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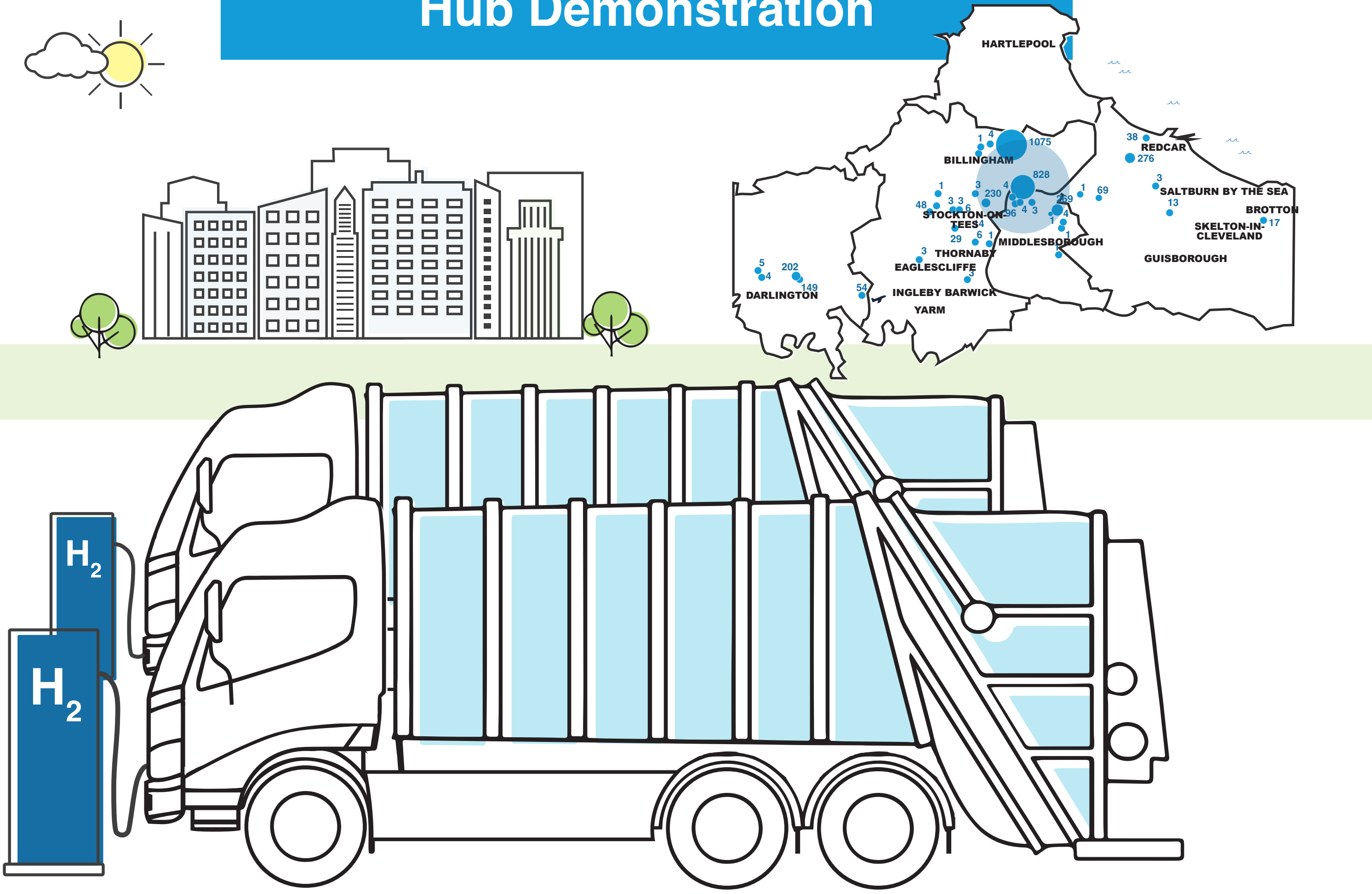
Preparing for Fuel Cell Vehicle Rollout:

Trials, Analysis and Deployment Planning for Hydrogen Fleets

Tees Valley Hydrogen Transport Hub Demonstration



Special thanks to all organisations that provided input and support during the project in particular AV Dawson, Darlington Borough Council, Middlesbrough Borough Council, Northern Gas Networks, Redcar & Cleveland Borough Council, Stockton on Tees Borough Council, Teesside International Airport, and Tees Valley Combined Authority.

Infographic Summary

In March 2021, the Department for Transport published the 'Tees Valley Multi-Modal Hydrogen Transport Hub Masterplan' and announced £3 million of government funding to kick start the development of the UK's first hydrogen transport hub[1].

The Hydrogen Transport Hub is planned to be fully operational by 2025 and will provide the facilities for the production, storage, and distribution of renewable (green) hydrogen to a network of hydrogen refuelling stations supporting operational trials across the Tees Valley region with an estimated daily peak demand by 2025-30 of 13,000 kg/day.

This report summarises the findings of the Trials, Analysis and Deployment Planning for Hydrogen Fleets project delivered by Ballard Motive Solutions and Cenex as part of the Tees Valley Hydrogen Transport Hub Demonstration competition[2] funded by the Department for Transport and delivered in partnership with Innovate UK.

FLEET ENGAGEMENT

- Workshops to engage fleets
- Understanding of barriers & opportunities

VEHICLE TRIALS

- Trial planning
- Qualitative feedback from users & fleet managers
- Hydrogen van user training
- Data monitoring & analysis of vehicle usage

ASSESSMENT OF H2 DEMAND POTENTIAL

- Data gathering from fleets
- Automation of Cenex Fleet Advice Tool
- Hydrogen uptake potential
- Mapping of hydrogen demand

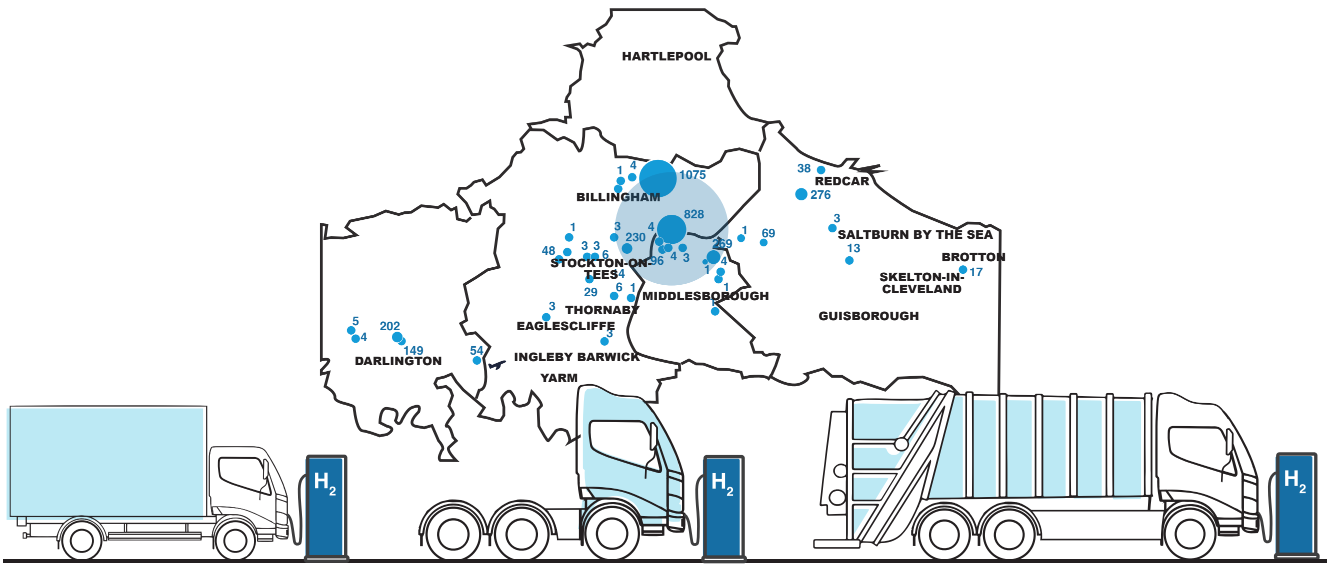
ECONOMIC ANALYSIS

- Calculation of current fuel costs
- Hydrogen break even cost scenarios versus diesel

ROADMAP TO FUTURE DEPLOYMENT

- Identification of barriers to wider update
- Planning for future vehicle & hydrogen station trials

Key Findings



Potential hydrogen demand:

- **920 vehicles** assessed from **seven** different fleet operators
- Average daily hydrogen demand of **3,600 kg** if all vehicles are replaced (29% of projected Hydrogen Transport Hub demand by 2030)
- **1,000 kg** of potential hydrogen demand by 2025 from **17 tractor units**, **36 rigid trucks**, and **153 vans**

Opportunities for hydrogen fuel cell vehicles:

- **44t tractor units** and **26t rigid trucks** (mostly RCVs) based near the Port of Middlesborough area
- Real-world ranges of **170 to 470 miles**, an additional **65 to 265 miles** compared to battery electric vehicles
- **89%** of vehicles assessed can complete twice their average daily mileage using fuel cell electric vehicles

Support Required

- Availability of suitable fuel cell vehicles meeting fleet specifications and requirements
- Hydrogen refuelling stations at viable locations for initial trials & deployments
- Hydrogen priced at **£5.80 / kg** or lower to achieve fuel cost parity with diesel

Executive Summary

In March 2021, the Department for Transport published the 'Tees Valley Multi-Modal Hydrogen Transport Hub Masterplan' and announced £3 million of government funding to kick start the development of the UK's first hydrogen transport hub[1]. During the primary operational trial period of the Hub between 2025-2030 there is an estimated total demand for green hydrogen of up to 13,000 kg / day.

This report summarises the findings of the Trials, Analysis and Deployment Planning for Hydrogen Fleets project delivered by Ballard Motive Solutions and Cenex as part of the Tees Valley Hydrogen Transport Hub Demonstration competition[2] funded by the Department for Transport and delivered in partnership with Innovate UK. By engaging with local fleets, the project aimed to develop a pipeline of trials and deployments from 2022 onwards by identifying which applications are best suited to fuel cell vehicles and highlighting the potential hydrogen demand by location.

Fleet Engagement and Trials

Throughout the project local fleet operators were engaged with through one to one discussions as well as two online workshops organised by Cenex. The purpose of the fleet engagement was to increase knowledge of hydrogen vehicles and infrastructure, identify barriers to adoption, recruit fleets for hydrogen fleet reviews, and to develop a group of organisations that may be interested in partaking in further trials of fuel cell vehicles.

The main barriers identified by the fleets were the costs of vehicles and infrastructure and lack of hydrogen refuelling stations at required locations.

Because of these barriers, few fleets have immediate plans to introduce hydrogen vehicles, but most would be willing to trial them. Most fleets are considering introducing some fuel cell vehicles by 2030 assuming that suitable, affordable, vehicles are available and are supported by a network of reliable hydrogen refuelling stations supplying low-cost green hydrogen.

Between November 2021 and March 2022 Ballard Motive Solutions supplied a total of five Renault Kangoo ZE H2 small vans for real-world operational trials with three organisations. The fleet operators were content that the demonstration trial proved the concept of using fuel cell vehicles and hydrogen refuelling infrastructure. It was noted that end users require simplicity of refuelling and that the range extended electric vehicle required charging overnight and the occasional hydrogen refuel at a separate location. Overall, fleet operators were positive about the trial and ready to trial more applicable vehicles such as fuel cell electric RCVs.

