MILFORD HAVEN: ENERGY KINGDOM

# Summary Report

## Developing the business case for a publicly accessible hydrogen refueller

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# Table of Contents

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This report has been prepared utilising both information gathered directly by Riversimple through vehicle trials as part of the MHEK project, and through information provided by others for the accuracy of which Riversimple is not responsible.

We emphasise that the forward-looking projections, forecasts or estimates are based upon interpretation or assessments of available information at the time of writing. The realisation of the prospective financial information is dependent upon the continued validity of the assumptions upon which it is based. Actual events frequently do not occur as expected, and the differences may be material. For this reason, we accept no responsibility for the realisation of any projection, forecast, opinion or estimate.

# Executive Summary

# Executive Summary – The business case for a publicly accessible hydrogen refueller

As part of the Milford Haven Energy Kingdom project, this activity aimed to demonstrate the real world use of a hydrogen passenger vehicle and evaluate the business case for a publicly accessible hydrogen refueller.

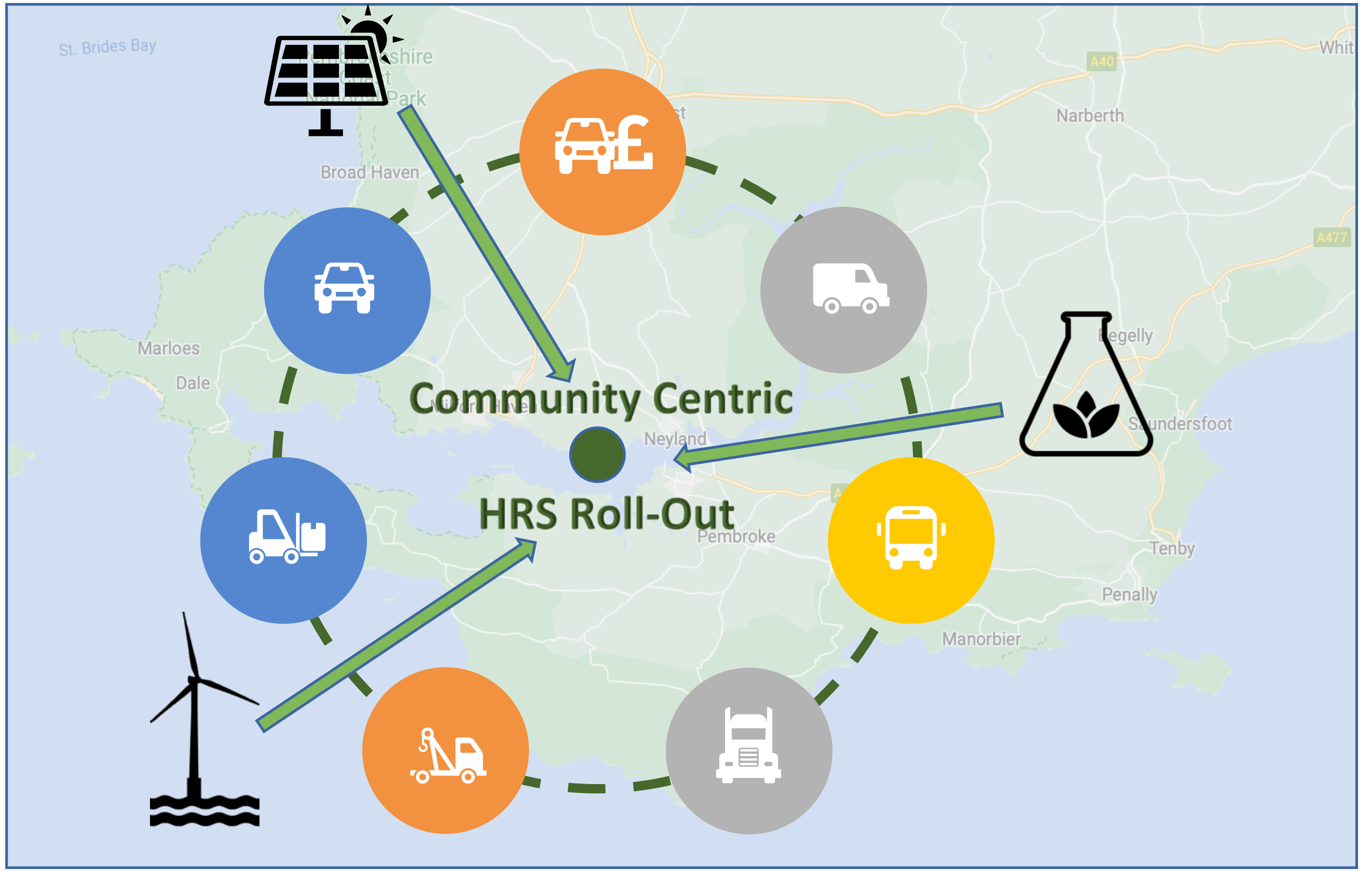
To evaluate future hydrogen demand, an analysis of the role of hydrogen across multiple transportation modes was completed: passenger vehicles, fleets, light commercial vehicles, buses, heavy goods vehicles, off-highway vehicles and emergency vehicles all being within scope. From this analysis it was concluded that demand could be in the range of 1740 to 1920 kg/day at the point where ICE vehicles were no longer in use (2050 case).

The transition towards this demand will be influenced by a combination of factors, with operating costs, capital costs and legislation all having a significant impact.

- With regards to passenger vehicles, a tipping point may be achieved once total cost of ownership (TCO) of FCEVs reaches that of BEVs. For households that cannot home charge, this will be reached sooner. An efficient vehicle architecture such as the Riversimple Rasa allows for a competitive TCO at current commercial hydrogen prices.
- With respect to commercial vehicles and public transportation, FCEVs offer a compelling proposition in terms of utility and convenience – both being similar to current ICE vehicles. Pre-commercial products are now available.

Through focusing initially on passenger vehicles, captive fleets, light commercial vehicles and buses to seed the demand for hydrogen, potentially supported by local incentives, a case can be built for daily demand at a level that allows for a commercially viable community refueller, using hydrogen produced locally from a variety of sources. Given that no single mode of transport can initially provide enough demand to seed the market, it is essential that any refueller is publicly accessible.

Building the business case for refuellers from the bottom-up at a community level, tailored to specific local demand and fuel supply conditions maximises the potential for commercial success. Replicated across the country this then forms the skeleton of a national hydrogen refuelling infrastructure.



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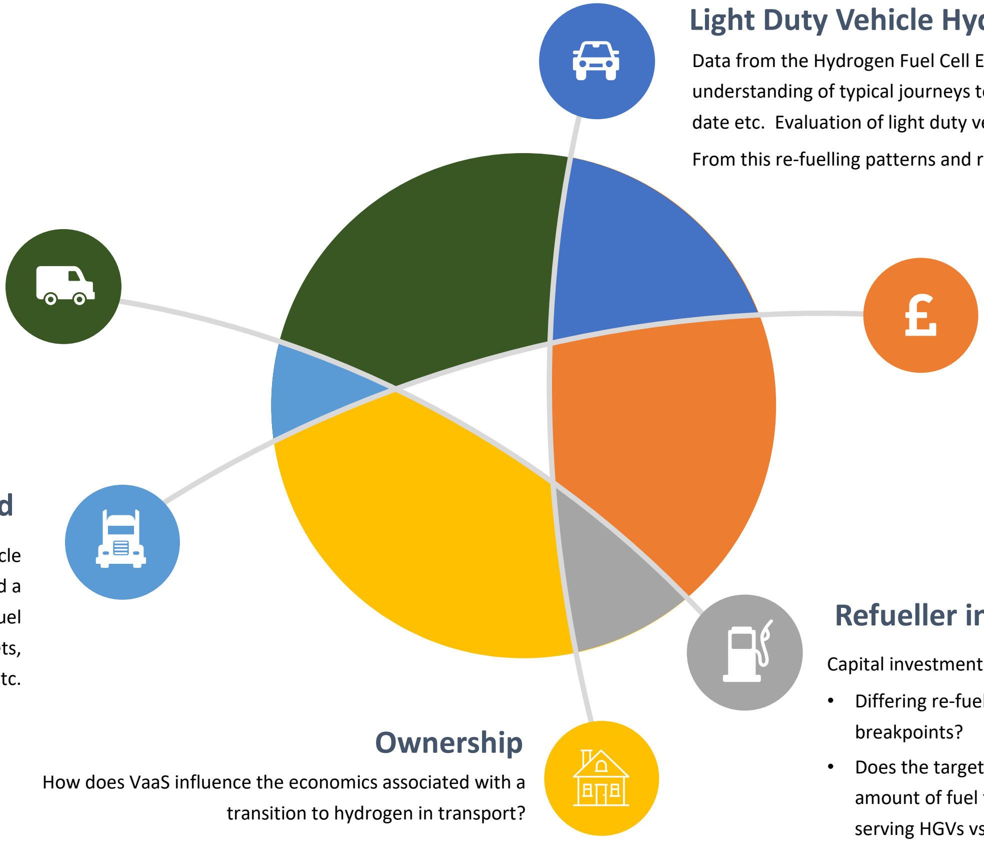
# Key Messages

# Modelling potential hydrogen demand and necessary investment

Hydrogen has a role to play across multiple vehicle sectors – all of which must be understood to enable a view of total demand, and hence the investment required to support H2 supply



### Fleet vehicle hydrogen demand

Fleet data is available from project partners and collaborators including Pembrokeshire County Council, Port of Milford Haven, the local health board and local utility companies. Data covers passenger vehicles, small vans and larger commercial vehicles for both commuting and business use cases.

### Wider hydrogen demand

The project has gathered wider vehicle demand data from the region to build a complete picture of potential fuel demand. This includes: commercial fleets, hauliers, taxi firms, hire firms, tourism etc.

### Ownership

How does VaaS influence the economics associated with a transition to hydrogen in transport?

(NOTE: Vehicle-as-a-Service – the application of Mobility as a Service (Maas) to single user applications)

### Light Duty Vehicle Hydrogen Demand

Data from the Hydrogen Fuel Cell Electric Vehicle/Rasa Demostration enables a detailed understanding of typical journeys to be developed: destination, duration, topography, time, date etc. Evaluation of light duty vehicle mix.

From this re-fuelling patterns and requirements can be estimated.

### Hydrogen supply and cost

Availability of low-cost electricity to support electrolysis. Usage in H2 vehicles vs BEVs Green hydrogen cost now, 2030 and 2050

- How does this cost forecast impact potential consumer demand? Comparison to current fossil fuels, and future PV alternatives.
- How much hydrogen will be available to support vehicles Is this enough to satisfy demand?

### Refueller investment

Capital investment for re-fueller for different demand cases.

- Differing re-fuelling capacities – what are the investment breakpoints?
- Does the target market have an impact – for example the amount of fuel that each re-fuelling activity involves. i.e. serving HGVs vs passenger vehicles

# Key messages – passenger vehicle market

## The passenger vehicle market is rapidly evolving

The uptake of zero emission passenger vehicles is rapidly increasing, in part supported by legislation. The UK Government has announced that sales of petrol and diesel vehicles will be outlawed from 2030, a situation mirrored across many global markets. In response, car-makers are releasing an expanding range of full battery electric vehicles to meet this demand, many OEMs committing to phasing out fossil fuels ahead of the government deadline. In 2021, full BEVs achieved a 10.6% market share for new vehicle sales, albeit in a total market that was 30% lower than normal due to Covid.

Whilst the headline sales of BEVs are encouraging, zero emission vehicles only make up 2% of the total vehicle parc across the UK, and only 0.6% in Pembrokeshire. The AA has forecast that by 2030, only 25% of the parc will be zero emission.

## Barriers to zero emission vehicle adoption

Several factors have been identified as barriers to the uptake of battery electric vehicles including:

- Lack of availability of public charging points (cited by 59% of respondents)
- The purchase price is higher than a petrol or diesel car (43%)
- The range of available models is limited (39%)
- No charging available at home (37%)
- No charging available at offices (36%)

A number of these can be addressed. The number of vehicles available continues to increase, although battery electric vehicles continue to have limitations in terms of range, payload and towing capacity (of relevance for commercial vehicles). Furthermore, the availability of publicly available charging points continues to improve, although from a low base – across Pembrokeshire there being only 13 rapid chargers (summer 2022).

## Cost and convenience are critical factors for passenger vehicles

Whilst battery costs are reducing, the purchase price of battery electric vehicles remains significantly higher than fossil-fuelled equivalents. Lower running costs for BEVs are cited; however, the annual total cost of ownership (TCO) for a small, 200 mile-range BEV is still ~50% higher than the UK's historically best-selling vehicle, the Ford Fiesta. To achieve the same 500 mile range as the Fiesta, a BEV's annual TCO would be 400%, driven by very high initial purchase price.

The TCO concern is further exacerbated for users who cannot home charge – estimated to be ~33% of UK households, a situation mirrored in Milford Haven. The cost of electricity from rapid chargers is between 250% and 350% higher than the UK average home electricity charge. Accessing rapid chargers is inconvenient in comparison to home-charging. This creates a further significant barrier to wide-scale adoption.

To achieve net zero by 2050 with 100% of the passenger vehicle parc being zero emission, affordability and convenience issues need to be resolved.

## A role for hydrogen in passenger vehicles

Hydrogen enables zero emission mobility with a similar customer experience to current fossil-fuelled vehicles, allowing for long-range and rapid refuelling. The vehicles also avoid the penalties for drivers who are unable to home charge.

## Application of technology is important

There are hydrogen-fuelled passenger vehicles already on the market. These have packaged hydrogen powertrains within a traditional vehicle architecture, necessitating high power and high-cost fuel cell stacks. The resulting vehicles are technologically advanced but currently expensive and do not address the affordability question. This currently limits demand, which in turn does not provide an incentive for investment into refuelling infrastructure.

