clear intent to purchase may encourage manufacturers to increase vehicle supply with potential investment in production facilities in NE Scotland.
- **Continued engagement with HRS providers and investors** to develop a regional network of refuelling sites, working from the initial spatial location analysis proposed in this report.
- **Focus on HDVs as the earliest opportunity to maximise HRS demand and reduce emissions.** Study analysis has shown that BEVs offer the earliest and cheapest option for light duty vehicle replacement. Hydrogen looks most appropriate for HDVs which use more fuel, and have higher emissions, than light duty equivalents. The next logical step for a regional Hydrogen Hub would be to engage with current and future HDV OEMs to better understand vehicle availability prior to building in private sector HDV involvement in order to build demand from vehicles using the regional trunk road network, as well as public sector fleets. This would lead to regional specialist HDV facilities for retrofitting and maintenance being established to service large scale hydrogen vehicle deployment across the NES region, which would support NES' wider energy transition and job creation ambitions.

1 Background, Scope and Methodology

1.1 Background to the Study

Aberdeen City Council (ACC) and its partners Opportunity North East (ONE) and Scottish Enterprise (SE) commissioned Cenex to carry out a review of potential hydrogen demand from 12 North East Scotland (NES) fleets.

Cenex understands from the ITQ that the overall aim for this project is to establish the potential for hydrogen vehicle deployment in order to raise demand for hydrogen in the city and establish Aberdeen as a *hydrogen hub*. This will primarily help deliver one of the objectives from the Aberdeen City Region Hydrogen Strategy and Action Plan 2015-2025[2] to promote vehicle deployment by a range of stakeholders in the region.

Increasing the number of hydrogen vehicles on the road will increase demand for hydrogen which should help lower the per unit cost of the fuel and help towards the eventual reduction of upfront vehicle costs. This work will therefore have secondary objectives in line with the hydrogen strategy to expand production and distribution of renewable hydrogen and develop hydrogen refuelling infrastructure by generating increased demand. We understand that ideally the region would like to reach NES hydrogen demand levels of 1,000 kg per day within two years and 3,500 kg in five years. Reviewing public sector fleets to identify potential opportunities for deployment of hydrogen vehicles will help build this demand.

Other objectives for this work are to:

- Identify sufficient potential use cases for hydrogen vehicles to leverage private sector investment in the deployment of hydrogen refuelling stations (HRS) backed by renewable energy generation.
- Help build the case for organisations in the vehicle supply chain to improve the availability of hydrogen vehicles at viable prices in a range of vehicle categories.
- Identify refuelling requirements to support additional hydrogen vehicles.
- Facilitate closer collaboration between the public sector and vehicle and infrastructure supply chains.
- Inform a joint public sector procurement exercise to maximise value for money.

This study has been partly funded by Interreg Europe project Smart HyAware, which aims to promote hydrogen-electric mobility by tackling main infrastructural, technological and market uptake barriers.

1.2 The North East Scotland Context

There are ambitious targets set at EU, UK, and Scottish government levels for reductions of greenhouse gas (GHG) emissions and increased use of low emission vehicles and renewable energy. The long-term driver for this is Scotland’s commitment to reach net-zero GHG emissions by 2045[3]. Scottish Government (SG) has also set two pledges which will stimulate increased use of hydrogen and EV technology in the medium term. These are to:

- Phase out the need for new petrol and diesel cars and vans by 2030[4].
- Phase out petrol and diesel cars, and the need for new conventionally-fuelled vans, in public sector fleets by 2025[5].
- Phase out the need for new petrol and diesel vehicles in public sector fleets by 2030[5].

Although hydrogen can help achieve these policy objectives, there is as yet no specific overarching national strategy for this technology in the UK; one is expected from the UK Government in 2021. The SG published its Hydrogen Policy Statement in December 2020[6]; a Scottish Hydrogen Action Plan supported by £100m of funding is expected in 2021.

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[2] http://archive.northsearegion.eu/files/repository/20150918111637_AberdeenHydrogenStrategy_March2015.pdf

[3] https://www.gov.scot/policies/climate-change/reducing-emissions/

[4] https://www.gov.scot/publications/securing-green-recovery-path-net-zero-update-climate-change-plan-20182032/

[5] https://www.gov.scot/publications/protecting-scotlands-future-governments-programme-scotland-2019-20/

[6] https://www.gov.scot/publications/scottish-government-hydrogen-policy-statement/

In the NES, Aberdeen City Council (ACC), working with public and private sector partners, is developing and implementing its own strategies and initiatives to exploit the potential for hydrogen to decarbonise road transport. ACC is leading efforts to rebrand the city as Europe's energy capital. This includes a strategy to transition away from economic reliance on the supply and use of mineral fuels towards an energy system comprising zero emission tailpipe vehicles powered by renewable energy generation.

The key guiding document is the Aberdeen City Region Hydrogen Strategy and Action Plan 2015-2025 which aims to develop a hydrogen economy in Aberdeen by developing infrastructure, increasing fleet uptake, developing supply chain and training opportunities, hydrogen storage/grid balancing, and production of green hydrogen through connection to renewables. Aberdeen has the potential to become an exemplar region in the deployment of hydrogen vehicles and develop a major cross-sectoral hub for hydrogen technologies (also sometimes referred to as a hydrogen valley).

Hydrogen must also support economic growth and transition of jobs to clean technologies in Aberdeen. The Regional Economic Strategy (2015)[7] highlights that hydrogen can help diversify NES employment, requiring transferable skills from the oil and gas sector. Other relevant strategies include the Nestrans Regional Transport Strategy report, which notes that the North East region is seeking to be a leading player in the development and deployment of alternative fuels, including hydrogen fuel cells.

Alongside these strategies, Aberdeen is pioneering the deployment of hydrogen vehicles. Its activities include:

- Deploying hydrogen powered buses, with 15 double deckers operated by First Group as part of the FCH JU JIVE project.
- Managing both Interreg NSR HyTrEc2 and Interreg NWE HECTOR projects which are developing the fuel cell electric vehicle (FCEV) market and promoting the North Sea Region as a centre of excellence for FCEVS
- Supporting vehicle and infrastructure deployments under projects including Hytime, H2ME, Fuel Cell Cargo Pedelecs and ACHES.
- Participating in Smart HyAware intended to encourage hydrogen vehicle adoption across Aberdeen City Region.
- Hosting two HRS and an expanding fleet including fuel cell buses, diesel/ hydrogen transit vans and electric with hydrogen range extenders, fuel cell cars, fuel cell SUVs, dual-fuel hydrogen street sweepers and dual-fuel 26t hydrogen refuse collection vehicles. Aberdeen's HRS have already supported trials of hydrogen vehicles from neighbouring regional fleets such as Aberdeenshire Council and supplied hydrogen to Belfast for bus deployments.

Aberdeen has undertaken consultation with regional fleet operators to assess the appetite for adopting hydrogen vehicles and willingness to pay for this technology. The city, and indeed the wider region, is now ideally placed to build on the network of engaged stakeholders to identify specific opportunities for deployment of hydrogen vehicles.

The key challenges for public sector fleet uptake of hydrogen are the lack of vehicles on the market and the expected high upfront cost of new vehicles. In Cenex's experience, hydrogen vehicles are generally more expensive than EVs on a total cost of ownership (TCO) basis. However, comparisons should include costs associated with grid upgrades such as new substations to support widespread EV adoption, as well as considering anticipated reduced costs of hydrogen fuel reflecting increased demand. In these conditions, the business case for hydrogen may be more attractive.

The Aberdeen City Region Hydrogen Strategy and Action Plan 2015-2025 states the fleets consulted would consider paying a small cost premium (£5-10k) for a trial project, but most would want cost-parity for wider deployments. Initially, upfront cost premiums are likely to exceed that level and therefore funding from Scottish or UK government departments to support upfront and/or running costs may be required. The analysis provided by this report can act as an evidence base to help

[7] https://investaberdeen.co.uk/images/uploads/Regional_Economic_Strategy_0.pdf

secure such funding and guide spending. Aberdeen has a strong track record in attracting investment in its hydrogen projects and can build on this to tap into new funding sources such as the Scottish Government's £62 million Energy Transition Fund.

1.3 Scope

As per the ITQ, our analysis has examined options to increase hydrogen demand over three-year and five-year periods, i.e. up to 2023 and 2025, respectively. The individual tasks outlined in the ITQ are shown in Appendix 1.

The vehicle types in scope in this report are cars, commercial vehicles (vans and HGVs), and non-road going vehicles such as street sweepers.

The focus of the study analysis is zero tailpipe emission replacement options, so the primary scope is fuel cell electric vehicles (FCEVs), fuel cell range-extended electric vehicles (FC REEVs) and pure electric vehicles. In segments where no zero tailpipe option is available and/or practical, dual-fuel internal combustion engine vehicles which use hydrogen and diesel (H2ICE) are considered.

1.4 Methodology

The study will be delivered by six linked Work Packages (WPs) as shown below.

WP1: Fleet Baselining
- Review fleet data supplied
- Review duty cycle data

WP2: Market Assessment
- Desktop review of roadmaps
- Supplier engagement

WP3: Fleet Demand Scenarios
- ZEV suitability assessment
- Scenario development and analysis

WP4: Refuelling Infrastructure
- Review of current infrastructure
- H_2 demand scenarios
- Cost estimates and comparisons
- Spatial analysis

WP5: Whole Life Cost Analysis
- Whole life cost modelling
- H_2 cost sensitivity analysis

WP6: Summary and Next Steps
- Presentation of draft findings
- Workshop
- Final report

The remainder of this report describes the findings of the study reported as WPs 1 to 6. The linkage of the individual WPs to each of the 12 tasks of the original ITQ is highlighted at the start of each WP.

2 WP1: Fleet Data Baselining

Task 1: Assessment of fleets across the range of vehicle categories, applications and duty cycles including plant types.

2.1 Introduction

The aim of this project was to establish the composition and location of NES fleets in order to assess their collective potential for the introduction of hydrogen vehicles and associated refuelling infrastructure to 2023 and 2025. 12 NES fleets participated in the study, as shown in Table 1:

Table 1: NES Fleets Participating in this Study

	Name Used in this Report	Number of Vehicles
Aberdeenshire Council	Aberdeenshire	845
Aberdeen City Council	ACC	495
Angus Council	Angus	253
Highland Council	Highland	1,087
Moray Council	Moray	445
NatureScot	NatureScot	110
North East Scotland College	NESCol	21
NHS Grampian	NHS	319
Robert Gordon University	RGU	13
Royal Mail	Royal Mail	145
Scottish Water	Scottish Water	343
Scottish Environmental Protection Agency	SEPA	17

Given the diverse nature and operation of the fleets shown in Table 1, the project's first task was to collect data from each in a common format to facilitate analysis of the potential for fleet hydrogen update. The methodology used to collect and process the data is summarised below.

2.2 Methodology

Data was collected from the 12 fleets and processed as follows:

1. **Data collection template issued to each fleet**: the template asked for as much detail as fleets were able to give on each of their vehicles.
2. **Vehicles segmented into types**: once data was returned by the fleets, individual vehicles listed were categorised into segments by gross vehicle weight (GVW) and axle configuration where appropriate.

- The most important parameters for the subsequent analysis were vehicle type, location, fuel consumption, annual mileage and operation days per week. If these parameters were missing from the fleet list and could not be provided by the fleet manager, appropriate values for each vehicle type were assumed based on averages from Cenex's fleet database and the operational days per week were assumed to be five.
- Fleet operators provided the drive cycles each vehicle completes, aligned with Cenex's internal classification (congested, urban, regional, motorway, mixed). If this was not provided, a mixed duty cycle was assumed.

2.3 Results

2.3.1 Numbers of Vehicles Analysed in the Study

- **3,902** vehicles were listed across the 12 fleets.
    - **3,766** vehicles were analysed.
    - **156** vehicles were not analysed due to a lack of data, particularly on niche duty cycles with significant auxiliary loads, and would require bespoke individual fleet analysis.

2.3.2 Locations and Types of Vehicles Analysed in the Study

Figure 1 shows the base locations of the vehicles analysed in the study and Figure 2 shows the same data displayed by vehicle type. Further analysis of the fleet data to derive the potential for replacement of vehicles by zero emission options is in Section 4 (WP3).

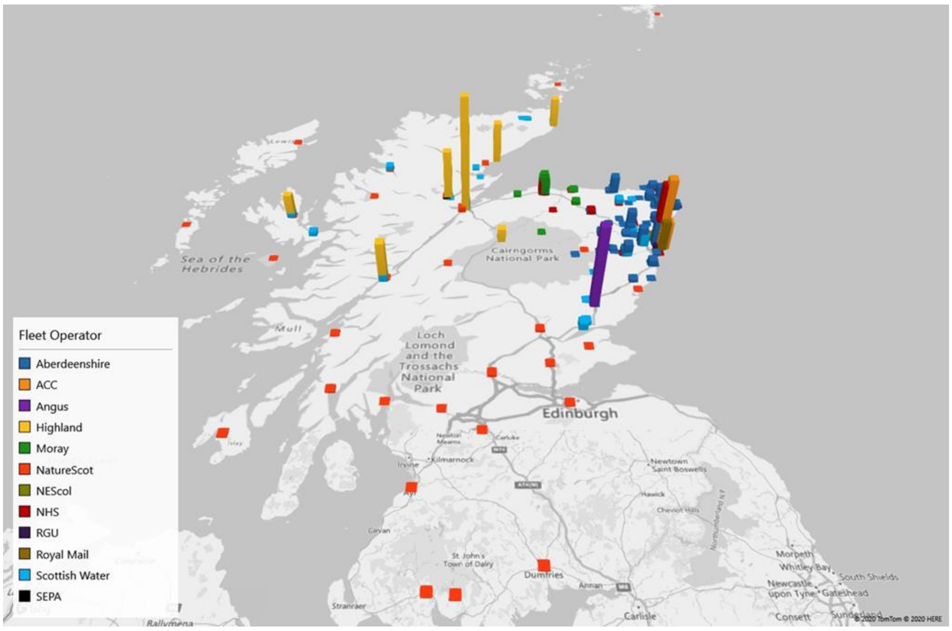

Figure 1: Location of NES Fleets Analysed

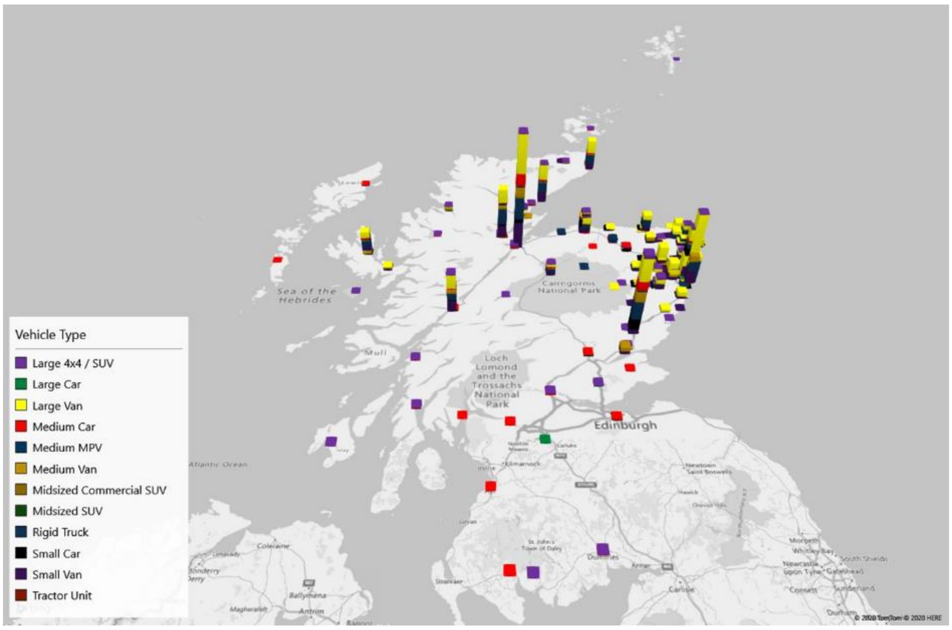

Figure 2: NES Fleet Vehicle Types by Location

3 WP2: Market Assessment

Task 10: Assessment of the supplier/OEM market options for electric and hydrogen fleet replacement, gaps in vehicle alternatives and likely market uptake.

3.1 Introduction to the Electric and Hydrogen Vehicle Types in this Report

Figure 2 in the previous section shows that the 12 NES fleets operate a diverse selection of vehicles, ranging from small passenger cars to large rigid trucks as refuse collection vehicles (RCVs). This section of report considers the availability of hydrogen and electric vehicles across the vehicle segments of relevance to the NES fleets.

The following electric and hydrogen vehicles are discussed in this report:

- **BEV** – battery electric vehicle: a vehicle that derives all its power from electricity provided by an external electrical source such as a chargepoint and stored in an on-board battery. Examples include the Nissan Leaf car and the Nissan e-NV200 van.
- **FCEV** – fuel cell electric vehicle: an electric vehicle which derives its power from the conversion of hydrogen and oxygen to electricity in a fuel cell. FCEVs typically also use a relatively small hybrid battery to capture regenerative braking energy and provide peak power support to the fuel cell. Examples include the Toyota Mirai and Hyundai Nexo cars.
- **FC REEV** – fuel cell range extended electric vehicle: these have larger batteries which can be charged with electricity from a chargepoint, as well as a fuel cell which runs on hydrogen. Either or both power sources can be used to drive the vehicle and top up the battery, thereby providing the vehicle with longer range than a BEV variant. An example is the Symbio (now Renault) Kangoo ZE H2 light duty van.
- **H2ICE** – dual fuel diesel/hydrogen internal combustion engine vehicle: these vehicles co-combust hydrogen and diesel in a conventional engine. Examples are van and refuse collection vehicle (RCV) conversions by ULEMCo.

The report also discusses the following groups of vehicles:

- **HDV (heavy duty vehicle)** – vehicle above 3.5t.
- **LDV (light duty vehicle)** – vehicle 3.5t and below (i.e., in this context essentially cars and vans).
- **FC** – fuel cell vehicle, comprising FCEV and FC REEV.
- **HFC** – hydrogen and fuel cell vehicle, encompassing FCEV, FC REEV and H2ICE.
- **ZEV** – zero emission vehicle: a term used in this report for an electrically-powered vehicle with zero tailpipe emissions, which includes BEV, FCEV or FC REEV.

3.2 Hydrogen Technology and Deployment Roadmaps of Relevance to the UK

3.2.1 Introduction

Technology and deployment roadmaps provide an industry-consensus overview of the expected evolution of HFC technologies in the medium- and long term and are important in establishing the current and future direction of policy and funding. The consensus position from the OEM (original equipment, or mass market, manufacturers) passenger car roadmaps, such as the Ricardo examples shown below, is that BEVs will dominate the market. FCEVs are forecast to be a small part of the 2030 powertrain mix for larger D, sports utility vehicle (SUV) and E category prestige vehicles, consistent with car company positioning. A similar position holds on light commercial vehicles (LCVs).

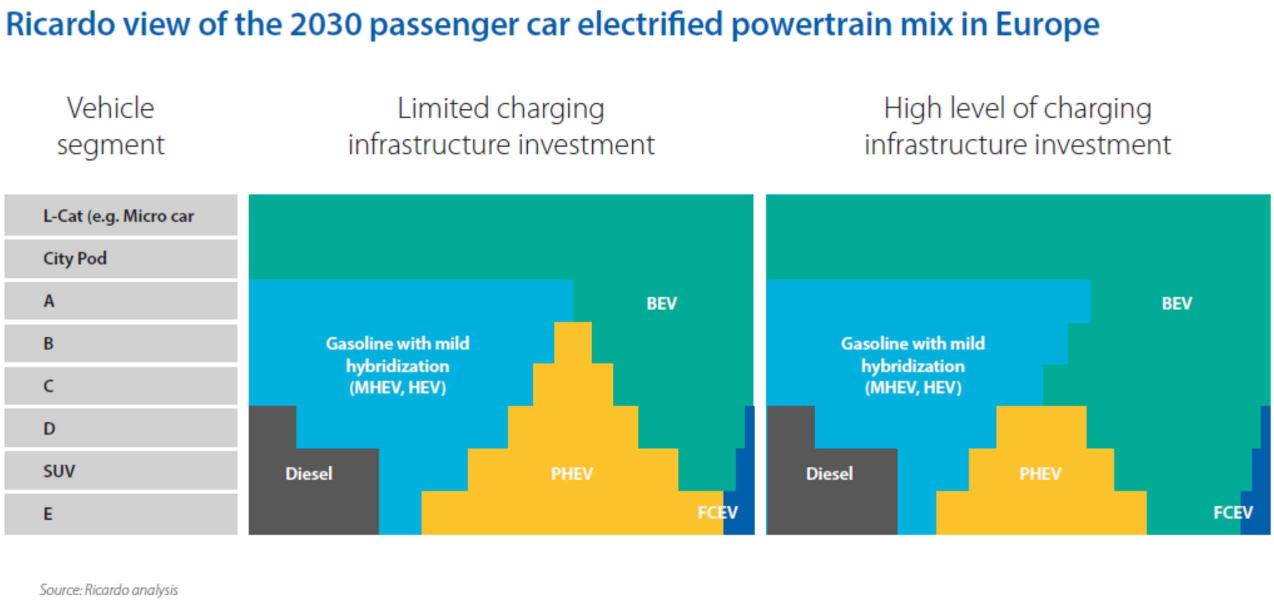

Figure 3: Ricardo overview of the evolution of the EU passenger car fleet[8]

This consensus position carries over to hydrogen-oriented roadmaps, which position FCEVs as alternatives to BEV in heavier vehicles, where ZEV performance is valued but battery weight is an issue in terms of limiting payload; for example, heavy goods vehicles (HGVs) are problematic for electric battery powertrains as heavy load, long duty cycles and high mileage requirements all need to be met. Worldwide there is growing interest in hydrogen fuel cell power trains for HGVs, as exemplified by the 2019 Hydrogen Europe Roadmap[9], which presents HFC technologies in HGVs and buses as 'no-regret' moves:

[8] Ricardo, *The Future for Low Carbon Vehicles, Hybrid and Electric Vehicles?* (2017), https://futurepowertrains.co.uk/wp-content/uploads/2016/11/steve-doyle.pdf

[9] Hydrogen Europe Roadmap (2019): https://fch.europa.eu/sites/default/files/Hydrogen%20Roadmap%20Europe_Report.pdf