Opportunities for Hydrogen Vehicle Deployment in the Tees Valley

Cenex analysed fleet data from seven local operators to assess the potential opportunities for trialling and deploying additional hydrogen vehicles across the Tees Valley Region. In total 920 vehicles were assessed including 495 light commercial vehicles (LCV) and 425 heavy goods vehicles (HGV) representing approximately 0.6% of the LCVs and 12% of the HGVs in the region. Based on fuel consumption data, these vehicles emit 13,370 tonnes of greenhouse gas emissions on a fuel lifecycle basis (equivalent to 5,722 diesel passenger cars) and 4,390 kg of nitrogen oxides (one of the main air quality pollutant emissions).

Executive Summary

Cenex modelling (assuming component efficiencies of 30% for a diesel drivetrain, 51% for a fuel cell system, 95% for an inverter (DC-AC) and 90% for an electric motor) showed that if all 920 vehicles were replaced by fuel cell electric vehicles there would be an average daily hydrogen demand of 3,600 kg. This is equivalent to 29% of the 12,500 kg of demand projected for the Hydrogen Transport Hub by 2030. 31% (1,050 kg) of the hydrogen demand comes from 26t rigid trucks, 27% (903 kg) comes from 44t tractor units, and 16% (553 kg) comes from 18t rigid trucks. These three vehicle segments account for 75% of the potential hydrogen demand from the fleets studied and are therefore critical to the future deployment of hydrogen vehicles within these fleets.

Further analysis highlighted the long-term advantages of hydrogen vehicles over battery electric options, particularly in terms of range. The project found that fuel cell electric vehicles provide additional operational flexibility by providing an additional 65 to 265 miles of maximum range compared to battery equivalents. Based on this analysis, 44t tractor units are better suited to fuel cell electric vehicles as battery electric vehicles would require high powered charging both during the shift and overnight.

Mapping Tees Valley Hydrogen Demand

Lack of confidence in the availability of hydrogen infrastructure was one of the main barriers highlighted in stakeholder consultation. Therefore, ensuring that the rollout of hydrogen infrastructure targets sites of early demand is crucial for wider adoption. Mapping demand from vehicle locations showed that 2,280 kg (or 63% of the total) of the potential hydrogen demand falls within a four-mile radius that is approximately centred around Port of Middlesbrough; this area covers key locations from four of the seven fleets assessed and therefore offers a good candidate location for hydrogen refuelling stations to support further operational trials across several applications.

Fuel Costs of Hydrogen Vehicles

Fuel cell vehicles are more energy efficient than diesel equivalents. Nevertheless, based on the current hydrogen public market price of £10/kg, this efficiency is offset by higher unit fuel costs resulting in higher running costs for potential hydrogen replacement vehicles (it is likely that large fleet users would be able to obtain hydrogen at a lower price than this). Based on the £10/kg market price, annual fuel costs for fuel cell electric vehicles can currently increase by £430 for small vans up to £32,900 for 44t tractor unit (assuming an average diesel price of £1.16/litre exc. VAT and an electricity price of £0.135 / kWh for a small/medium non-domestic user). A 26t refuse collection vehicle could achieve fuel cost parity with diesel vehicles at ~£5.80 / kg (a 42% reduction on current public market levels), with fuel cost parity with battery electric vehicles achieved at ~£2.20 / kg (a 72% reduction). For context, the Hydrogen Council forecasts a 60% cost reduction of hydrogen by 2030 for the end user (from $11.2 to $4.5).

Executive Summary

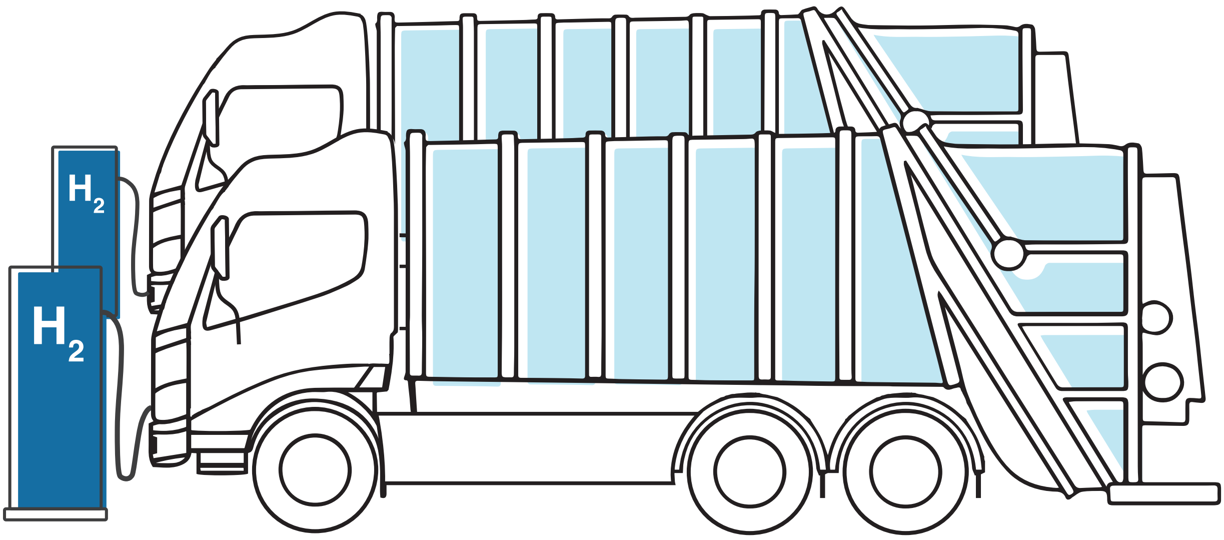
Conclusions and Next Steps

This project has shown that engagement with stakeholders and analysis can reduce risk around demand and better inform development of the Tees Valley Multi-Modal Hydrogen Transport Hub. The report highlights the following short-term opportunities in the region:

- **Vehicles,** led by 26t rigid trucks (mostly refuse collection vehicles) and 44t tractor units
- **Locations,** with 2,280 kg of potential hydrogen demand within a four-mile radius around Port of Middlesbrough covering two local authority depots and two private sector fleet operator depots.
- **Additional considerations:** fuel cell vehicles should be trialled and deployed where they provide an operational or practical benefit compared to battery electric vehicles

Next steps for enabling vehicle trials in the short-medium term include:

- Development and demonstration of suitable fuel cell vehicles to meet operational requirements.
- Infrastructure and hydrogen fuel supply for initial vehicle trials across several locations linked to clusters of early demand.
- Green hydrogen priced at £5.80/kg would allow fleet operators to achieve fuel cost parity with their diesel vehicles without additional funding.
- Grant funding for the additional purchase cost of fuel cell vehicles.
- Assurances that vehicles will be supported sufficiently to allow for fleet wide adoption (e.g., servicing, maintenance, warranty, workshop training and readiness, education for public).



1 Introduction

In March 2021, the Department for Transport published the ‘Tees Valley Multi-Modal Hydrogen Transport Hub Masterplan’ and announced £3 million of government funding to kick start the development of the UK’s first hydrogen transport hub[3].

The Hydrogen Transport Hub is planned to be fully operational by 2025 and will provide the facilities for the production, storage, and distribution of green hydrogen (produced using renewable electricity) to a network of hydrogen refuelling stations supporting operational trials across the Tees Valley region. During the primary operational trial period of 2025-2030 there is an estimated total demand for green hydrogen of up to 13,000 kg / day.

This report summarises the findings of the Trials, Analysis and Deployment Planning for Hydrogen Fleets project delivered by Ballard Motive Solutions and Cenex as part of the Tees Valley Hydrogen Transport Hub Demonstration competition[4] funded by the Department for Transport and delivered in partnership with Innovate UK.

The overall aim of the project is to demonstrate hydrogen vehicles in real-world fleet operations and to inform the long-term development of the Hydrogen Transport Hub by:

- Engaging with local authorities and other fleet operators to build collaborations.
- Growing the demand for green hydrogen by demonstrating fuel cell range extended small vans.
- Developing a pipeline of trials and deployments from 2022 onwards by identifying which applications are best suited to fuel cell vehicles and highlighting the potential hydrogen demand by location.
- Developing an automated hydrogen fleet review process to enable fleet operators to make informed decisions around operational suitability, emissions savings potential, and what support may be required for a future transition to fuel cell vehicles by better understanding vehicle total cost of ownership.

1.1 Ballard Motive Solutions

Arcola Energy was founded with the aim of bridging the gap between the development of new hydrogen fuel cell technologies and deployment-ready applications.

Following more than 10 successful years of growth, in November 2021 Arcola Energy was acquired by Ballard Power Systems, a leading supplier of fuel cell modules, to create Ballard Motive Solutions[5], a supplier of complete fuel cell powertrain systems.

1.2 Cenex

Cenex[6] was established as the UK’s first Centre of Excellence for Low Carbon and Fuel Cell technologies in 2005.

Today, Cenex focuses on low emission transport & associated energy infrastructure and operates as an independent, not-for-profit research technology organisation (RTO) and consultancy, specialising in the project delivery, innovation support and market development. We also organise Cenex-LCV, the UK’s premier low carbon vehicle event, to showcase the latest technology and innovation in the industry.

2 Project Overview

The project was undertaken in two main parts with Ballard Motive Solutions delivering five Renault Kangoo ZE-H2 small vans for demonstration trials and Cenex developing regional deployment scenarios based on the results of hydrogen fleet reviews from seven local fleet operators.

The project process shown below aimed to:

- Give fleet operators real-world experience of operating and refuelling hydrogen vehicles.
- Gain an understanding of the current barriers to deploying further fuel cell vehicles.
- Highlight which vehicle types and applications are best suited to using fuel cell vehicles.
- Quantify the maximum potential hydrogen demand and refuelling locations for a selection of fleets.
- Highlight the importance of hydrogen fuel price on the total cost of ownership of fuel cell vehicles.
- Provide strategic advice to the Tees Valley Region on the potential for H2 vehicle deployment by the participating fleets.