## The Riversimple approach is different

The network electric architecture developed for the Rasa allows for a more efficient and cost effective powertrain. Through decoupling cruising and acceleration/hill climb demands and adopting a lightweight vehicle structure, the Rasa is able to use a significantly smaller and lower cost fuel cell system. The trials in the Milford Haven Energy Kingdom project aimed to validate both vehicle use and convenience, and vehicle efficiency to determine potential hydrogen demand.

# Key messages – anticipating demand

## Hydrogen demand from commercial vehicles

Hydrogen offers further opportunities as a fuel in mobility sectors where range and/or payload have commercial value. Of the ~102,000 vehicles registered in Pembrokeshire 73% are passenger vehicles, 3% motorcycles and the remaining 24% commercial vehicles - the largest proportion being light commercial vehicles (vans). It is worth noting that the best selling vehicle in the UK is not a car, but the Ford Transit (2021 data).

Vans and commercial vehicles in general are difficult to decarbonise economically. For full battery electric vehicles, increasing range increases battery weight and cost and reduces available payload. Time spent rapid charging is unproductive time. Hydrogen powertrains enable range to be added without a significant payload penalty, with refuelling times comparable to fossil fuels.

## Assessing total hydrogen demand in Milford Haven

The FCEV Rasa vehicle demonstration within the Milford Haven Energy Kingdom project has enabled an understanding of real-world hydrogen demand from a small passenger vehicle. The vehicle demonstration also allows customer feedback regarding vehicle use and utility which will inform design decisions for future vehicles with a similar powertrain.

## Methodology to assess potential demand in Milford Haven

Using data from the Department for Transport for vehicle registrations, from Transport for Wales for number of journeys and journey times, and from the vehicle demonstration (NHS, Port of Milford Haven and Pembrokeshire County Council), total passenger vehicle/van passenger miles per week can be simulated. Demographic and housing stock data for the Milford Haven area allows for an assessment of the proportion of households that cannot home charge a BEV and hence hydrogen would be the main zero emission alternative. The passenger vehicle/van simulation, combined with data for bus, heavy goods vehicles and other vehicles for which range and utilization rates are critical (for example blue-light services), enables a range of demand scenarios to be simulated. This approach results in a maximum demand case of ~1740 – 1920 kg/day for Milford Haven – the range corresponding to different passenger vehicle demand profiles.

## The critical issue is timing of H2 demand from vehicles

In the 2050 timescale, the scenarios simulated suggest that investment in infrastructure to deliver >1700kg of hydrogen per day, covering a range of vehicle applications, is justified - there being, for several customer segments and vehicle use cases, no alternative. The challenge relates to anticipating how the demand will evolve in the short-to-medium term.

## Hydrogen cost is a tipping point

Significant demand for hydrogen in passenger vehicles may be triggered once the running costs are equivalent or lower than that for a battery electric equivalent. This tipping point is strongly influenced by the efficiency of the vehicles themselves.

The average energy cost of a battery electric vehicle, is 5p per mile, based on the UK-wide average domestic electricity costs in 2021. For a customer who cannot home charge, the energy costs increase to 12.5p per mile. To achieve running cost parity, hydrogen costs for a Hyundai Nexo owner would need to reduce to £2.09/kg for a customer who could home charge a BEV, or £5.26/kg for a customer who could not (both based on real-world range).

The vehicle demonstration data for the Rasa shows that this tipping point could be achieved much sooner with the use of a lightweight and efficient vehicle architecture. In the vehicle demonstration the Rasa achieved 110 miles/kg of H2, less than planned due to motors and fuel cells running at less than quoted efficiency. Even under these conditions, to achieve cost parity with a BEV, hydrogen costs would need to achieve £5.48/kg for a customer who could home charge, £13.76/kg for a customer who could only rapid charge.

These calculations are based on 2021 electricity prices – if the increase in electricity costs seen in 2022 is maintained, and hydrogen costs can achieve £5/kg, then all FCEV passenger vehicles currently available become competitive with a home-charged BEV in terms of running cost.

# Key messages – infrastructure investment

## Tipping point for other vehicles

For vehicles other than passenger vehicles, the tipping point towards hydrogen is different and more closely associated with use case and convenience:

- The electrification of light commercial vehicles is currently constrained by limitations in terms of range and/or payload. Convenience is severely limited by the need for long recharging times during a working day. Hydrogen vans have the potential to offer similar convenience to diesel, with zero emissions. Sales of hydrogen vans are commencing in the UK in the short term.
- In rural areas where buses need to operate across longer ranges and at higher average speeds, hydrogen offers a path to zero emission public transportation. Operating costs for hydrogen buses are already competitive with diesel equivalents. Capital costs remain the main constraint towards wide-scale adoption, although with mass-production costs are expected to reduce significantly. Government policy and incentives will be important to seed this market.
- Heavy duty goods vehicles are considered a ‘difficult to electrify’ market for which fuel cells have already been identified as a suitable technology. Operating margins for haulage firms are tight, so current high capital costs for FCEVs are a barrier to adoption. There are several FCEV HGVs in development for mass production from 2025 with larger scale adoption expected from 2030.
- Other vehicle groups include emergency response vehicles, for which 24/7 availability is mandatory which, combined with high on-board power demands, make pure BEV vehicles unsuitable.

## Scalable investment

Given the challenges associated with anticipating the rate of change of demand, a scalable investment approach is sensible. Within the Milford Haven Energy Kingdom project, Fuel Cell Systems have supplied a refueller capable of delivering 2kg of hydrogen per day. This uses Enapter AEM electrolysers to produce hydrogen on-site. The system is modular, allowing for additional electrolysers to increase throughput in stages: 4kg, 10kg, 40kg per day being achievable. However, we can see from the demand analysis that full potential demand is many times higher than this, and practically one HGV would be enough to fully utilise a day’s supply – thereby removing the opportunity for other road-users to refuel. Furthermore, on-site electrolysis suffers from similar constraints to rapid/ultra-rapid battery electrical vehicle charging in that high voltage electricity supplies are required – a potential limitation in seeking a suitable location. However, there are expectations for significant reductions in the cost of electrolyser technologies which may offer a commercially viable solution in future.

There are established businesses offering a ‘hub and spoke’ approach whereby hydrogen can be delivered today at a cost of between £7/kg and £10/kg with a minimum daily demand of ~300kg/day. The hydrogen is delivered to site using the most economical hydrogen source available in the region. This demonstrates that it is possible to achieve the cost required to enable a transition to hydrogen today, at a scale that is aligned with potential demand. In this model green hydrogen costs are tied to local regional production costs – hence as larger scale (and cheaper) production comes on stream, costs offered to consumers will potentially reduce.

## Large scale projects in Pembrokeshire have the potential to meet transport demand

A recent proposal to Pembrokeshire County Council from a company looking to build out a 50 MW solar farm and 10 MW electrolyser has stated a likely green hydrogen sale price of £4.50/kg in 2026.

A larger scale proposal has also been put to the Council based on a 110 MW electrolyser in the Pembroke area, with a similar sale price for H2. This price is likely to come down substantially as major renewable electricity projects come on stream in the region and around the UK, in tandem with falling technology costs.

# What is Milford Haven: Energy Kingdom?

## Introduction to the Project

# Milford Haven Energy Kingdom

## Project Objectives

The objective of Milford Haven: Energy Kingdom was to establish seed markets for use of hydrogen around the Milford Haven Waterway, by integrating a wide range of major energy facilities, renewable energy generators and energy consumers in the community, using a systems architecture that can be implemented with commercial-ready solutions and which focusses on underlying fundamentals and is therefore robust in the face of regulatory change.

Design integration for a trading platform draws upon the system configuration developed via a novel approach to systems architecting, developing full technical, configuration, process and performance integration in the form of function specifications and associated information necessary for equipment and installation procurement.

Drawing upon UK and international precedent, the system was designed and detailed in compliance with UK technical standards, including necessary technical details to satisfy required safety and environmental strictures for the core system. This included renewable (green) hydrogen production, compressed hydrogen storage, HRS (hydrogen refuelling station) layout, vehicle refuelling location, local hydrogen reticulation and hybrid heat pump requirements.

The systems detailed design was provisioned to accommodate the small-scale data gathering pilot installations associated with two Rasa fuel cell light duty vehicles, as well as the heat pump and other domestic hydrogen appliance deployment in an unoccupied residential building (within a commercial building envelope on the Milford Haven Port Authority facility).

A novel fuel cell vehicle transport as a service model was user-tested.

Detailed feasibility design was also undertaken to determine the practical integration of a wide range of potential hydrogen energy assets, including power-to-gas injection, heavy duty port equipment, hydrogen use in local Milford Haven power plant and Pembroke CCGT, anaerobic digestion, decarbonised gas inclusion, offshore wind-derived green hydrogen provision, hydrogen repurposing potential at LNG facilities, large scale storage of hydrogen on existing hydrocarbon storage sites (e.g.: Puma) and potential anchor load hydrogen offtake at the Valero refinery site. The integration of these various facilities, including interconnecting gas networks, was evaluated and viability determined.

## Public Description of the Project

A national transition from natural gas to hydrogen is increasingly seen as a likely, perhaps necessary, component of full decarbonisation by 2050.  Large scale hydrogen markets may provide essential cross-vector system balancing and inter-seasonal energy storage for an energy system dominated by the UK's abundant renewables, especially high-capacity factor, offshore wind and marine resources. This gas to hydrogen transition can most effectively build out from the UK's critical natural gas infrastructure.

The Milford Haven Waterway is at the centre of nationally important energy infrastructure, with major energy-related investment underway, targeting efficiency and decarbonisation. Facilities include South Hook LNG terminal, Dragon LNG terminal, RWE's 2.2GW CCGT, and National Grid's NTS pipeline that connects the Milford Haven Waterway with other assets like Grain LNG terminal, in Kent, and St Fergus gas terminal, Aberdeenshire.

The Milford Haven Energy Kingdom Detailed Design project focussed on developing diverse, local seed markets to support the transition to hydrogen and renewables of the cluster of major energy infrastructure along the Milford Haven Waterway. This transition will occur via a mixture of pathways available locally -- meeting heating and transportation needs of local communities, including via fuel cell vehicles; creating transport solutions for Pembrokeshire's 4.2 million annual tourists; H2 production from curtailed onshore wind and solar generators; and improving off-take markets for offshore renewables in the South-Western Approaches, including the consented Pembrokeshire Demonstration Zone (PDZ).

Project partners Pembrokeshire County Council, Riversimple, Milford Haven Port Authority, Wales and West Utilities, and Offshore Renewable Energy Catapult, with assistance and support from Energy Systems Catapult, RWE, Western Power Distribution, Arup and Welsh Government Energy Services, have designed a local, renewables hydrogen energy system for the Milford Haven Waterway.

# Milford Haven Energy Kingdom

The Milford Haven Energy Kingdom Detailed Design project features a flexibility trading platform to lower costs for consumers using hydrogen-ready hybrid heat pumps and hydrogen fuel cell vehicles, and to help lift constraints on local development of solar, wind and offshore renewable power generation. A novel system architecture allows integration from national to local network levels, and future integration of major natural gas infrastructure and current and future large-scale hydrogen infrastructure.

The project will immediately build hydrogen-ready features and technologies into the Port's housing, commercial and renewables projects and will allow local people to test real-world hydrogen vehicles and home heating equipment.

For perspective, 50 MW renewable electricity generation and a 10 MW green hydrogen electrolyser would result in circa 4,000 kg H2/day. However, lower load factors (which would be the case for electrolysers connected directly to renewable generators) will require a larger electrolyser capacity to produce this quantity of fuel. An approximate hydrogen design requirement is 15 – 20 kg H2/day for a fuel cell bus. A fleet of 200 buses will therefore require approximately 3,000 – 4,000 kg H2/day.

## Extended Project Benefits

Milford Haven will generate export opportunities as technical and business models are replicated in the UK and abroad. This project will be replicable in any area with a heat and transport demand and will be most appropriate in areas meeting any of the following criteria:

- Poor electricity grid infrastructure – in areas where there is poor grid infrastructure (such as the west of Wales) hydrogen fueled transport and heating will reduce network loads, particularly as a shift occurs towards electric vehicles and heating;
- Rural areas – given that hydrogen powered vehicles have longer ranges compared with electric vehicles, similar systems may be appropriate for those living in rural parts of the county such as mid-Wales or the north of Scotland;
- Areas with high renewable energy resource – electrolysis of water to create hydrogen from renewable resources will be replicable in areas with high wind, solar or offshore resource, and
- Areas with the potential to import hydrogen.

## Project Partners

Pembrokeshire County Council

ARUP

CATAPULT Offshore Renewable Energy

CATAPULT Energy Systems

riversimple

WALES&WEST UTILITIES

GIG CYMRU NHS WALES | Bwrdd Iechyd Prifysgol Hywel Dda University Health Board

Port of Milford Haven

# Milford Haven Energy Kingdom – Work Packages

## WP5: Hydrogen Vehicle Demo and Service Design

The Milford Haven Energy Kingdom Project has been broken down into 11 distinct work packages.