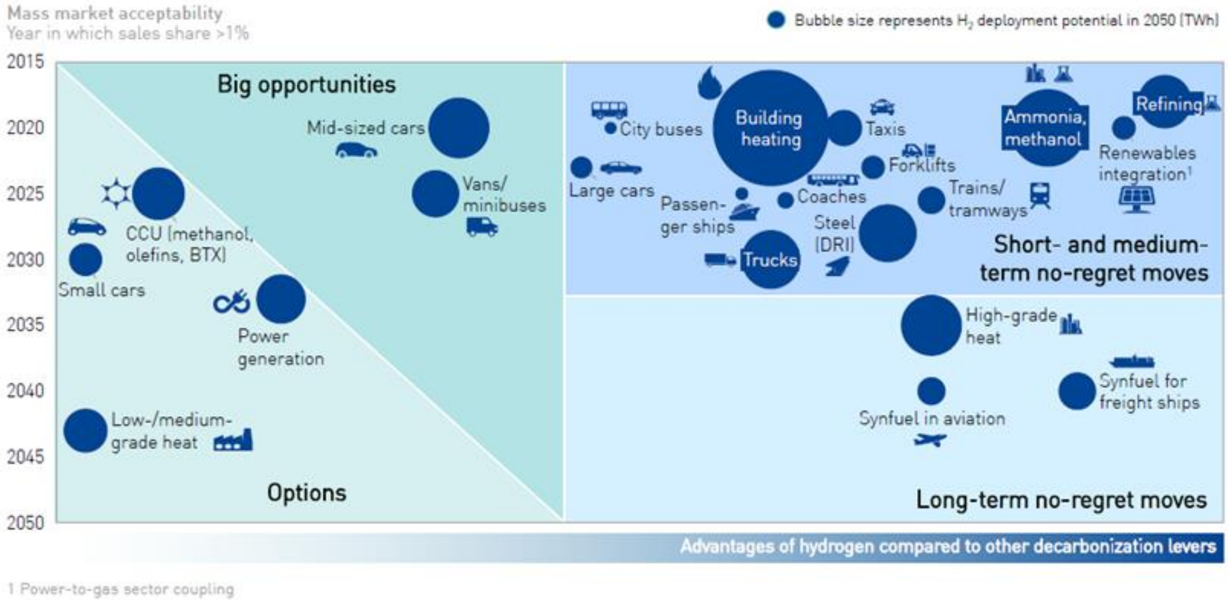

Figure 4: Hydrogen Europe Roadmap Showing No-Regret HFC Applications in HDVs

3.2.2 Hydrogen Refuelling Infrastructure Roadmap

Based on an overview of all industry roadmaps, Cenex has created the following UK-specific technology adoption roadmaps for hydrogen in transport applications. Hydrogen infrastructure developments are perceived as the limiting step in hydrogen and fuel cell vehicle deployments. Therefore, Cenex's hydrogen infrastructure roadmap is presented first in Figure 5 below:

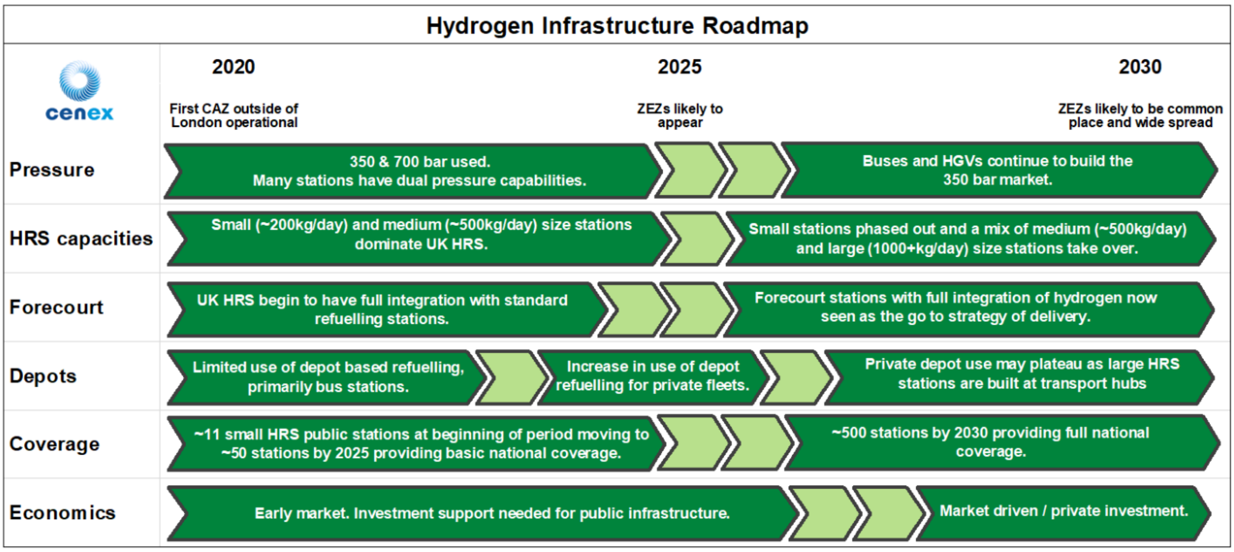

Figure 5: UK Hydrogen Infrastructure Roadmap

3.2.3 Hydrogen Vehicle Roadmap

Figure 6 presents the likely mass-market adoption pathway for classes of HFC vehicles in the UK that are within the scope of this report (cars, LCVs, RCVs and HGVs).

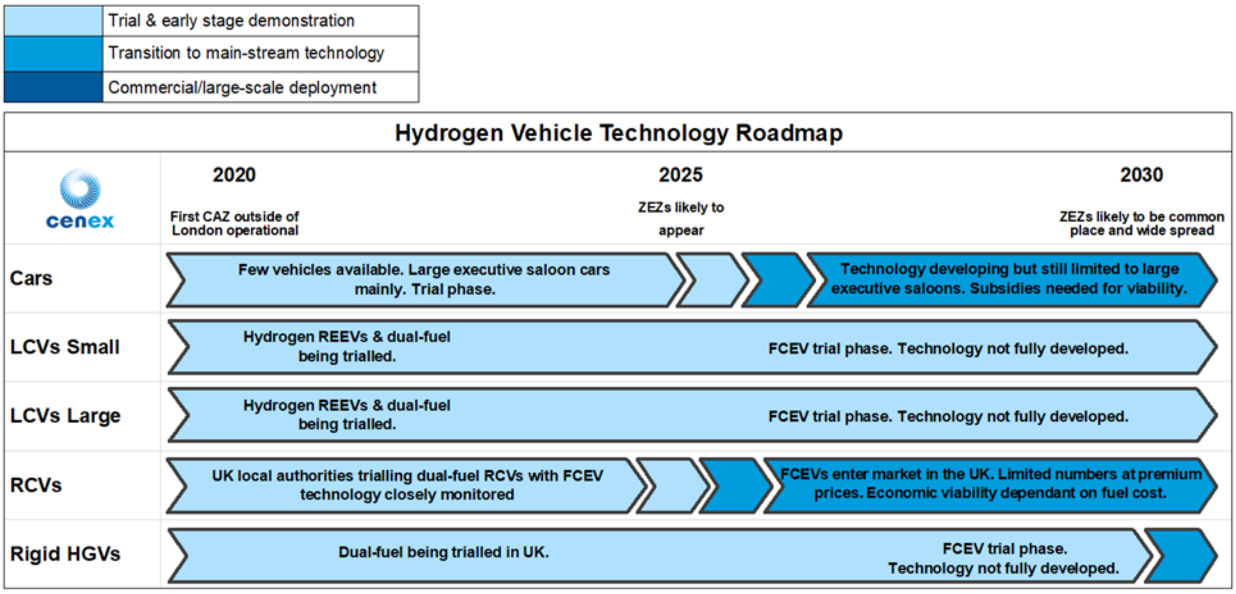

Figure 6: UK Hydrogen Road Transport Roadmap

The following summary points are relevant for the vehicle types and timeframe (2020-25) of this study:

Cars

- A small number of FCEV cars are available in upper market segments. These will continue to be available, primarily through funded trials and demonstrations.
- Significant price premiums over conventional vehicles will constrain uptake.

LCVs

- BEVs with ever-larger batteries are emerging from OEMs; for example, Ford recently announced the E-Transit will be available from 2022 with a 67 kWh battery and a claimed range of over 200 miles[10].
- Hydrogen vans are currently only available as conversions in the UK, either as a range extender on small electric vans, or as a dual fuel system on diesel powered vehicles. There is as yet no business case for fleets to switch to this technology; any deployments will rely on funding support.

HGVs

- BEV options are emerging from OEMs, such as Scania, with battery sizes of up to 300 kWh[11] and claimed single-charge ranges of 250 km.
- Hydrogen vehicles are currently only available on small scale trials, either as a range extender with a small battery, or as a dual fuel system on diesel powered vehicles. These trials are primarily focused on mainland Europe, Japan and the USA. There is as yet no business case for fleets to switch to this technology; any deployments will rely on funding support.

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[10] https://www.ford.co.uk/future-vehicles/new-e-transit

[11] https://www.electrive.com/2020/11/27/scania-announces-market-launch-of-bev-phev-trucks

Moving to the 2025-2030 timeframe, the following further points emerge:

- Hydrogen vehicle technology is forecast to improve with vehicles achieving longer ranges and better efficiencies. However, competition from improved EVs will mean that uptake remains low in passenger and light duty segments.
- As it does not offer zero emissions, dual fuel hydrogen and diesel technology is likely to remain a niche technology for applications where zero emission options are not practical.
- FCH HGVs will reach prototype and demonstration phase in the UK, with articulated trucks the primary target due to their lack of suitability for replacement by EVs. Widespread availability and uptake are unlikely before 2030.

3.3 Supplier Engagement

Cenex held discussions with potential hydrogen vehicles suppliers to verify the messages from the roadmapping research described above. The OEMs, systems integrators and vehicle converters contacted during the study are shown in Table 2.

Table 2: Potential Hydrogen Vehicle Suppliers Contacted

OEMs	Niche Suppliers / System Integrators
Hyundai	Arcola
Symbio/Renault	Holthausen
Toyota	ULEMCo

The discussions were aimed at understanding their vehicle introduction plans in the study timescales (2023 and 2025) and also, where possible, to obtain pricing information.

Full details of the discussions are bound by confidentiality; where agreed by suppliers, feedback and cost details have been passed directly to the study sponsors in a confidential appendix. Key messages that emerged from study research and supplier discussions are summarised in the bullet points below:

3.3.1 OEMs

- The 2023 (and 2025) project timescales are a significant challenge to obtaining HFC vehicles from OEMs in all vehicle types.
- UK right hand drive (RHD) preference adds an additional challenge to obtaining early market releases of vehicles.
- There will be no OEM RHD FCEV vans on offer in the near-term to 2023.
- There are no/limited OEM UK plans for FC HGV trials in the short term, although recent ambitious announcements, such as Hydrogen Europe's ambition to deploy 100,000 HFC HGV and 5,000 HRS[12] by 2030, may mean that some come to the UK by 2025.
- Any hydrogen refuelling infrastructure deployed by NES fleets must be H350/T20 compliant, or at least capable of being certified by the OEM to fuel type IV tanks (composite lined), to ensure compatibility with future OEM vehicles, including HGVs and buses.

3.3.2 Niche Vehicle Suppliers, Integrators and Converters

- HFC vehicles from niche suppliers are already operating in the NES as part of projects such as HyTrEc2.

[12] https://hydrogeneurope.eu/news/coalition-statement-another-milestone-uptake-fuel-cell-trucks

- Suppliers remain open and committed to supplying further vehicles, particularly if volume can be guaranteed through large-scale project activity and/or aggregated deployment.
- Niche FCEV/FC REEV supply options are emerging in larger vehicle segments; RCVs in particular are seen as a key market by these players. These will be at much higher costs than diesel incumbents.
- Engagement with individual suppliers could provide low-volume HFC options in other segments (e.g., vans). These will be at much higher cost than diesel incumbents.
- Suppliers indicated that order volumes of 100s of vehicles would reduce unit prices by around 20%.

3.4 Implications of the Supplier Engagement and Desktop Research

The research and supplier engagement carried out in this WP has shown that the relatively low availability of OEM FCEVs in all vehicle segments in the study timeframe is exacerbated by the UK's RHD preference. OEM pure fuel cell vehicle models of acceptable maturity in all non-car segments are only likely to appear after 2025. The research has also shown that OEM BEVs in segments of relevance to NES fleets (vans, and even RCVs) are increasing in capability and maturity.

The picture from low-volume suppliers is more positive. For example, FCEV/FC REEV supply options are emerging in 12t/18t/26t RCV segment, which is seen as a key market by these suppliers. Low production volumes are deliverable by these companies, though at increased price per unit, and all the converters and niche vehicle suppliers consulted in the study were confident in their ability to increase production to meet the number of vehicles and delivery dates that customers request (and are willing to pay for). Importantly, suppliers indicated that order volumes in the 100s would reduce vehicle unit prices by around 20%, which provides further support for one of the projects key aims of lowering unit cost by aggregated procurement across the NES (further detail of the unit prices and volume price reductions were supplied to the study sponsors in a separate appendix).

Working with low volume suppliers carries more risk to fleets than working with established OEMs, particularly regarding service, maintenance, and long term support for deployed vehicles. Nevertheless, given the limited OEM FCEV availability, these suppliers represent the best option for NES fleets to obtain HFC vehicles by 2023 and even 2025.

There are further potential upsides in working with the niche vehicle supply chain, including regional economic development. As an example of the potential synergies of deploying innovative vehicles with regional capability development and job creation opportunities, Arcola, a key potential supplier of heavy duty FC vehicles to the NES, is due to begin operations at the MSIP in Dundee in 2021[13].

[13] https://www.msipdundee.com/msip-welcomes-first-tenant/

4 WP3: Fleet Demand Scenarios

Task 1: Assessment of fleets across the range of vehicle categories, applications and duty cycles including plant types.

Task 3: Likely take up low carbon vehicles over 3 and 5 year profiled period.

Tasks 8 and 12: Any other element that should be included in a thorough fleet review with the aim of adopting hydrogen /other low carbon vehicles.

4.1 Introduction

This WP analyses the vehicle data from the fleets (processed as described in Section 2) to map out the potential ZEV compatibility and associated energy demand across all vehicle types.

4.2 Methodology

The fleet data from Section 2 was analysed as described below. Data sources used in the work (for example, in the associated emissions analysis) are presented in Appendix B.

1. **Calculate the baseline energy requirements of the current fleet of vehicles**:

- 93% of the fleet vehicles analysed use diesel, with some electric, hydrogen, mild hybrid, plug in hybrid and petrol vehicles. To provide a clear comparison of technological options across all fleets and types, a diesel equivalent within the same vehicle category was modelled in all cases.
- Baseline diesel fuel consumption (from reported annual mileage and annual fuel usage or estimated in the absence of provided data) was validated by cross-referencing against real-world fuel consumption data from independent vehicle testing. Reported fuel consumption seen as unrealistic compared to real-world values was checked with the fleet concerned.
- The fuel consumption was converted to energy consumption in kWh using net calorific / lower heating value (LHV; heat contained within any water vapour produced is not recovered).

2. **For each vehicle calculate the theoretical energy demand (hydrogen, electricity) of a ZEV of the same type**

- A ZEV efficiency factor was applied to the calculated energy consumption of each vehicle to get the equivalent ZEV efficiency. The ZEV efficiency factors are taken from Cenex's internal databases and are derived from independent, real-world, testing of passenger and commercial vehicles.
- For BEVs, the required average battery size to complete the daily requirements for each vehicle has been analysed to assess the suitability of BEV technology when compared to available battery sizes for each vehicle segment. The assumed battery sizes are shown in Appendix C.
- For FCEVs, the required hydrogen tank size to complete the average and maximum daily mileage have been calculated based on currently available vehicles. A FC REEV architecture was used to model the van segment as, based on the supplier engagement described in WP2, no pure fuel cell models are likely to be available in the project timeframes. The hydrogen tank and battery sizes assumed are shown in Appendix C.
- The calculated energy consumption described above applies to the average fuel consumption given by the fleets and therefore only captures average days. Therefore, a maximum daily driving distance based on two standard deviations (SDs) from the mean was calculated, using a distribution based on detailed data logging of NES fleets from previous Cenex work in the HyTrEc2 project.
- The technology is deemed *ZEV compatible* (BEV, FCEV or FC REEV) if it is capable of performing the maximum daily driving distance without needing a recharge or refuel.

3. **The daily and annual H_2 and electricity consumption of ZEV compatible vehicles was calculated**

4.3 Scope of the Fleet Analysis

Section 3 discussed the availability of ZEVs in the 2023 and 2025 timeframes, concluding that RHD OEM pure FC models of acceptable maturity in all non-car segments are only likely to appear after 2025. As a consequence, Sections 4.4 to 4.6.1 present a *combined BEV/FC scenario* for ZEV adoption in the NES fleets. This means that:

- In vehicle segments where a BEV *is* operationally compatible, it is assumed that the BEV option is the preferred choice (due to the wider OEM availability, and likely lower cost, of BEVs as discussed in Section 3).
- In vehicle segments where the BEV *is not* operationally compatible, the FCEV/FC REEV option is taken if it is operationally compatible.
- The H_2 and electricity consumption figures presented assume that all vehicles replaced with ZEV equivalents. It does *not* mean that the vehicles are necessarily available.

It should also be noted that:

- *Operational compatibility* in the following slides means that a BEV or FCEV *if available* could perform the daily duty cycle of the vehicle that it is replacing, it does *not* mean that one is available.
- Cost is *not* part of this analysis (the whole-life cost, WLC, of vehicles is discussed separately in WP5/Section 6).

4.4 Results of the ZEV Compatibility Analysis in Key Vehicle Segments

4.4.1 Small Vans

Figure 7 shows the results of the ZEV compatibility analysis for the small vans in the NES fleets.

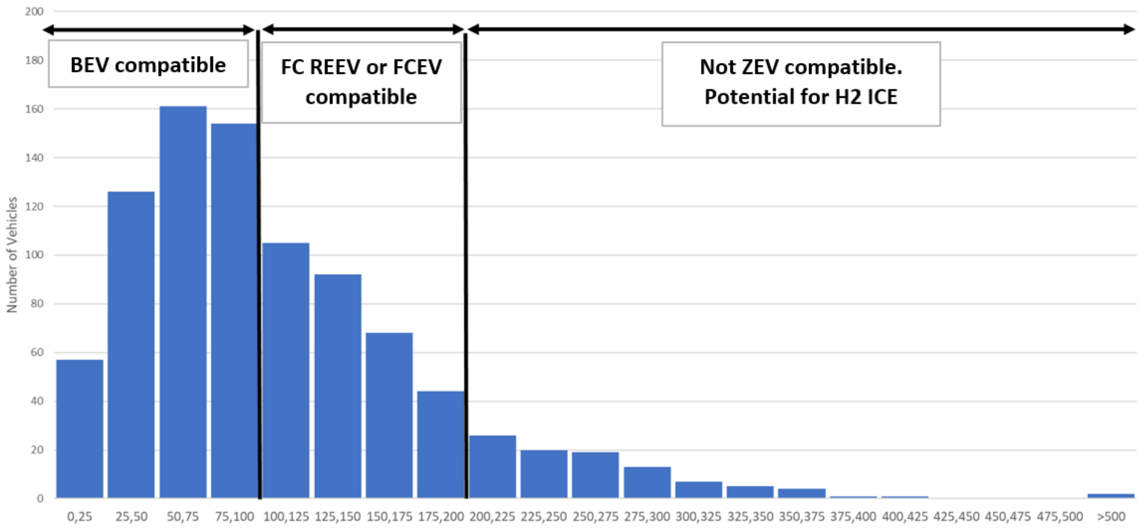

Figure 7: ZEV Compatibility of NES Fleet Small Vans

The figure shows that the vast majority of fleet (87%) is compatible with a BEV (53%) or FC REEV (further 34%) option. The modelled small van has a nominal battery size of 36 kWh, and a 4 kg H_2 tank. For comparison, the Renault Kangoo ZE H2 has a 33 kWh battery and ~2 kg tank; for further details see Appendix C.

4.4.2 Large Vans

Figure 8 shows the results of the ZEV compatibility analysis for the large vans in the NES fleets.

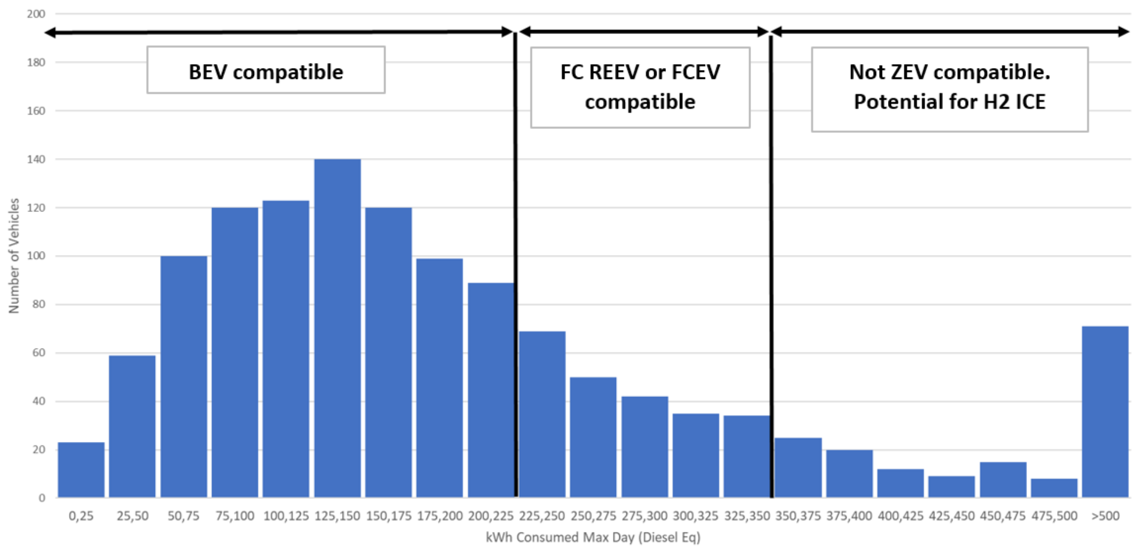

Figure 8: ZEV Compatibility of NES Fleet Large Vans

The figure shows that the vast majority of fleet (90%) is compatible with a BEV (66%) or FC REEV (further 24%) option. The modelled large van has a nominal battery size of 70 kWh, and a 6 kg H_2 tank. For comparison, the Renault Master ZE H2 has 33 kWh battery and ~4 kg tank; for further details see Appendix C.

4.4.3 Large (26t) RCVs

Figure 9 shows the results of the ZEV compatibility analysis for the 26t RCVs in the NES fleets.

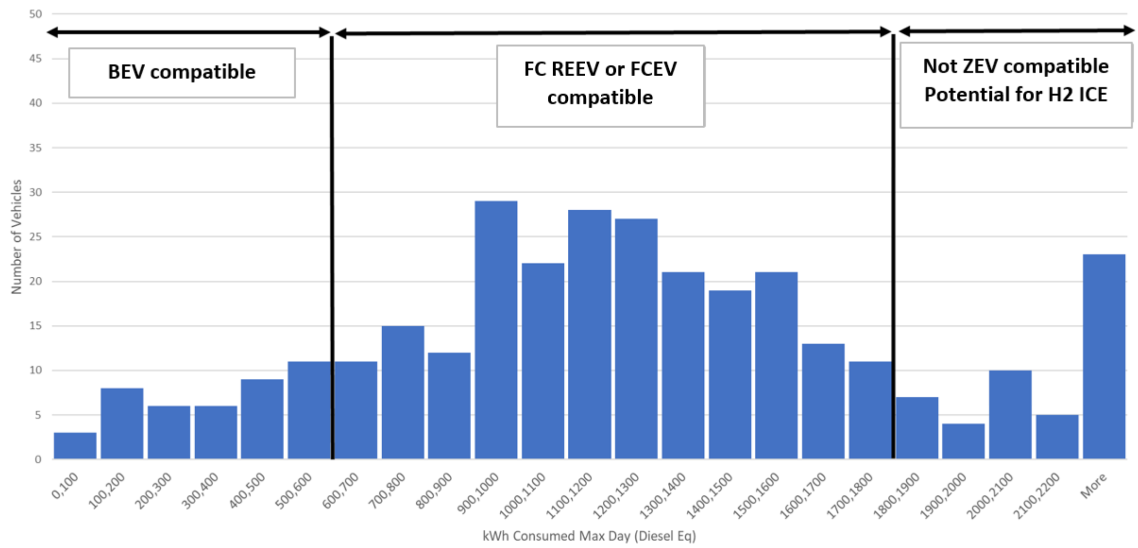

Figure 9: ZEV Compatibility for Large (26t) RCVs in NES Fleets

The figure shows that the majority of fleet (86%) is compatible with a ZEV option, although as expected for these larger vehicles the FC architecture offers the best option for most (74%) with a further 12% potentially compatible with a BEV option (for details of the modelled 26t vehicle see Appendix C).