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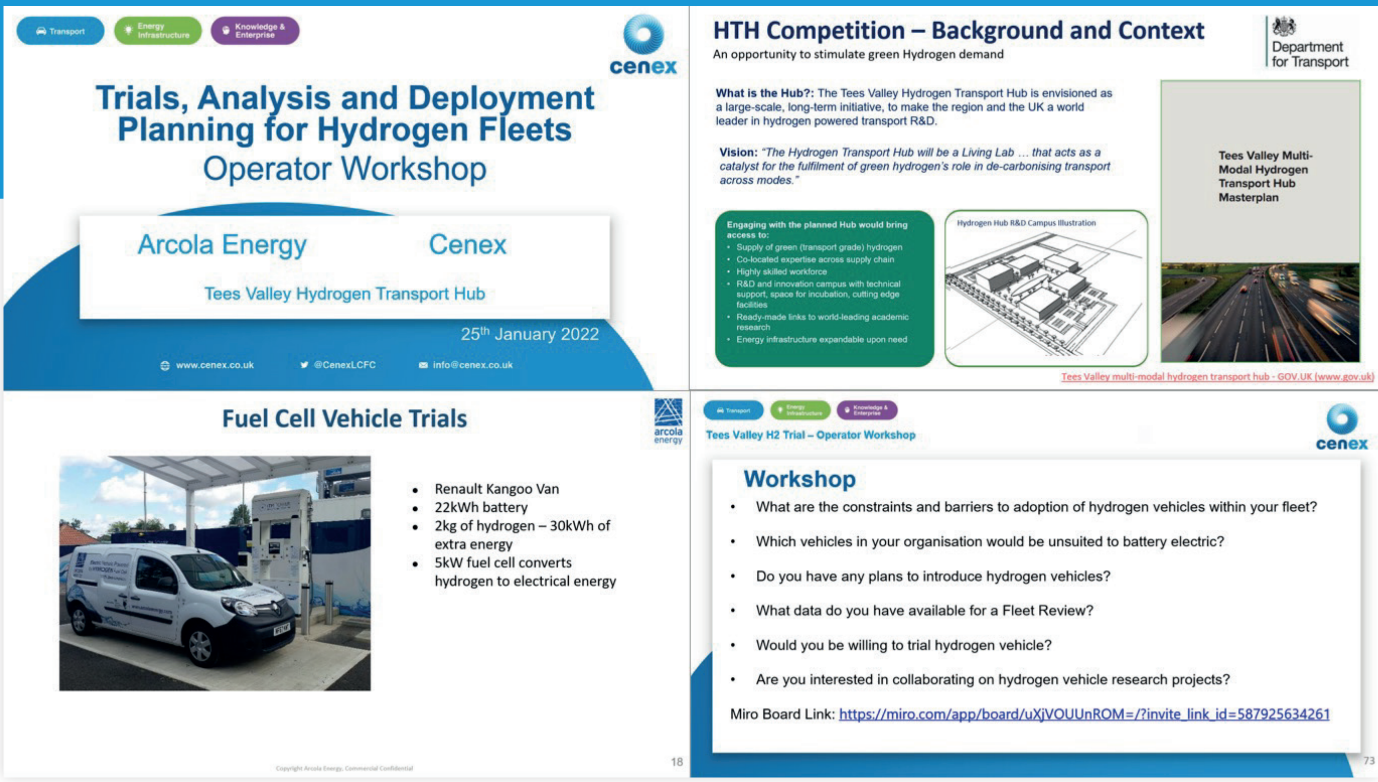
3 Fleet Engagement and Trials



Throughout the project local fleet operators were engaged with through one to one discussion as well as a series of online workshops organised by Cenex.

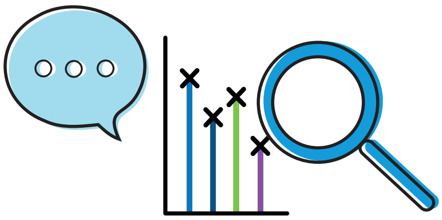
The purpose of the fleet engagement was to increase knowledge of hydrogen vehicles and infrastructure, identify barriers to adoption, recruit fleets for hydrogen fleet reviews, and to develop a group of organisations that may be interested in partaking in further trials of fuel cell vehicles. This was achieved through a combination of presentations, discussions, and by using visual collaboration tools such as Miro.

Two workshops were held, the first aimed specifically at local authorities and the second open other Tees Valley fleet operators.

The primary focus was to engage with fleets operating refuse collection vehicles (RCVs) and other energy intensive vehicle types. RCVs are one of the main contributors to local authority fleet emissions and are a key product focus for Ballard Motive Solutions.

Figure 1: Hydrogen Refuse Collection Vehicle (Source: Ballard Motive Solutions)

3 Fleet Engagement and Trials



3.1 Workshop Outcomes

- **25 attendees representing 18 different organisations** (local authorities, utilities companies, public service providers)

- Hydrogen Training Zone delivered
  - Hydrogen policy, rules, and regulations
  - Hydrogen vehicles
  - Hydrogen refuelling stations

- **What are you most worried about?**
  - **Costs (vehicles, hydrogen, infrastructure)**
    – 5 responses
  - **Lack of hydrogen refuelling stations / infrastructure at required locations**
    – 4 responses
  - Public perception and understanding
    – 3 responses
  - Other
    – 5 responses

- **What are the other barriers to adoption of hydrogen vehicles in your fleet?**
  - Low infrastructure reliability / resilience, large number of sites require a distributed network of hydrogen refuelling infrastructure
    – 8 responses
  - **Vehicles do not exist or have not been proven to meet operational requirements** such as payload capacity, towing capacity, off-road capabilities, and power take-off
    – 5 responses
  - Total cost of ownership remains very challenging (high purchase costs, few leasing options, purchase costs are not yet offset by running cost savings)
    – 3 responses
  - Other
    – 2 responses

- **Which of your vehicles are currently not suitable for replacement by battery electric vehicles?**
  - Pickup trucks, 3.5t vans, heavy goods vehicles with additional operational constraints (e.g. RCVs, gritting vehicles, hook loaders, high mileage tractor units)

- **Do you have any plans to introduce hydrogen vehicles?**
  - Few fleets have immediate plans to introduce hydrogen vehicles but **there is a strong willingness to trial vehicles**.
  - Most **fleets are considering introducing some fuel cell vehicles by 2030** assuming that suitable, affordable, vehicles are available and are supported by a network of reliable hydrogen refuelling stations supplying low-cost green hydrogen.

3 Fleet Engagement and Trials

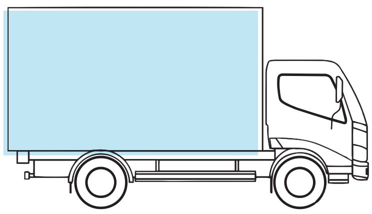
3.2 Fleet Trials

Between November 2021 and March 2022 Ballard Motive Solutions supplied a total of five Renault Kangoo ZE H2 small vans for real-world operational trials with three organisations.

The trials are described in detail in Appendix 1. The primary purpose of the demonstration trial was to improve understanding of hydrogen vehicles by giving fleet operators hands on experience of operating and refuelling them in real-world conditions.

The table below shows the summary statistics for vehicles 1 and 2 over a three-month period from 9th December 2021 to 7th March 2022. These vehicles were operated exclusively by Redcar & Cleveland Borough Council, primarily from the Skelton Depot.

The fleet operators were content that the demonstration trial proved the concept of using fuel cell vehicles and hydrogen refuelling infrastructure. It was noted that end users require simplicity of refuelling and that the range extended electric vehicle required charging overnight and the occasional hydrogen refuel at a separate location. **Overall, fleet operators were positive about the trial and ready to trial more applicable vehicles such as fuel cell electric RCVs.**



STATISTIC	VALUE
Total mileage logged	928 miles
Total number of days logged	54 days
Maximum daily mileage	40 miles
Extrapolated annual mileage	1,915 miles per vehicle
Typical hours of operation	Between 7am and 4pm
Average daily driving time	40 mins

4 Opportunities for Hydrogen Vehicle Deployment in the Tees Valley

Cenex analysed fleet data from seven local operators to assess the potential opportunities for trialling and deploying additional hydrogen vehicles across the Tees Valley Region.

An automated fleet review process was developed for battery electric and fuel cell electric commercial vehicles ranging from small vans to 44t tractor units. This was based on the 'Fleet Advice Tool', previously developed by Cenex, which assesses the operational suitability, total cost of ownership, and emissions of low emission vehicles technologies using data from independent real-world vehicle testing.

As shown in the fleet review process below the tool was updated to include three improvements:

- Hydrogen tank capacities were added to all ten commercial vehicle segments based on the specifications of vehicles that are available in the UK today or are coming soon.
- Drivetrain efficiencies were researched[7] and implemented to convert diesel fuel economy to hydrogen / electricity consumption in vehicle segments where independent real-world test data is currently unavailable.
- Electricity grid[8,9] and hydrogen electrolysis[10] greenhouse gas emissions factors were updated, including a projection to 2030.

Finally, the fleet advice tool was transitioned from a manual Microsoft Excel based tool to a software tool with automated reporting capabilities. Automation of the fleet review analysis and standard report contents was critical to deliver the volume of fleet reviews required by the project timescales.

Determine hydrogen vehicle specifications and energy factors

Gather fleet data
- Fleet list & locations
- Annual mileage & fuel use

Calculate baseline for diesel vehicle energy consumption and emissions

Calculate average daily electricity and hydrogen consumption (scaled to diesel vehicle fuel economy)

Assess operating range suitability by comparing average daily mileage to real-world operating range

Calculate potential hydrogen demand by location and compare to equivalent number, type, and power of chargepoint

Calculate greenhouse gas and air quality emissions over time

Produce recommendations for vehicle trials and deployments against fleet replacement schedule

4 Opportunities for Hydrogen Vehicle Deployment in the Tees Valley

4.1 Tees Valley Fleet Baselining

Cenex gathered fleet data including vehicle details, locations, mileage and fuel records, and replacement dates from the seven fleets listed below. For the purposes of this report the fleet data has been combined and processed as one ‘Tees Valley Fleet’.

- AV Dawson
- Darlington Borough Council
- Middlesbrough Borough Council
- Northern Gas Networks
- Redcar & Cleveland Borough Council
- Stockton on Tees Borough Council
- Teesside International Airport

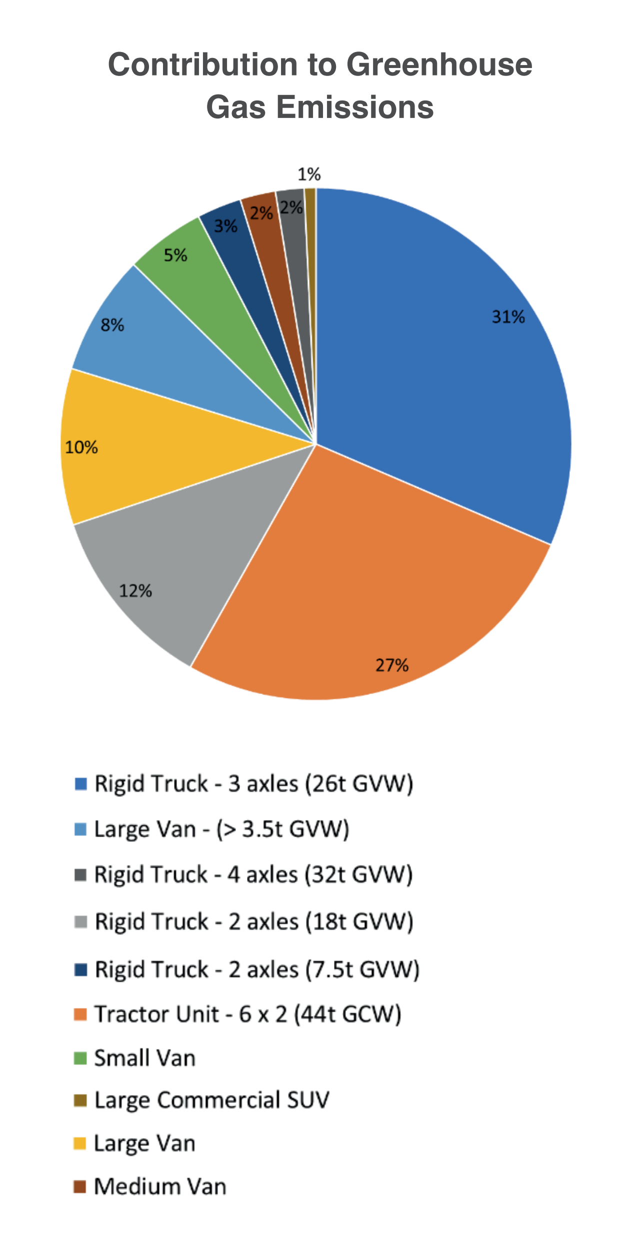
In total 920 vehicles were assessed including 495 light commercial vehicles (LCV) and 425 heavy goods vehicles (HGV). In 2020 there were 77,517 LCVs and 3,514 HGVs licensed by the Tees Valley Combined Authority member authorities[11]. As such the vehicles in this report represent approximately 0.6% of the LCVs and 12% of the HGVs in the region.