This report falls within the scope of Work Package 5; Hydrogen vehicle demonstration and service design.

| Work Package | Organisation |
|---|---|
| **WP1: System architecture development** | CATAPULT Energy Systems |
| **WP2: Flexibility trading platform development** | CATAPULT Energy Systems<br>ARUP<br>Port of Milford Haven |
| **WP3: Major energy facilities design development** | ARUP<br>CATAPULT Offshore Renewable Energy<br>WALES&WEST UTILITIES |
| **WP4: Households & building loads design development** | ARUP<br>CATAPULT Offshore Renewable Energy<br>WALES&WEST UTILITIES |
| **WP5: Hydrogen vehicle demo and service design** | riversimple<br>Pembrokeshire County Council |
| **WP6: Hydrogen-ready heating demo** | Port of Milford Haven |
| **WP7: Commercial models** | ARUP<br>CATAPULT Offshore Renewable Energy |
| **WP8: Design integration** | ARUP<br>CATAPULT Energy Systems<br>WALES&WEST UTILITIES |
| **WP9: Finance & Investment** | Pembrokeshire County Council<br>CATAPULT Offshore Renewable Energy<br>ARUP |
| **WP10: Stakeholder engagement** | Pembrokeshire County Council<br>CATAPULT Offshore Renewable Energy<br>ARUP<br>CATAPULT Energy Systems |
| **WP11: Project management** | CATAPULT Offshore Renewable Energy |

# WP5 – Fuel Cell Electric Vehicle demonstration

## Introduction, work package scope and approach taken

# Milford Haven Energy Kingdom – FCEV Rasa vehicle demonstration goals

## Original objective of having cars in the project

At the start of the MHEK project, the objective of having vehicles within the overall project scope was defined as follows:

*Investible & scalable business model innovation is one of the core objectives of the PFER grant programme. Riversimple's vehicles are designed exclusively for a Vehicle-as-a-Service (VaaS) business model, in which the company pays for all fuel used by the vehicles for their lifetime.*

*The company's rollout strategy corresponds to local energy systems - catchment by catchment, around a single, centrally located refueller. It is anticipated that maximising the utilisation of each refueller by focusing on local mobility services for use within the catchment will provide infrastructure providers with the confidence to invest. We will be calculating the potential transport demand for H2 from locally tethered vehicles in the MH local areas which in turn feeds into the feasibility of supply of that quantity of hydrogen from locally generated sources and the cost.*

*The project will be also be developing the business case for publicly accessible refuellers, based on a combination of empirical data from real world usage of the Rasas and anticipated usage by other forms of vehicle extrapolated from current fleet usage patterns at Pembroke CC.*

*Interconnectivity of transport, heat, gas and electricity provides a more investible case for local hydrogen generation and storage than a single use case alone.*

*UK manufactured, head-turning H2 vehicles in use around the port of Milford Haven:*

- *demonstrating the potential of hydrogen as a transport fuel in the MH:EK locality*
- *inspiring end user demand in the MH:EK locality and beyond*

Through this report we will address these objectives.

Riversimple Rasa demonstrator vehicle at hydrogen refueller in Milford Haven

# Milford Haven Energy Kingdom – FCEV Rasa vehicle demonstration goals

## Outline of the demonstration

The FCEV Rasa vehicle demonstration activity has been broken down into the following specific tasks:

Task 5.1 – Vehicle build

Task 5.2 – Refueller installation

Task 5.3 – User testing

Task 5.4 – Use pattern and user experience analysis

Task 5.5 - Transport solutions design – includes port vehicles and public transport.

Deliverable – Demonstrator project report

Furthermore, the availability of demonstrator vehicles supports WP10 (Stakeholder Engagement), through community engagement and educational support, which will also be covered in this report.

Riversimple Rasa demonstrator vehicles at hydrogen refueller in Milford Haven

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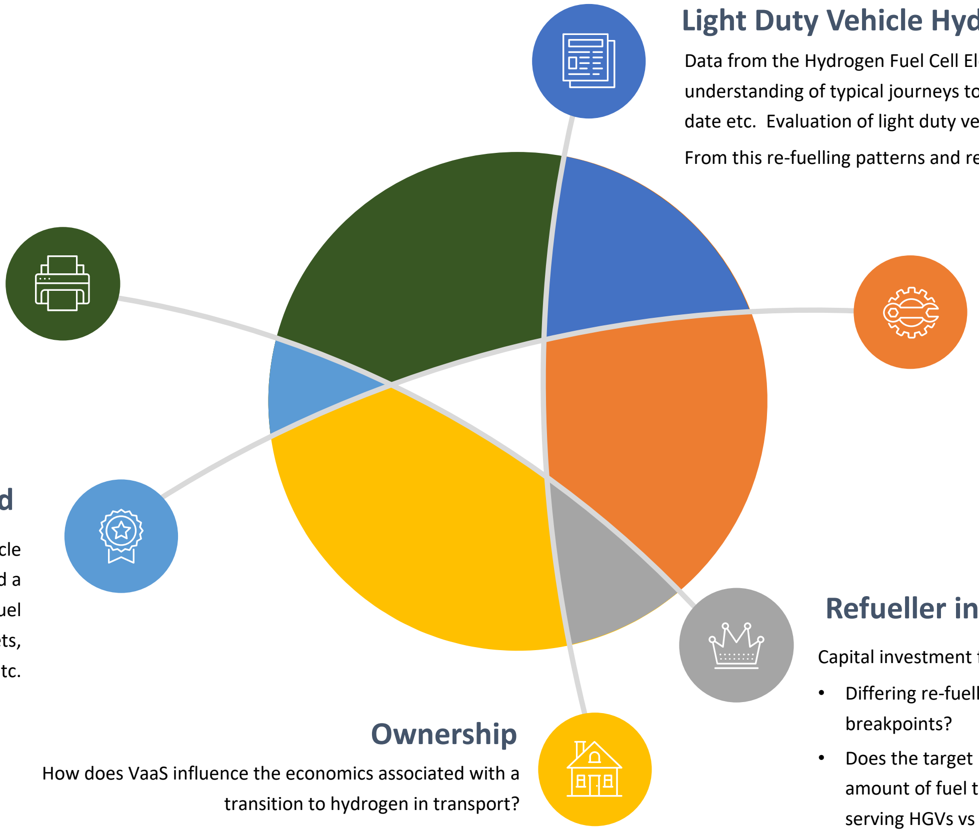

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Availability of low-cost electricity to support electrolysis. Usage in H2 vehicles vs BEVs  Green hydrogen cost now, 2030 and 2050

- How does this cost forecast impact potential consumer demand?  Comparison to current fossil fuels, and future PV alternatives.
- How much hydrogen will be available to support vehicles Is this enough to satisfy demand?
- To what degree does location drive H2 cost?

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Capital investment for re-fueller for different demand cases.

- Differing re-fuelling capacities – what are the investment breakpoints?
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How does VaaS influence the economics associated with a transition to hydrogen in transport?

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# 3 key questions covered in this report

## Potential hydrogen demand in Milford Haven area

Assessing potential demand for hydrogen at a publicly accessible refuelling station across the following mobility sectors:

- Privately owned passenger vehicles. Is there a role for hydrogen, given the strong push for battery electric vehicles? This review is supported by the vehicle trials underway as part of the MHEK project.
- Light commercial vehicles. Does hydrogen offer any compelling advantage to commercial users?
- Light vehicle fleets. Does hydrogen have a specific role to play vs battery electric vehicles?
- Buses. The advantages of hydrogen for buses in certain use cases/duty cycles has already been documented. How does this apply to Milford Haven?
- Heavy duty vehicles (trucks). These vehicles are ‘hard to decarbonise’ – what is the potential for hydrogen, and associated demand in Milford Haven?
- Other uses – is there a requirement from other sectors such as heavy duty off-highway (agriculture, forestry, quarrying, construction, mining) or marine?

Whilst all of these sectors have the the potential to transition to become hydrogen-fuelled, we will also consider which of these are the most significant in terms of supporting the business case for a publicly accessible refueller.

## Timing the shift to hydrogen – what are the tipping points?

UK Government legislation is providing a strong incentive for vehicle manufacturers to shift away from fossil fuels.

- To date. Introduction of purchase incentives for zero emission passenger vehicles and vans. Strong tax incentives for company car users to migrate to ZEVs.
- 1st April 2022. Removal of tax rebate on red diesel for the mining, quarrying and construction industries.
- 2030. End of sales of new conventional internal combustion engine passenger vehicles and vans (either petrol or diesel).
- 2032. End of sales of non-zero emission buses and mini-buses.
- 2035. End of sales of new hybrid passenger vehicles and vans
- 2035. End of sales of petrol or diesel trucks < 26 tonnes.
- 2040. End of sales of petrol or diesel heavy goods vehicles over 26 tonnes.

Each of these legislative changes, combined with shifts in technology will have an impact on the rate of the transition of the total vehicle parc from fossil fuels to zero emission, and hence the rate at which demand for hydrogen will evolve.

## Is there a case for a publicly assessable hydrogen refueller?

Does the potential demand for hydrogen, and the timing for that demand, enable an economic case for a publicly accessible hydrogen refueller to be developed?

To evaluate the economic case we need to understand the different technologies available to produce and deliver hydrogen, and the scale at which these are economic:

- Small scale, electrolyse on-site
- Medium-large scale, tanker supply
- Large scale, electrolyse on site.

*Do these technologies enable hydrogen to be sold at a cost which is attractive to potential customers, whilst delivering an acceptable payback on the investment?*

# Light duty hydrogen vehicles

## Assessing potential hydrogen demand

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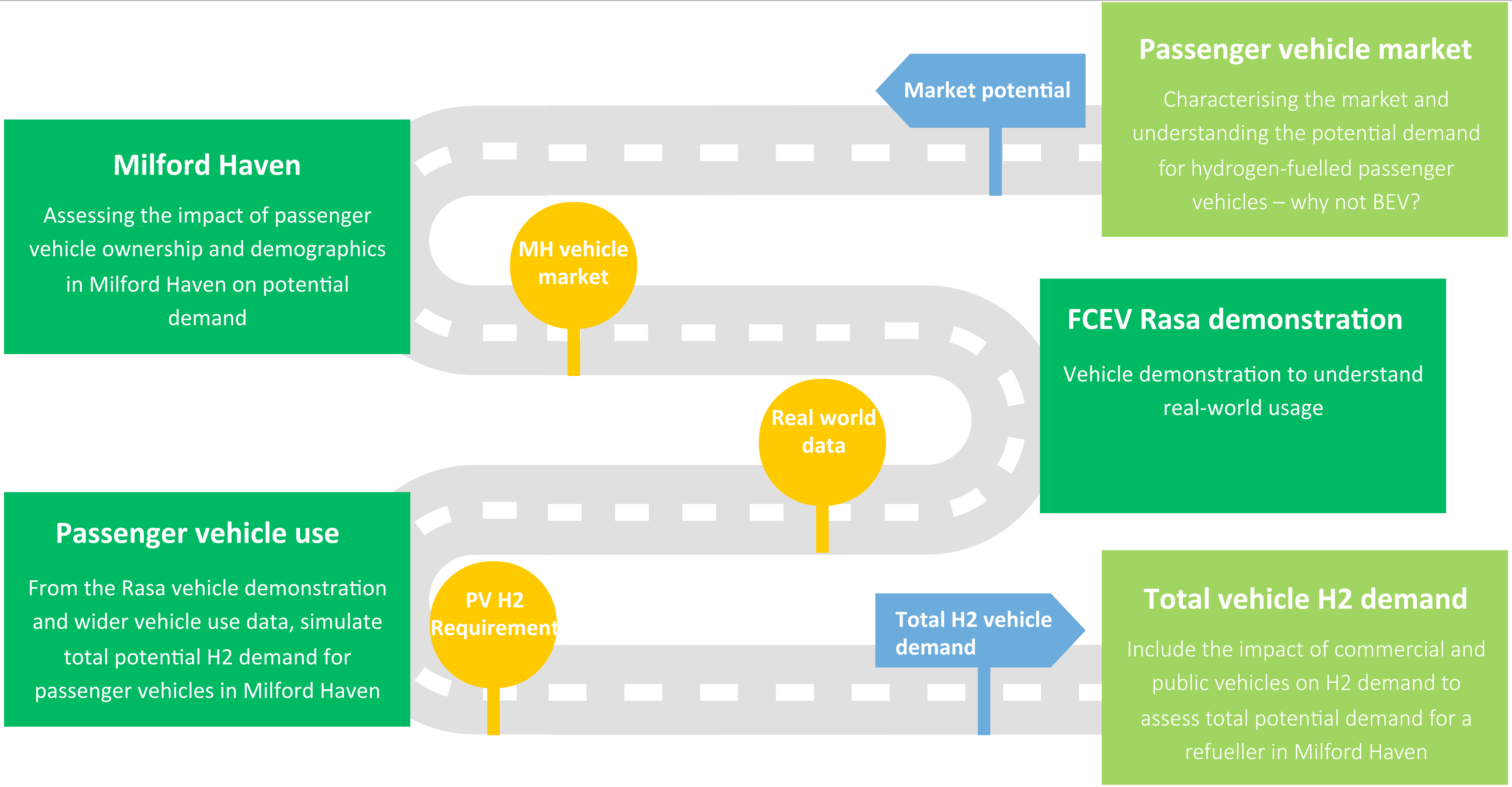
# Methodology – assessing potential demand for hydrogen in Milford Haven



**Milford Haven**

Assessing the impact of passenger vehicle ownership and demographics in Milford Haven on potential demand

**MH vehicle market**

**Market potential**

**Passenger vehicle market**

Characterising the market and understanding the potential demand for hydrogen-fuelled passenger vehicles – why not BEV?