4.5 Introduction to the Presentation of the Fleet Analysis

The two sections that follow summarise the fleet analysis work. Each individual fleet analysis has at least four components:

1. A **table** gives the vehicles analysed and their mileages
2. A **map** shows the location of the vehicles
3. A **table** gives details of the ZEV compatibility analysis and associated hydrogen and electricity demand for ZEV replacement vehicles
4. Two **graphs** summarise the ZEV replacement options and hydrogen demand shown in the ZEV compatibility analysis

In addition, the all fleets analysis has two further elements:

1. A **table** giving the emissions of the current fleet and the potential emissions reduction if all ZEV compatible vehicles are replaced.
2. Two **tables** giving indicative ZEV replacement numbers and associated hydrogen demand to 2023 and 2025 based on a seven year fleet vehicle replacement policy, and

As stated previously, the aim of this project is to establish the composition and location of NES fleets in order to assess their *collective* potential for the introduction of hydrogen vehicles and associated refuelling infrastructure to 2023 and 2025. Analysis and presentation of individual fleet data was *not* in scope of the proposal of work.

Nevertheless, we have agreed to provide summary feedback of individual fleet data which appears in Section 4.7. Each individual fleet section also shows a RAG (red-amber-green) rating which indicates the quality of the data provided by each fleet, and therefore gives an indication of:

- The level of confidence in the analysis (green = relatively high confidence as the input data was comprehensive, red = much lower confidence as the input data was sparse), and
- The additional effort that would be required to provide a full review for each fleet (green = relatively low effort as most data has already been supplied, red = high effort as the individual fleet review would need to start from scratch due to lack of data).

Further detail on any of the individual fleet work presented in Section 4.7 would require further bespoke analysis of the individual fleet data, which Cenex would be happy to discuss with individual fleets as a follow on to this work. The individual fleet analysis will not be discussed further in this report.

4.6 Results: All Fleets

Table 3. NES Region Fleet Composition

	Number of Vehicles	% of Combined Fleet	Average Annual Mileage
Small Car	302	8%	8,810
Medium Car	195	5%	7,010
Medium MPV	35	1%	7,520
Midsized SUV	7	0%	5,220
Midsized Commercial SUV	9	0%	9,030
Large Car	14	0%	5,400
Large 4x4 / SUV	122	3%	9,460
Small Van	905	23%	9,570
Medium Van	318	8%	12,220
Large Van (< 3.5t GVW)	1,000	26%	9,500
Large Van (> 3.5t GVW)	263	7%	10,650
Rigid Truck 2 axles (7.5t GVW)	88	2%	20,250
Rigid Truck 2 axles (18t GVW)	275	7%	12,200
Rigid Truck 3 axles (26t GVW)	321	8%	13,170
Rigid Truck 4 axles (32t GVW)	35	1%	21,000
Tractor Unit 4 x 2 (40t GCW)	1	0%	92,000
Tractor Unit 6 x 2 (44t GCW)	9	0%	42,560
Tractor Unit 6 x 4 (44t GCW)	3	0%	69,280
Grand Total	**3,902**	**100%**	**10,576**

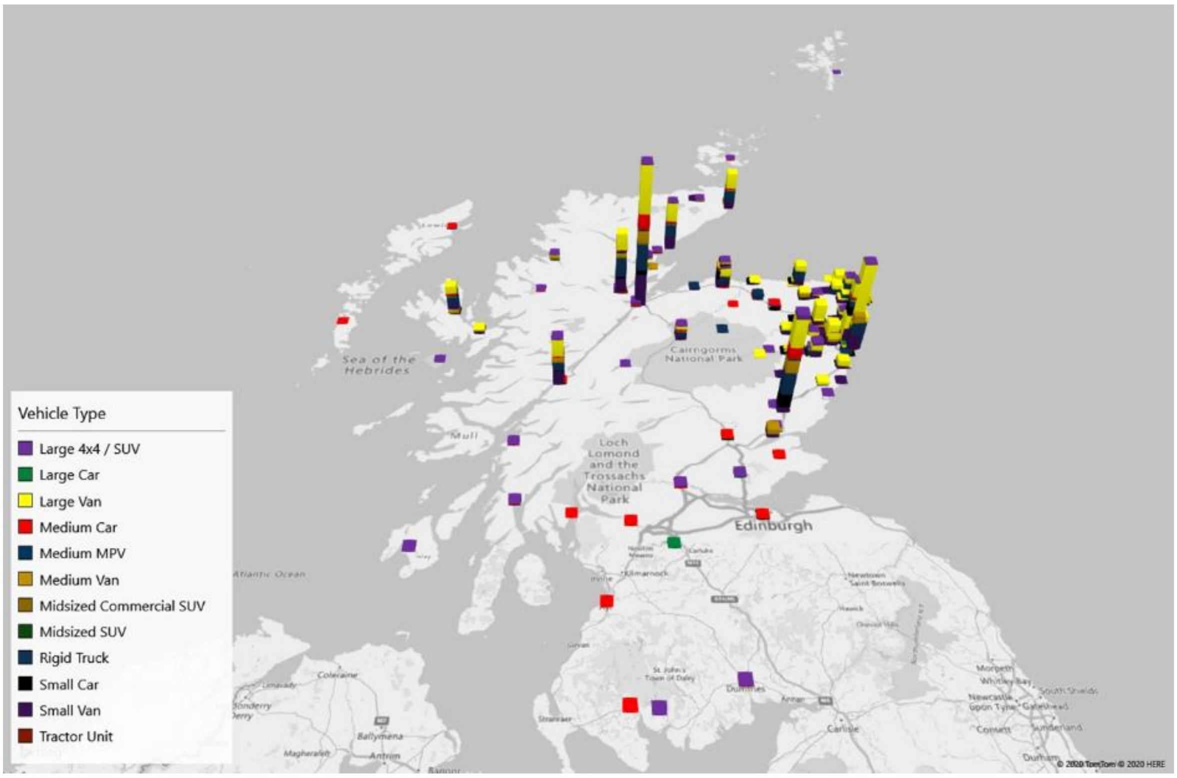

Figure 10. Fleet Location Map by Vehicle Type.

Table 4: All NES Fleets ZEV Compatibility

	# of vehicles	BEV % Compatible	% FCEV Only Compatible	% Not ZEV Compatible	Annual Electricity (MWh)	Annual H_2 (tonnes)
Small Car	302	95%	2%	3%	575	1
Medium Car	195	85%	7%	8%	318	1.7
Medium MPV	35	71%	17%	11%	63	0.2
Midsized SUV	7	100%	0%	0%	15	0
Midsized Commercial SUV	9	67%	33%	0%	23	0.8
Large Car	14	100%	0%	0%	31	0
Large 4x4 / SUV	122	59%	33%	8%	206	15
Small Van	905	53%	34%	12%	2,106	12
Medium Van	318	60%	28%	12%	1,197	6
Large Van (< 3.5t GVW)	1,000	66%	24%	10%	4,023	17.5
Large Van (> 3.5t GVW)	263	53%	20%	27%	814	4
Rigid Truck 2 axles (7.5t GVW)	88	14%	86%	0%	54	82
Rigid Truck 2 axles (18t GVW)	275	48%	47%	4%	1,516	153
Rigid Truck 3 axles (26t GVW)	321	12%	74%	13%	418	403
Rigid Truck 4 axles (32t GVW)	35	11%	63%	26%	37	46.5
Tractor Unit 4 x 2 (40t GCW)	1	0%	0%	100%	0	0
Tractor Unit 6 x 2 (44t GCW)	9	0%	11%	89%	0	2
Tractor Unit 6 x 4 (44t GCW)	3	0%	0%	100%	0	0
Total	**3,902**	**57%**	**32%**	**11%**	**11,396**	**745**

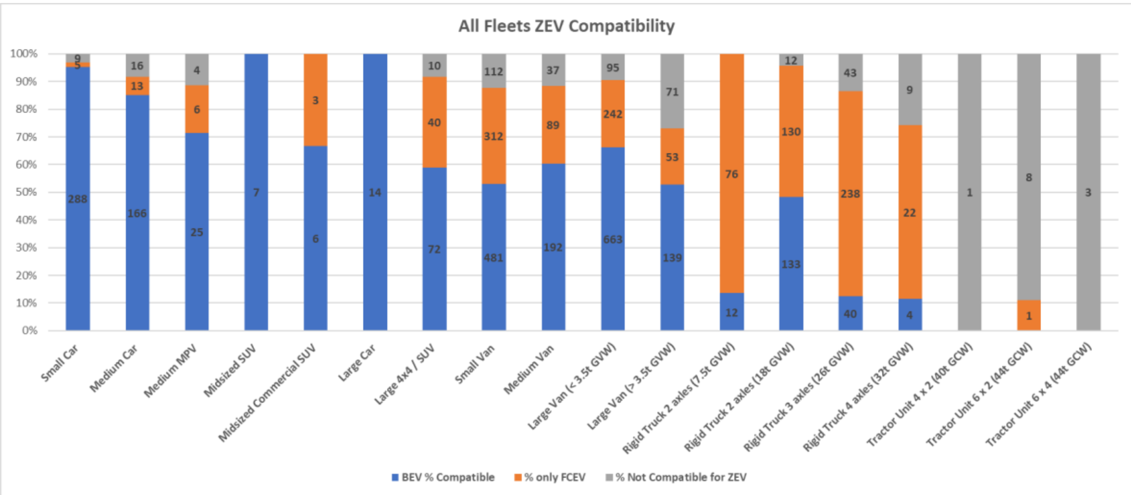

Figure 11: All Fleets ZEV Compatibility

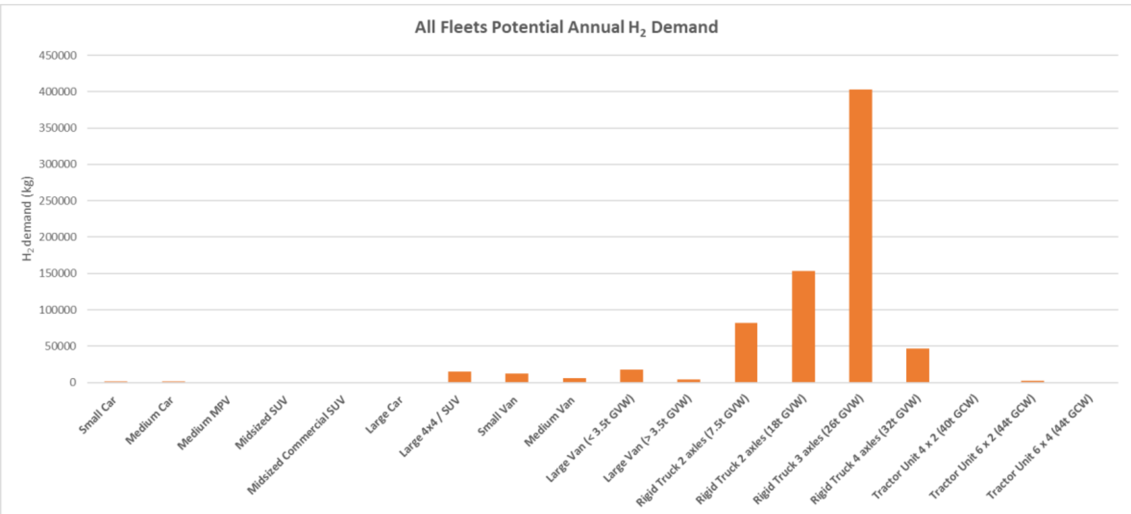

Figure 12: All Fleets Potential Annual H_2 Demand by Vehicle Type

4.6.1 Emissions Analysis

One of the main aims of this study is estimation of the potential for replacement of current NES fleet vehicles with ZEVs. This will result in considerable tailpipe emission (both tank to wheel (TTW) GHG and air quality (AQ)) savings in the fleets as both EVs and FC vehicles have zero tailpipe emissions.

The scale of overall well to wheel (WTW) GHG emission savings will depend on the source of electricity and hydrogen used to recharge/refuel ZEV replacements. Currently, EVs charged with grid electricity have a lower WTW footprint than conventionally-fuelled vehicles, and these WTW savings will continue to grow as the electricity grid is progressively decarbonised. However, FC vehicles fuelled with non-renewable grey hydrogen, derived from steam methane reforming (SMR, which accounts for around 95% of hydrogen production worldwide at present) or grid electrolysis, do not provide significant greenhouse gas savings over conventional equivalent vehicles. Therefore, finding a reliable source of low or zero carbon (green) hydrogen (for example from renewable electrolysis) is key to obtaining significant (up to 100%) WTW emission savings from FC vehicles.

Table 5 gives the WTW and AQ (NOx and PM) emissions of the current fleet (see Appendix B for details of sources of emissions data used in the calculations). The table also shows the associated WTW GHG savings for the replacement of ZEV compatible vehicles based on the use of non-renewable and renewable electricity and hydrogen to power the vehicles (AQ savings are not shown).

Table 5: Annual Emissions of Current Fleet with Reductions for the Introduction of ZEV Compatible Vehicles Under Different Energy Mixes

	Current Fleet			ZEV Compatible Replacement, Non-Renewable Energy*		ZEV Compatible Replacement, 100% Renewable Energy+	
	WTW CO_2 (tonnes/y)	NOx (tonnes/y)	PM (kg/y)	WTW CO_2 (tonnes/y)	% Reduction	WTW CO_2 (tonnes/y)	% Reduction
Small Car	770	0.81	6.24	259	67%	95	88%
Medium Car	495	0.54	4.25	303	40%	172	65%
Medium MPV	102	0.12	0.84	70	34%	39	61%
Midsized SUV	13	0.01	0.08	4	70%	0	100%
Midsized Commercial SUV	37	0.02	0.17	18	55%	0	99%
Large Car	22	0.02	0.17	9	62%	0	100%
Large 4x4 / SUV	604	0.59	3.30	413	36%	145	76%
Small Van	2,859	3.59	22.46	2,053	32%	873	69%
Medium Van	1,700	1.54	10.31	1,128	37%	470	72%
Large Van (< 3.5t GVW)	5,481	8.51	21.80	3,357	42%	1,363	75%
Large Van (> 3.5t GVW)	1,806	2.40	7.79	1,388	25%	977	46%
Rigid Truck 2 axles (7.5t GVW)	1,483	1.97	34.05	1,153	32%	34	98%
Rigid Truck 2 axles (18t GVW)	5,443	7.41	69.29	3,936	34%	1,130	79%
Rigid Truck 3 axles (26t GVW)	10,639	9.24	114.88	8,795	24%	3,176	70%
Rigid Truck 4 axles (32t GVW)	1,514	0.79	13.40	1,319	19%	650	57%
Tractor Unit 4 x 2 (40t GCW)	139	0.03	0.65	139	0%	139	0%
Tractor Unit 6 x 2 (44t GCW)	690	1.44	22.35	680	2%	652	5%
Tractor Unit 6 x 4 (44t GCW)	454	0.24	4.66	454	0%	454	0%
Total	**34,252**	**39**	**337**	**25,478**	**31%**	**10,371**	**70%**
Notes	* Non-renewable energy mix assumes SMR hydrogen and UK grid electricity + 100% renewable energy assumes wind electricity and wind electrolytic hydrogen						

The table shows that the replacement of conventional vehicles by ZEVs will significantly lower emissions, but that the savings are crucially dependent on the source of energy used by the vehicles. The following key points emerge:

- **Emissions savings are maximised by the use of renewable electricity and hydrogen.** The use of renewable electricity and hydrogen to power the ZEV compatible vehicles more than doubles the WTW emissions savings to 70% over the conventional fleet. This finding agrees with previous analysis in the Hydrogen Mobility Europe (H2ME) project, where the use of renewable hydrogen in particular was found to be crucial in achieving WTW GHG savings for FCEVs in all European Countries[14][15].
- **HDVs have higher emissions than LDVs.** Therefore, replacing HDVs with ZEV equivalents where possible is critical in achieving overall fleet decarbonisation goals. The implication of this for the Hydrogen Hub business case is discussed further in Section 7.
- **The vast majority of residual emissions are from non-ZEV compatible vehicles.** Under the relatively conservative assumptions used for this analysis (i.e., basing the compatibility on a maximum day of usage rather than an average day, see Section 4.8.1 for further discussion), 11% of the fleet deemed non-ZEV compatible. Table 4 shows that, in general, HDVs are more likely to have non-ZEV compatible duty cycles than lighter vehicles. Finding a zero emission replacement for these vehicles represents a considerable challenge in the study timeframes, and likely beyond.

[14] https://h2me.eu/wp-content/uploads/2020/11/H2ME-D4.19-Public-FV-Public-summary-Well-to-Wheels-%E2%80%A6.pdf

[15] As noted in the previous reference, a full life cycle assessment (LCA) will be necessary to determine the overall emissions impact of vehicles that are fuelled by large amounts of renewable electricity and hydrogen, as the WTW emissions from their fuel usage becomes less significant compared to those from other aspects of their life cycle.

4.6.2 2023 and 2025 NES Fleet Vehicle Replacement Scenarios

Even though the NES has strong political will and ambition to replace its vehicles by ZEV equivalents, it is unlikely (particularly given the issues with vehicle availability discussed in Section 3) that this can be achieved in the short term, and will be better achieved as part of a planned vehicle replacement process. The tables below provide ZEV compatible replacement numbers and associated hydrogen and electricity demands for the milestone years defined by the study – 2023 and 2025 – based on a seven year vehicle replacement cycle (i.e., in 2023 and 2025 it is assumed that any vehicle that has been in service for seven years or longer is replaced. It will be replaced by a ZEV equivalent, if compatible).

Table 6: ZEV Compatibility and Associated Energy Requirement for Vehicles Replaced by 2023

	# of Vehicles Replaced	BEV % Compatible	% FCEV Only Compatible	% Not ZEV Compatible	Annual Electricity (MWh)	Annual H_2 (tonnes)
Small Car	59	100%	0%	0%	116	**0**
Medium Car	36	100%	0%	0%	67	**0**
Medium MPV	9	89%	11%	0%	19	**0.03**
Midsized SUV	0	-	-	-	0	**0**
Midsized Commercial SUV	1	100%	0%	0%	2	**0**
Large Car	0	-	-	-	0	**0**
Large 4x4 / SUV	54	63%	28%	9%	84	**6**
Small Van	333	56%	38%	6%	870	**5**
Medium Van	65	52%	46%	2%	328	**2**
Large Van (< 3.5t GVW)	341	67%	23%	10%	1,466	**6**
Large Van (> 3.5t GVW)	105	57%	20%	23%	365	**1**
Rigid Truck 2 axles (7.5t GVW)	50	12%	88%	0%	30	**48**
Rigid Truck 2 axles (18t GVW)	127	43%	52%	6%	579	**80**
Rigid Truck 3 axles (26t GVW)	185	12%	77%	11%	220	**247**
Rigid Truck 4 axles (32t GVW)	21	14%	67%	19%	28	**28**
Tractor Unit 4 x 2 (40t GCW)	0	-	-	-	0	**0**
Tractor Unit 6 x 2 (44t GCW)	7	0%	14%	86%	0	**2**
Tractor Unit 6 x 4 (44t GCW)	2	0%	0%	100%	0	**0**
Total	**1,395**	**52%**	**39%**	**9%**	**4,173**	**426**

Table 7: ZEV Compatibility and Energy Requirement for Vehicles Replaced by 2025

	# of Vehicles Replaced	BEV % Compatible	% FCEV Only Compatible	% Not ZEV Compatible	Annual Electricity (MWh)	Annual H_2 (tonnes)
Small Car	143	100%	0%	0%	291	**0**
Medium Car	77	83%	9%	8%	127	**1**
Medium MPV	20	85%	10%	5%	40	**0.1**
Midsized SUV	2	100%	0%	0%	7	**0**
Midsized Commercial SUV	1	100%	0%	0%	2	**0**
Large Car	7	100%	0%	0%	18	**0**
Large 4x4 / SUV	83	55%	36%	8%	126	**12**
Small Van	576	53%	35%	11%	1,443	**8**
Medium Van	145	51%	39%	10%	632	**4**
Large Van (< 3.5t GVW)	582	65%	25%	10%	2,505	**11**
Large Van (> 3.5t GVW)	188	56%	21%	23%	649	**3**
Rigid Truck 2 axles (7.5t GVW)	64	14%	86%	0%	42	**62**
Rigid Truck 2 axles (18t GVW)	200	45%	50%	6%	1,004	**116**
Rigid Truck 3 axles (26t GVW)	253	12%	77%	11%	308	**334**
Rigid Truck 4 axles (32t GVW)	31	13%	61%	26%	37	**39**
Tractor Unit 4 x 2 (40t GCW)	0	0%	0%	0%	0	**0**
Tractor Unit 6 x 2 (44t GCW)	9	0%	11%	89%	0	**2**
Tractor Unit 6 x 4 (44t GCW)	3	0%	0%	100%	0	**0**
Total	**2,384**	**54%**	**36%**	**10%**	**7,232**	**591**

4.7 Results: Individual Fleets

4.7.1 Aberdeen City Council

Table 8. ACC Fleet Composition and Data Quality RAG Rating

ACC	Good fleet list		
	Number of Vehicles	% of Combined Fleet	Average Annual Mileage
Small Car	4	1%	630
Medium Car	6	1%	7,550
Medium MPV	2	0%	2,750
Large Car	1	0%	4,820
Large 4x4 / SUV	2	0%	2,730
Small Van	87	18%	5,560
Medium Van	59	12%	6,200
Large Van (< 3.5t GVW)	194	39%	4,890
Large Van (> 3.5t GVW)	31	6%	7,610
Rigid Truck 2 axles (7.5t GVW)	4	1%	4,450
Rigid Truck 2 axles (18t GVW)	53	11%	12,280
Rigid Truck 3 axles (26t GVW)	51	10%	7,330
Rigid Truck 4 axles (32t GVW)	1	0%	3,290
Grand Total	**495**	**100%**	**6,350**

Figure 13. ACC Location Map by Vehicle Type.