The table below shows the number and type of vehicles assessed including the most common models and vehicle configurations. The vehicle segments highlighted in light green account for 47% of the combined fleet, but also 80% of the greenhouse gas emissions.

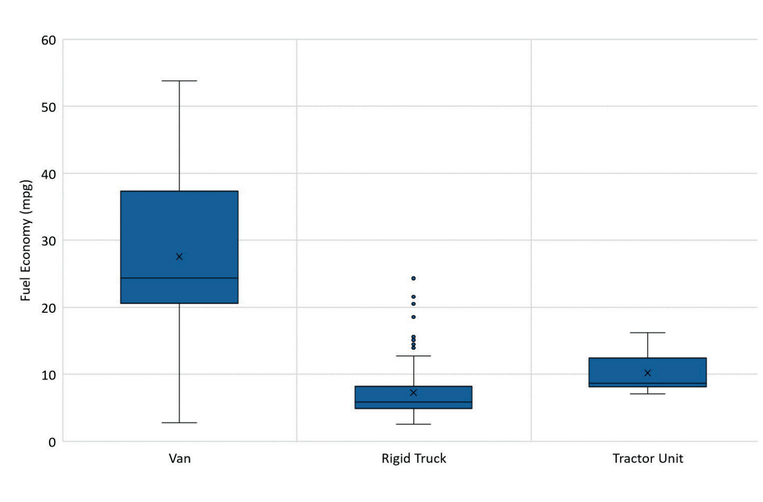
VEHICLE SEGMENT	NUMBER OF VEHICLES	MOST COMMON MODEL	MOST COMMON CONFIGURATION
Small Van	199	Ford Transit Connect	Panel Van
Medium Van	71	Ford Transit Custom	Panel Van
Large Commercial SUV	17	Mitsubishi L200	Pick-Up
Large Van	208	Ford Transit	Panel Van
Large Van - (> 3.5t GVW)	157	Iveco Daily	Minibus
Rigid Truck - 2 axles (7.5t GVW)	39	Iveco Eurocargo	Tipper
Rigid Truck - 2 axles (18t GVW)	65	DAF LF	Gritting Vehicle
Rigid Truck - 3 axles (26t GVW)	128	Mercedes-Benz Econic	Refuse Disposal
Rigid Truck - 4 axles (32t GVW)	5	Mercedes-Benz Arocs	Skip Loader
Tractor Unit – 6 x 2 (44t GCW)	31	Scania R Series	Dropside Lorry
Total	**920**	-	-

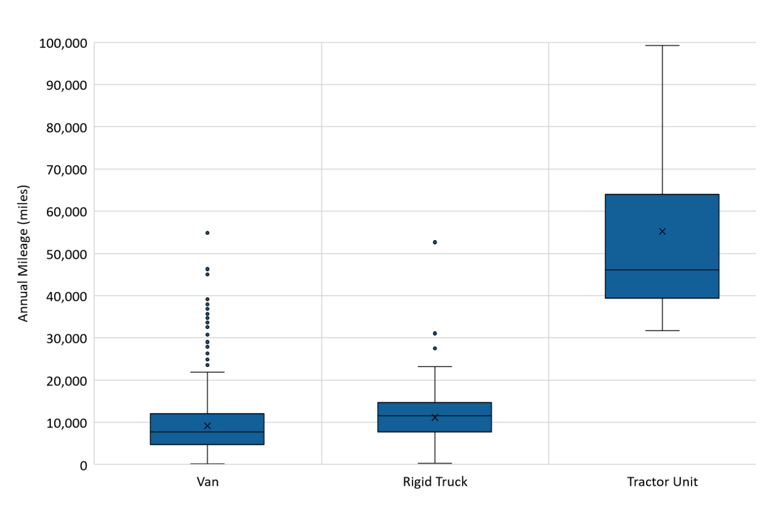
4 Opportunities for Hydrogen Vehicle Deployment in the Tees Valley

Overall, **the combined fleet emits 13,370 tonnes of greenhouse gas emissions on a fuel lifecycle basis, this is equivalent to 5,722 diesel passenger cars**, and 4,390 kg of nitrogen oxides (one of the main air quality pollutant emissions). The contribution to greenhouse gas emissions is **shown below**.



The box and whisker plots **below** show the distribution of annual mileage and fuel economy for vans, rigid trucks, and tractor units respectively.





This shows that 75% of vans have an annual mileage of less than 12,000 miles with a median fuel economy of 24.4 mpg. This compares to 14,700 miles at 5.8 mpg for rigid trucks and 64,000 miles at 8.6 mpg for tractor units. With most vehicles operating for five days a week this equates to typical maximum daily mileages of 46 miles, 57 miles, and 246 miles respectively.

4 Opportunities for Hydrogen Vehicle Deployment in the Tees Valley

VEHICLE SEGMENT	AVERAGE DAILY MILEAGE (MILES)	AVERAGE DAILY HYDROGEN CONSUMPTION (KG)	NUMBER OF VEHICLES	TOTAL DAILY HYDROGEN DEMAND (KG)
Rigid Truck - 3 axles (26t GVW)	47	8.2	128	1,050
Tractor Unit – 6 x 2 (44t GCW)	212	29.1	31	903
Rigid Truck - 2 axles (18t GVW)	38	8.5	65	553
Large Van	34	1.3	208	261
Large Van - (> 3.5t GVW)	34	1.5	157	239
Small Van	37	0.7	199	132
Rigid Truck - 2 axles (7.5t GVW)	33	2.3	39	89
Medium Van	30	0.9	71	61
Rigid Truck - 4 axles (32t GVW)	82	10.4	5	52
Large Commercial SUV	36	1.2	16	19

4.2 Potential Hydrogen Demand and Infrastructure Requirements

Using the average daily mileage and fuel economy it is possible to estimate the average daily hydrogen consumption as shown above.

In most cases this has been achieved by assuming component efficiencies of 30% for a diesel drivetrain, 51% for a fuel cell system, 95% for an inverter (DC-AC), 90% for an electric motor, and where applicable 87% for charging efficiency (electric vehicle charging infrastructure calculations only).

The table shows that if all the vehicles that have been assessed were replaced by fuel cell electric vehicles there would be an average daily hydrogen demand of 3,600 kg. This is equivalent to 29% of the 12,500 kg of demand projected for the Hydrogen Transport Hub by 2030.

This is likely a best-case scenario as it assumes that i) no vehicles are replaced by battery electric vehicles in the meantime and ii) that fuel cell vehicles do not have batteries that can be plugged in to charge (i.e., not a fuel cell range extender configuration as used in the Renault Kangoo ZE H2 vehicles that were trialled by some of the fleets). 31% (1,050 kg) of the hydrogen demand comes from 26t rigid trucks, 27% (903 kg) comes from 44t tractor units, and 16% (553 kg) comes from 18t rigid trucks. These three vehicle segments account for 75% of the potential hydrogen demand from the fleets studied and are therefore critical to the future deployment of hydrogen vehicles within these fleets.

4 Opportunities for Hydrogen Vehicle Deployment in the Tees Valley

4.3 Mapping Regional Hydrogen Demand

Lack of confidence in the availability of hydrogen infrastructure was one of the main barriers highlighted in stakeholder consultation. Therefore, ensuring that the rollout of hydrogen infrastructure targets sites of early demand is crucial for wider adoption. To better understand the potential refuelling requirements **the map below** shows the average daily hydrogen demand by location.

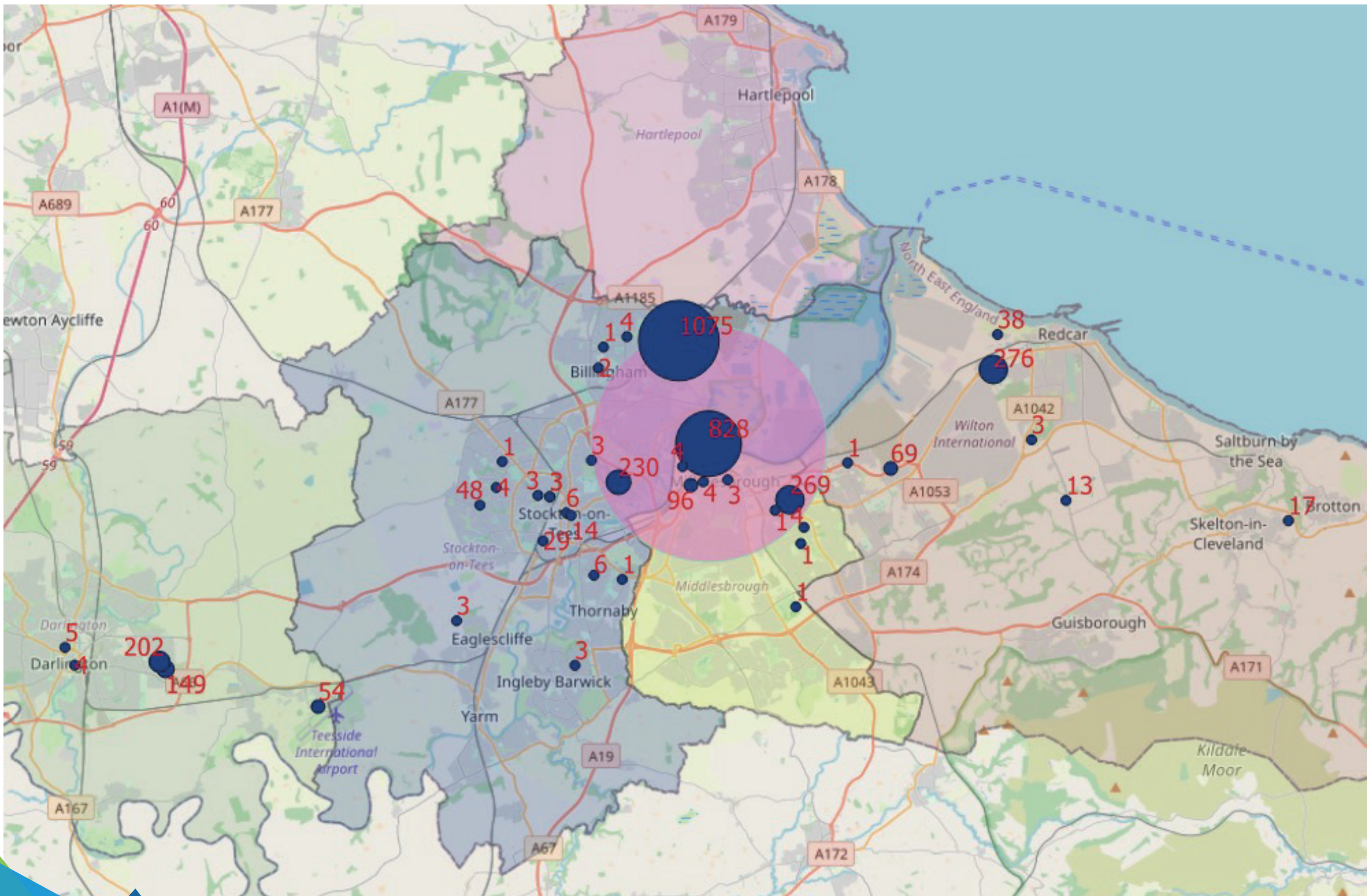
In total the seven fleets assessed have 55 sites consisting of the following:

- Five major locations with 65 to 181 vehicles each.
- 21 main locations with a median of 24 vehicles each (including the five above).
- 34 smaller locations such as schools and satellite depots / sites.