**FCEV Rasa demonstration**

Vehicle demonstration to understand real-world usage

**Real world data**

**Passenger vehicle use**

From the Rasa vehicle demonstration and wider vehicle use data, simulate total potential H2 demand for passenger vehicles in Milford Haven

**PV H2 Requirement**

**Total H2 vehicle demand**

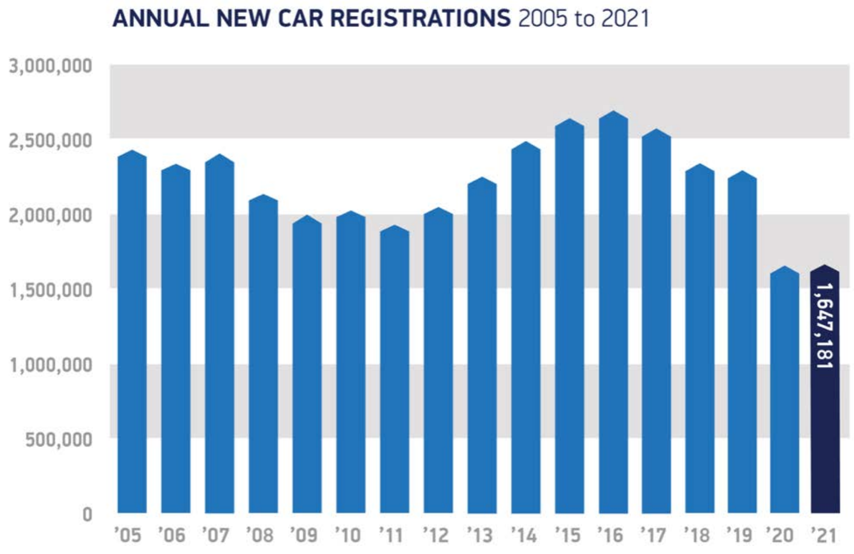
**Total vehicle H2 demand**

Include the impact of commercial and public vehicles on H2 demand to assess total potential demand for a refueller in Milford Haven

# New passenger vehicle sales across the UK

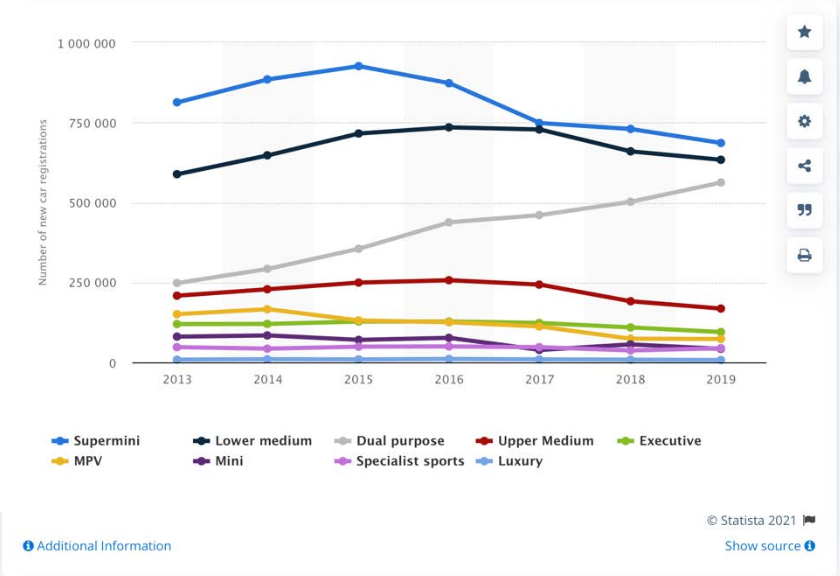
**Historically annual sales in excess of 2 million vehicles, dominated by 3 vehicle segments**

Within the UK, vehicle sales are dominated by vehicles within the B-segment (super-mini), C-segment (lower medium) and SUV (dual-purpose) segments. These B, C and SUV segments are represented by vehicles such as the Vauxhall Corsa, Volkswagen Golf and Nissan Qashqai – all within 'affordable' vehicle segments. Smaller, lighter vehicles in the B and C segments have been the slowest to fully electrify, since these segments are more price sensitive – the high cost of batteries acting as a barrier for vehicle manufacturers seeking to maintain profitability. The Tesla 3 was one of the best-selling vehicles in the UK in 2022, although the only BEV. This vehicle would be classified in the upper medium segment, as a premium vehicle.



SOURCE DATA: SMMT

## VEHICLE SALES BY SEGMENT – 2013 to 2019



SOURCE DATA: SMMT

## 2021 SALES

| Vehicle | No. of registrations |
|---|---|
| Vauxhall Corsa | 40914 |
| Tesla Model 3 | 34783 |
| Mini Hatch | 31792 |
| Mercedes Benz A Class | 30710 |
| Volkswagen Polo | 30634 |
| Volkswagen Golf | 30240 |
| Nissan Qashqai | 29920 |
| Ford Puma | 28697 |
| Kia Sportage | 27611 |
| Toyota Yaris | 27415 |

# What do we mean by Plug-in, Zero and Ultra-Low Emission passenger vehicles?

**There are multiple technologies currently available – not all being ZEV or ULEV**

As vehicle manufacturers have developed alternative powertrains to traditional petrol and diesel internal combustion engines, a large number of different solutions have been proposed.

The Venn diagram (from Department of Transport) shows the different electric vehicle types that are available. From 2030, traditional internal combustion engine vehicles will be outlawed for sale in the UK, limiting choice to those vehicles shown here – categorized from A to F.

In 2035, this restriction will extend such that only passenger vehicles categorized as ZEVs (category D and E) will be available for sale. In practical terms this means full battery electric vehicles (BEVs) and hydrogen fuel-cell vehicles (FCEVs).

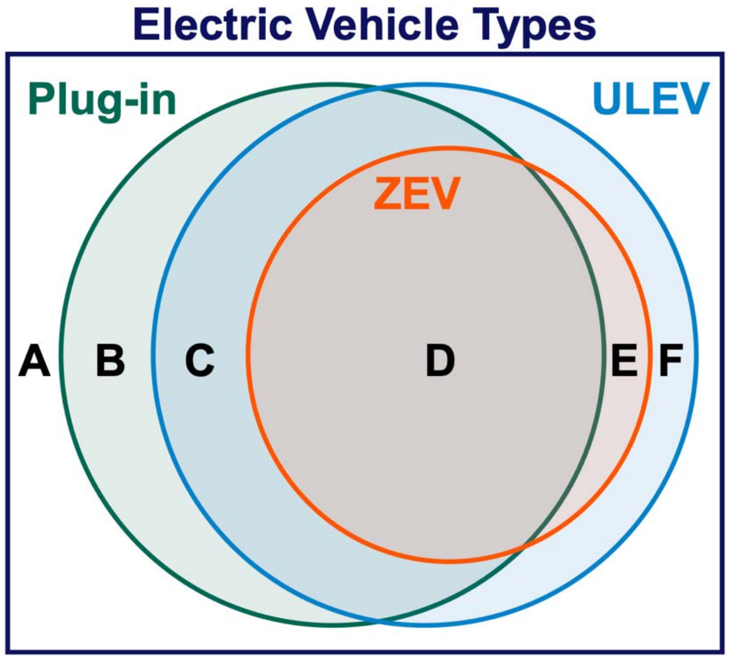


Chart courtesy of Department for Transport, Vehicle Licensing Statistics, 29th Sept 2021

**Key**

**A: Hybrid Electric Vehicles (HEVs) that are too high- emitting to count as ULEVs, e.g. Toyota Yaris HEV.**

**B: Plug-in Hybrid Electric Vehicles (PHEVs) that are too high-emitting to count as ULEVs, e.g. BMW X5 PHEV.**

**C: Plug-in Hybrid Electric Vehicles (PHEVs) and Range-Extended Electric Vehicles (R-EEVs), e.g. Mitsubishi Outlander PHEV and BMW I3S REX respectively.**

**D: Battery Electric Vehicles (BEVs), e.g. Tesla Model 3, Nissan Leaf, and Nissan e-NV200 (van).**

**E: Fuel Cell Electric Vehicles (FCEVs) that use hydrogen, e.g. Toyota Mirai, Hyundai Nexo or Riversimple Rasa.**

**F: Hybrid Electric Vehicles (HEVs) that are low-emitting, e.g. a series of Toyota Prius HEVs in 2016/17.**

# Zero and low emission passenger vehicle sales

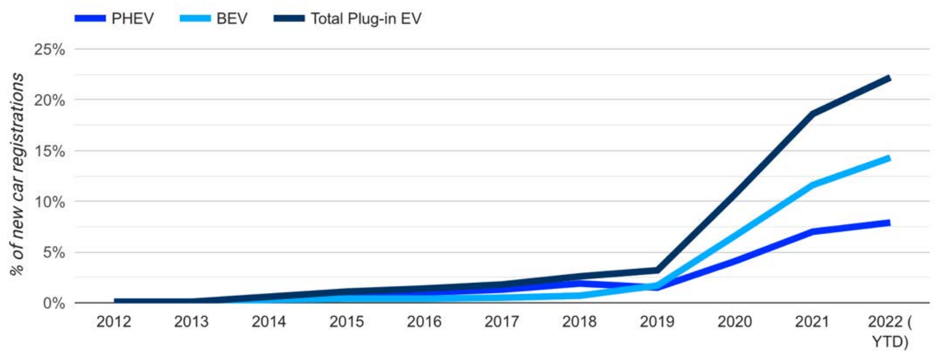
## Battery electric passenger vehicle sales are rapidly increasing

Across all segments the market for zero and low emission vehicles in the UK is rapidly increasing. The SMMT have reported that the UK's auto market saw the EV market share (both BEV and PHEV) for new vehicle sales reach 33.2% in December 2021, a significant increase vs the share of 23.4% in December 2020. Full battery electric vehicles saw a market share of 25.5%, a 50% increase in share, year-on-year. Conversely, diesel vehicles saw a significant decline from 11.9% (Dec 2020) to 4.8% (Nov 2021).

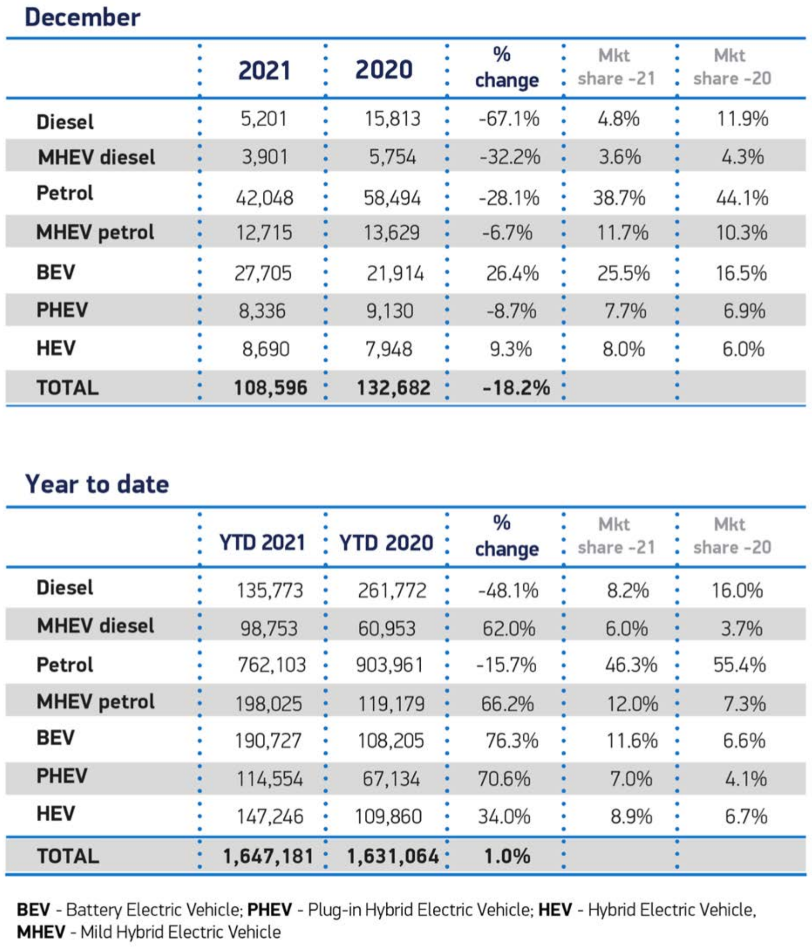
Evaluating 2021 data for January to November, BEVs have reached a market share of 11.6%, albeit in a total market that is approximately 30% lower than pre-pandemic levels.

When considering the potential demand for alternatives to fossil fuels (such as electricity or hydrogen), we need to look more widely at the total vehicle parc, rather than new vehicle sales.

Annual market share – plug-in market share of new car registrations (2012 to date)



Source: SMMT, OLEV, DfT Statistics. Updated: February 2022



**December**

| | 2021 | 2020 | % change | Mkt share -21 | Mkt share -20 |
|---|---|---|---|---|---|
| **Diesel** | 5,201 | 15,813 | -67.1% | 4.8% | 11.9% |
| **MHEV diesel** | 3,901 | 5,754 | -32.2% | 3.6% | 4.3% |
| **Petrol** | 42,048 | 58,494 | -28.1% | 38.7% | 44.1% |
| **MHEV petrol** | 12,715 | 13,629 | -6.7% | 11.7% | 10.3% |
| **BEV** | 27,705 | 21,914 | 26.4% | 25.5% | 16.5% |
| **PHEV** | 8,336 | 9,130 | -8.7% | 7.7% | 6.9% |
| **HEV** | 8,690 | 7,948 | 9.3% | 8.0% | 6.0% |
| **TOTAL** | **108,596** | **132,682** | **-18.2%** | | |

**Year to date**

| | YTD 2021 | YTD 2020 | % change | Mkt share -21 | Mkt share -20 |
|---|---|---|---|---|---|
| **Diesel** | 135,773 | 261,772 | -48.1% | 8.2% | 16.0% |
| **MHEV diesel** | 98,753 | 60,953 | 62.0% | 6.0% | 3.7% |
| **Petrol** | 762,103 | 903,961 | -15.7% | 46.3% | 55.4% |
| **MHEV petrol** | 198,025 | 119,179 | 66.2% | 12.0% | 7.3% |
| **BEV** | 190,727 | 108,205 | 76.3% | 11.6% | 6.6% |
| **PHEV** | 114,554 | 67,134 | 70.6% | 7.0% | 4.1% |
| **HEV** | 147,246 | 109,860 | 34.0% | 8.9% | 6.7% |
| **TOTAL** | **1,647,181** | **1,631,064** | **1.0%** | | |

**BEV** - Battery Electric Vehicle; **PHEV** - Plug-in Hybrid Electric Vehicle; **HEV** - Hybrid Electric Vehicle, **MHEV** - Mild Hybrid Electric Vehicle

Source: SMMT

# Evaluation of vehicles in use across the UK

In 2021 only 2% of the current vehicle parc across the UK is zero – emission.