Table 9: ACC ZEV Compatibility

	# of vehicles	BEV % Compatible	% FCEV Only Compatible	% Not ZEV Compatible	Annual Electricity (kWh)	Annual H_2 (kg)
Small Car	4	100%	0%	0%	646	0
Medium Car	6	100%	0%	0%	14,860	0
Medium MPV	2	100%	0%	0%	2,893	0
Large Car	1	100%	0%	0%	1,400	0
Large 4x4 / SUV	2	100%	0%	0%	4,799	0
Small Van	87	93%	6%	1%	166,594	207
Medium Van	59	100%	0%	0%	193,286	0
Large Van (< 3.5t GVW)	194	97%	3%	1%	550,472	414
Large Van (> 3.5t GVW)	31	90%	3%	6%	150,793	138
Rigid Truck 2 axles (7.5t GVW)	4	75%	25%	0%	14,755	645
Rigid Truck 2 axles (18t GVW)	53	60%	36%	4%	368,805	31,876
Rigid Truck 3 axles (26t GVW)	51	24%	76%	0%	140,244	65,442
Rigid Truck 4 axles (32t GVW)	1	100%	0%	0%	9,619	0
Total	**495**	**88%**	**11%**	**1%**	**1,619,166**	**98,723**

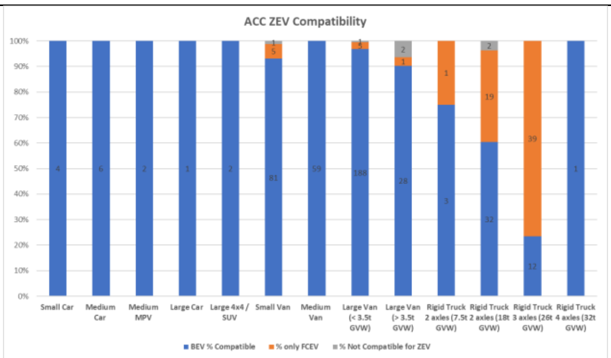

Figure 14: ACC ZEV Compatibility

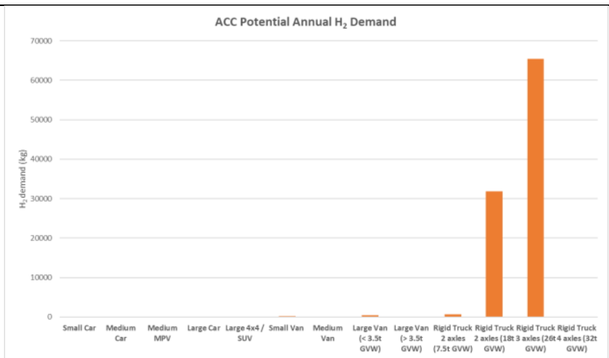

Figure 15: ACC Potential H_2 Demand by Vehicle Type

4.7.2 Aberdeenshire Council

Table 10. Aberdeenshire Fleet Composition

Aberdeenshire	Good fleet list		
	Number of Vehicles	% of Combined Fleet	Average Annual Mileage
Medium Car	11	1%	4,780
Medium MPV	1	0%	8,850
Midsized SUV	2	0%	9,070
Large 4x4 / SUV	13	2%	8,620
Small Van	208	26%	10,650
Medium Van	19	2%	10,680
Large Van (< 3.5t GVW)	311	39%	10,440
Large Van (> 3.5t GVW)	73	9%	13,400
Rigid Truck 2 axles (7.5t GVW)	10	1%	12,410
Rigid Truck 2 axles (18t GVW)	44	6%	14,130
Rigid Truck 3 axles (26t GVW)	89	11%	15,040
Rigid Truck 4 axles (32t GVW)	19	2%	20,370
Grand Total	**800**	**100%**	**11,633**

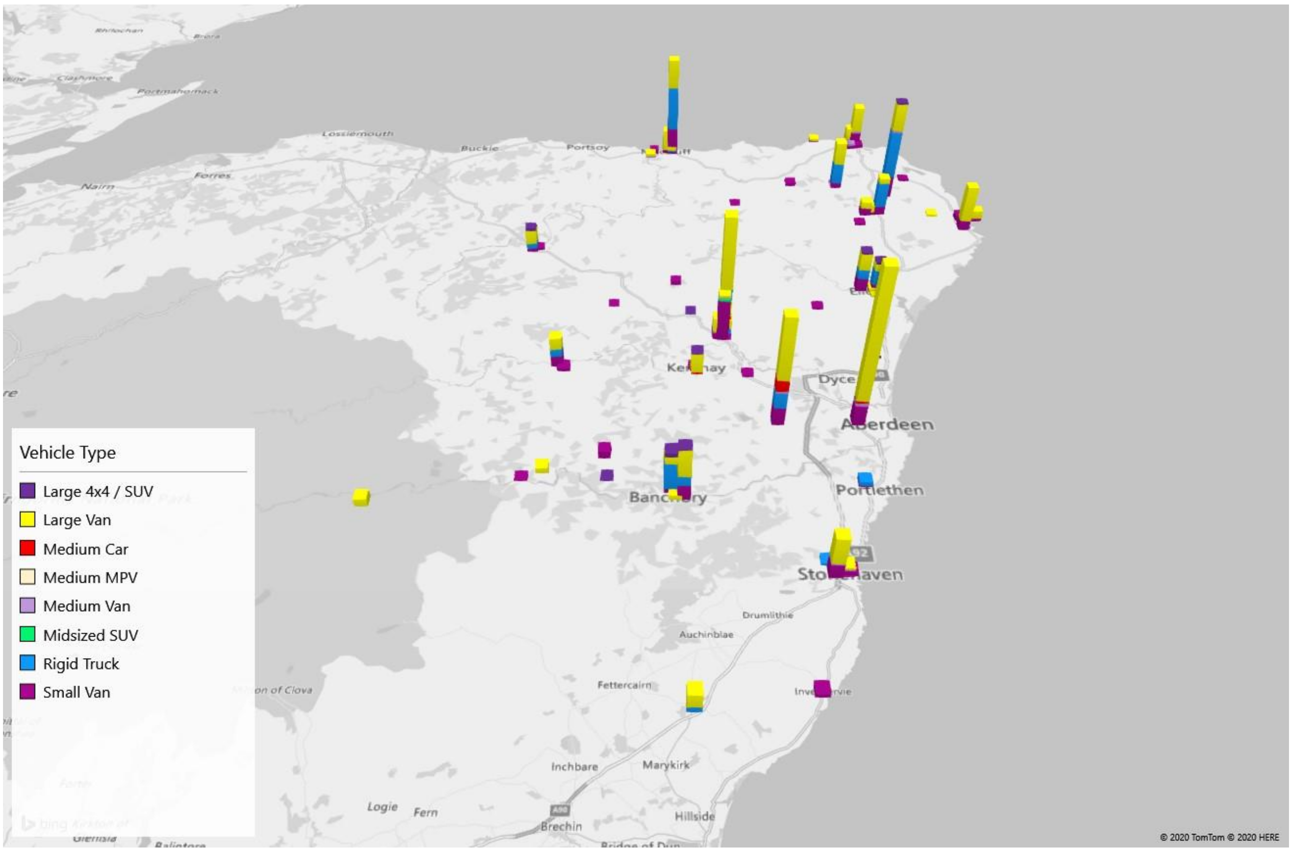

Figure 16. Aberdeenshire Location Map by Vehicle Type.

Table 11: Aberdeenshire ZEV Compatibility

	# of vehicles	BEV % Compatible	% FCEV Only Compatible	% Not ZEV Compatible	Annual Electricity (kWh)	Annual H_2 (kg)
Medium Car	11	100%	0%	0%	16,986	0
Medium MPV	1	0%	100%	0%	2,319	26
Midsized SUV	2	100%	0%	0%	7,360	0
Large 4x4 / SUV	13	69%	31%	0%	18,243	1,685
Small Van	208	47%	44%	9%	562,656	3,826
Medium Van	19	79%	21%	0%	80,468	340
Large Van (< 3.5t GVW)	311	65%	28%	7%	1,437,454	6,340
Large Van (> 3.5t GVW)	73	29%	30%	41%	209,127	1,519
Rigid Truck 2 axles (7.5t GVW)	10	20%	80%	0%	8,727	4,554
Rigid Truck 2 axles (18t GVW)	44	43%	57%	0%	229,273	31,909
Rigid Truck 3 axles (26t GVW)	89	13%	83%	3%	100,379	126,367
Rigid Truck 4 axles (32t GVW)	19	5%	74%	21%	458	28,266
Total	**800**	**48%**	**47%**	**7%**	**2,673,451**	**204,833**

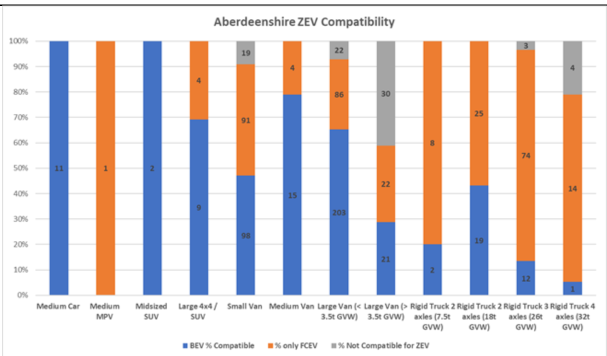

Figure 17: Aberdeenshire ZEV Compatibility

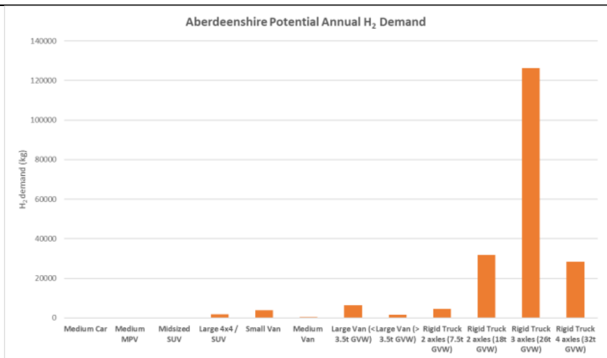

Figure 18: Aberdeenshire Potential H_2 Demand by Vehicle Type

4.7.3 Angus Council

Table 12. Angus Fleet Composition

Angus	Good fleet list		
	Number of Vehicles	% of Combined Fleet	Average Annual Mileage
Small Car	36	14%	10,230
Medium Car	26	10%	7,780
Medium MPV	5	2%	7,440
Large Car	1	0%	5,600
Large 4x4 / SUV	10	4%	9,200
Small Van	15	6%	9,130
Medium Van	33	13%	12,710
Large Van (< 3.5t GVW)	38	15%	6,630
Large Van (> 3.5t GVW)	31	12%	6,910
Rigid Truck 2 axles (7.5t GVW)	16	6%	11,120
Rigid Truck 2 axles (18t GVW)	4	2%	6,600
Rigid Truck 3 axles (26t GVW)	29	12%	12,510
Rigid Truck 4 axles (32t GVW)	8	3%	24,730
Grand Total	**252**	**100%**	**9,892**

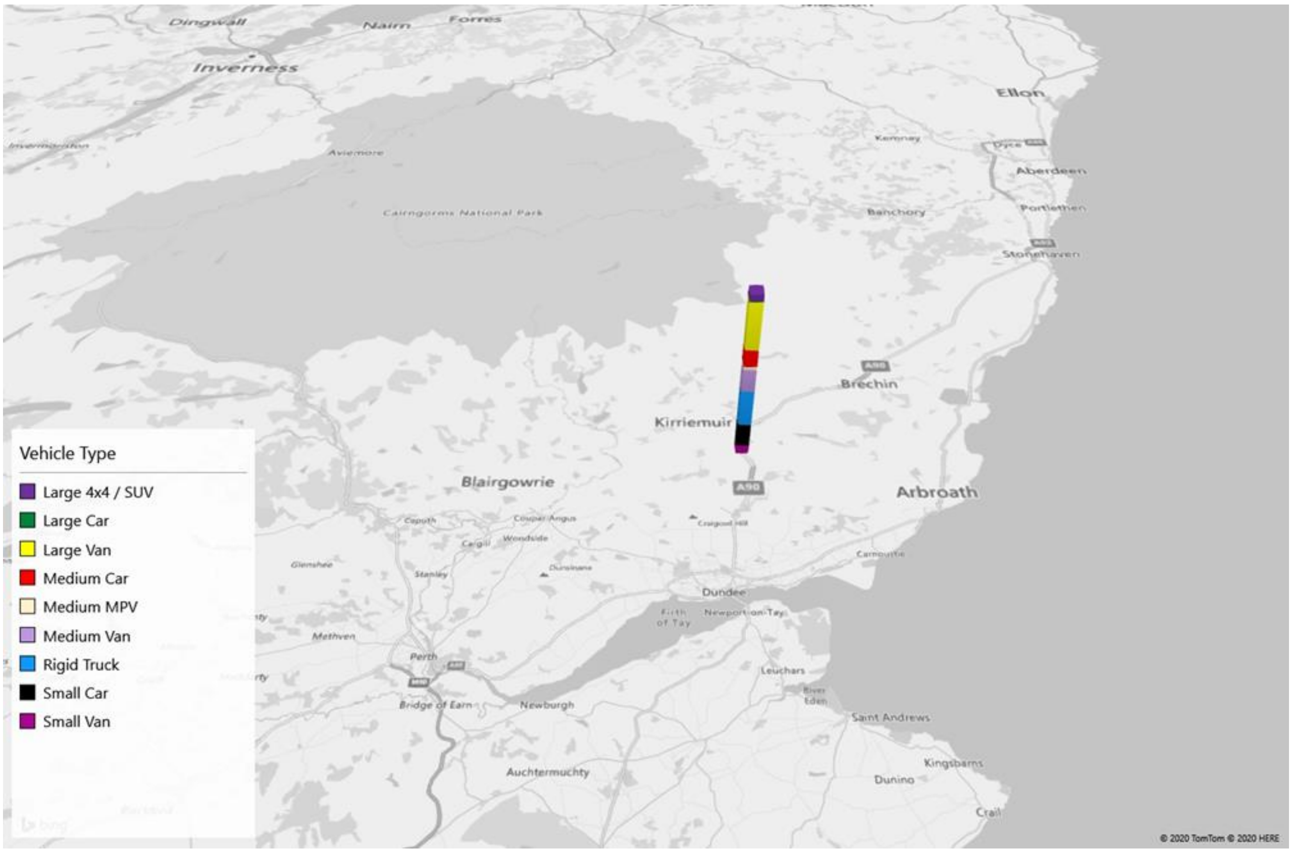

Figure 19. Angus Location Map by Vehicle Type.

Table 13: Angus ZEV Compatibility

	# of vehicles	BEV % Compatible	% FCEV Only Compatible	% Not ZEV Compatible	Annual Electricity (kWh)	Annual H_2 (kg)
Small Car	36	86%	11%	3%	64,313	1,019
Medium Car	26	85%	8%	8%	32,353	685
Medium MPV	5	60%	40%	0%	11,060	69
Large Car	1	100%	0%	0%	1,741	0
Large 4x4 / SUV	10	70%	30%	0%	25,046	1,150
Small Van	15	40%	53%	7%	38,782	303
Medium Van	33	67%	21%	12%	130,421	442
Large Van (< 3.5t GVW)	38	84%	11%	5%	162,233	311
Large Van (> 3.5t GVW)	31	58%	23%	19%	108,554	567
Rigid Truck 2 axles (7.5t GVW)	16	0%	100%	0%	0	11,782
Rigid Truck 2 axles (18t GVW)	4	75%	25%	0%	50,315	990
Rigid Truck 3 axles (26t GVW)	29	0%	100%	0%	0	57,490
Rigid Truck 4 axles (32t GVW)	8	0%	75%	25%	0	15,531
Total	**252**	**56%**	**38%**	**6%**	**624,818**	**90,339**

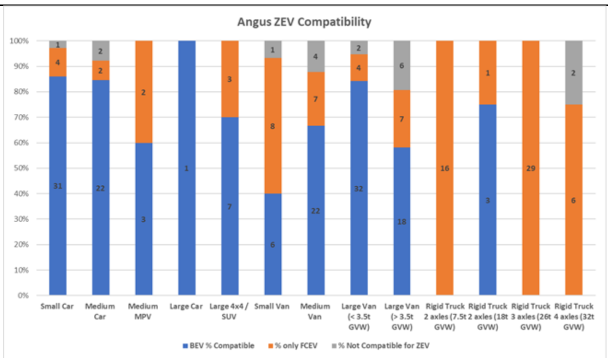

Figure 20: Angus ZEV Compatibility

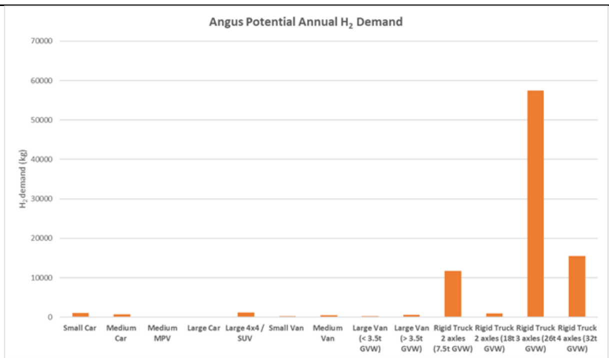

Figure 21: Angus Potential H_2 Demand by Vehicle Type

4.7.4 Highland Council

Table 14. Highland Fleet Composition

Highland	Good fleet list		
	Number of Vehicles	% of Combined Fleet	Average Annual Mileage
Small Car	22	2%	5,970
Medium Car	74	8%	6,870
Medium MPV	22	2%	8,050
Midsized Commercial SUV	8	1%	9,750
Large Car	1	0%	8,800
Large 4x4 / SUV	8	1%	9,770
Small Van	246	25%	8,460
Medium Van	54	5%	8,830
Large Van (< 3.5t GVW)	235	24%	9,760
Large Van (> 3.5t GVW)	73	7%	6,380
Rigid Truck 2 axles (7.5t GVW)	19	2%	10,080
Rigid Truck 2 axles (18t GVW)	122	12%	9,300
Rigid Truck 3 axles (26t GVW)	97	10%	12,150
Rigid Truck 4 axles (32t GVW)	1	0%	20,020
Grand Total	**982**	**100%**	**8,986**

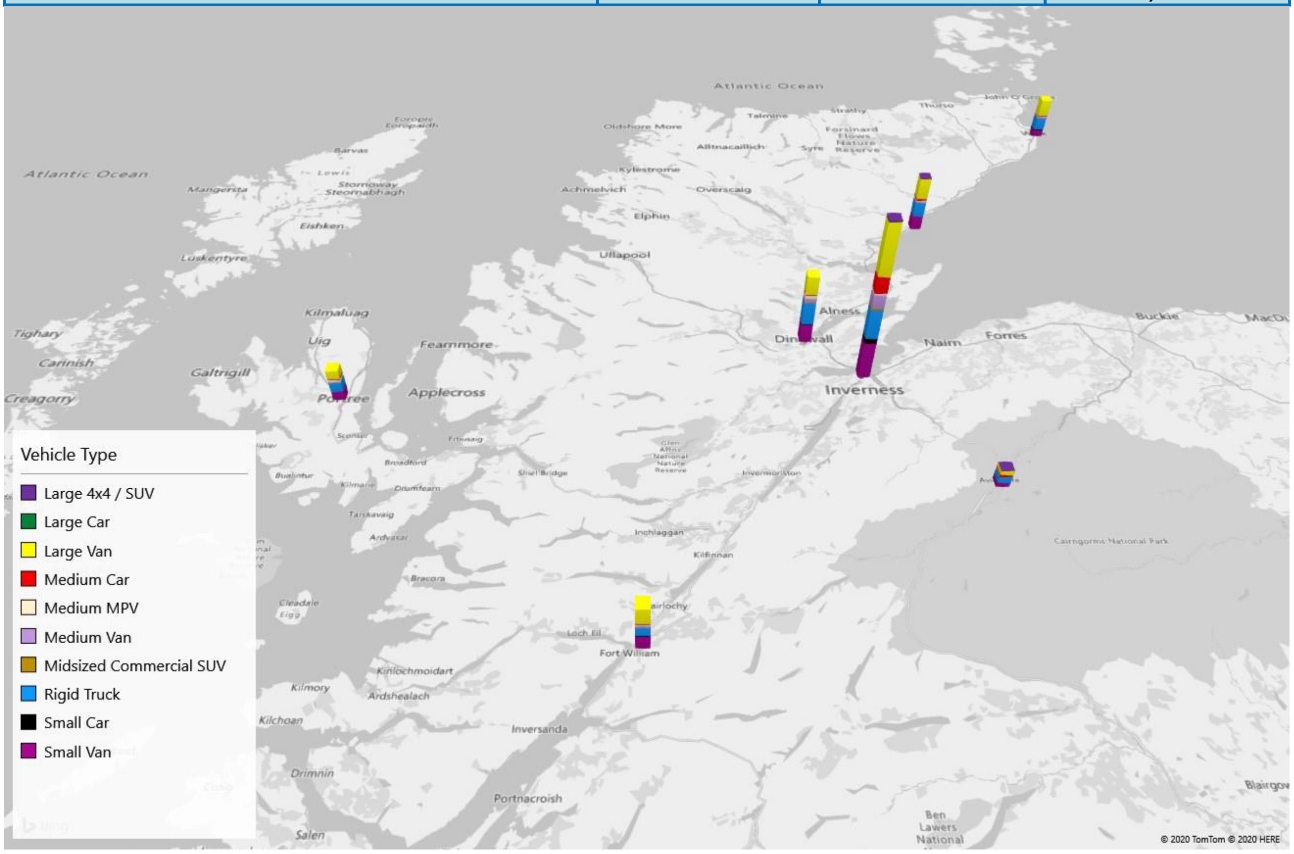

Figure 22. Highland Location Map by Vehicle Type.