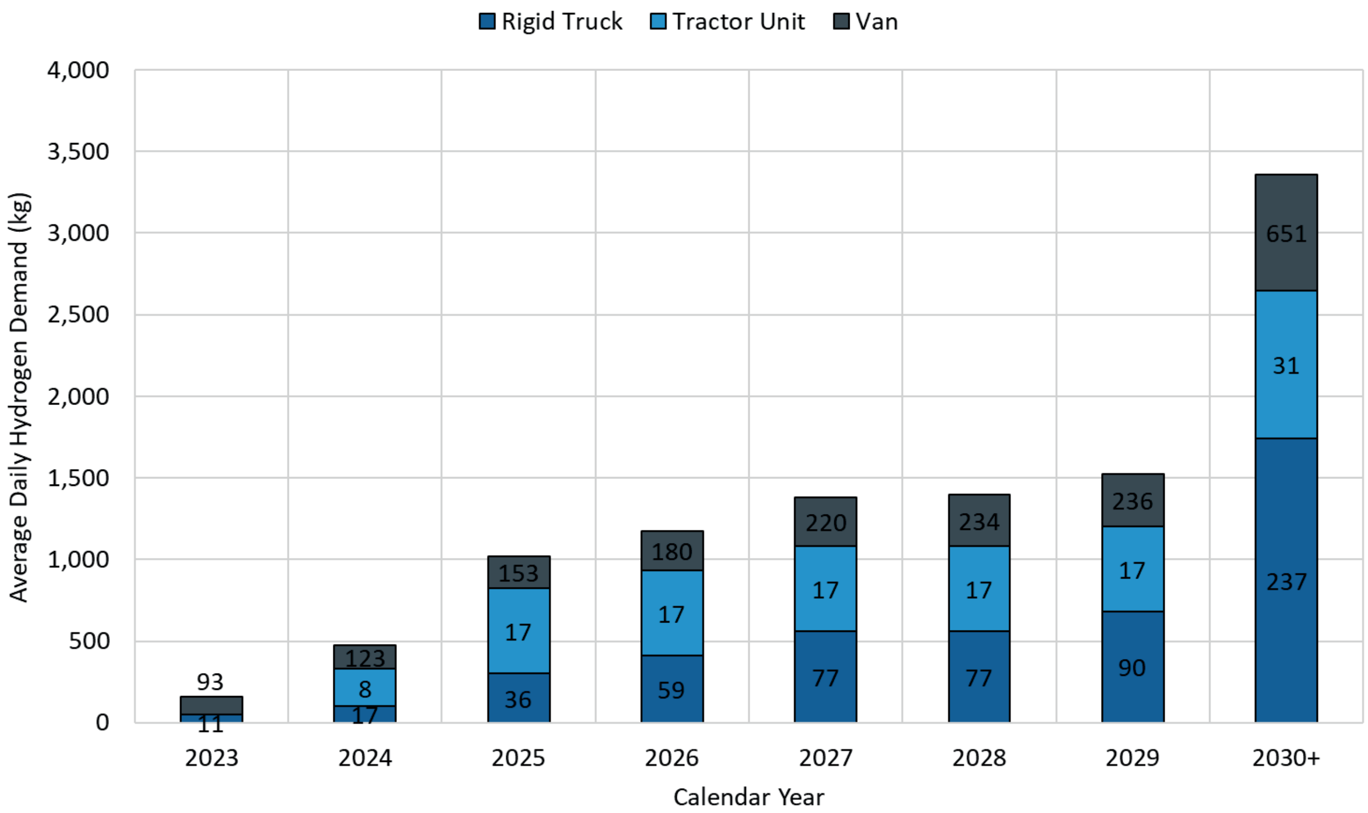
2,280 kg (or 63% of the total) of the potential hydrogen demand falls within a four-mile radius that is approximately centred around Port of Middlesbrough; this area covers key locations from four of the seven fleets assessed and therefore offers a good candidate location for hydrogen refuelling stations to support further operational trials across several applications.

4.4 Fleet Replacement Scenario

82% of the vehicles assessed have ownership periods of seven to ten years (self-reported by the fleets or estimated based on vehicle age). **The chart on the next page** shows the potential hydrogen demand by year assuming that vehicles are replaced with fuel cell electric vehicles according to the estimated replacement schedule.



4 Opportunities for Hydrogen Vehicle Deployment in the Tees Valley



All vehicles due for replacement in or before 2022 have been deferred by one lifecycle and reported as 2030+, which reflects the relative lack of vehicle options and refuelling infrastructure in the next 12 months. The data labels show the number of vehicles due for replacement each year with the potential hydrogen demand shown on the y-axis.

Hydrogen demand could potentially increase to 500 kg per day in 2024 but this is at least partially reliant upon a large uptake of 123 fuel cell electric vans.

Hydrogen demand doubles again to 1,000 kg in 2025 when there could be a total 17 tractor units and 36 rigid trucks powered by green hydrogen. Given the current age of the fleets most of the potential hydrogen demand may be recognised after 2030, this is due to the likely introduction of another generation of diesel vehicles with ownership periods of seven to ten years.

4.5 Comparison of Potential EV Charging Requirements

For context, the same locations were assessed to quantify the potential additional power required to charge fleets of battery electric vehicles. Currently there can be significant costs for upgrading the local electricity network and these are generally passed on to the customer by the Distribution Network Operator. As such, installing hydrogen refuelling infrastructure can be more cost competitive at sites with high equivalent power demands.

Two scenarios are shown below.

- One with unmanaged charging (where all vehicles are plugged in at the same time and charged at maximum available power as determined by the chargepoint or on-board charger).

4 Opportunities for Hydrogen Vehicle Deployment in the Tees Valley

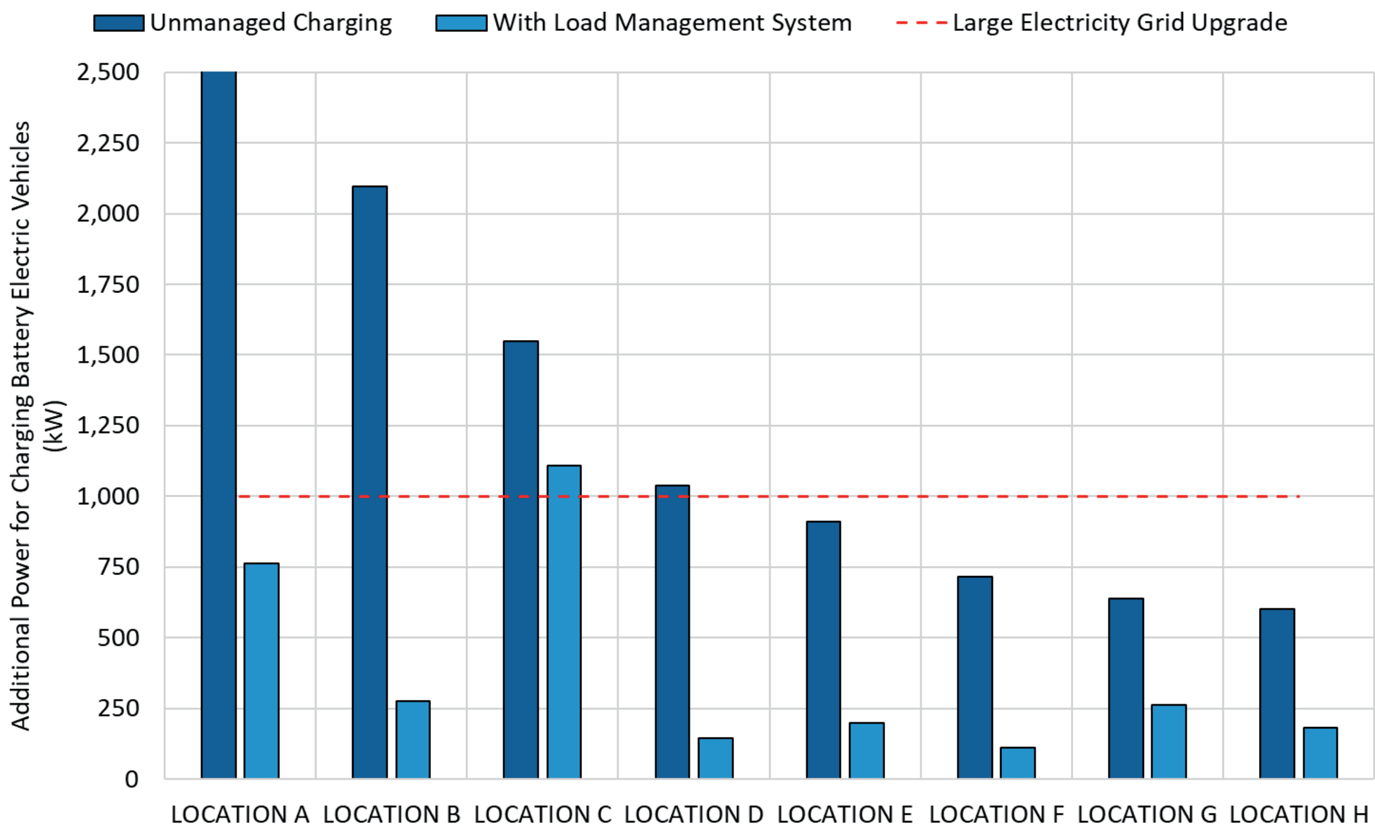
- The second scenario shows the average additional power if a load management system is used. In this scenario it is assumed that the required energy is delivered at a reduced power over a charging period of 16 hours overnight. A maximum charging power of 50 kW has been assumed, but it should be noted that five tractor units require between 50 kW and 100 kW to fulfil their overnight charging requirement.

Four of the locations assessed have additional power requirements of more than 1,000 kW in the unmanaged charging scenario, locations which are highlighted as requiring a large electricity upgrade in **the graph below**.

The additional power requirements reduce to between 143 kW and 1,107 kW (i.e., only one site requires additional power of more than 1,000 kW) if a load management system is implemented (a 77% reduction on average). The size of this reduction is dependent on the daily energy requirement of each vehicle compared to its maximum charging capability.

The UK Electric Vehicle Supply Equipment Association estimate that potential grid connection costs could be up to £75,000 for a medium connection of 200 kVA – 1,000 kVA and between £60,000 and £2 million pound for large connections above 1,000 kVA[12].

It is strongly recommended that fleet operators develop fleet and infrastructure strategies that consider all potential costs associated with introducing zero emission vehicle technologies at depot scale.



4 Opportunities for Hydrogen Vehicle Deployment in the Tees Valley

4.6 Operating Range Suitability

The potential hydrogen demand discussed previously in this Section relies on several factors including the availability of operationally suitable fuel cell vehicles, but also the relative suitability of battery electric vehicles.

There are currently ~68 battery electric commercial vehicles available or coming soon[13]. Most of these vehicles are available from original equipment manufacturers (OEM) and cover all vehicle segments from small vans to tractor units. Conversely there are relatively few commercially available fuel cell commercial vehicles. As such, **fleet operators are encouraged to identify, assess, trial, and implement zero emission vehicle technologies as part of a continuous process** (rather than a one-off activity).