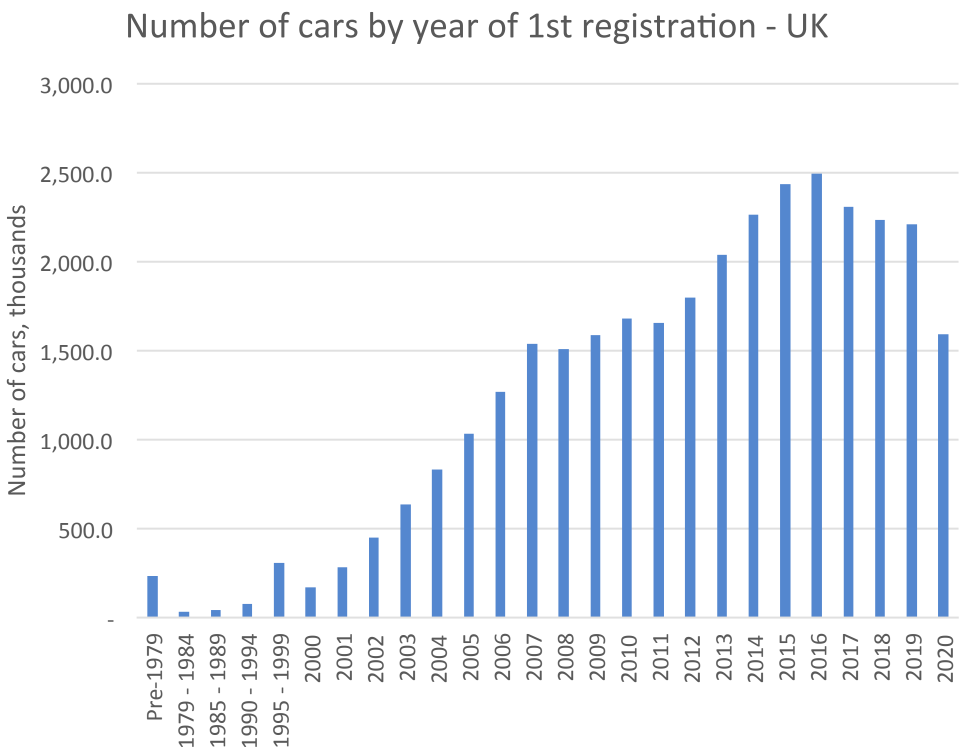
A significant gap remains to achieving net zero

**The vehicle parc remains predominantly internal combustion engine**

Data from the UK Government DVLA shows that there were 39.2 million vehicles registered in the UK in 2021 of which 32.03 million were cars, 4.37 million light goods vehicles, 501 thousand heavy goods vehicles, 1.385 million motorcycles and 140 thousand buses and coaches.

Ricardo evaluated that the average useful lifespan for a passenger vehicle on UK roads is 14.4 years and for a van 13.6 years. Whilst new sales of ULEVs are encouraging, the long life of current internal combustion engine vehicles means that the evolution towards full decarbonisation of personal transport will take some time. A new ICE vehicle purchased in 2022 would potentially still be on the roads in 2036 – long after new ICE and hybrid vehicles have been outlawed in the UK.

Whilst there has been a recent rapid increase in BEV sales, UK Department of Transport data shows only 564,694 ULEV vehicles registered in the UK at the end of Q2 2021. This means that zero and low emission vehicles represent less than 2% of the total vehicle parc. This shows that there is a massive and sustained increase in zero emission sales required to significantly reduce transport emissions.



Source: Department for Transport, Statistical Data Set, All Vehicles

# ULEV registrations in Wales

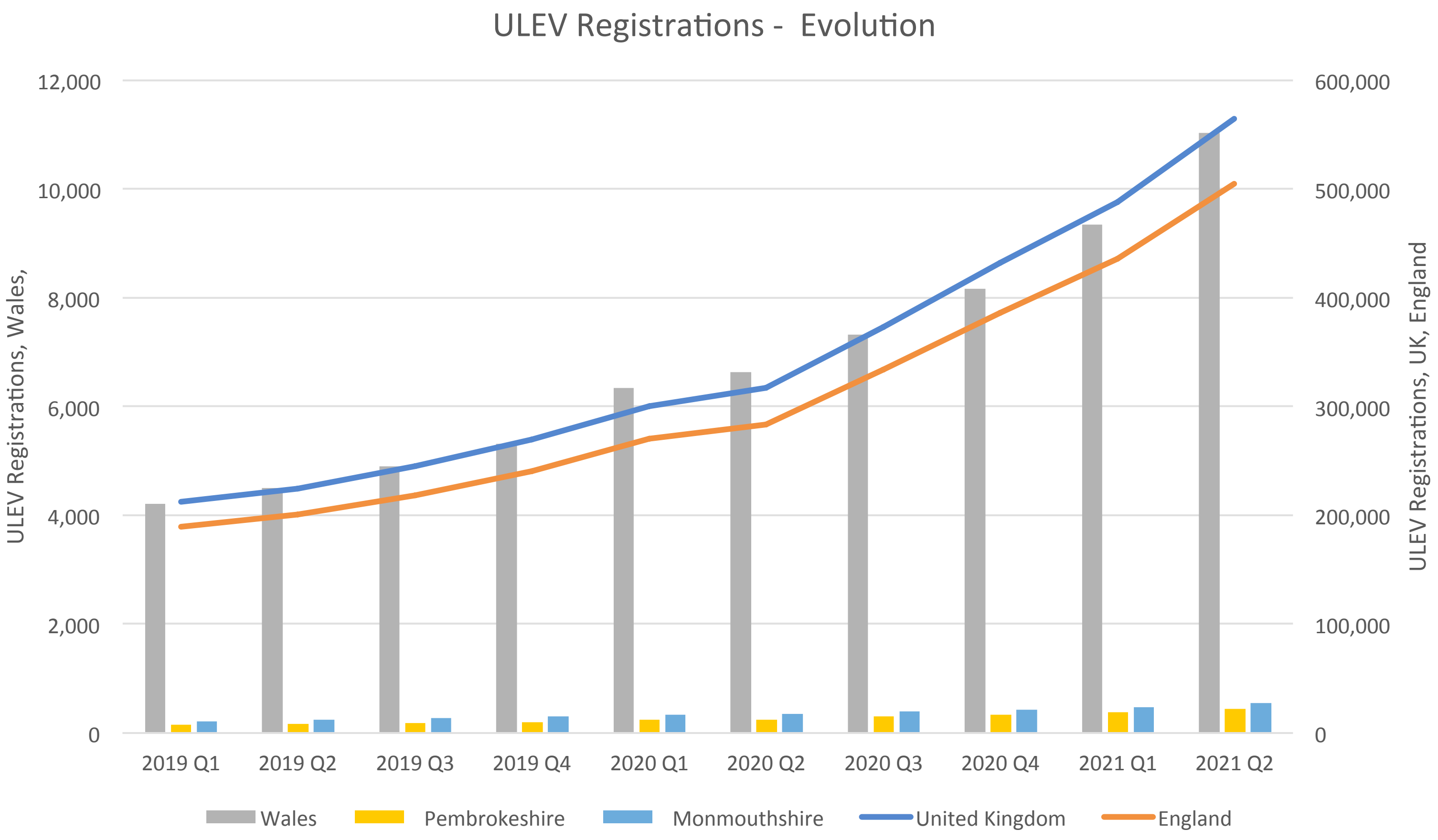
## Only 0.6% of the vehicle parc in Pembrokeshire is zero emission

**ULEV registrations in Pembrokeshire, Monmouthshire and Wales overall.**

The evolution of ULEV vehicle registrations in Wales has followed a similar trend to England and the United Kingdom.

With respect to the Milford Haven study, zero emission vehicle sales and ownership data is not available at the level of granularity to allow analysis at this level. However, data by local authority is available: at the end of Q2 2021 there were 445 ULEV passenger vehicles registered in Pembrokeshire out of a total of 74,846 passenger vehicles, or 0.6% of total passenger vehicle registrations. This is significantly less than the national average.

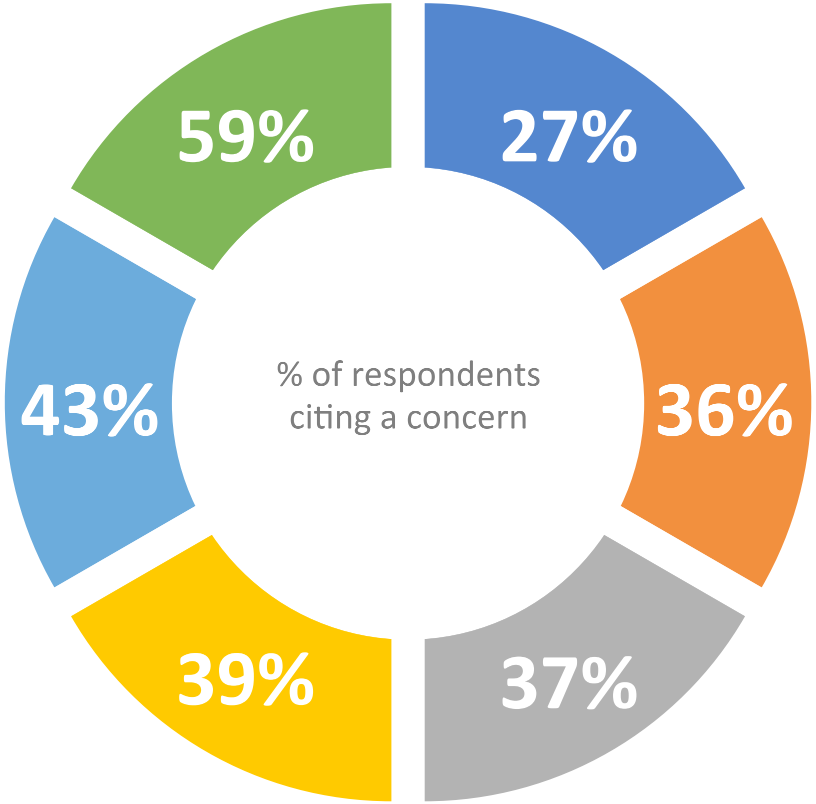
The potential reasons for the lower uptake of ULEV vehicles in Pembrokeshire vs the national average and implications for future hydrogen demand from passenger vehicles are explored later in this report.



Source: Department for Transport, Statistical Data Set, All Vehicles

# What are the barriers to BEV uptake nationally?

Research carried out in 2021 (Arval Mobility Observatory Barometer) has identified a number of factors restricting the uptake of battery electric vehicles, the predominant zero emission technology currently offered by vehicle manufacturers. Whilst range anxiety was historically raised as the primary barrier to adoption, this survey identifies a lack of public charging points and purchase price as the most significant factors. However, these are both a manifestation of range anxiety. BEVs with high range capability are now available, although at very high cost. A similar survey carried out by the RAC in 2021 concluded that customers expected a range of 375 miles to transition from ICE to BEV, although RAC black box data showed that the average UK journey in 2021 was actually 10 miles,. In the same survey, 78% of respondents stated that the upfront costs of an electric vehicle were too high compared to an ICE vehicle of a similar size. Similarly Strategy &'s 2021 Digital Auto Report 2021 concluded that range and charging options were the main barriers to BEV adoption in both Germany and the US.



**PUBLIC CHARGING POINTS**
Lack of availability of public charging points

**PURCHASE PRICE**
Purchase price higher than a petrol or diesel car

**MODEL RANGE**
Range of models available is limited

**RELIABILITY**
Question marks regarding reliability – unfamiliarity with technology

**WORKPLACE CHARGING**
No charging facilities available at work/ offices

**HOME CHARGING**
No charging facilities available at home

Source: Arval Mobility Observatory Barometer, 2021

# Barriers to BEV uptake – focus on fleet vehicles in Milford Haven

## Results from Fleet Manager interviews

The project included interviews with fleet managers across Milford Haven; both within project partner organisations (for example, Port of Milford Haven, Pembrokeshire County Council) and local utility companies. This enabled a more local view of the barriers to BEV uptake to be formed, the key characteristics being described below:

## Range Anxiety

Whilst the Arval survey did not identify range as a high priority barrier to uptake for BEVs for personal use, this was clearly a concern from the interviews with fleet managers where vehicle use was the primary consideration in deciding which vehicles were to be procured.

- Most fleet managers wanted a vehicle with a range of at least 200 miles.
- For the utility companies in particular, access to vehicles 24/7 was important – utility fleet vehicles can be on call 24/7, so having these vehicles out of action for long periods of time to re-charge is unacceptable. For one fleet the majority of cars are hybrids because the staff can be called out to business at night, so the vehicle cannot be left to charge overnight.
- Poor range in winter was cited by a number of respondents, including utility fleets, who need reliable vehicles all year round including when the weather is cold. This increased range anxiety amongst drivers who were wary of BEVs due to the potential to be stranded on a job.

## Work-place charging is important

Nearly all the fleets mentioned that the biggest limiting factor preventing them from having more BEVs was lack of infrastructure.

- In many cases the number of charging points is not yet good enough for most of the fleet to be fully battery electric. Several of the Fleet Managers suggested that the reason they do not have more BEVs in their fleet is because they do not have capacity to install more charging points, which they need to support more vehicles. In other cases, limitations were associated with the availability of parking spaces that could have a dedicated charger associated with them.
- At the time of interview, Hywel Dda University Health Board did not have any BEVs as part of their fleet because they didn't have the charging infrastructure in place.

## Home charging is sometimes the only solution

Several respondents who cited difficulties associated with work-place charging were advocates of supporting home charging, given that many of the fleet vehicles were parked overnight at home. In these cases there had been some consideration towards paying for the charging point at the home address. The utility companies went further, including home charging within their strategy and in one case providing a financial incentive for drivers to have charging points installed at home. Potential concerns were raised with this approach, however:

- Vehicles need to be relatively easily relocated when business needs change
- Difficult to manage if a driver leaves the company

These cases assume off-street parking to enable a home charger to be installed.

***Public electric charging points were described as being too unreliable for the fleets to use as they were often out of order. Most Fleet Managers gave the impression that it would be easier for them to procure more zero emission vehicles if they were to have a hydrogen refueler nearby (compared to installing another charging point). This is because they believe one hydrogen refueller can service more vehicles more quickly than installing a charging station.***

# Home charging availability

## Home charging availability - nationwide

The Arval survey reported that 37% of respondents cited lack of availability of home charging as a barrier to the use of a battery electric vehicle.