Table 15: Highland ZEV Compatibility

	# of vehicles	BEV % Compatible	% FCEV Only Compatible	% Not ZEV Compatible	Annual Electricity (kWh)	Annual H_2 (kg)
Small Car	22	59%	5%	36%	12,972	49
Medium Car	74	66%	15%	19%	77,226	1,056
Medium MPV	22	68%	14%	18%	34,739	92
Midsized Commercial SUV	8	63%	38%	0%	21,566	848
Large Car	1	100%	0%	0%	2,736	0
Large 4x4 / SUV	8	75%	25%	0%	23,268	487
Small Van	246	57%	31%	11%	486,852	2,500
Medium Van	54	72%	22%	6%	167,787	639
Large Van (< 3.5t GVW)	235	62%	27%	11%	929,688	4,288
Large Van (> 3.5t GVW)	73	77%	16%	7%	216,617	797
Rigid Truck 2 axles (7.5t GVW)	19	26%	74%	0%	18,315	8,925
Rigid Truck 2 axles (18t GVW)	122	44%	49%	7%	558,789	48,646
Rigid Truck 3 axles (26t GVW)	97	12%	57%	31%	130,349	83,036
Rigid Truck 4 axles (32t GVW)	1	0%	100%	0%	0	1,719
Total	**982**	**56%**	**34%**	**10%**	**2,680,904**	**153,081**

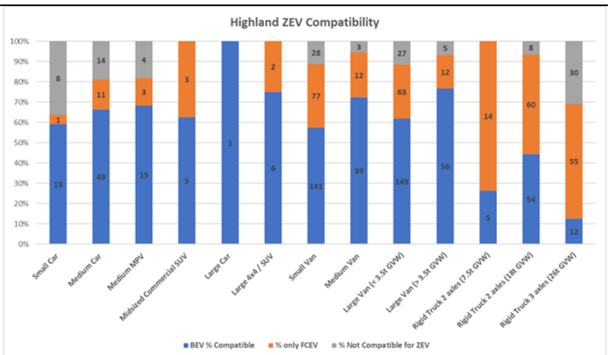

Figure 23: Highland ZEV Compatibility

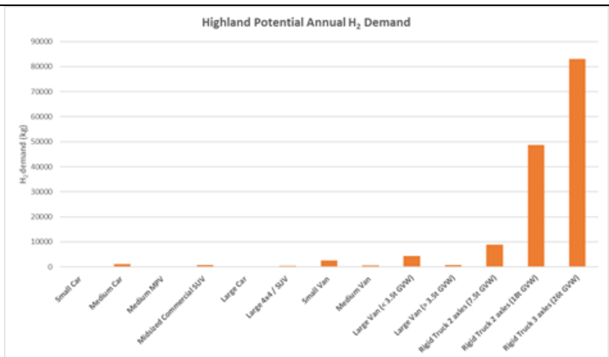

Figure 24: Highland Potential H_2 Demand by Vehicle Type

4.7.5 Moray Council

Table 16. Moray Fleet Composition

Moray	Good fleet list		
	Number of Vehicles	% of Combined Fleet	Average Annual Mileage
Small Car	76	17%	10,150
Medium Car	7	2%	10,790
Large 4x4 / SUV	7	2%	13,230
Small Van	107	24%	11,120
Medium Van	24	5%	10,890
Large Van (< 3.5t GVW)	102	23%	10,710
Large Van (> 3.5t GVW)	27	6%	18,600
Rigid Truck 2 axles (7.5t GVW)	12	3%	13,840
Rigid Truck 2 axles (18t GVW)	32	7%	17,960
Rigid Truck 3 axles (26t GVW)	38	9%	18,370
Rigid Truck 4 axles (32t GVW)	5	1%	19,380
Tractor Unit 6 x 4 (44t GCW)	3	1%	69,280
Grand Total	**440**	**100%**	**13,020**

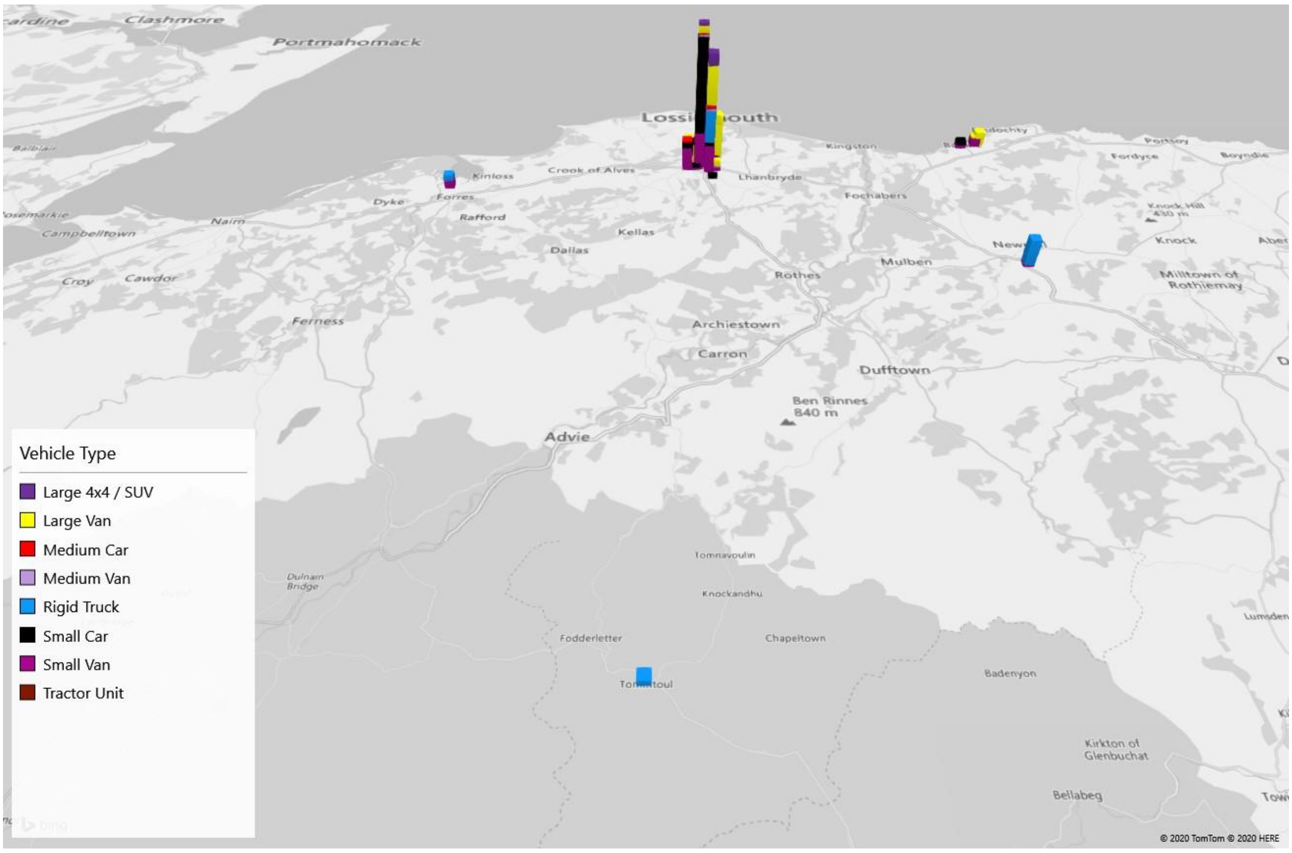

Figure 25. Moray Location Map by Vehicle Type.

Table 17: Moray ZEV Compatibility

	# of vehicles	BEV % Compatible	% FCEV Only Compatible	% Not ZEV Compatible	Annual Electricity (kWh)	Annual H_2 (kg)
Small Car	76	100%	0%	0%	166,772	0
Medium Car	7	100%	0%	0%	25,419	0
Large 4x4 / SUV	7	57%	29%	14%	19,006	819
Small Van	107	45%	42%	13%	286,950	1,827
Medium Van	24	67%	33%	0%	111,438	590
Large Van (< 3.5t GVW)	102	55%	37%	8%	499,988	2,855
Large Van (> 3.5t GVW)	27	7%	15%	78%	27,910	286
Rigid Truck 2 axles (7.5t GVW)	12	17%	83%	0%	12,504	7,931
Rigid Truck 2 axles (18t GVW)	32	44%	50%	6%	167,560	25,633
Rigid Truck 3 axles (26t GVW)	38	5%	76%	18%	28,832	53,085
Rigid Truck 4 axles (32t GVW)	5	40%	20%	40%	27,403	920
Total	**440**	**45%**	**32%**	**23%**	**1,373,782**	**93,946**

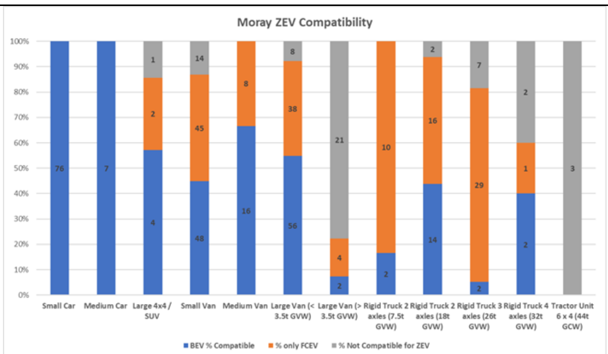

Figure 26: Moray ZEV Compatibility

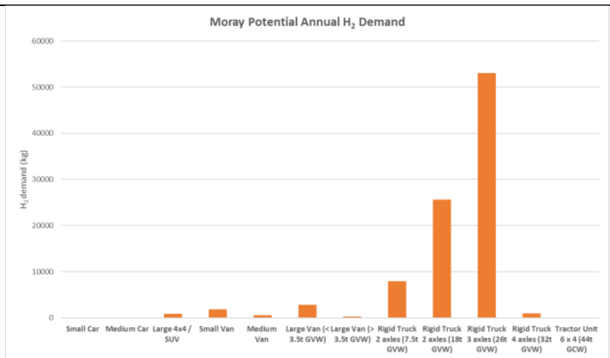

Figure 27: Moray Potential H_2 Demand by Vehicle Type

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4.7.6 NatureScot

Table 18. NatureScot Fleet Composition

NatureScot	MPG missing		
	Number of Vehicles	% of Combined Fleet	Average Annual Mileage
Small Car	15	14%	5,110
Medium Car	43	39%	6,490
Medium MPV	2	2%	5,500
Midsized SUV	5	5%	3,680
Midsized Commercial SUV	1	1%	3,250
Large Car	4	4%	4,570
Large 4x4 / SUV	32	29%	4,420
Small Van	8	7%	5,340
Grand Total	**110**	**100%**	**5,371**

Figure 28. NatureScot Location Map by Vehicle Type.

Table 19: NatureScot ZEV Compatibility

	# of vehicles	BEV % Compatible	% FCEV Only Compatible	% Not ZEV Compatible	Annual Electricity (kWh)	Annual H_2 (kg)
Small Car	15	100%	0%	0%	22,744	0
Medium Car	43	100%	0%	0%	84,777	0
Medium MPV	2	100%	0%	0%	4,238	0
Midsized SUV	5	100%	0%	0%	7,327	0
Midsized Commercial SUV	1	100%	0%	0%	1,731	0
Large Car	4	100%	0%	0%	10,462	0
Large 4x4 / SUV	32	94%	6%	0%	66,900	687
Small Van	8	100%	0%	0%	16,208	0
Total	**110**	**99%**	**1%**	**0%**	**214,386**	**687**

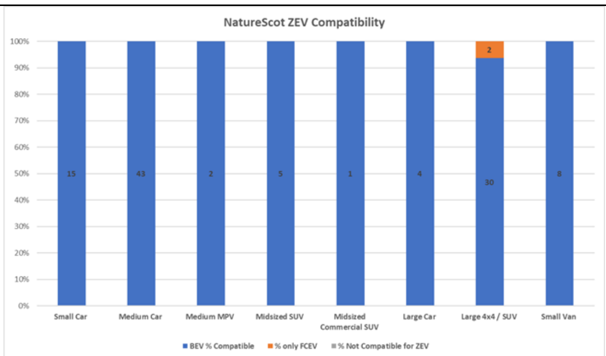

Figure 29: NatureScot ZEV Compatibility

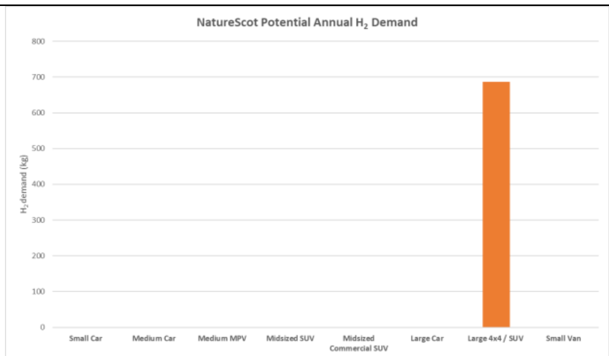

Figure 30: NatureScot Potential H_2 Demand by Vehicle Type

4.7.7 North East Scotland College

Table 20. NESCol Fleet Composition

NESCol	MPG missing		
	Number of Vehicles	% of Combined Fleet	Average Annual Mileage
Small Car	6	29%	2,060
Medium Car	4	19%	6,060
Large Car	3	14%	3,960
Large 4x4 / SUV	1	5%	4,580
Medium Van	2	10%	18,950
Large Van (> 3.5t GVW)	5	24%	4,990
Grand Total	**21**	**100%**	**5,520**

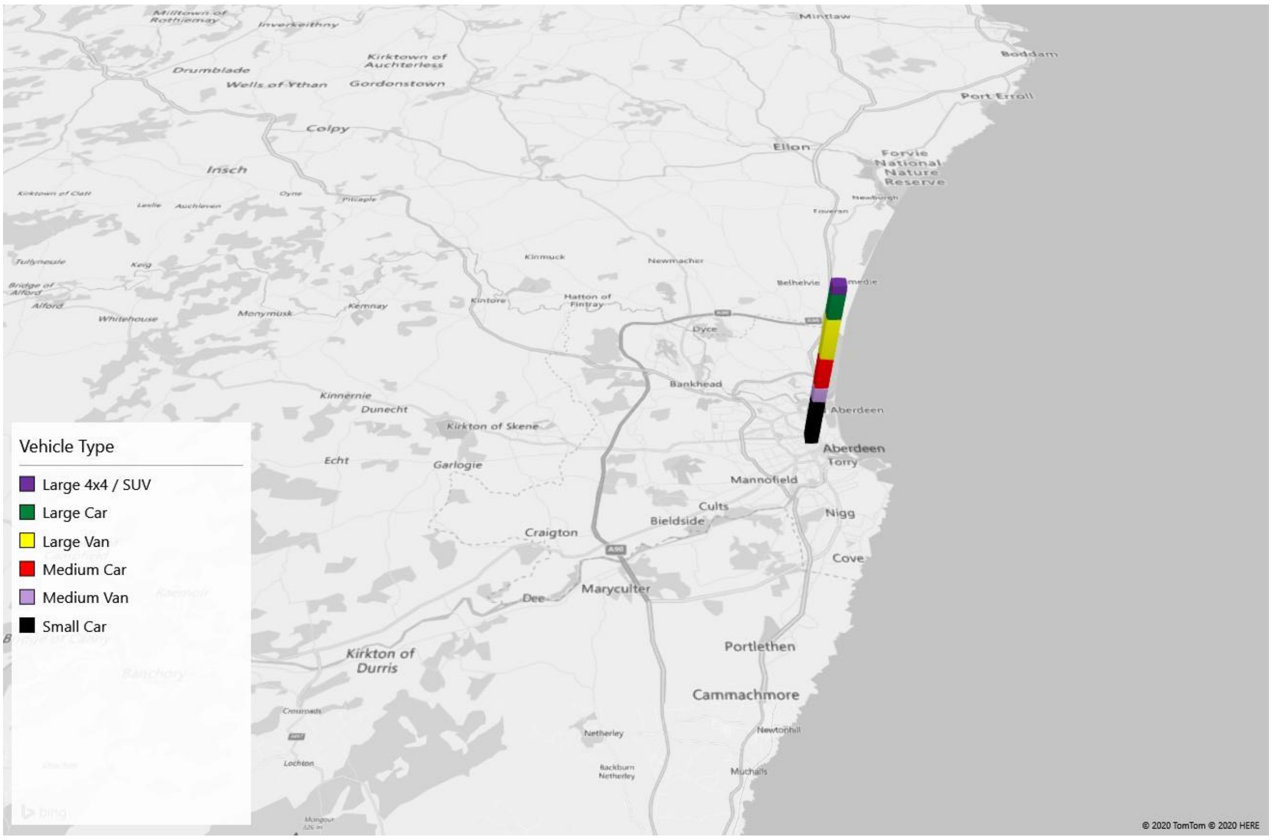

Figure 31. NESCol Location Map by Vehicle Type.

Table 21: NESCol ZEV Compatibility

	# of vehicles	BEV % Compatible	% FCEV Only Compatible	% Not ZEV Compatible	Annual Electricity (kWh)	Annual H_2 (kg)
Small Car	6	100%	0%	0%	3,660	0
Medium Car	4	100%	0%	0%	7,363	0
Large Car	3	100%	0%	0%	6,800	0
Large 4x4 / SUV	1	100%	0%	0%	2,658	0
Medium Van	2	0%	50%	50%	6,441	73
Large Van (> 3.5t GVW)	5	100%	0%	0%	14,668	0
Total	**21**	**83%**	**8%**	**8%**	**41,590**	**73**

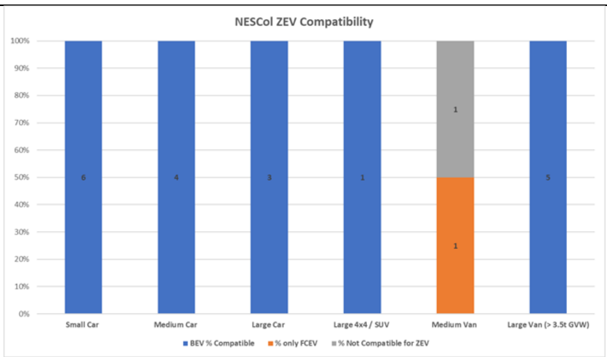

Figure 32: NESCol ZEV Compatibility

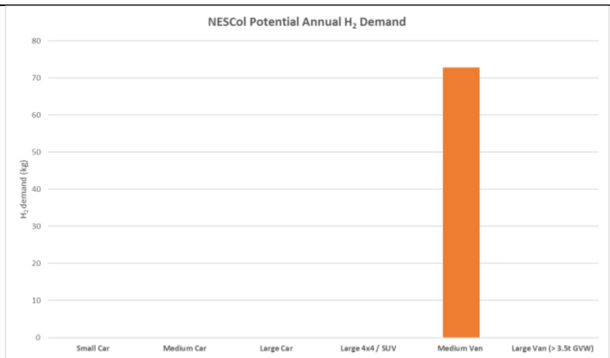

Figure 33: NESCol Potential H_2 Demand by Vehicle Type

4.7.8 NHS Grampian

Table 22. NHS Fleet Composition

NHS	No individual vehicle data		
	Number of Vehicles	**% of Combined Fleet**	**Average Annual Mileage**
Small Car	142	50%	9,150
Medium Car	18	6%	6,790
Medium MPV	2	1%	6,830
Large Car	2	1%	8,400
Large 4x4 / SUV	2	1%	14,500
Small Van	58	20%	9,600
Medium Van	7	2%	10,450
Large Van (< 3.5t GVW)	32	11%	10,020
Large Van (> 3.5t GVW)	6	2%	8,890
Rigid Truck 2 axles (18t GVW)	15	5%	11,250
Grand Total	**284**	**100%**	**9,344**

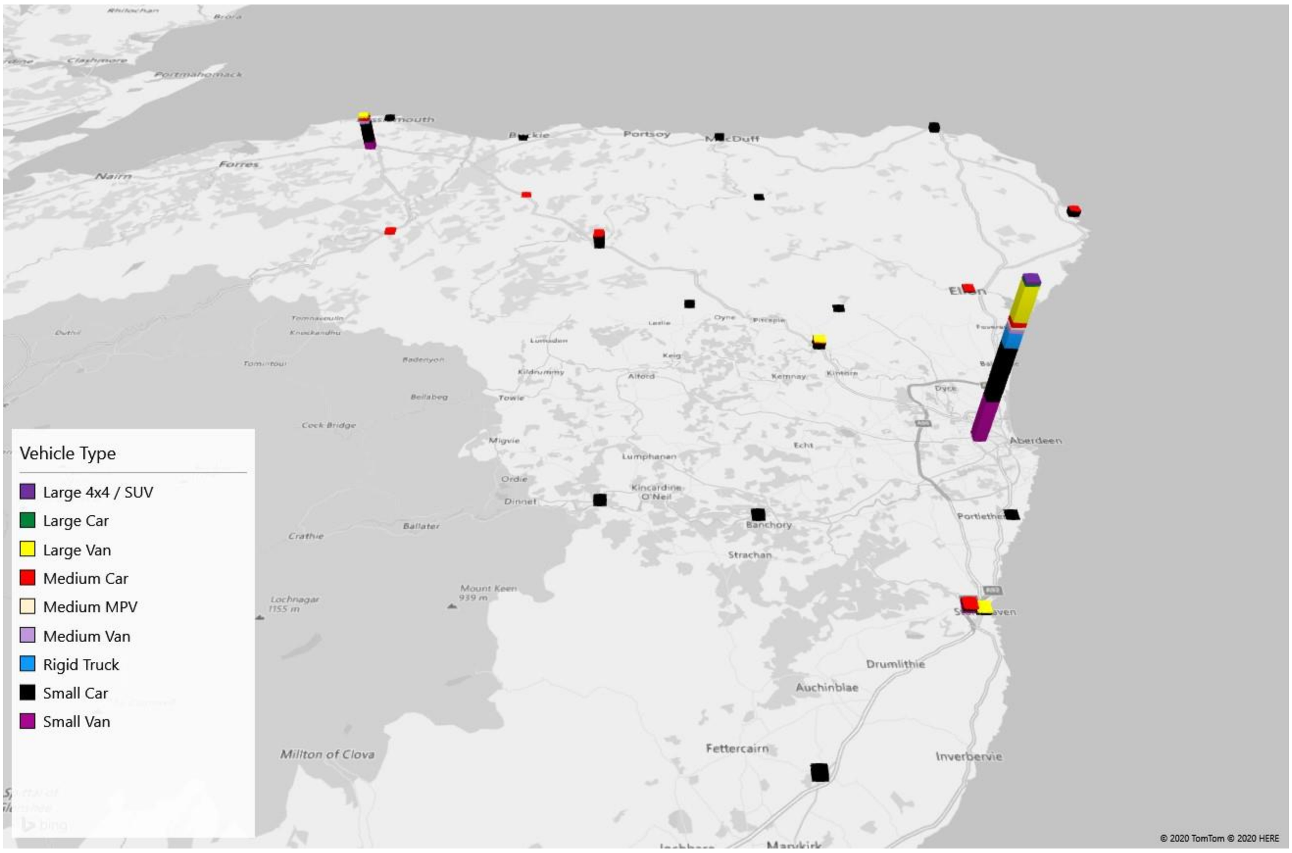

Figure 34. NHS Location Map by Vehicle Type.

Table 23: NHS ZEV Compatibility

	# of vehicles	BEV % Compatible	% FCEV Only Compatible	% Not ZEV Compatible	Annual Electricity (kWh)	Annual H_2 (kg)
Small Car	142	100%	0%	0%	303,692	0
Medium Car	18	100%	0%	0%	39,475	0
Medium MPV	2	100%	0%	0%	4,420	0
Large Car	2	100%	0%	0%	5,223	0
Large 4x4 / SUV	2	0%	100%	0%	0	663
Small Van	58	50%	50%	0%	181,533	1,088
Medium Van	7	86%	14%	0%	30,347	58
Large Van (< 3.5t GVW)	32	66%	34%	0%	167,294	745
Large Van (> 3.5t GVW)	6	67%	33%	0%	30,493	127
Rigid Truck 2 axles (18t GVW)	15	67%	33%	0%	138,276	5,222
Total	**284**	**73%**	**27%**	**0%**	**900,753**	**7,903**

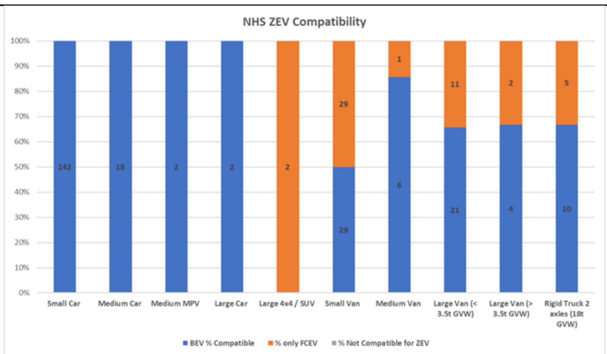

Figure 35: NHS ZEV Compatibility

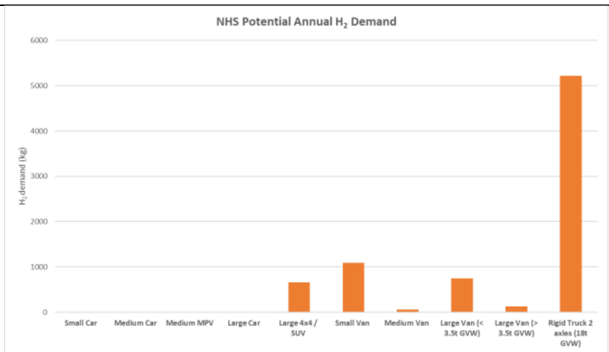

Figure 36: NHS Potential H_2 Demand by Vehicle Type

4.7.9 Robert Gordon University

Table 24. RGU Fleet Composition

RGU	**Good fleet list**		
	Number of Vehicles	**% of Combined Fleet**	**Average Annual Mileage**
Small Car	1	8%	650
Medium Car	1	8%	6,240
Large Car	1	8%	1,430
Small Van	4	31%	4,400
Large Van (< 3.5t GVW)	5	38%	7,150
Large Van (> 3.5t GVW)	1	8%	2,600
Grand Total	**13**	**100%**	**4,944**

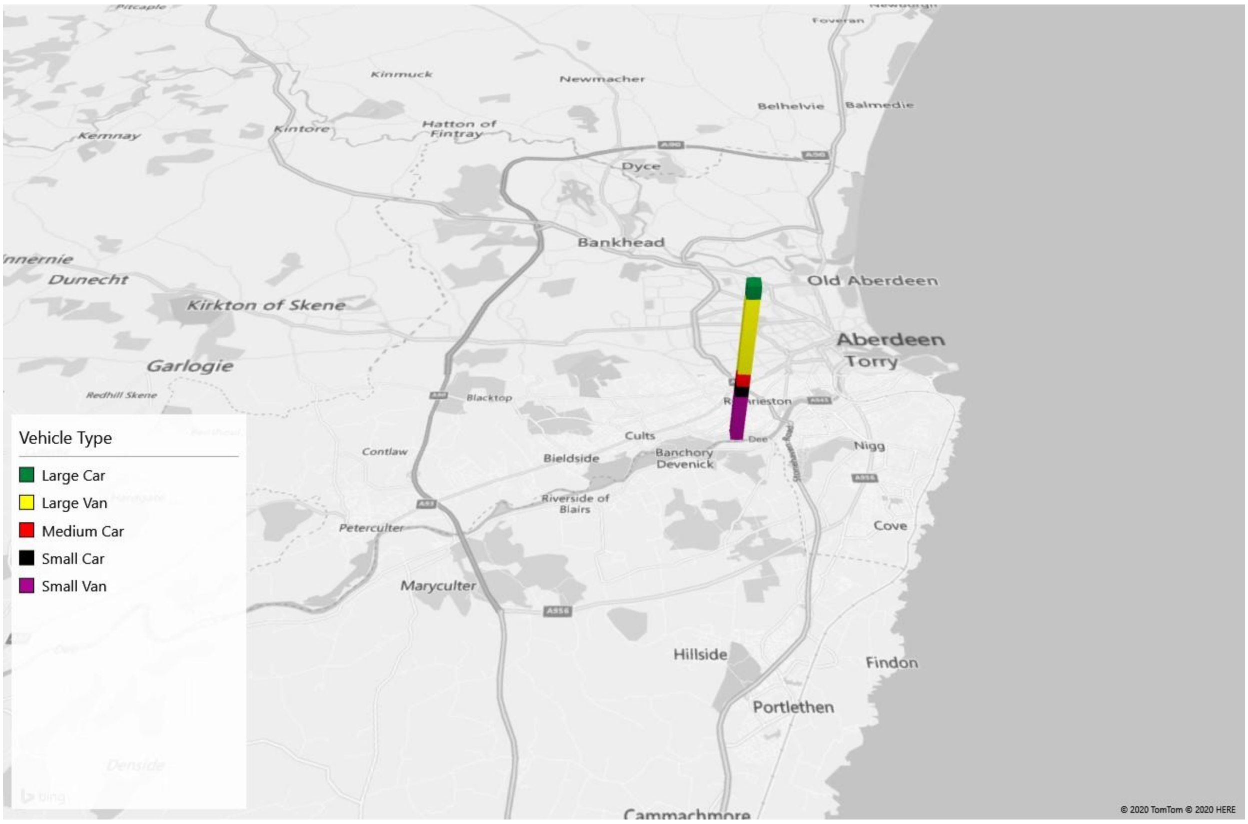

Figure 37. RGU Location Map by Vehicle Type.