This section presents an assessment of the daily fuel / energy consumption and real-world operating range suitability of battery electric and fuel cell electric vehicles. Fuel cell range extended electric vehicles and other 'plug-in' fuel cell vehicles have not been assessed but could have a potential role for certain applications and duty cycles.

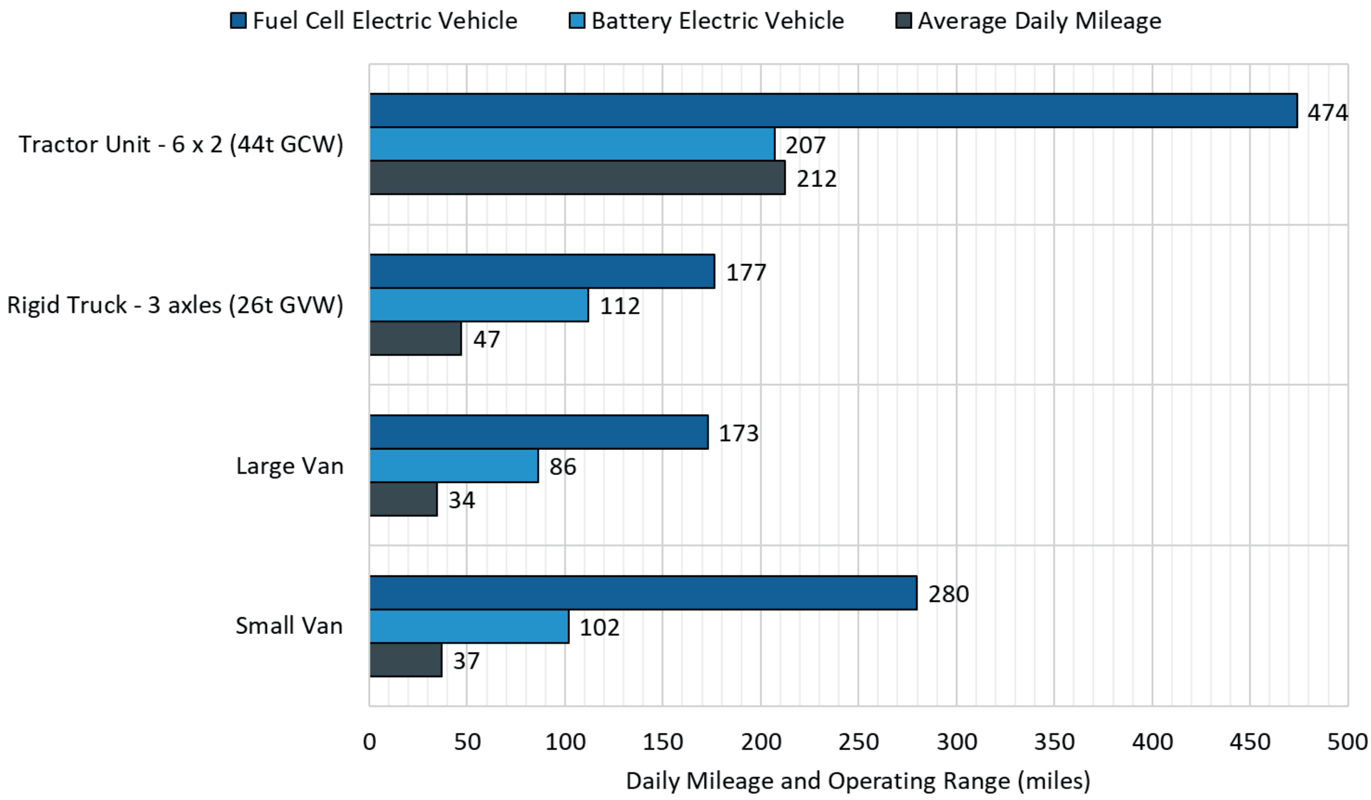
The **table below** shows the energy storage capacities for all vehicle segments assessed. Where possible all data is taken from actual vehicles, some hydrogen tank capacities are modelled as described in Appendix 2. Usable battery capacity has been assumed to be 90% of the nominal battery capacity based on previous testing of light commercial vehicles.

For **the remainder of the report the analysis will focus on the vehicle segments highlighted in bold**, these cover all major vehicle types (vans, rigid trucks, and tractor units) including the highest emitters whilst also providing a good comparison of relative operating range suitability.

VEHICLE SEGMENT	NOMINAL BATTERY CAPACITY - BEV* (kWh)	HYDROGEN TANK CAPACITY - FCEV* (kg)
Small Van	40	5.0
Medium Van	50	5.5
Large Commercial SUV	89	5.5
Large Van	50	5.7
Large Van - (> 3.5t GVW)	56	6.8
Rigid Truck - 2 axles (7.5t GVW)	81	8.5
Rigid Truck - 2 axles (18t GVW)	282	18.9
Rigid Truck - 3 axles (26t GVW)	300	30.0
Rigid Truck - 4 axles (32t GVW)	450	40.1
Tractor Unit – 6 x 2 (44t GCW)	540	65.0

* BEV = battery electric vehicle, FCEV = fuel cell electric vehicle

4 Opportunities for Hydrogen Vehicle Deployment in the Tees Valley



The **chart above** shows the estimated real-world operating range for selected vehicle segments based on the average daily mileage, diesel fuel economy, and zero emission vehicle energy consumption factors used in this report.

Battery electric vehicles currently have sufficient energy storage capacity to complete the average daily mileages for small vans, large vans, and 26t rigid trucks using between 36% and 42% of the battery each day. It should be noted that larger battery capacities are available in some vehicle segments. Using larger batteries extends operating range but at the cost of reduced payload, increased charging times at the same power, and increased purchase costs.

For vehicles or individual days with higher daily energy use (higher mileages or lower fuel economy), **fuel cell electric vehicles provide additional operational flexibility by providing an additional 65 to 265 miles of maximum range**. Based on this analysis, 44t tractor units used for this application are better suited to fuel cell electric vehicles as battery electric vehicles would require high powered charging both during the shift and overnight (for example 150 kW DC).

It is recommended that fleet operators should assess the daily energy requirements for each vehicle prior to trialling or deploying zero emission vehicle technologies. By recording daily mileage, daily fuel consumption, and operating times it is possible to assess both the day-to-day operating range suitability and best opportunities for refuelling or charging zero emission vehicles.

4 Opportunities for Hydrogen Vehicle Deployment in the Tees Valley

To better quantify the operating range suitability the **table below** shows the percentage of vehicles in each segment that can complete their average daily mileage using less than 80% of the vehicle's battery or hydrogen tank. The same metric is reported for a scenario where all vehicles undertook double their average daily mileage; this is intended to differentiate the technologies, but is purely theoretical as maximum daily mileages have not assessed as part of this report.

Based on average daily mileage:

- 93% of the fleet could be suitable for replacement by battery electric vehicles,
- This reduces to only 59% should vehicles be required to travel twice their daily mileage (the frequency of which has not been assessed).
- This difference is most notable for the 44t tractor units and 26t rigid trucks which reduce to 0% and 39% respectively.
- **Fuel cell electric vehicles can complete twice the average daily mileage for 89% of the 919 vehicles assessed.**

VEHICLE SEGMENT	NUMBER OF VEHICLES	SUITABILITY (AVERAGE DAILY MILEAGE)		SUITABILITY (TWICE DAILY MILEAGE)	
		BEV	FCEV	BEV	FCEV
Small Van	199	94%	99%	70%	97%
Large Van	208	92%	99%	65%	92%
Rigid Truck - 3 axles (26t GVW)	128	98%	99%	39%	98%
Tractor Unit – 6 x 2 (44t GCW)	31	45%	94%	0%	58%
Total Fleet (all vehicle types)	**920**	**93%**	**98%**	**59%**	**89%**

5 Fuel Costs of Hydrogen Vehicles

In addition to the practical considerations of using fuel cell electric vehicles (most notably vehicle and infrastructure availability) it is important that the economic business case is viable for fleet operators, hydrogen refuelling station operators, and hydrogen fuel suppliers.

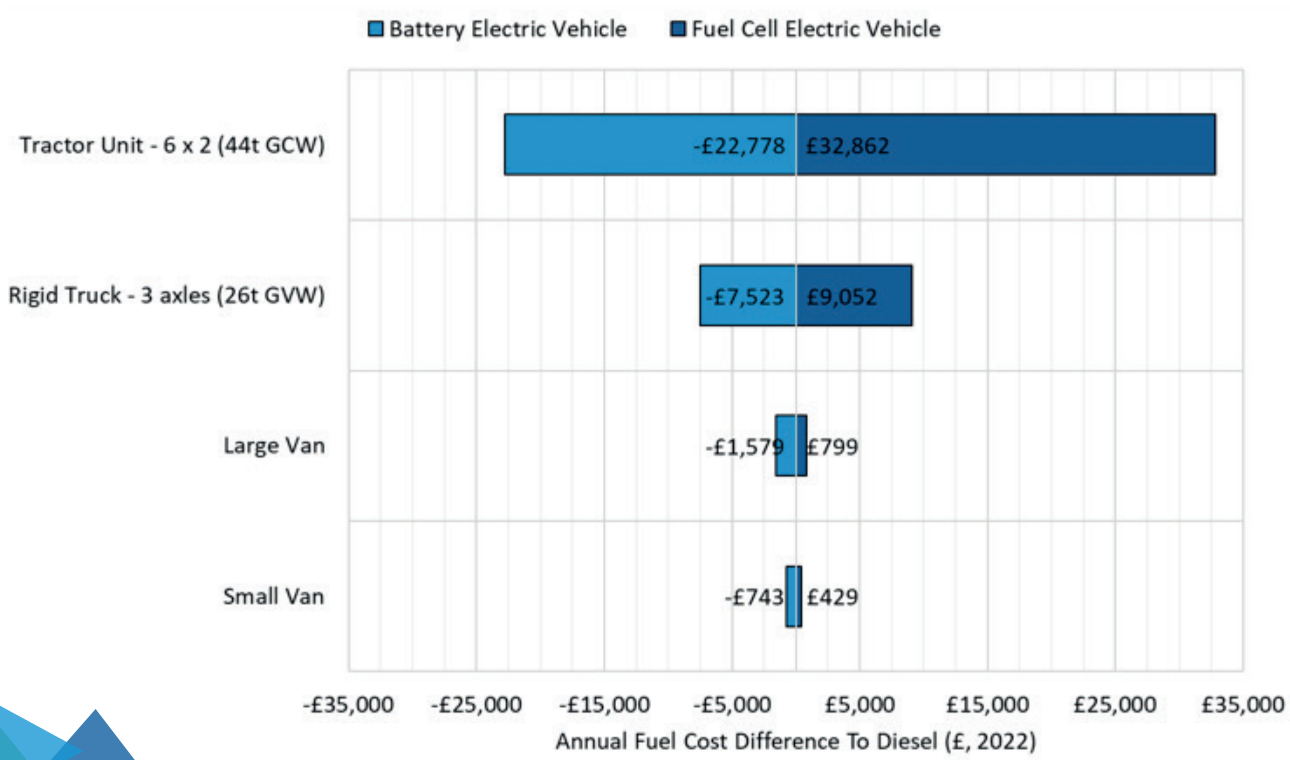
Vehicle total cost of ownership for a fleet operator is determined by the following factors:

- Vehicle depreciation cost (purchase cost and residual value, or equivalent leasing cost)
- Infrastructure costs (if applicable)
- Fuel costs
- Maintenance costs
- Vehicle excise duty
- Additional environmental charges

Because of the lack of certainty around current and future hydrogen vehicle and infrastructure purchase and maintenance costs, **this analysis focused solely on fuel costs**. By increasing the supply of green hydrogen, the hydrogen transport hub has the potential to reduce the cost of hydrogen to end users (often the dominate cost for heavy goods vehicles with high fuel usage).