In England 48.4% of the housing stock is either terraced or a flat/ maisonette and 37.1% of the housing stock is rented, factors that may prevent a significant proportion of the population to have access to home charging for BEVs.   This is mirrored across the EU27 with an average of 42% living in flats.

Whilst the UK Government announcement that all new properties must from 2022 be built with home charging capability, this only benefits future builds.  The Government target for new builds is 300,000 properties per year, with actual new builds in the year to 2021 being 183,450 (of which ~81% were houses).

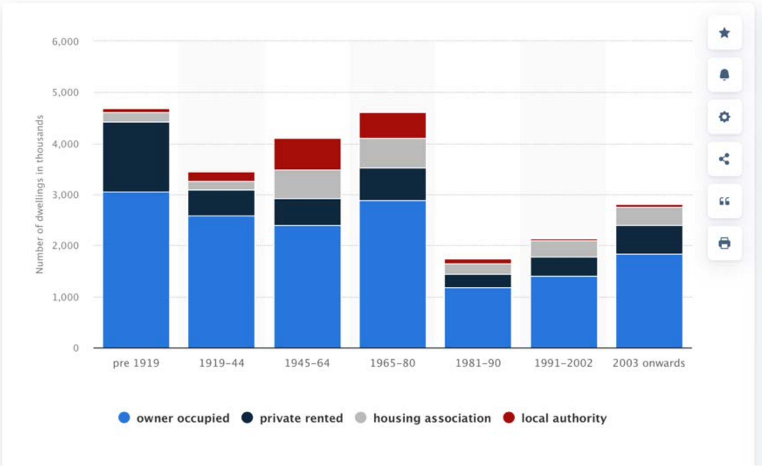
Data from March 2020 shows that there are 24.7 million residences within the UK, the majority of owner-occupied residences having been built pre-1919.

Whilst solutions for home charging for these difficult-to-reach properties have been proposed, such as under pavement cable routing, and lamp post-based solutions (see photo right), these are not a panacea, requiring significant public or private investment and often relying on the ability to park routinely outside a residence.

We can therefore conclude that for a significant proportion of the population lack of home charging will remain a barrier to BEV ownership long-term.

Age of dwellings in England in 2020, by tenure

*(in 1,000s)*



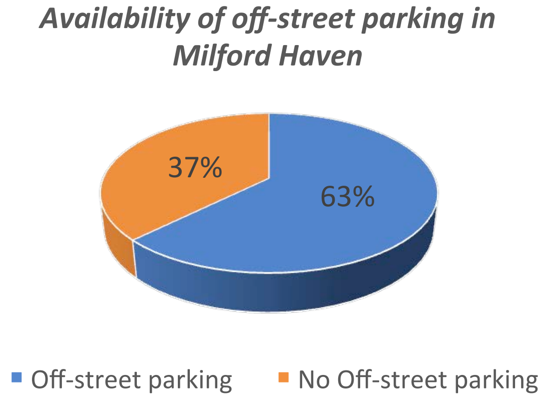
Source: United Kingdom (England); NatCen; Department for Communities and Local Government (UK); April 2020 to March 2021; 7,474 respondents

Roll-out of road-side EV charging solutions such as under pavement cable routing  and lamp-post charging do not offer a universal solution.

# Home charging availability – impact on Milford Haven

## Availability of home charging

A street-by-street analysis of Milford Haven reveals that ~37% of households do not have access to off-street parking facilities – very similar to the Arval feedback. Practically this acts as a barrier to the uptake of battery electric zero emission vehicles for those households.


*Availability of off-street parking in Milford Haven*

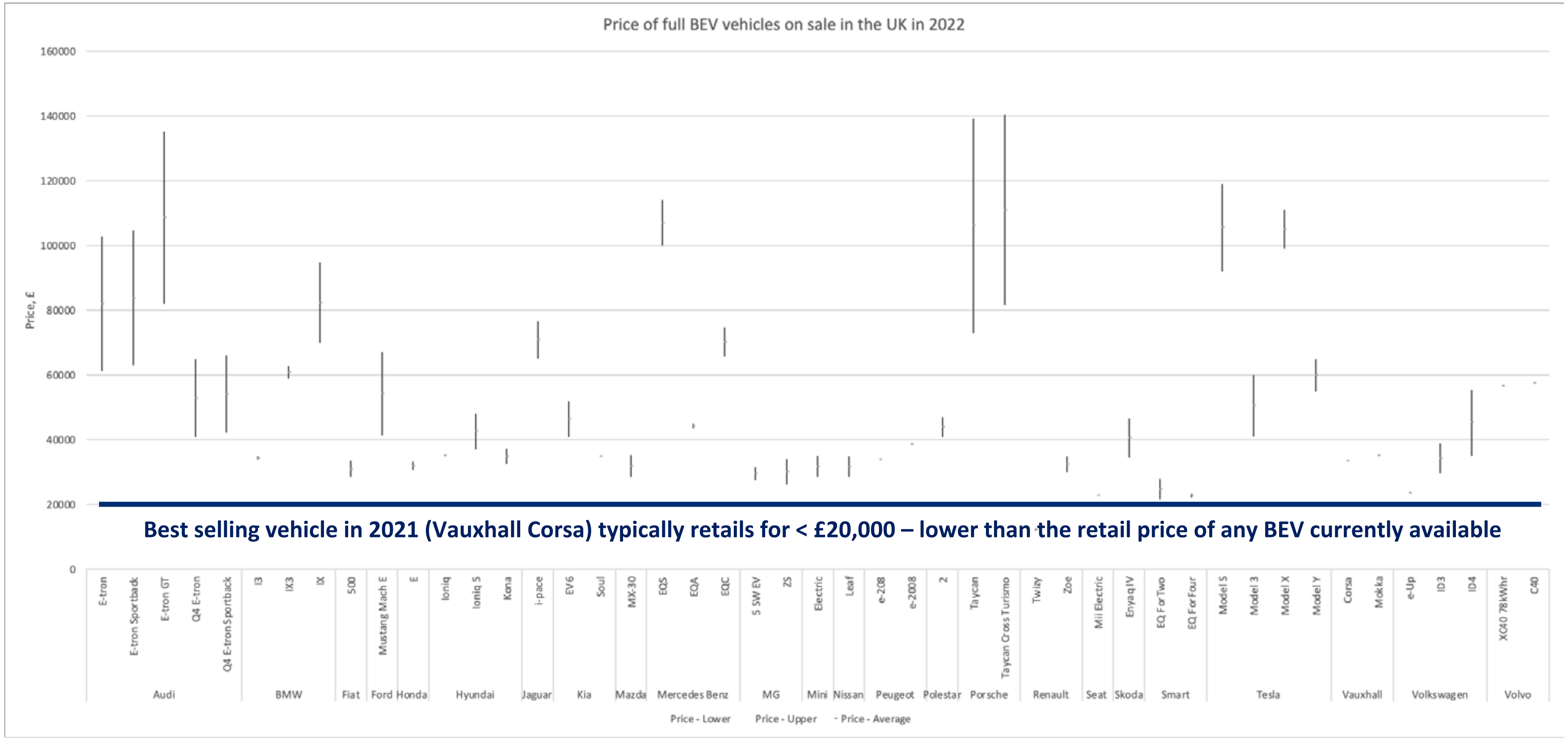
Source: housing survey carried out by Riversimple as part of MHEK WP5

# Model line-up and purchase price

## ULEV passenger vehicles are currently heavily skewed towards expensive models / brands.

The majority of recently introduced BEVs are in the upper-medium, executive and higher cost SUV segments – at a high price. There currently remains a lack of affordable BEV solutions that would allow for rapid uptake across all sectors of society.

There are expectations that battery costs will reduce over time allowing BEVs to more aggressively penetrate smaller vehicle segments. However, this is heavily dependent on raw material costs. An analysis of total cost of ownership of different ZEV solutions is covered later in this report.



**Best selling vehicle in 2021 (Vauxhall Corsa) typically retails for < £20,000 – lower than the retail price of any BEV currently available**

Source: Riversimple, retail price information for electric vehicles in the UK, March 2022

# Vehicle purchase price is impacting BEV demand

## Average BEV costs are significantly higher than ICE

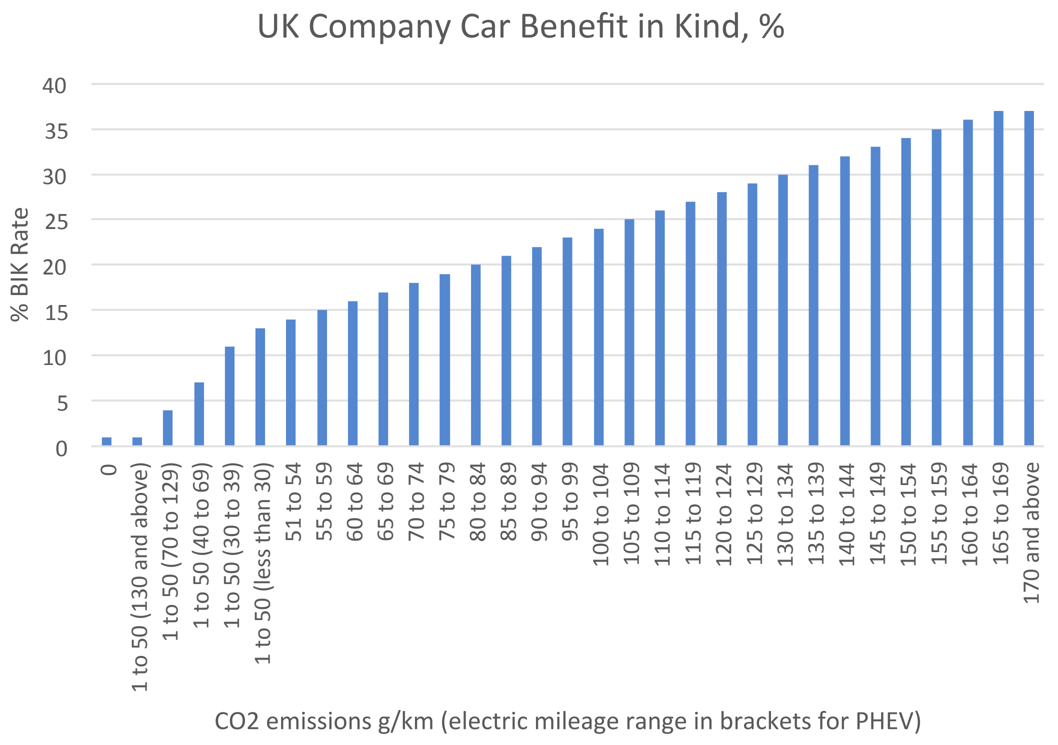
Vehicle OEMs have been introducing new BEV products to the market to the extent that there are now 24 brands with full BEV products on sale, with 47 models/nameplates. Limited model choice is arguably no longer a barrier to adoption (as per the Arval study). However, the majority of these vehicles are significantly more expensive than their ICE counterparts.

The typical price of an ICE vehicle in the B/C segments (both the largest selling new vehicle segments, and the largest proportion of the existing vehicle parc) is between £16k and £25k. This upper value is still lower than the cheapest full BEV – the entry price typically being around £29k. The average retail price of EVs currently on sale (measured in terms of a straight average across all name plates) is over £50k. A plug-in-car grant is currently available for retail customers, offering a £1,500 contribution towards vehicles whose recommended retail price is less than £32,000 (including VAT and delivery fees). (Note that the best-selling EV, Tesla 3 is not eligible for the UK Govt Plug-in Car Grant).

## Are BEV sales skewed towards company cars?

Of the 32.7 million cars on UK roads (2021 DVLA data), 2.7 million are company cars (8.2% of the total). BEVs and high range PHEVs have very attractive BIK rates for company car users – 1% for a full BEV regardless of purchase cost, which would suggest that BEVs have specific appeal to company car users. However, there is limited publicly available data to show the actual proportion of company cars that are zero emissions to validate this.

The high price of BEVs currently limits their adoption to relatively wealthy households, or company car users. In 2030 sales of pure diesel and petrol vehicles will be outlawed in the UK, followed by hybrids in 2035. Given the high price point of EVs and high running costs for households without access to home charging, how do we ensure ongoing freedom of personal mobility for all potential users?