Table 25: RGU ZEV Compatibility

	# of vehicles	BEV % Compatible	% FCEV Only Compatible	% Not ZEV Compatible	Annual Electricity (kWh)	Annual H_2 (kg)
Small Car	1	100%	0%	0%	166	0
Medium Car	1	100%	0%	0%	1,404	0
Large Car	1	100%	0%	0%	416	0
Small Van	4	75%	25%	0%	7,332	42
Large Van (< 3.5t GVW)	5	80%	20%	0%	14,083	79
Large Van (> 3.5t GVW)	1	100%	0%	0%	1,282	0
Total	**13**	**93%**	**8%**	**0%**	**24,681**	**121**

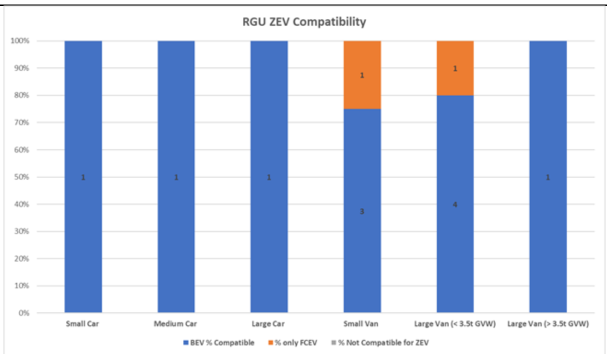

Figure 38: RGU ZEV Compatibility

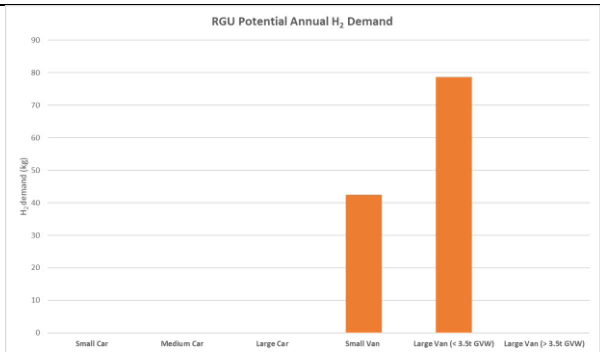

Figure 39: RGU Potential H_2 Demand by Vehicle Type

4.7.10 Royal Mail

Table 26. Royal Mail Fleet Composition

Royal Mail	Missing some mileage and MPG		
	Number of Vehicles	% of Combined Fleet	Average Annual Mileage
Small Van	71	49%	6,590
Medium Van	21	14%	11,730
Large Van (< 3.5t GVW)	20	14%	22,600
Rigid Truck 2 axles (7.5t GVW)	27	19%	40,900
Rigid Truck 2 axles (18t GVW)	3	2%	48,600
Tractor Unit 4 x 2 (40t GCW)	1	1%	92,000
Tractor Unit 6 x 2 (44t GCW)	2	1%	92,000
Grand Total	**145**	**100%**	**18,568**

Figure 40. Royal Mail Location Map by Vehicle Type.

Table 27: Royal Mail ZEV Compatibility

	# of vehicles	BEV % Compatible	% FCEV Only Compatible	% Not ZEV Compatible	Annual Electricity (kWh)	Annual H_2 (kg)
Small Van	71	73%	25%	1%	190,969	898
Medium Van	21	67%	33%	0%	109,194	531
Large Van (< 3.5t GVW)	20	0%	0%	100%	0	0
Rigid Truck 2 axles (7.5t GVW)	27	0%	100%	0%	0	48,514
Rigid Truck 2 axles (18t GVW)	3	0%	100%	0%	0	7,046
Tractor Unit 4 x 2 (40t GCW)	1	0%	0%	100%	0	0
Tractor Unit 6 x 2 (44t GCW)	2	0%	0%	100%	0	0
Total	**145**	**20%**	**37%**	**43%**	**300,164**	**56,989**

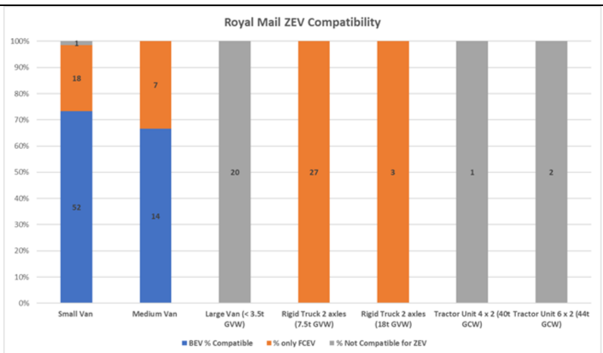

Figure 41: Royal Mail ZEV Compatibility

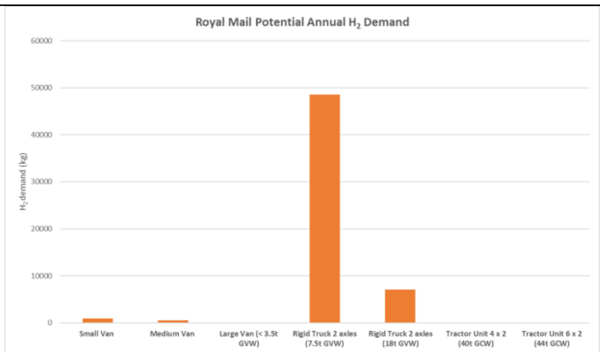

Figure 42: Royal Mail Potential H_2 Demand by Vehicle Type

4.7.11 Scottish Water

Table 28. Scottish Water Fleet Composition

Scottish Water	Good fleet list		
	Number of Vehicles	% of Combined Fleet	Average Annual Mileage
Medium Car	1	0%	12,000
Large 4x4 / SUV	44	13%	13,320
Small Van	97	28%	14,620
Medium Van	97	28%	18,130
Large Van (< 3.5t GVW)	61	18%	13,850
Large Van (> 3.5t GVW)	16	5%	20,300
Rigid Truck 2 axles (18t GVW)	2	1%	15,840
Rigid Truck 3 axles (26t GVW)	17	5%	16,250
Rigid Truck 4 axles (32t GVW)	1	0%	29,860
Tractor Unit 6 x 2 (44t GCW)	7	2%	28,430
Grand Total	**343**	**100%**	**15,980**

Figure 43. Scottish Water Location Map by Vehicle Type.

Table 29: Scottish Water ZEV Compatibility

	# of vehicles	BEV % Compatible	% FCEV Only Compatible	% Not ZEV Compatible	Annual Electricity (kWh)	Annual H_2 (kg)
Medium Car	1	100%	0%	0%	4,790	0
Large 4x4 / SUV	44	23%	57%	20%	38,530	9,628
Small Van	97	14%	36%	49%	154,083	1,409
Medium Van	97	22%	49%	29%	360,577	3,152
Large Van (< 3.5t GVW)	61	20%	56%	25%	254,670	2,455
Large Van (> 3.5t GVW)	16	25%	31%	44%	54,334	381
Rigid Truck 2 axles (18t GVW)	2	50%	50%	0%	2,661	1,931
Rigid Truck 3 axles (26t GVW)	17	12%	71%	18%	18,443	17,596
Rigid Truck 4 axles (32t GVW)	1	0%	0%	100%	0	0
Tractor Unit 6 x 2 (44t GCW)	7	0%	14%	86%	0	1,964
Total	**343**	**27%**	**36%**	**37%**	**888,089**	**38,517**

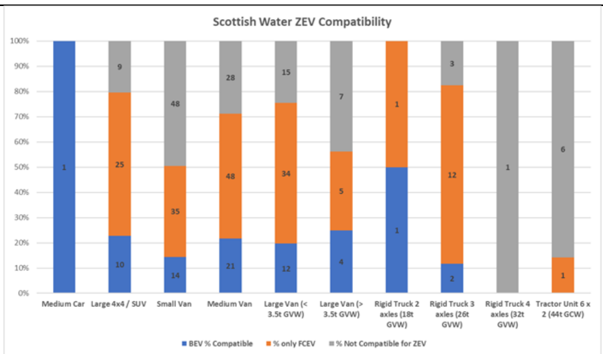

Figure 44: Scottish Water ZEV Compatibility

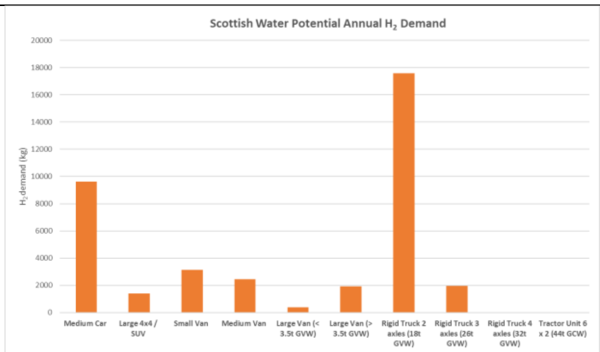

Figure 45: Scottish Water Potential H_2 Demand by Vehicle Type

4.7.12 SEPA

Table 30. SEPA Fleet Composition

SEPA	Missing some mileage and MPG		
	Number of Vehicles	**% of Combined Fleet**	**Average Annual Mileage**
Medium Car	4	24%	10,000
Medium MPV	1	6%	10,000
Large Car	1	6%	8,000
Large 4x4 / SUV	3	18%	4,130
Small Van	4	24%	11,400
Medium Van	2	12%	21,790
Large Van (< 3.5t GVW)	2	12%	6,500
Grand Total	**17**	**100%**	**10,151**

Figure 46. SEPA Location Map by Vehicle Type.

Table 31: SEPA ZEV Compatibility

	# of vehicles	BEV % Compatible	% FCEV Only Compatible	% Not ZEV Compatible	Annual Electricity (kWh)	Annual H_2 (kg)
Medium Car	4	100%	0%	0%	12,922	0
Medium MPV	1	100%	0%	0%	3,234	0
Large Car	1	100%	0%	0%	2,487	0
Large 4x4 / SUV	3	100%	0%	0%	7,194	0
Small Van	4	25%	75%	0%	14,023	135
Medium Van	2	0%	50%	50%	6,974	79
Large Van (< 3.5t GVW)	2	100%	0%	0%	7,413	0
Total	**17**	**75%**	**18%**	**7%**	**54,247**	**214**

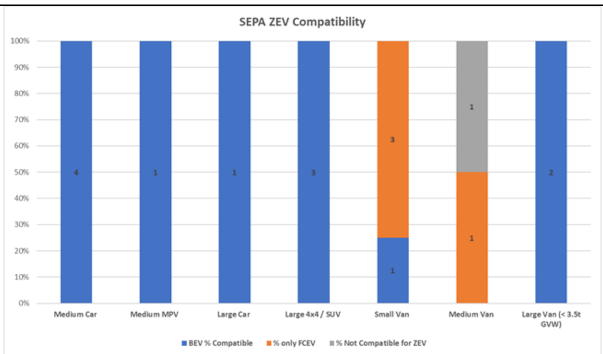

Figure 47: SEPA ZEV Compatibility

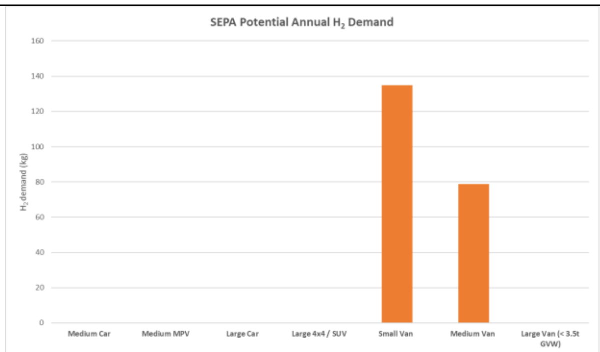

Figure 48: SEPA Potential H_2 Demand by Vehicle Type

4.8 Discussion of the ZEV Compatibility and Hydrogen Demand Analysis

Section 4.6 shows that under this combined BEV/FCEV scenario:

- **89% (57% BEV, 32% FC) of the NES fleet is potentially ZEV compatible**. It is also noted that any vehicle that is BEV compatible is also FC compatible (assuming proximity of a HRS); and, therefore, if fleets chose to deploy FC options rather than BEV options, **89% of the fleet is potentially FC compatible**.
- If all potentially compatible vehicles were replaced by ZEVs in the combined BEV/FC scenario, this would lead to an **annual H_2 demand of 745 tonnes/year**, **92% of which is from vehicles 7.5t and larger**.
- H2ICE technology presents a non-ZEV option for the non ZEV-compatible vehicles (and indeed all vehicles, as a H2ICE equivalent, if available, will be able to perform the daily duties of a ZEV), particularly HDVs.

A brief discussion of two aspects of the analysis follows.

4.8.1 Choice of an Estimated Maximum Day as a Basis for the ZEV Compatibility Analysis

As noted in Section 4.2, the ZEV compatibility analysis is based on an estimated maximum day's vehicle usage, rather than an average day. The choice was made to provide a relatively conservative basis to compare the different data from all 12 NES fleets – i.e., given the fact that some fleets were unable to provide the full data requested, it was considered best to take a relatively pessimistic view on the ability of ZEVs to replace the conventional vehicles currently in use, rather than take an approach which might prove too optimistic in the light of further detailed analysis of how individual vehicles are used by each fleet on a daily basis.

Detailed scenario analysis of the influence of different assumptions on the results is beyond the scope of this study and would in any case be more appropriate as part of the analysis of individual fleets. However, the broad effects can be seen by considering Figure 7. Use of a less onerous (lower distance) average day instead of a maximum day as a basis for ZEV compatibility would shift the three regions (BEV compatible, FC REEV and non-ZEV compatible) in the figure to the right – i.e., it would increase the number of BEV compatible vehicles at the expense of FC options and increase the overall ZEV compatibility to greater than 87%. A similar effect (i.e., increasing the proportion of BEV compatible vehicles relative to FC compatible) would be achieved by adding the possibility of opportunity (top up) charging for BEVs during a day's operation.

4.8.2 The Largest Potential H_2 Demand comes from Heavy Duty Vehicles

As noted above, 92% of the potential H_2 demand under this combined BEV/FC scenario is from vehicles 7.5t and larger. Given the relative energy consumption of light and heavy duty vehicles this result is not surprising; for example, FC cars currently use between 1-1.3 kg of H_2 per 100 km travelled[16], whereas FC buses use between 8kg and 9kg of H_2 to travel the same distance[17]. Prioritising the replacement of HDVs will therefore lead to the largest hydrogen demand; the implication of this finding for the business case for future hydrogen hubs is discussed in Section 7.

[16] https://h2me.eu/wp-content/uploads/2018/10/Vehicle-and-Infrastructure-Performance-Report_November-2017.pdf

[17] https://hydrogeneurope.eu/hydrogen-buses

5 WP4: Refuelling Infrastructure

Task 5: Refuelling requirements to support and likely volume of H_2 required, cost of production of H_2, and/ or cost of EV infrastructure.

5.1 Introduction

The analysis presented in the previous Section (WP3) gave the number of vehicles that could potentially be replaced by ZEVs in the NES fleets and quantified the associated hydrogen demand. This WP provides a qualitative view of how this hydrogen demand could be served by HRS at strategic locations (hubs) located to maximise station hydrogen demand and/or near future potential hydrogen production locations.

Also, as part of this WP, Cenex held discussions with potential HRS suppliers to obtain equipment costs and specifications. Full details of the discussions are bound by confidentiality; where agreed with suppliers, their inputs were used to develop a HRS business model with scenarios for vehicle hydrogen demand derived from WP3. This work has been passed directly to the study sponsors as a confidential appendix and will not be discussed further in this report.

5.2 Hydrogen Demand by Location

Figure 49 below shows the potential annual hydrogen demand in each location assuming all vehicles are replaced by ZEV equivalents under the mixed BEV/FCEV scenario described in Section 4 (empty squares show the locations of vehicles that have no hydrogen demand under this scenario):

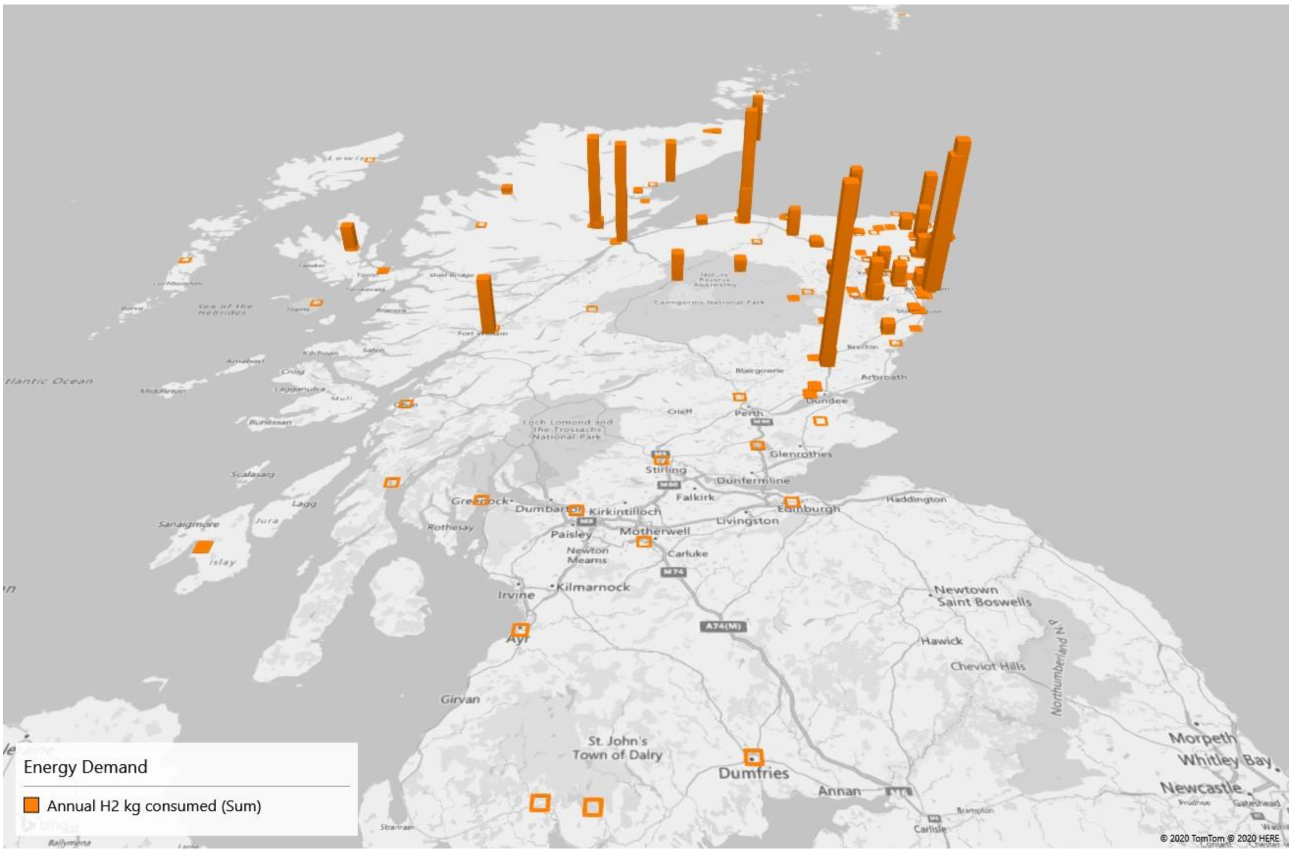

Figure 49: Potential Annual H_2 Demand (kg) from all NSR Fleets

While the demand is spread across many vehicle locations, the map shows that a small number of depots, particularly those where there are large numbers of heavy duty vehicles, have a relatively large hydrogen demand compared to others. The next Section looks at how the fleets could best be served by HRS at strategic locations (hubs) located to maximise station hydrogen demand and/or near future potential hydrogen production locations.

5.3 Current and Potential Future Hydrogen Refuelling Locations

5.3.1 Aberdeen as a Hydrogen Hub

Aberdeen currently has two HRS that serve the city's bus fleet and existing pool of hydrogen vehicles that have been deployed with support from projects such as HyTrEc2:

- Kittybrewster[18]: opened in 2015 as a bus refuelling station at 350 bar and upgraded in 2018 to support 700 bar car refuelling. The HRS is supplied by an-site electrolyser capable of generating up to 360 kg of hydrogen per day.
- ACHES (Aberdeen City Hydrogen Energy Storage), Cove[19]: opened in 2017 to refuel cars and light duty vehicles at 350 and 700 bar. The HRS is supplied by an on-site electrolyser capable of generating up to 130 kg of hydrogen per day.

Plans are underway to increase HRS numbers and capacity to form the *Aberdeen Hydrogen Hub*[20] to reinforce the city's position as a centre of hydrogen production and use. Based on discussions with the project sponsors, two further example sites in the city were added to this study as they are under consideration for the first locations for additional HRS for the Aberdeen Hydrogen Hub (n.b., it is emphasised that these locations are provisional, and the actual location of any additional HRS will be subject to funding and detailed planning):

- Aberdeen Energy Park (Bridge of Don)[21]
- Energy Transition Zone (Aberdeen South Harbour)[22]

As a first step to understand how the Aberdeen Hydrogen Hub could serve NES fleets, Figure 50 maps the distance of each location of potential NES hydrogen demand from the four current and potential HRS sites in Aberdeen. The map in Figure 50 shows that the Aberdeen Hydrogen Hub has the potential to satisfy large-scale demand from fleets that are based in and around the city which would need to travel less than 20 km to reach a HRS, and potentially others that travel through the city as part of their daily work. However, there are a number of large fleets, in particular those of Aberdeenshire, Angus, Highland and Moray, that are located more than 20 km away[23] from the Hydrogen Hub's HRS, and that cannot rely on the Aberdeen Hydrogen Hub for refuelling. For these councils, a distributed refuelling approach must be considered to make adoption of FC vehicles practical for them. This is discussed in the next Section.