Based on the average daily energy consumption from the fleet reviews, **the annual fuel costs for diesel commercial vehicles can range from £1,300 for a small van to £42,900 for a 44t tractor unit** (assuming an average diesel price of £1.16 / litre exc. VAT over the last year[14]).

The **chart below** shows the difference in annual fuel costs for battery electric and fuel cell electric vehicles based on an electricity price of £0.135 / kWh for a small / medium non-domestic user[15] and a hydrogen public market price of £10 / kg (it is likely that large fleet users would be able to obtain hydrogen at a lower price than this).



5 Fuel Costs of Hydrogen Vehicles

This shows that the **annual fuel costs for fuel cell electric vehicles can currently increase by £430 for small vans up to £32,900 for 44t tractor unit**, this gives an indication of the order of magnitude of the additional funding that would be required for fleet operators to achieve fuel cost parity.

In comparison battery electric vehicles already provide running cost savings that can additionally contribute to offsetting any increased purchase costs.

Based on the annual fuel / energy consumption it is possible to undertake a hydrogen fuel price sensitivity analysis to calculate the breakeven price of hydrogen at different diesel (and electricity) prices.

The **chart below** shows the hydrogen price sensitivity analysis for 26t rigid trucks (mostly RCVs).

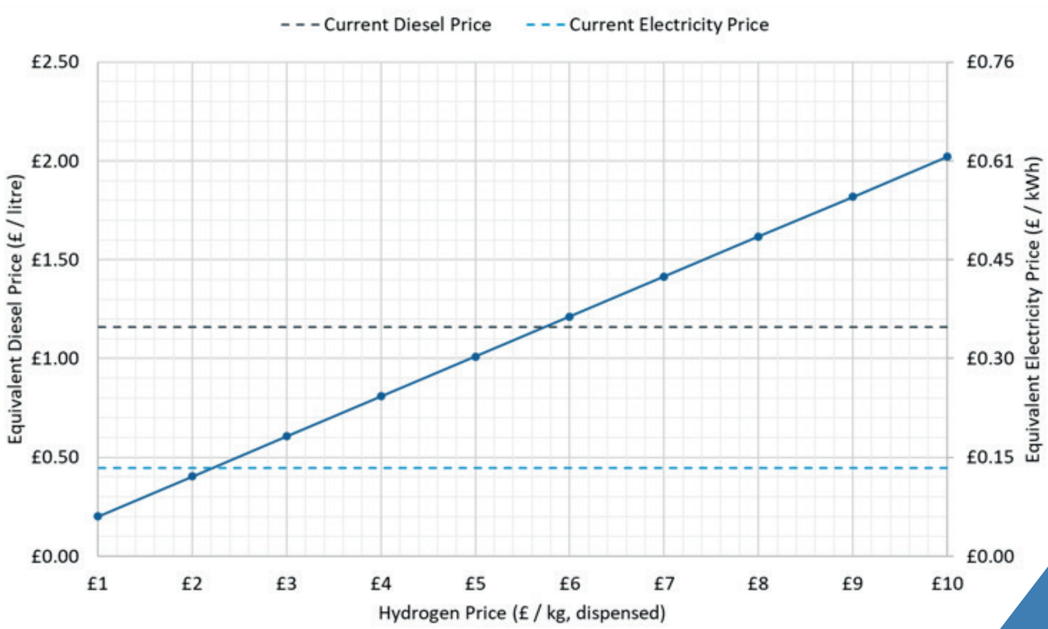
As engineering assumptions have been made about fuel cell electric vehicle energy consumption these results are representative of the overall combined fleet (real world energy consumption and costs will however vary more significantly by vehicle type and application).

This shows that based on today's hydrogen price of £10 / kg diesel and electricity would have to increase to £2 / litre and £0.61 / kWh respectively to achieve the same annual fuel costs (again assuming an average diesel price of £1.16 / litre exc. VAT and an electricity price of £0.135 / kWh for a small / medium non-domestic user).

Conversely **fuel cell electric vehicles could achieve fuel cost parity with diesel vehicles at ~£5.80 / kg (a 42% reduction on current levels)**, with fuel cost parity with battery electric vehicles achieved at ~£2.20 / kg (a 72% reduction).

For context, the **Hydrogen Council forecasts a 60% cost reduction of hydrogen by 2030 for the end user** (from $11.2 to $4.5)[16].

It is strongly recommended that fleet operators undertake a full total cost of ownership analysis (i.e., including vehicles and infrastructure costs) that consider all potential costs associated with introducing zero emission vehicle technologies at depot scale.



6 Roadmap for Trials and Deployment of Hydrogen Fuel Cell Vehicles

The ‘Tees Valley Multi-Modal Hydrogen Transport Hub Masterplan’ proposes an operational trial period from 2025-2030 during which 12,500 kg of green hydrogen would be produced each day via an industrial scale (25 MW) centralised hydrogen production facility.

Seven initial hydrogen refuelling stations will be located dependent on the requirements of the operational trial users with locations expected to cover major depots, the port, and the airport.

Prior to 2025, early engagement with stakeholders and the development of additional small-scale trials can reduce risk around demand and better inform development of the hub.

This report highlights the following opportunities as the most suitable for introducing hydrogen fuel cell vehicles into the seven fleets assessed between now and 2025:

Vehicle types and applications:

- 26t rigid trucks, mostly refuse collection vehicles (31% of total hydrogen demand)
- 44t tractor units (least well suited to battery electric vehicles)
- 18t rigid trucks, mostly gritting vehicles
- Large panel vans

Locations:

- 2,280 kg of potential hydrogen demand within a four-mile radius around Port of Middlesbrough covering two local authority depots and two private sector fleet operator depots.
- Locations A-C which could each require electricity gird upgrades of >1 MW to charge battery electric vehicles without a load management system and all fall within the port area.
- ~1,000 kg of potential hydrogen demand by 2025 from 17 tractor units, 36 rigid trucks, and 153 vans.

Support Required:

- Development and demonstration of suitable fuel cell vehicles to meet operational requirements.
- Infrastructure and hydrogen fuel supply for initial vehicle trials across several locations (e.g. temporary or mobile hydrogen refuelling stations).
- Green hydrogen priced at £5.80 / kg would allow fleet operators to achieve fuel cost parity with their diesel vehicles without additional funding.
- Grant funding for the additional purchase cost of fuel cell vehicles.
- Assurances that vehicles will be supported sufficiently to allow for fleet wide adoption (e.g., servicing, maintenance, warranty, workshop training and readiness, education for public).

Considerations:

- Fuel cell vehicles should be trialled and deployed where they provide an operational or practical benefit compared to battery electric vehicles.
- For example, 44t tractor units with high daily mileages and high power requirements for charging or the top 5% of RCV days recorded that could theoretically not be completed by battery electric vehicles as well as the top 20% of days requiring a 300 kWh battery.
- Where battery electric vehicles are already available and suitable, they provide immediate greenhouse gas and air quality emissions savings with the lowest running costs available today.

Appendices

1 Renault Kangoo ZE H2 Demonstration Trials

Between November 2021 and March 2022 **Ballard Motive Solutions supplied a total of five Renault Kangoo ZE H2 small vans for real-world operational trials with three organisations.**

In preparation for the trials Ballard Motive Solutions worked with each fleet to identify the most suitable site for the vehicle to be based at, this information was also communicated to Element 2 and Innovate UK to assist with planning of hydrogen refuelling infrastructure for the duration of the trials.

The trial vehicles were prepared for use by Ballard Motive Solutions who completed any repairs required to the fuel cell systems and tanks, serviced the vehicles, and undertook an MOT test. Training and support were provided throughout the trial by Ballard Motive Solutions.

Two CAN bus data loggers were also fitted to the first two vehicles and configured to log all available data for six weeks followed by essential data only for the remainder of the trial. Key parameters including vehicle speed, wheel torque, and battery power were all recorded but detailed fuel cell system data was not made available on the CAN bus and is therefore not reported.

Figure 2: Renault Kangoo ZE H2 (Source: Ballard Motive Solutions)

1.1 Trial Vehicle Specifications

The Renault Kangoo ZE H2 is a fuel cell range extended electric vehicle that was produced by Symbio FCell from 2015 onwards and distributed in the UK by Arcola Energy (now Ballard Motive Solutions).

The **table below** shows the key vehicle specifications, it is worth noting that although these vehicles were readily available for trial purposes they have effectively been discontinued and are not a focus of future product development.

BATTERY		RANGE	
Battery Capacity	22 kWh	Total Range (NEDC*)	220 miles at 700 bar
Charging Time	7.5h at 3.7 kW		
HYDROGEN FUEL CELL SYSTEM		**PAYLOAD & LOAD SPACE**	
Peak Power	5 kW	Payload	439 kg
H2 Consumption	0.087 g/s at peak power	Load Space	4.5 m^3
Tank Capacity	2.1 kg (equivalent to 32 kWh of additional usable energy)		
Refuelling Time	4-8 mins		

* New European Drive Cycle (now obsolete)