Source: UK Government, HMRC. Correct as of March 2022

# Model range and purchase price – impact on Milford Haven

## Understanding vehicle expenditure as a proportion of household income

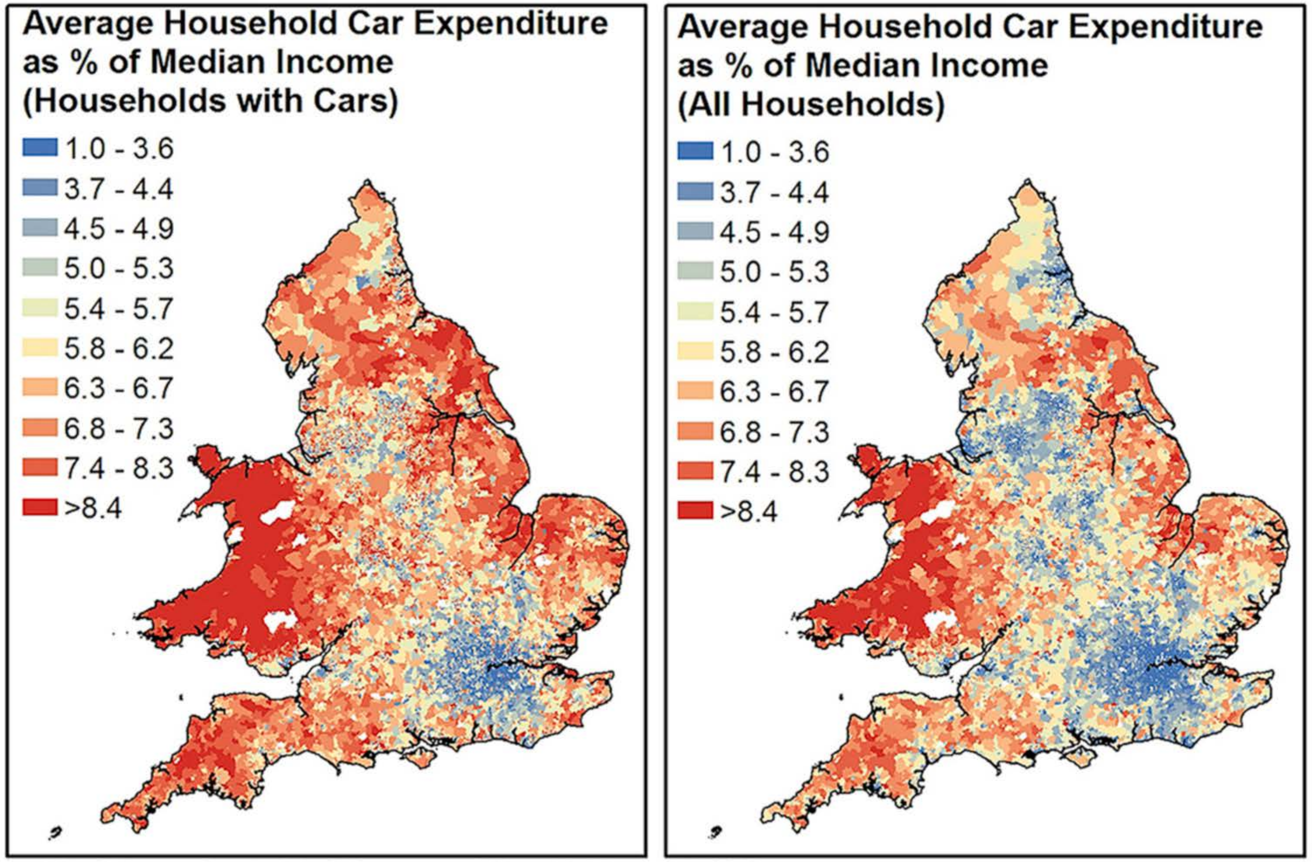
As reported earlier, 0.6% of the vehicle parc in the Pembrokeshire area is currently a ULEV vehicle vs an average of 2% across the UK.  There are 445 zero emission vehicles registered in Pembrokeshire compared to 12,857 in London and 48,527 in London and the South East (both Nov 2021 data).

As shown on the previous page the majority of recently introduced BEVs are sold at a high price.   There remains a lack of affordable BEV solutions that would allow for rapid uptake across all sectors of society.

Looking at the average household car expenditure as a % of median income it is clear that there is a wide disparity between households across the UK.  As an average, and remembering that internal combustion engine vehicles are on average 40% cheaper than zero emission equivalents, the percentage of household income spent on cars in London is under half that of the Pembrokeshire area (2012 data).

This is potentially one factor explaining the relatively low uptake of zero emission vehicles so far in the Pembrokeshire area,.  Another factor is availability of charging infrastructure, which we will explore next.

2020 data from the Office for National Statistics shows that average transport costs across the whole of the UK are 14% of total household expenditure, with those in full-time employment having to commit over 15% of their total expenditure to transport (vs 11% for those unemployed) – highlighting the importance of transport for employment.



Contains Ordnance Survey data © Crown copyright and database right 2012

Source: Transport Policy, July 2018

# Public charging infrastructure across the UK

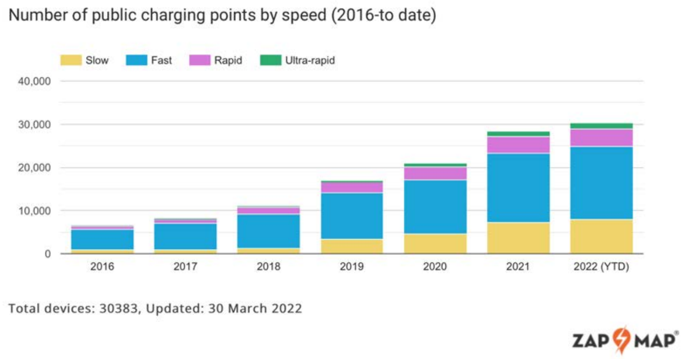
## Public charging infrastructure

Publicly available charging for BEVs is categorised in terms of charging power, and hence the speed at which a vehicle battery can be charged:

- 'Slow' chargers, operating at 3kW
- 'Fast' chargers, offering between 7kW and 22kW
- Rapid chargers, offering between 43kW and 50kW
- Ultra rapid charging offering between 100kW and 350kW

A 7kW public charging point provides up to 30 miles of range per hour of charge, whilst a 50kW charger would theoretically provide up to 180 miles of range in the same period.

Of the 30,383 charging devices now available in the UK, the majority are slow or fast chargers (source – ZapMap).



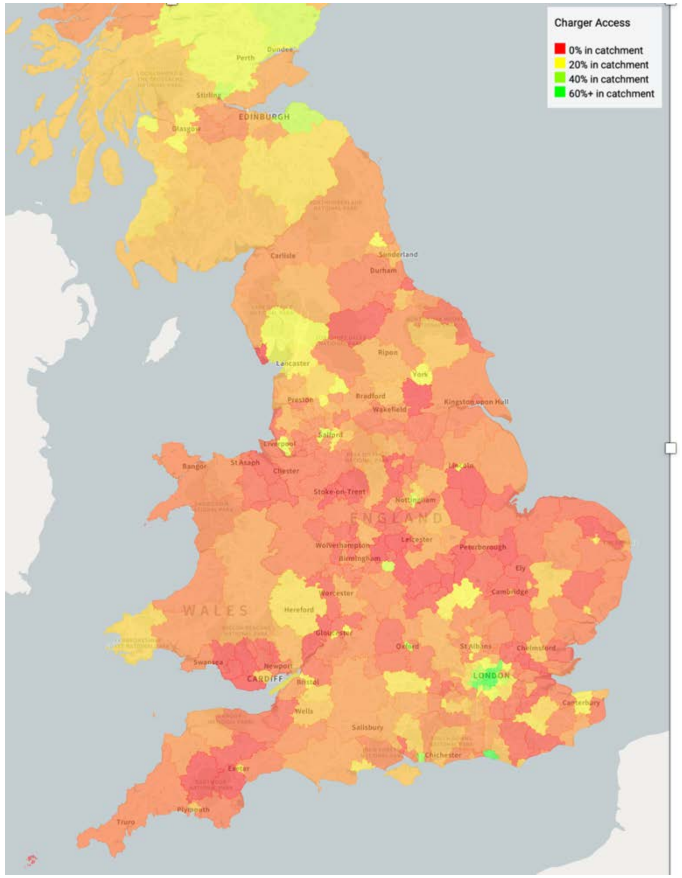
Source: Zap Map

## Rapid and ultra rapid charging availability

For those households for whom home charging is not an option, publicly accessible rapid and ultra-rapid charging is often quoted as the solution. However, this provision is currently patchy, unreliable, and expensive.

Zap Map have assessed the proportion of households without off-street parking, so-called 'on-street households' that are within a 5 minute walk of a public charger. As the map shows, there are very few locations across the UK where there is better than 40% coverage, with the large majority between 0% and 20%. Pembrokeshire (including Milford Haven) has a coverage rate of 20%.

This view does not fully represent the current difficulties associated with BEV charging, however. Of the 30,383 publicly accessible electric vehicle charging devices installed in the UK only 5,434 are rapid devices. Arguably, for an EV-owning household without access to home charging, only rapid charging is useful, since the charging time associated with non-rapid charge points is typically several hours, especially with large BEV batteries required to deliver usable driving ranges over 200 miles.

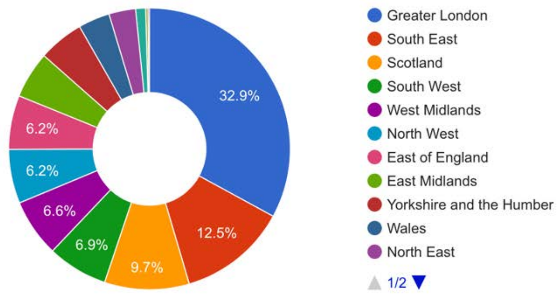


Source: Zap Map

# Public charging infrastructure – UK distribution

## Public charging infrastructure is unevenly distributed across the UK, with Wales lagging on all metrics

Distribution of UK charging points by geographical area



Total devices: 30383, Updated: 30 March 2022

Source: Zap Map

**Chart 3 Public charging devices per 100,000 of population by UK country and region** Table ECVD_01a

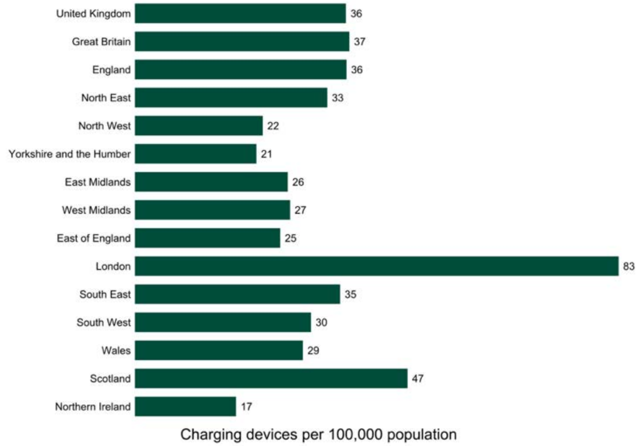
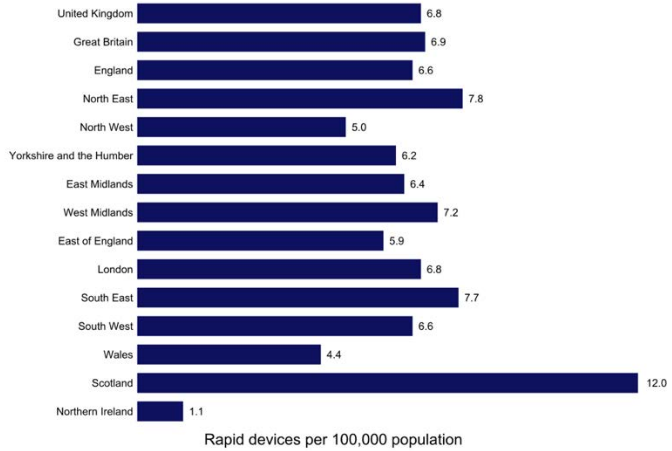


**Chart 4 Public rapid charging devices per 100,000 of population by UK country and region** Table ECVD_01b



### Public charging availability in Wales

The availability of public chargers in Wales is ~20% lower than the UK average and 65% lower than London.

### Rapid charging in Wales lags behind England and Scotland

The availability of rapid chargers in Wales is lower than the majority of the UK with 4.4 rapid chargers per 100,000 population (only Northern Ireland is worse).

Source: Department for Transport

# Rapid charging availability in Milford Haven

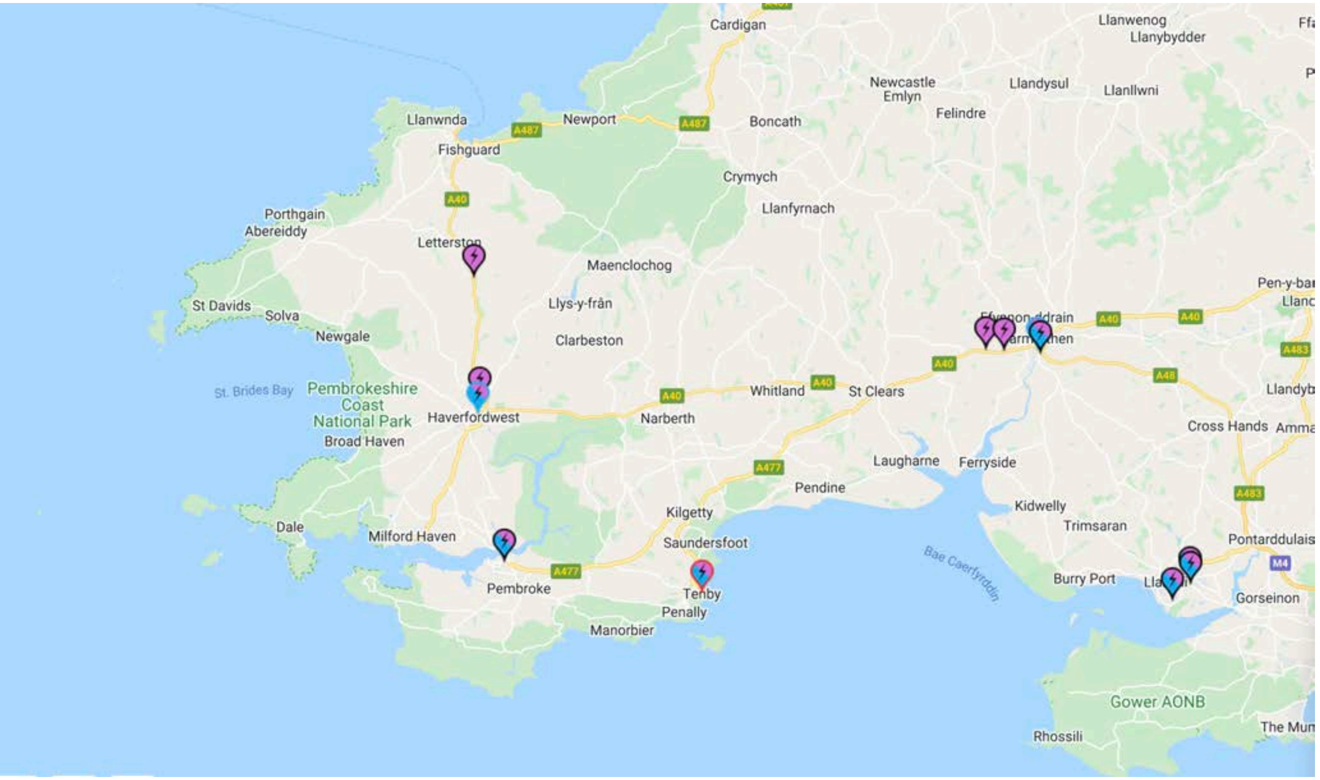
**Limited availability of rapid chargers is an impediment to electrification of the vehicle parc in Milford Haven**

As can be seen from the previous page, the availability of rapid chargers in Wales is lower than the majority of the UK with 4.4 rapid chargers per 100,000 population (only Northern Ireland is worse).