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[18]https://www.boconline.co.uk/en/images/Case%20study%20Kittybrewster%20Aberdeen%20hydrogen%20refuelling%20station_tcm410-563229.pdf

[19] https://news.aberdeencity.gov.uk/refuelling-station-launched-as-aberdeen-leads-the-way-in-hydrogen-technology/

[20]https://news.aberdeencity.gov.uk/a-hydrogen-hub-in-aberdeen-to-capitalise-on-the-citys-expertise-was-today-agreed-at-committee/

[21] https://aeip.co.uk/

[22] https://www.gov.scot/news/gbp-62-million-fund-for-energy-sector/

[23] **A note on the distances discussed in this WP:** Consultation with fleet stakeholders during this project has confirmed that HDV fleets are generally accustomed to, and set their operating patterns based on, on-site (bunker) refuelling. There is considerable scepticism amongst fleet managers as to the practicality of travelling any appreciable distance at the start of, or end of, a shift to refuel at non-depot locations; this is particularly true of larger vehicles such as RCVs which typically travel less than 50 miles per day. Nevertheless, to establish an initial benchmark of how distributed refuelling might work, it was agreed with the study coordinators that 20 km (12 miles) would be set as the upper distance limit that fleet vehicles might travel to off-site locations to refuel. This allows a first cut visualisation of how distributed refuelling could work for the NES fleets considered in the study.

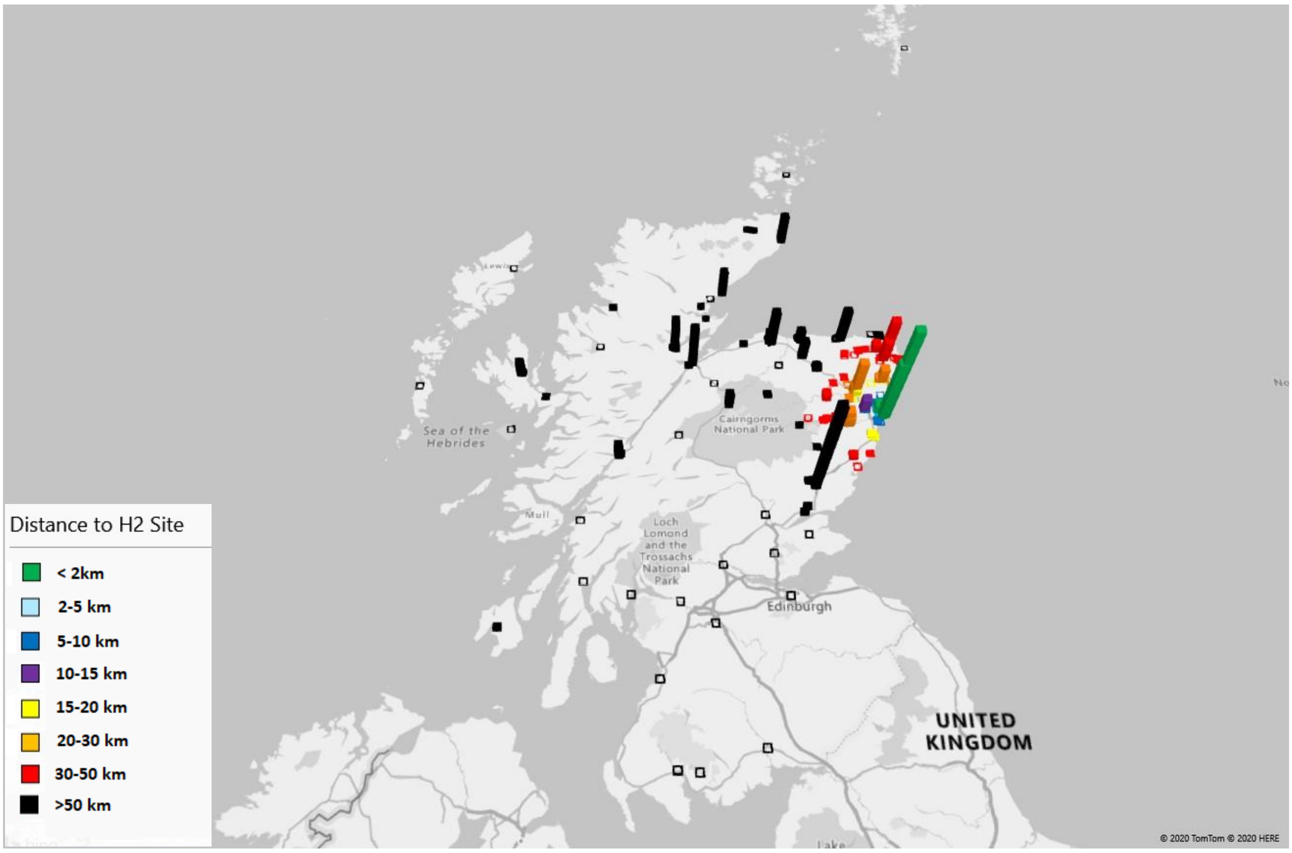

Figure 50: Distance Mapping of Potential NES Hydrogen Demand to Aberdeen Hydrogen Hub HRS

5.3.2 Additional Potential HRS Locations Based on Demand and/or Hydrogen Availability

Based on discussions with project stakeholders and consideration of the hydrogen demand in each location, five additional sites were added to the refuelling mapping analysis to create a distributed HRS network aligned with potential NES fleet demand:

- Elgin (initially aimed at Moray Council vehicles. Also on A96)
- Forfar (initially aimed at Angus Council vehicles. Also on A90)
- Inverness (initially aimed at Highland Council vehicles. Also strategic junction of A9/A82/A96)
- Inverurie (initially aimed at Aberdeenshire Council vehicles. Also on A96)
- Peterhead (conveniently located for Aberdeenshire Council vehicles. Also on A90. In addition, Buchan Biogas has expressed interest in developing hydrogen production at its Peterhead anaerobic digester)

Together with the Aberdeen Hydrogen Hub locations discussed in the previous section, a total of nine locations as shown in Figure 51 were therefore considered in this part of the location assessment:

Figure 51: Existing and Potential HRS Locations Used in this Analysis

The updated distance mapping with all nine current and potential future HRS is shown in Figure 52

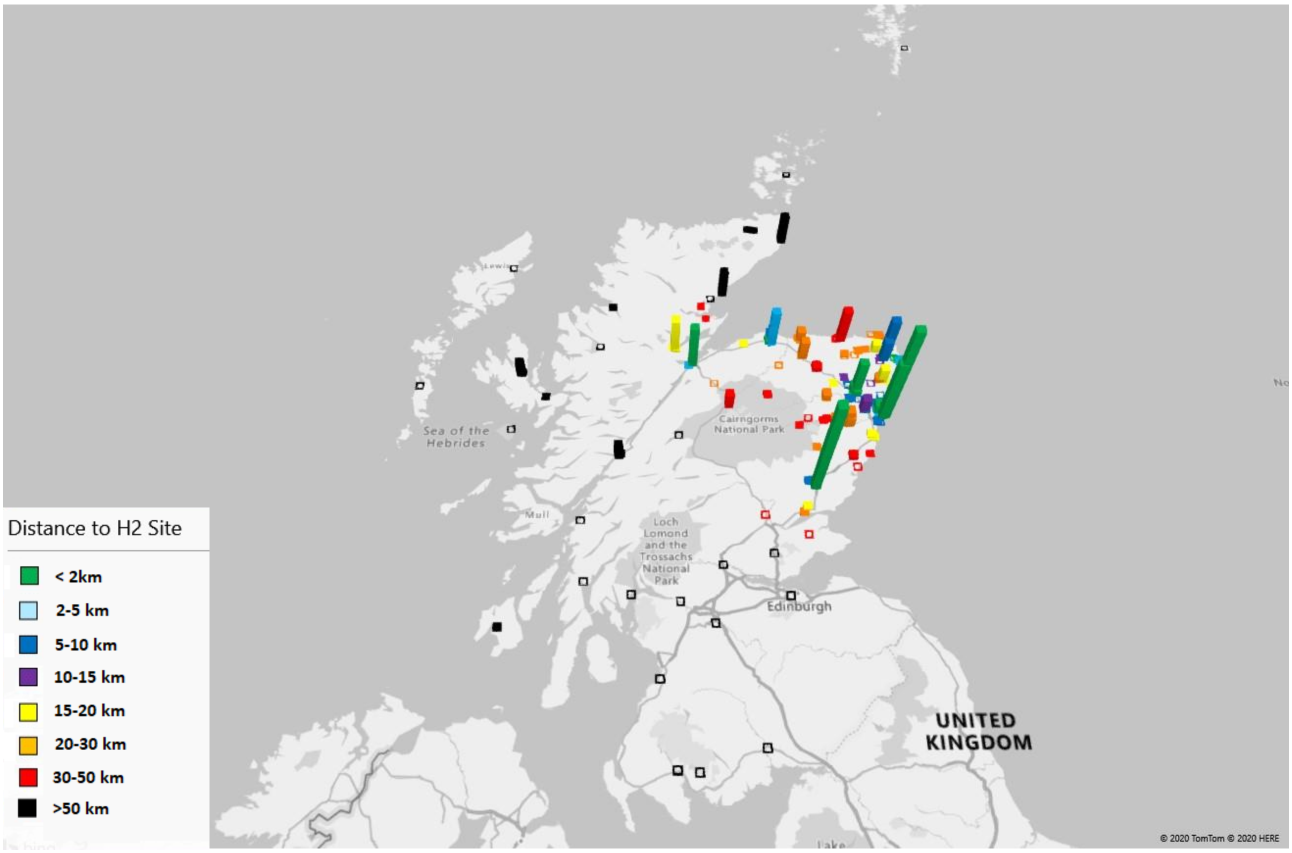

Figure 52: Distance Mapping of Potential NES Hydrogen Demand to All HRS Considered in the Study

Comparing Figure 52 to Figure 50 demonstrates the merits of the distributed HRS approach. The Aberdeen Hydrogen Hub can serve fleets that operate in and around the city, including Aberdeen City Council and potentially others such as Royal Mail. The additional HRS outside of the Hub are more practical for some individual NES fleets compared to the centralised Aberdeen Hydrogen Hub model: for example, a HRS located in Inverness is primarily aimed at Highland Council, but could also serve NatureScot and Scottish Water vehicles, with the potential of future use by public and private sector fleets that use the trunk road network around the city, as shown in Figure 53.

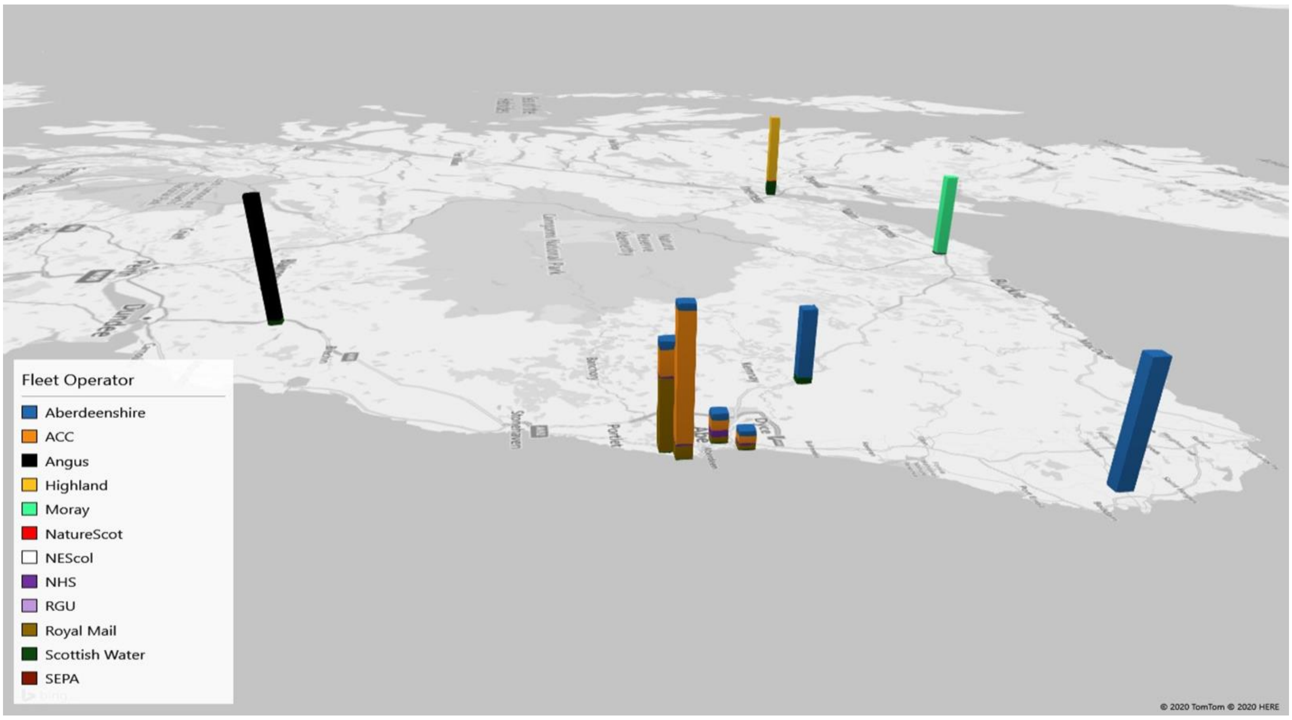

Figure 53: Potential Daily HRS Usage by Fleet if all NES Vehicles were Replaced by ZEVs (Figure Oriented E-W to Allow Visualisation of All Aberdeen HRS)

5.3.3 Quantifying Hydrogen Demand at Each Location

Table 32 gives the maximum potential daily usage (i.e., assuming that all ZEV compatible vehicles are replaced) by individual NES fleet vehicles located within 20km of the potential HRS network shown in Figure 51.

Table 32: Potential Daily HRS Usage by Individual NES Fleets if all Vehicles were Replaced by ZEVs

	Aberdeenshire	ACC	Angus	Highland	Moray	NatureScot	NESCol	NHS	RGU	Royal Mail	Scottish Water	SEPA	Total kg per working day
Aberdeen Cove	19	57	0	0	0	0	0	4	0	166	2	0	**248**
Aberdeen Kittybrewster	16	23	0	0	0	0	0	16	0	13	3	0	**71**
Potential Aberdeen AEP	12	16	0	0	0	0	0	5	0	9	3	0	**45**
Potential Aberdeen ETZ	14	285	0	0	0	0	0	4	0	31	2	0	**336**
Potential Elgin	0	0	0	0	257	0	0	1	0	0	4	0	**262**
Potential Forfar	0	0	347	0	0	0	0	0	0	0	14	0	**361**
Potential Inverness	0	0	0	259	0	2	0	0	0	0	59	0	**320**
Potential Inverurie	172	0	0	0	0	0	0	0	0	0	17	0	**189**
Potential Peterhead	281	0	0	0	0	0	0	0	0	0	0	0	**281**
Total kg per working day	**514**	**381**	**347**	**259**	**257**	**2**	**0**	**30**	**0**	**219**	**104**	**0**	**2,113**

It is stressed again that this table assumes that all ZEV compatible vehicles are replaced, it does not mean that such vehicles are available. In planning for any future HRS rollout programme, the table above also needs to be cross referenced with the 2023 and 2025 vehicle replacement scenarios described in Section 4.6.2 to scale the potential hydrogen demand according to the number of vehicles deployed in those years.

5.4 Electric Vehicle Recharging

5.4.1 Introduction

Although the main focus of this study is establishing the potential hydrogen demand from NES fleets, given that the analysis presented in WP3 (Section 4) supports a combined BEV/FC approach to fleet replacement it is appropriate to take a brief, high-level, look at EV infrastructure implications of ZEV replacement, particularly given the concerns expressed by stakeholders regarding the ability of the electricity distribution network to support EV charging for fleets in remote locations.

5.4.2 Methodology

To manage the scope of this part of the study, it was agreed with the project sponsors that the focus would be on LDVs (i.e., cars and vans under 7.5t) only. The number and specification of EV charging infrastructure required by ZEV compatible vehicles at each fleet location was proposed using the key assumption that all LDV EVs will simultaneously charge overnight. This approach reduces the complexity of running a fleet of EVs, as no staff time is required to shift vehicles on and off chargepoints. It also reduces the peak electrical demand of the depot, as charging will not take place during peak business hours. This assumption ultimately results in every EV having its own chargepoint.

The specification of the chargepoint was assumed to be 7kW, as a chargepoint of this power would be capable of providing every vehicle within the scope of this project with a full overnight charge. For the purpose of this analysis, we have assumed that twin-socket, free-standing chargepoints will be installed, with each unit requiring 14.5 kVA of power capacity. In some fleet locations, cost savings could be achieved by deploying single-socket, wall-mounted chargepoints, but determining whether or not these chargepoints would be appropriate for a given site would require a site-level assessment, which is not within the scope of this project.

Estimates for EV usage and EV charging infrastructure at each fleet location were combined with publicly available distribution network capacity information from Scottish and Southern Energy Networks (SSEN). Data from SSEN was used to determine the peak demand headroom for each primary substation in Northern Scotland. For the purpose of this analysis, peak headroom was calculated as being the nameplate capacity of each primary substation, minus the maximum demand it currently meets.

Using spatial analysis, the additional electrical demand from future EV charging at each fleet location was aggregated and added to the current maximum demand of the nearest primary substation.

The results of this analysis highlights fleet locations where, when combined with other fleet locations that are likely to be supplied by the same primary substation, the installation of EV chargepoints is likely to trigger the need to reinforce the primary substation. Grid reinforcements of this nature are expensive and often challenging.

It should be noted that this analysis is limited to primary substations, as data for lower voltage distribution network infrastructure is not made publicly available by SSEN. This analysis therefore does not reveal potential costs associated with upgrading secondary substations located nearer to each site. In order to determine these costs, individual fleet analysis would be required to obtain connection budget estimates for each site from SSEN. Cenex would be happy to discuss this follow on work with individual fleets.

5.4.3 Results

Figure 54 shows the results of this high-level analysis of EV charging capacity for BEV compatible LDVs. The map reveals that the situation appears to be favourable in the vast majority of locations (shown as green circles on the map), with the main point of potential concern being depots concentrated in south Aberdeen (red circles on the map). For these fleets in particular, further investigation of the local distribution network is recommended before committing to large-scale BEV rollout.

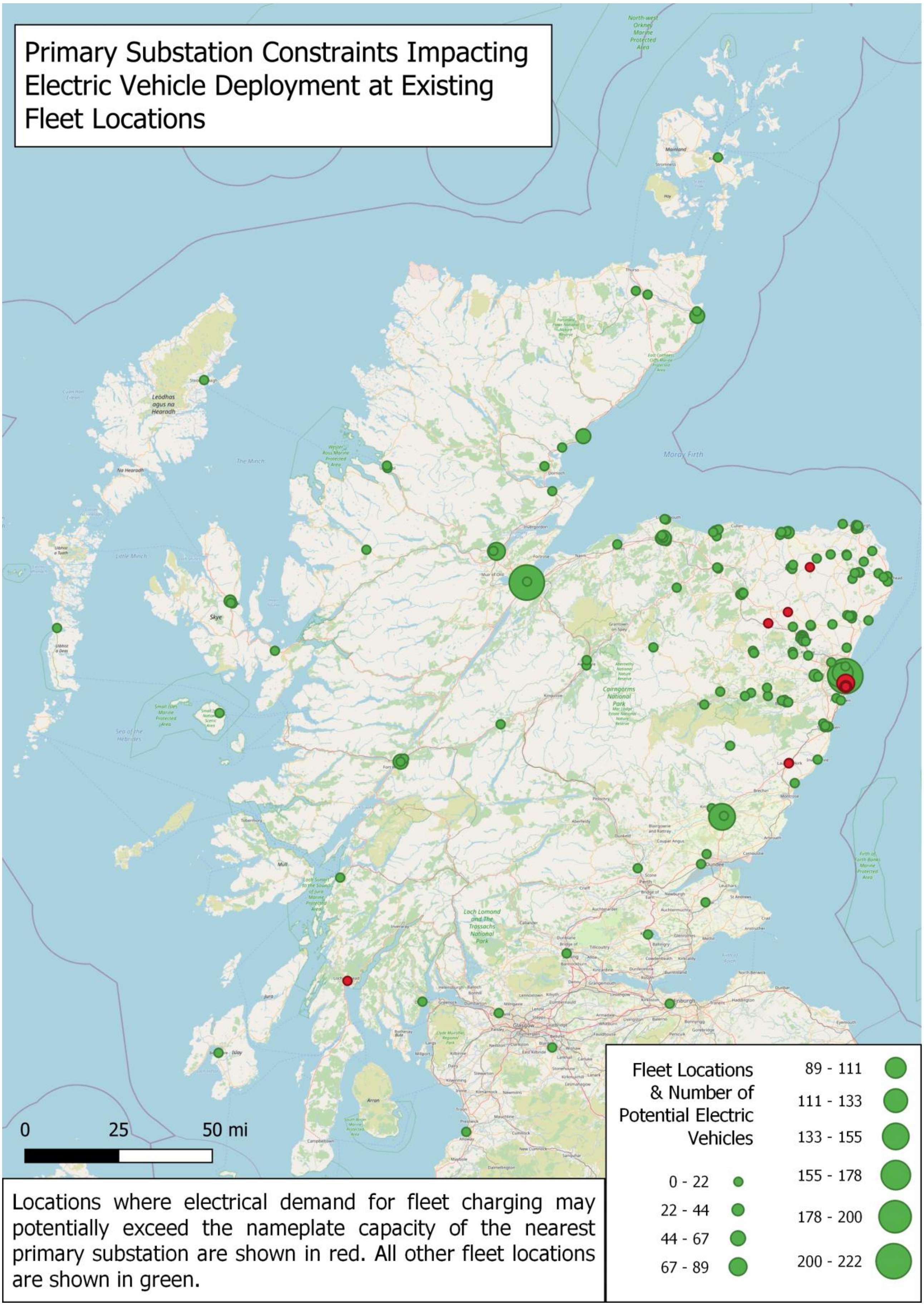

Figure 54: High-Level View of Potential EV Charging Constraints for NES Fleets

6 WP5: Whole Life Cost Analysis

Task 2: Assessment of upfront and running costs of low carbon vehicles.

Task 4: Capital/revenue costs including purchase, lease options, additional training for drivers and mechanics.

Task 6: Assessment of whole life costs for mass deployment of H_2 vehicles compared to infrastructure + EVs.

6.1 Introduction

A vehicle whole life cost (WLC) analysis (also known as total cost of ownership, TCO) has five main elements:

- Lifetime: the period of ownership of the vehicle by the fleet, assumed to be seven years for all vehicles in this study as discussed in Section 4.
- Depreciation: in a vehicle purchase (as opposed to lease) case, this is the difference between the purchase cost and residual value at the end of the vehicle's fleet lifetime.
- Fuel or energy (a running cost). All prices quoted are ex. VAT.
- Maintenance (a running cost).
- Taxes (a running cost). It is assumed that ZEV compatible vehicles will pay no, or much lower, vehicle taxes than diesel equivalents in the study timeframes. Nevertheless, since tax rates for heavier FC vehicles in particular have not been decided, road taxes have been omitted from this analysis.