Appendices

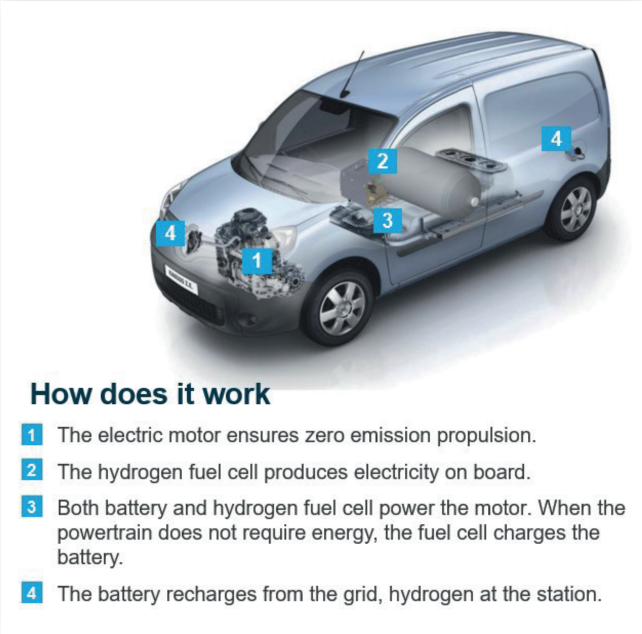


Figure 3 Kangoo ZE H2 Schematic Source: Ballard Motive Solutions

1.2 Deployment Details

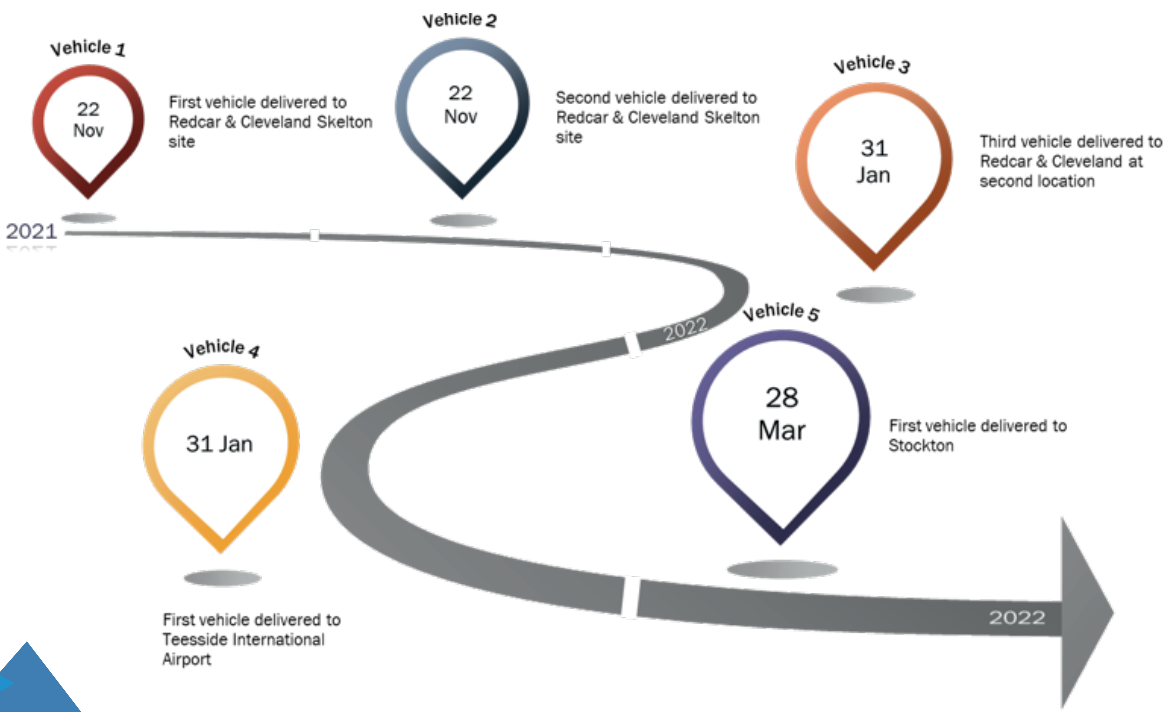
The trial vehicles were delivered in three phases as shown in the timeline below. All vehicles operated from their start date to at least the end of the project on 31st March 2022. In phase 2 of the project (January to February) the mobile hydrogen refueller was moved from Redcar & Cleveland to Teesside International Airport.

1.3 Trial Summary Results

The primary purpose of the demonstration trial was to improve understanding of hydrogen vehicles by giving fleet operators hands on experience of operating and refuelling them in real-world conditions.

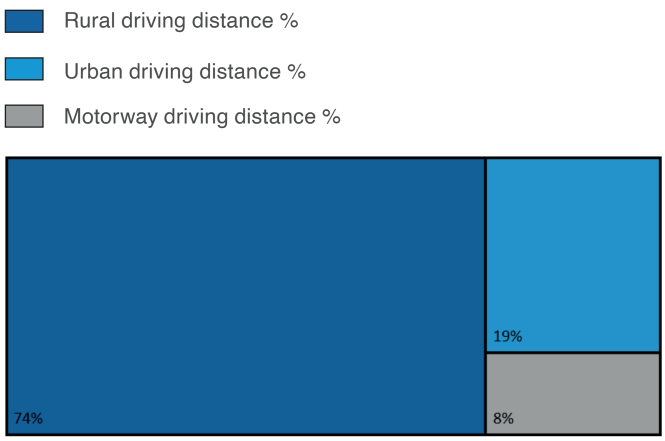
The table below shows the summary statistics for vehicles 1 and 2 over a three-month period from 9th December 2021 to 7th March 2022. These vehicles were operated exclusively by Redcar & Cleveland Borough Council, primarily from the Skelton Depot.

STATISTIC	VALUE
Total mileage logged	928 miles
Total number of days logged	54 days
Maximum daily mileage	40 miles
Extrapolated annual mileage	1,915 miles per vehicle
Typical hours of operation	Between 7am and 4pm
Average daily driving time	40 mins

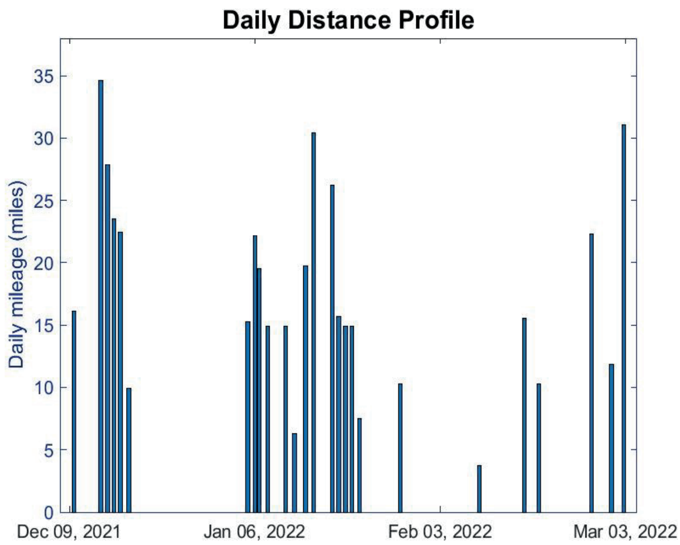


Appendices

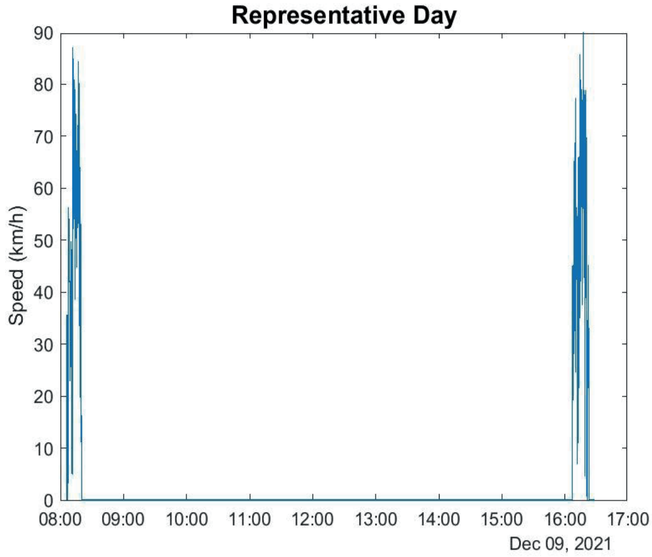
Analysis of the drive cycle data shows the vehicles mainly operated in rural driving environments (74% of the miles) with the remainder in urban environments such as the surrounding towns and villages. Only 8% of miles were categorised as motorway style driving (higher speed, fewer stop / starts). These findings are consistent with the geography of the region with 32.5% of the population based in rural areas[17].



The daily distance profile below shows that the vehicles were used intermittently with an equivalent of two to three days a week usage on average (with periods of sustained usage such as the 13th to 17th December and 17th to 21st January).



The representative day below shows that the vehicles were typically used first thing in the morning and last thing in the working day, this is consistent with business travel between sites rather than daily operational duties.



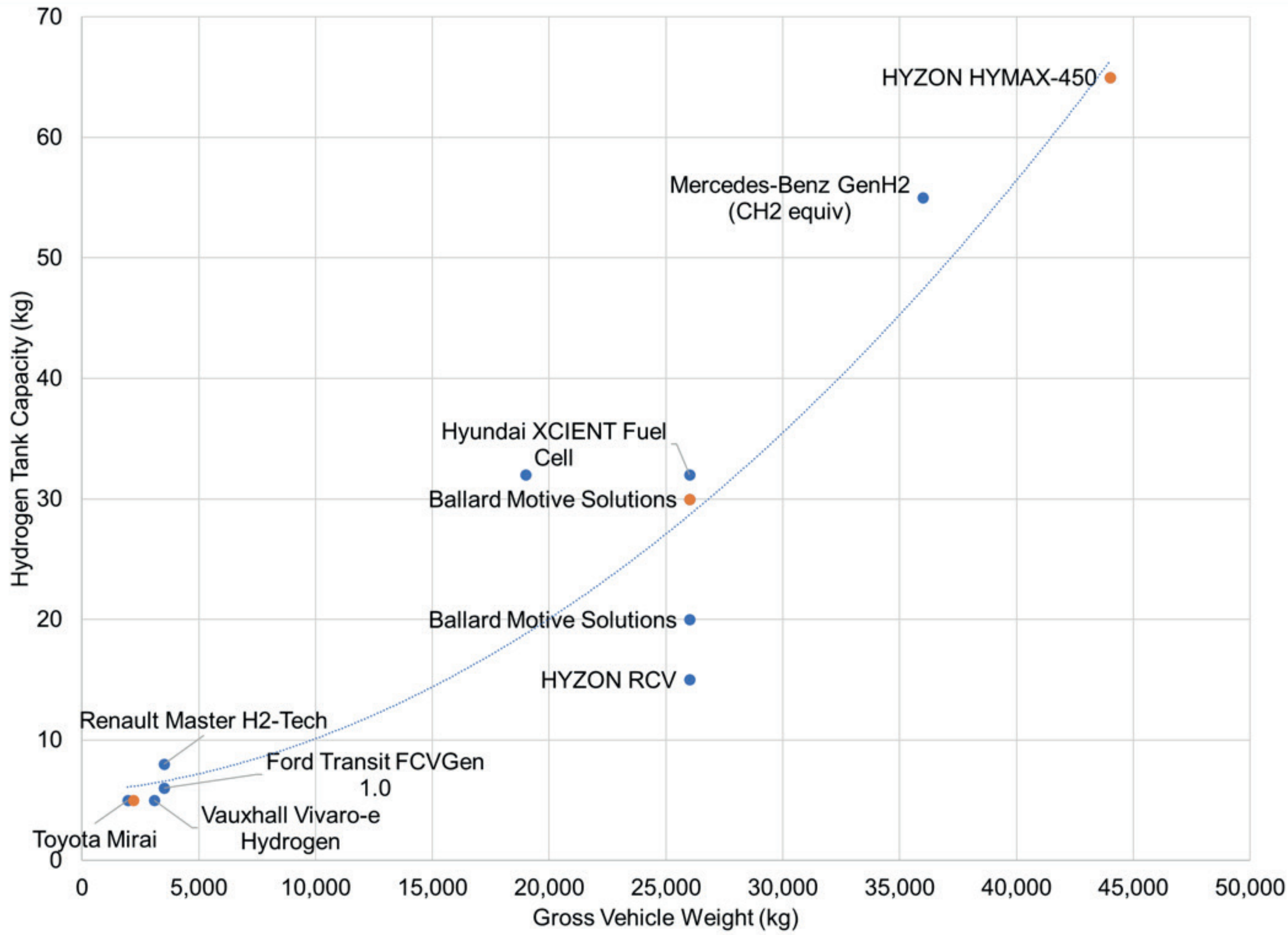
The fleet operators were content that the demonstration trial proved the concept of using fuel cell vehicles and hydrogen refuelling infrastructure. It was noted that end users require simplicity of refuelling and that the range extended electric vehicle required charging overnight and the occasional hydrogen refuel at a separate location. Overall, **fleet operators were positive about the trial and ready to trial more applicable vehicles such as fuel cell electric RCVs.**

Appendices

2 Hydrogen Tank Capacity Assumptions

The chart below shows the hydrogen tank capacities of fuel vehicles that are currently available or coming soon.

This information has been used to interpolate the tank capacities for the vehicle segments discussed in the main report. For example, there are currently no reported tank capacities for 32t rigid trucks, based on the data below 40.1 kg seems to be a reasonable assumption for the 'standard' tank capacity.



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