WP2 (Section 3.3) discussed the confidential nature of cost discussions carried out with suppliers during this project. This means that depreciation, a key element of the WLC for FC vehicles due to their present high initial purchase costs, cannot be discussed further here; the full WLC calculations have been shared separately with the study sponsors as a confidential appendix.

This Section will therefore focus on running costs, with particularly reference to the cost that hydrogen would need to reach for FC vehicles to reach parity with conventional incumbents. This is useful information for understanding the cost implications of ZEV vehicle uptake as, at least for the non-commercial NES fleets that are participating in this study, vehicle depreciation costs may be at least partly offset by public funding support for vehicle purchase if such funds could be won.

6.2 Running Cost Analysis

6.2.1 Assumptions

This Section compares the running costs of diesel, BEV and FC variants for two representative NES fleet vehicle segments: light vans and 18t RCVs. It uses the following assumptions:

- Fuel costs:
  - Diesel: bulk purchase cost of 95 pence per litre (based on discussions with fleet stakeholders).
  - Electricity 0.13p/kWh (average of peak and off-peak rates).
  - Hydrogen: £10/kg (current market price).
- Maintenance costs: taken from Cenex's database. Costs for BEVs and FC vehicles are assumed to be lower (amount dependent on vehicle size).

6.2.2 Fuel Costs Only

The figures below show the lifetime fuel costs for diesel, BEV, and FC variants of light duty vans and 18t RCVs. While the absolute values are different in the two figures, both show that:

- The BEV variant has the lowest fuel cost.

- In both cases, the FC variant is considerably more expensive to fuel than a diesel or BEV equivalent.

The figures show that hydrogen costs need to reduce substantially (by at least 44%) to achieve lifetime fuel cost parity with the diesel equivalent.

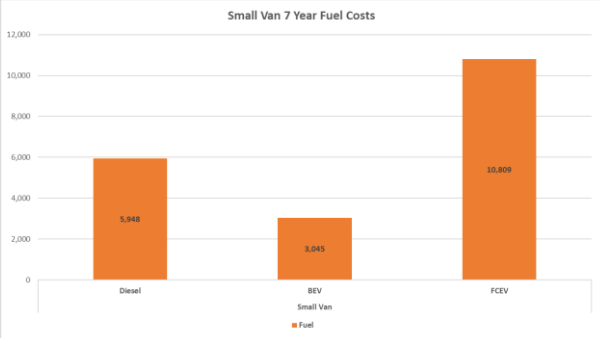

Figure 55: Small Van Fuel Costs

Price of hydrogen required to reach fuel cost parity with diesel: £5.50/kg

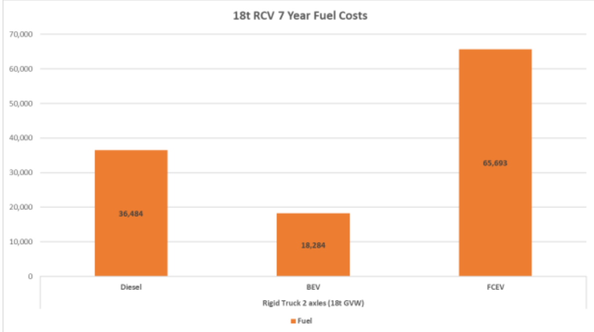

Figure 56: 18t RCV Fuel Costs

Price of hydrogen required to reach fuel cost parity with diesel: £5.60/kg

6.2.3 Running Costs

The figures below redraw the graphs of the previous Section to show running costs (fuel plus maintenance) for diesel, BEV, and FC variants of light duty vans and 18t RCVs. While the absolute values are different in the two figures, both show that:

- For all variants fuel costs dominate running costs.
- The BEV variant has the lowest running cost.
- In both cases, the FC variant is considerably more expensive to run than a diesel or BEV equivalent.

In both cases, a considerable reduction in hydrogen price from £10/kg would again be needed to achieve running cost parity with the diesel equivalent. Although the assumed lower maintenance for the FC small van lowers the required price reduction somewhat (by 7% to 38%) over the case where fuel costs only are considered (it is acknowledged that there is uncertainty over whether the maintenance costs of FC vehicles, particularly immature models, would actually be lower than those for a diesel equivalent). Consideration of vehicle taxes in the analysis, if applied solely to diesel vehicles, would further reduce the hydrogen price reduction required for running cost parity with diesel.

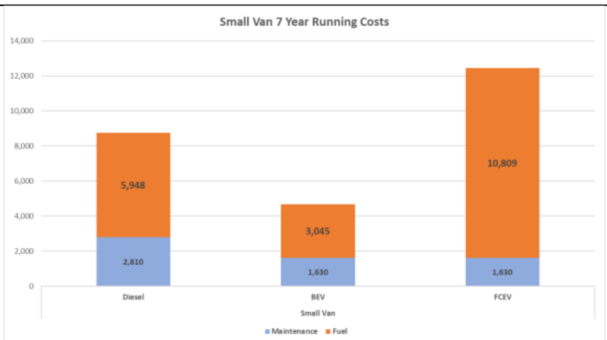

Figure 57: Small Van Running Costs

Price of hydrogen required to reach running cost parity with diesel: £6.20/kg

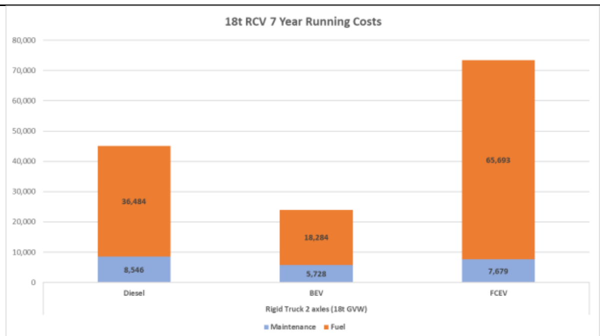

Figure 58: 18t RCV Running Costs

Price of hydrogen required to reach running cost parity with diesel: £5.60/kg

7 WP6: Discussion and Next Steps

Task 7: Next steps/further recommended work.

Task 9: Potential risks/barriers to adoption.

Task 11: A fleet workshop on options available and vehicle availability/ performance. An on-line workshop presenting the main findings and conclusion to the project stakeholders was held on 1st December 2020.

7.1 Discussion

7.1.1 Strategic Fit

ACC and its partners are commended for the 'hub' approach they have taken to stimulate hydrogen demand and use. As this report has shown, hydrogen struggles to demonstrate cost-competitiveness against EVs on an individual basis and at small scale. Only by deploying at scale and in a wide range of use cases will hydrogen be able to compete with other options and realise its potential as a low carbon, low cost fuel. The Aberdeen Hydrogen Hub can help the region contribute to national targets around GHG emissions and climate change and help achieve objectives around economic development and job creation.

Section 1 of this report detailed how the activity in this project aligns with national, regional, and local strategies on hydrogen and low carbon transport. Activity to increase the supply and uptake of hydrogen for road transport, particularly for HDVs, is in line with the December 2020 Scottish Government Hydrogen Policy Statement[24]. The statement will be followed by a Hydrogen Action Plan in 2021 that will be supported by a £100 million investment over the next five years.

7.1.2 Opportunities

Hydrogen vehicles are ideal for use on higher daily mileage duty cycles where vehicle downtime for refuelling needs to be minimised. Benefits of hydrogen compared to EVs include longer range on a single charge or tank of fuel, shorter refuelling times, ability to integrate with the energy system to store and use renewable energy, and, potentially, mitigated costs associated with the large scale deployment of chargepoint infrastructure at depots to support EVs. There are also potential economic benefits through job creation and business growth in manufacturing, servicing, and operation of hydrogen vehicles.

In undertaking this project, Cenex noted the high levels of engagement and support from the fleets involved, and their willingness to share data to contribute to the analysis described in Section 4. Having this group of engaged and willing fleets gives the region a great opportunity to identify and exploit opportunities for deploying hydrogen in road transport in a wide range of use cases.

The Hub approach can help increase the supply and use of hydrogen from renewable energy sources. The NES is ideally placed to unlock the potential for renewable energy, with significant current and planned offshore generation capacity. While use of renewable hydrogen in buses, council vehicles, and car clubs has already been demonstrated, this report has shown that there is significant potential for use in commercial vehicles as well.

Scotland lends itself well to regional clusters of hydrogen economy, as shown by successful deployment activity in Orkney and in and around Aberdeen. Ideally, these clusters should include applications outside of road transport, as increased demand for hydrogen is likely to reduce per unit fuel costs, and help spread the cost of investment in infrastructure such as electrolysers and pipelines. Specific cross-sectoral opportunities include:

- **Rail**: Transport Scotland aims to decarbonise rail traction energy through the removal of diesel passenger trains from the Scottish network by 2035. Transport Scotland's Rail Services Decarbonisation Action Plan: Pathway to 2035[25] recognises that hydrogen is likely to have a role to play in achieving this objective. ACC and its partners should ensure lines of

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[24] https://www.gov.scot/publications/scottish-government-hydrogen-policy-statement/

[25] https://www.transport.gov.scot/media/47906/rail-services-decarbonisation-action-plan.pdf

communication are open with key regional rail stakeholders including ScotRail and Network Rail. Arcola Energy has recently announced that it is working with the Hydrogen Accelerator to demonstrate Scotland's first hydrogen powered train at COP 26 in November 2021[26].

- **Low carbon heat and power**: Work underway in Orkney, where the UK's first smart grid connects renewable energy generation to Orkney's distribution network at a considerably lower cost than conventional network connection, provides an exemplar for the NES. The 'Surf 'n' Turf' project demonstrates a fully integrated energy model, with hydrogen produced by electrolysers using electricity from tidal and onshore wind turbines, and then used in a fuel cell to provide low carbon heat and power.

- **Marine**: As with rail, hydrogen is one of two technologies (along with battery electric) that can potentially help ferries and other vessels deliver net zero carbon emissions. Affordable hydrogen from renewable sources could make this the more attractive of the two options for operators, and refuelling infrastructure at the port could potentially be shared between the road and marine sectors. Cenex has previously provided consultancy to a marine operator which would be keen to participate in funded R&D activity in this area.

Increasing use of hydrogen for road transport can help contribute to the objective of the overall Hydrogen Hub to maximise regional economic opportunities associated with the shift from fossil fuel production and use to a hydrogen powered future. The Hydrogen Hub aims to put Aberdeen at the forefront of a developing hydrogen economy and maintain the region's profile and credentials as a centre of excellence for hydrogen deployment. Broadening the demand base for hydrogen can only serve to help achieve this ambition. Ultimately if the region is successful in positioning itself as the UK's leading hydrogen centre of excellence, it may attract vehicle manufacturers and converters to base production facilities here, creating jobs and improving prosperity.

7.1.3 Barriers and Mitigating Options

While there are significant environmental and economic opportunities for the NES, this report has also identified four barriers that are likely to constrain fleet uptake of hydrogen vehicles. These are outlined below, with strategies for mitigation included in the following recommendations sub-section.

- **Lack of vehicle availability**. Currently there are no hydrogen powered commercial vehicles available from mass market manufacturers in the UK. There are small scale deployments elsewhere (for example the roll-out of Hyundai trucks in Switzerland which started in October 2020), and niche converters can produce fuel cell and dual fuel trucks. This issue is compounded by the relatively small size of the right hand drive commercial vehicle market globally, which means initial production runs are likely to focus on left hand drive countries.

- **High cost**. As a result of the small-scale production of hydrogen vehicles by OEMs and converters, there is a significant upfront cost premium compared to diesel vehicles and even to EVs. This plus the relatively high fuel costs (even assuming these fall over time) means that on a WLC basis, hydrogen is not expected to compare favourably to diesel or EVs over the next few years. Even if the WLC outcomes improve (for example through further reductions in fuel costs), vehicles are highly likely to have an upfront cost premium for many years to come. This in itself can be a barrier for public sector organisations in particular where budgets are constrained, and investment may be hard to justify.

- **Gaps in fleet data**. Cenex notes that most of the organisations participating in this project were able to provide granular data in an appropriate format showing vehicle mileage and fuel consumption. However, this was not the case for all fleets, which prevented more detailed and comprehensive suitability analysis being undertaken. In addition, if fleets do not have this information readily available, it may make it difficult for them to specify and procure hydrogen vehicles, as they may be unable to define requirements and forecast WLCs.

- **Proposed timescales**. ACC asked Cenex to consider options to increase hydrogen demand over three-year and five-year periods, i.e., up to 2023 and 2025. Given the lack of vehicles

[26] https://www.arcolaenergy.com/press/arcola-energy-and-consortium-of-rail-industry-leaders-will-deliver-the-first-scottish-hydrogen-powered-train

on the market, and expected to reach the market in the short-term, and the significant investment that would be needed to fund expensive hydrogen vehicles, these timescales look challenging to say the least. 2030 would look a lot more favourable as a target date for significant deployment of hydrogen in road transport. Interim targets for 2023 and 2025 could instead focus on funded trials of increasing scale and complexity, following the excellent work that has been done with buses.

7.2 Recommendations

This sub-section proposes recommendations for ACC and partners to capitalise on the opportunities and overcome the barriers described above.

The consortium of public sector fleets should come together to form a regional Hydrogen Road Transport Working Group to provide structured engagement and collaboration between stakeholders. This could be chaired by ACC or another organisation committed and willing to drive forward progress towards a hydrogen future. Attendees should initially comprise the organisations which participated in this project. Suggested objectives of the group are to:

- Ensure fleets are kept up to date with the latest technology developments, vehicle availability and funding opportunities.
- Develop and submit collaborative funding applications. Working as a coherent region with a clear strategy for hydrogen vehicle adoption is likely to strengthen funding applications.
- Develop partnerships between fleet operators, vehicle manufacturers and infrastructure providers to deliver demonstration projects and disseminate results.
- Explore options for joint procurement to reduce the costs of vehicles and infrastructure.
- Discuss the barriers to accelerating hydrogen adoption and work to identify and implement solutions.
- Ensure alignment with other strategies and activities in the region and the rest of Scotland.

We also recommend engagement with stakeholders outside this fleet group. This could be undertaken either by inviting organisations to join the working group, or through separate bilateral meetings. Key stakeholders are likely to include vehicle manufacturers and converters, private sector fleets, infrastructure providers, renewable energy generators, Crown Estate Scotland, Highlands & Islands Enterprise, the Hydrogen Accelerator at the University of St Andrews, Marine Scotland, Michelin Scotland Innovation Parc (particularly the accelerator programme), Scottish Enterprise, Scottish Government, Scottish Hydrogen and Fuel Cell Association, and Transport Scotland. Objectives of the stakeholder engagement work should include:

- Engagement with vehicle manufacturers and converters to improve the availability and affordability of right hand drive vehicles. Showing a clear intent to purchase may encourage manufacturers to increase supply – and potentially even invest in production facilities in NE Scotland. We are encouraged by the forthcoming relocation of Arcola to MSIP in Dundee and their interest in RCVs, and dialogue with OEMs may also be beneficial.
- Engagement with refuelling infrastructure providers and investors to develop a regional network of refuelling sites, working from the locations proposed in this report. The analysis undertaken by Cenex can act as an evidence base, helping de-risk investments in new facilities. There is also a need for additional spatial analysis to understand how refuellers in key locations could meet future demand from private sector freight operators. Cenex has experience and a methodology to do this, based on due diligence reports for major gas fuel suppliers.
- Updating and refining the cost estimates used in this report for vehicle acquisition and fuel purchase. Suppliers may be more willing to engage in detailed discussions about cost with potential end users than with an outsourced organisation, particularly if they believe there is a serious pan-regional willingness to switch over to hydrogen vehicles at scale.

Even taking the steps above, the reality is that hydrogen vehicles will continue to be more expensive to purchase and operate than diesel, and, at least in the short term, EVs as well. ACC and partners have a strong track record of attracting funding to support hydrogen deployment in other vehicle types, particularly buses. It is highly likely that similar funding levels will be needed to trial and prove the benefits of hydrogen vehicles in real-world settings. Potential funding sources include Scottish Government's Energy Transition Fund, the APC, Innovate UK, and (subject to eligibility) the Connecting Europe Facility and the FCH JU. Cenex understands that the European Commission will fund a large-scale zero emissions HGV deployment project, though it remains to be seen whether this will be open to municipal and other specialist vehicles, rather than just conventional HGVs. By whatever means they are funded, R&D trials will be required to prove the real-world benefits of hydrogen and improve supplier and end-user confidence in the technology.

The scope of this project included cars as well as commercial vehicles. We also note that Aberdeen has seen some deployment of hydrogen into cars, most visibly the Toyota Mirai models in the Co-wheels fleet. That said, we recommend that ACC and its partners focus on deploying hydrogen in larger vehicles and allow the market to continue the switch to EVs for cars and light duty commercial vehicles. In these use cases, new EVs have a long enough range such that there is no practical benefit to fuel cell vehicles, and there is a clear financial preference for EVs over hydrogen – and increasingly over petrol and diesel. Unless there is a strategic driver to go for hydrogen at any cost, we suggest that this end of the market is not suitable for deployment of the fuel.

If hydrogen looks most appropriate for heavy duty vehicles (HDVs), and as shown in the analysis of Section 4 these use the most fuel anyway, the next logical step for a hub would be to look for private sector HDV involvement to build demand, as well as public sector fleets. The hub approach would look to add HDV demand from strategic corridors in NE Scotland. Cenex has developed a methodology to assess the potential for this, using the demand models used in this report together with vehicle movement data that we have used in other business case analysis for hydrogen and biomethane stations.

8 Appendices

8.1 Appendix A. Tasks from the ITQ (000-CWTX2891)

1. Assessment of fleets across the range of vehicle categories, applications and duty cycles including plant types;
2. Assessment of upfront and running costs of low carbon vehicles;
3. Likely take up low carbon vehicles over 3 and 5 year profiled period;
4. Capital/ revenue costs including purchase, lease options, additional training for drivers and mechanics;
5. Refuelling requirements to support and likely volume of H2 required, cost of production of H2, and/ or cost of EV infrastructure;
6. Assessment of whole life costs for mass deployment of H2 vehicles compared to infrastructure + EVs;
7. Next steps/further recommended work (recommendations for Aberdeen by September); and
8. Any other element that should be included in a thorough fleet review with the aim of adopting hydrogen /other low carbon vehicles.
9. Potential risks/barriers to adoption;
10. Assessment of the supplier/OEM market options for electric and hydrogen fleet replacement, gaps in vehicle alternatives and likely market uptake;
11. A fleet workshop on options available and vehicle availability/ performance; and
12. Any other element that should be included in a thorough fleet review with the aim of adopting hydrogen/other low carbon vehicles.

8.2 Appendix B – Fleet Review References

Table 33 shows a table of references that are used together with Cenex's internal knowledge base used during this work. It should be noted that wherever possible data provided by the fleet takes priority over supplementary data sources (such as baseline fuel economy) and likewise, independent real-world data takes priority over information provided by suppliers.

Table 33 - Table of Fleet Review References

Parameter	Reference
Vehicle Details	**Driver and Vehicle Licensing Agency (DVLA)** https://ukvehicledata.co.uk/dvla-data-api
Annual Mileage	**Driver and Vehicle Standards Agency (DVSA)** https://www.gov.uk/check-mot-history
Baseline Fuel Economy	**Emissions Analytics** – Passenger Vehicles and LCVs https://www.emissionsanalytics.com/
	Low Carbon Vehicle Partnership (LowCVP) – HGVs https://www.lowcvp.org.uk/
Greenhouse Gas Emissions Factors and Energy Content	**UK Government** https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2020 **JEC WTW Report v5**[27] https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/jec-well-tank-report-v5, pathway GPCH3b https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/jec-well-tank-report-v5, pathway WDEL1/CH2
Air Quality Pollutant Emissions Factors	**National Atmospheric Emissions Inventory (NAEI)** https://naei.beis.gov.uk/data/ef-transport
Low Emission Vehicle Energy Consumption (Examples from the public domain)	**Cenex** – ULEV passenger vehicles and LCVs https://www.cenex.co.uk/ **Cenex, Emissions Analytics and LowCVP** – LCVs and HGVs Unpublished testing of plug-in commercial vehicles completed on behalf of LoCITY in 2019 Dedicated to Gas - Assessing the Viability of Gas Vehicles Emissions Testing of Urban Delivery Commercial Vehicles Emissions Testing of Gas-Powere Commercial Vehicles
Vehicle Costs Purchase Cost Maintenance Costs Predicted Residual Values	**Fleet News and Commercial Fleet** – Passenger vehicles and LCVs https://www.fleetnews.co.uk/car-running-costs-calculator https://www.commercialfleet.org/tools/van/running-costs/ **Logistics UK (formerly the FTA)** – HGVs (diesel only) https://logistics.org.uk/distribution-costs **Vehicle Suppliers and Fleet Operators** – Any remaining technologies
Fuel Prices	Diesel: Cenex database and discussions with NES stakeholders **Department for Business, Energy and Industrial Strategy (BEIS)** – electricity https://www.gov.uk/government/statistical-data-sets/gas-and-electricity-prices-in-the-non-domestic-sector **Low Emission Fuel Suppliers** – hydrogen

[27] https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/jec-well-wheels-report-v5

8.3 Appendix C – Fleet Review Assumptions

The tables below show the assumed hydrogen tank capacities (FCEV/FC REEV) and battery sizes (BEVs) in the ZEV compatibility analysis described in Section 4.

Table 34: Hydrogen Tank Capacities Used in ZEV Compatibility Analysis

	Total Hydrogen Tank Capacity	Example Model
Large 4X4/SUV	6.3 kg	Hyundai Nexo
Large Car	5 kg	Toyota Mirai
Large Van	5.7kg	Master ZE (with battery converted to H2)
Medium Car	5 kg	None, assumed Mirai fills role
Medium MPV	3.3 kg	None, assumed Kangoo fills role
Medium Van	5.7kg (4.32kg & 33kWh battery equivalent)	None, assumed Master ZE fills role
Midsized Commercial SUV	6.3 kg	None, assumed Nexo fills role
Midsized SUV	6.3 kg	None, assumed Nexo fills role
Small Car	5 kg	None, assumed Mirai fills role
Small Van	3.3 kg (1.8 kg & 33 kWh battery equivalent)	Kangoo (Symbio, with battery converted to H_2)
Rigid Truck (7.5t GVW)	32.1 kg	Based on only current example of H_2 rigid, Hyundai Xcient
Rigid Truck (18t GVW)	32.1 kg	Hyundai Xcient
Rigid Truck (26t GVW)	32.1 kg	Based on only current example of H_2 rigid, Hyundai Xcient
Rigid Truck 32t GVW)	32.1 kg	Based on only current example of H_2 rigid, Hyundai Xcient
Tractor Unit 4x2 (40t GCW)	32.1 kg	Hyundai Xcient 4x2
Tractor Unit 6x2 (44t GCW)	32.1 kg	Hyundai Xcient 4x2
Tractor Unit 6x4 (44t GCW)	32.1 kg	Hyundai Xcient 4x2

Table 35: Battery Sizes Used in ZEV Compatibility Analysis

	Nominal Battery Size (kWh)
Large 4X4/SUV	68
Large Car	68
Large Van (<3.5t GVW)	70
Large Van (>3.5t GVW)	70
Medium Car	56
Medium MPV	36
Medium Van	68
Midsized Commercial SUV	56
Midsized SUV	56
Small Car	45
Small Van	36
Rigid Truck (7.5t GVW)	75
Rigid Truck (18t GVW)	216
Rigid Truck (26t GVW)	216
Rigid Truck 32t GVW)	216
Tractor Unit 4x2 (40t GCW)	216
Tractor Unit 6x2 (44t GCW)	216
Tractor Unit 6x4 (44t GCW)	216

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