Within the Milford Haven region there are (as of end Q2 2021) 5 rapid chargers available, an average of 3.9 per 100,000 population. Even with an ultra-rapid 150kW charger it will take approximately 40 minutes to charge to 80% a 90kWhr battery (as fitted to many longer range EVs). This equates to a through put of 1.5 vehicles per hour, or ~20 per day per charger – hence only 100 vehicles per day for this local network. A 90kWhr battery allows for a range of approximately 250 miles – hence a vehicle covering a typical annual mileage would need to charge on average once per week If home charging was not available. The current Milford Haven area rapid charging infrastructure could serve a maximum of 700 BEVs (or approximately 4% of the local vehicle parc).

Since the majority of vehicle charging takes place at home, the total number of publicly available charging points does not need to cover 100% of the vehicle parc, being used on an intermittent basis. However, **the Society for Motor Manufacturers and Traders (SMMT) has still estimated that 507 publicly accessible charging points need to be installed every day across the UK between now and 2035 to keep up with potential demand.**

Within Pembrokeshire there is a plan to commission 13 new rapid chargers by mid summer 2022 on the Pembrokeshire CC/Pembrokeshire Coast National Park charging network. As a result there will be 16 rapid and circa 140 Fast (22 kW) chargers on the Pembrokeshire CC/Pembrokeshire Coast National Park network by mid-summer 2022. This infrastructure is required to not only serve local residents, but the influx of visitors to the Pembrokeshire region.



Source: Zap Map

# Rapid charging impact on affordability

**Affordability of rapid charging is a major impediment to BEV uptake for customers who cannot home charge**

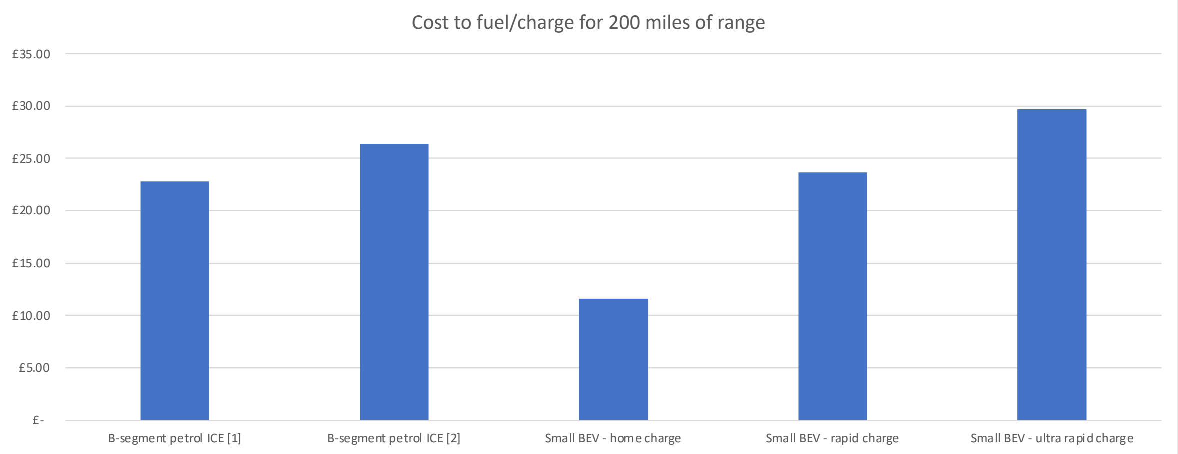
A reliance on rapid charging also has a significant impact on the affordability of BEVs. BEV owners who are able to charge at home benefit from domestic energy tariffs.

The 2021 average domestic electricity price in South Wales was 19.4p/kWhr (Source: BEIS), although this has increased on average by 18% in the 1st quarter of 2022. Rapid and ultra-rapid charging costs are significantly higher – in a typical range of £0.49 to £0.69 per kWhr. Pembrokeshire CC/Pembrokeshire Coast National Park currently charge £0.35 /kWh for rapid charging but this is set to increase due to recent electricity price rises.

Given the price premium for rapid charging it is unsurprising that 79% of BEV charging takes place at home, whilst as already discussed over 1/3 of UK properties have no off-street parking at night – of particular concern in towns and cities.

Practically, this means that households that do not have the opportunity to charge BEVs at home will pay a premium of between 175% and 400% for electricity for their vehicle – a major issue for affordability. In May 2022 the RAC reported that homeowners without a driveway or garage could expect to pay around £78 a month more than those that have access to a charger at home.

It should also be noted that for those with home charging, the My Electric Avenue research project showed that across Britain, 32% of local electricity networks (312,000 circuits) will require intervention when 40% – 70% of customers have EVs due to the increased demand. This study was based on clusters of Nissan Leaf customers with a 24kWh battery. With increased battery capacities, the outcome will be more severe. In the absence of network intervention, customers who could theoretically home charge may still be forced to use the rapid charging network.



Note:

B-segment petrol ICE – Vauxhall Corsa (best selling car in UK in 2021)

Small BEV – Vauxhall Corsa-e

[1] – 2021 average petrol cost

[2] – 2022 average petrol cost

Home electric cost: £0.27/kWhr

Rapid charge costs based on Shell Recharge Rapid charging network:£0.55/kWhr

Ultra-rapid costs based on Ionity charging network (noting that Corsa-e can only charge at 100kW): £0.69/kWhr

# The Importance of maintaining personal mobility

## Minimising inequalities in mobility

In March 2019, the UK Government Office for Science published the report "Inequalities in Mobility and Access in the UK Transport System". This study evaluated the impact of inequalities in terms of different access to mobility, differences in travel across different social groups, and potential inequalities as a result of the future mobility landscape.

Quoting the conclusions of this report:

"The report demonstrates that mobility and accessibility inequalities are highly correlated with social disadvantage. This means that some social groups are more at risk from mobility and accessibility inequalities than others:

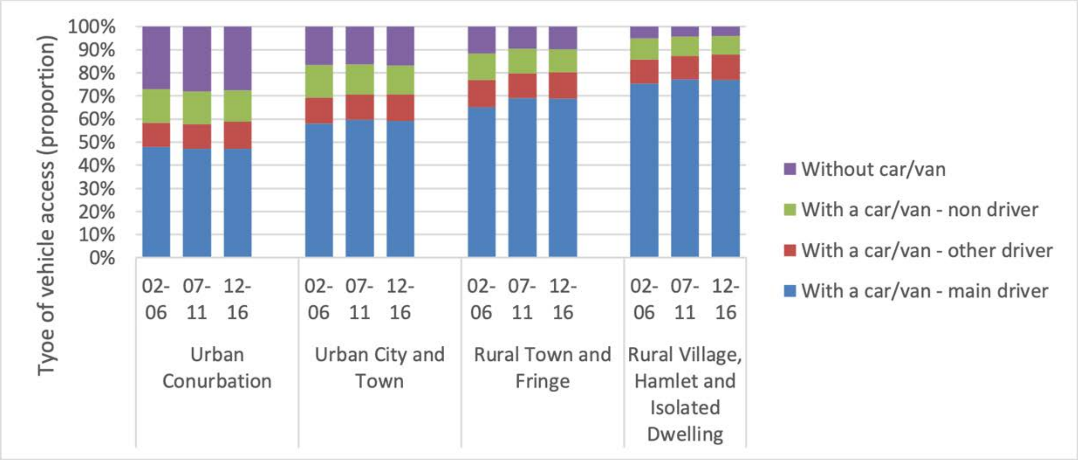
- Car owners and main drivers in households are least mobility constrained across all social groups. They make more trips over longer distance for all journey purposes giving them higher levels of access to activity opportunities;
- Lowest income households have higher levels of non-car ownership, 40% still have no car access – female heads of house, children, young and older people, black and minority ethnic (BME) and disabled people are concentrated in this group;
- In addition, there are considerable affordability issues with car ownership for many low-income households."

The report also highlights the disparity between rural and urban locations, a lack of public transport options in rural and rural town/fringe driving the need for higher levels of car ownership.

## Specific concerns relating to electric and hybrid vehicles.

The report makes very specific observations regarding the impact of electric and hybrid vehicles, reflecting some of the issues already raised in this report:

- The policy focus on EV technology to reduce emissions may exacerbate concerns regarding affordability of private transport.
- Although the cost of electric vehicles may achieve parity with conventional petrol and diesel cars, low income households may still be unable to afford them. Many households in the UK opt to buy cheaper, second hand vehicles.
- Potentially limited access to charging stations for those that do not have off-road parking and for people living in houses unsuitable for plug-in cars (Mullen and Marsden, 2016)



# Summary – barriers to BEV adoption in Milford Haven

## Returning to the key barriers to EV adoption

In summary, considering in turn the barriers to EV adoption discussed earlier, in particular those of relevance to Milford Haven.

| | |
|---|---|
| **AFFORDABILITY** | Data shows that the proportion of household expenditure allocated to mobility is several times higher in Wales (including Pembrokeshire) than more urban parts of the UK. Affordability of transportation is critical, and given that the area is predominantly rural, in reality this means transportation by car. Whilst BEVs are gaining in popularity, cost is a major barrier to adoption, with few BEVs costing less than £30,000, and most longer range BEVs being in excess of £40,000. Without major cost/ price reductions there is a likelihood that customers will resist transitioning to zero emission mobility and may ultimately lose access to personal transportation. |
| **VEHICLE RANGE and CONVENIENCE** | Fleet managers interviewed raised the specific issue of range requirements, especially in the case of light commercial vehicles, and given that the vehicle is a working tool the need to be able to re-fuel quickly and conveniently, something that is currently difficult to achieve for BEVs. |
| **PRIVATE CHARGING** | Over 1/3 of households in the Milford Haven area do not have access to off-street parking – a barrier to installation of home-charging capabilities. This is similar to the UK as a whole. For these households, charging a BEV is typically limited to public charging infrastructure. In addition to a lack of availability of public chargers, those that are available are typically much higher cost than charging at home. This reinforces the affordability barrier against BEV adoption for lower income households. |
| **PUBLIC CHARGING** | The number of rapid chargers in Wales is currently significantly lower than the UK average. Plans are in place to increase the number of public rapid and fast charging points across Pembrokeshire to 16 and 140 respectively by the summer of 2022, however, these are required to service both residents and visitors. |

# Light duty hydrogen vehicles

An alternative to BEVs

MH2
ENERGY KINGDOM
DEYRNAS YNNI

# Alternatives to BEV passenger vehicles - hydrogen

## A reminder of the challenges

Electric powertrain architectures are typically designed to fit within a traditional vehicle layout: in-board motors, reduction gears and power electronics replacing the ICE, with batteries packaged to utilise the space vacated by fuel and exhaust systems. Electrification within these traditional architectures, ICE design and manufacturing paradigms requires high-power and high-power density drivetrains. Whilst battery costs have reduced owing to advances in cell technology, recent commodity price increases have negated some are these benefits and batteries still constitute a significant proportion of the cost (and weight) of BEVs. As a consequence, price sensitive market segments such as city cars and small vans are currently served by BEVs with very limited range. Long term, a significant increase in demand for battery raw materials combined with supply constraints is likely to maintain upward pressure on costs.

As already discussed, market acceptance of small ZEVs is further constrained as 79% of BEV charging takes place at home whilst over 1/3 of UK properties have no off-street parking at night – of particular concern in cities. Home charging is further complicated as large batteries are required for a comparable range to ICE vehicles which take a considerable time to charge (e.g. 90kWhr battery takes 13hrs to charge on a home wall-box).

## Light commercial vehicles are a particular concern

The cost vs weight vs range paradox is particularly acute for small van applications. Whilst BEV vans exist with comparable payloads to ICE variants, currently range is compromised. A significant increase in range through adoption of a larger battery, to meet retailer requirements, will have a major impact on available payload - a 64kWhr battery weighs ~450kg.

## A role for fuel cell electric vehicles

FCEVs have a complementary role to play and most established OEMs see hydrogen fuel as the long-term goal, since they provide a similar customer experience to the current ICE offer and address the proportion of the market for whom home charging of BEVs is not an option.

However, sales of FCEVs have so far been limited: established vehicle OEMs are heavily invested in fixed assets to deliver traditional vehicle architectures sold through a franchised dealer network - a system currently optimised around ICE. Furthermore, traditional steel/aluminium body-in-white structures necessitate a high power/high power density fuel-cell system to deliver adequate performance. The current high cost of this system and sale-of-product business model necessitates a high retail price, comparable to BEVs with a similar range. FCEVs currently on sale such as the Toyota Mirai and Hyundai Nexo are in larger, ‘premium’ vehicle segments.

High vehicle cost combined with a lack of refuelling infrastructure is currently limiting sales volume potential in the UK. H2 infrastructure suppliers have indicated a strong willingness to invest in fuel supply but vehicle volume is necessary – a ’chicken-and-egg’ situation similar to the initial challenges associated with BEVs and availability of rapid chargers. The final section of this report will explore infrastructure options in more detail.

Whilst FCEVs can address refuelling convenience and range concerns for households hesitant to move away from ICE, the current high cost of fuel cell electric vehicles does not address issues of affordability, and the need to minimize inequalities in mobility as already described.

*To address this concern a different approach to zero emission mobility is required*

Hyundai Nexo FCEV ( available in UK 2022)

# FCEV Rasa vehicle demonstrator

*A different approach: through designing from the outset for Vehicle-as-a-Service, total life costs are more important than build cost.  Efficiency, durability and circularity improve profitability.*

*The interests of the manufacturer, the user and the planet are aligned.*

# Riversimple Rasa – designing for Vehicle-as-a-Service (VaaS)

## A shift towards mobility services

The consequence of using traditional architectures for FCEVs, rather than aligning with the characteristics of fuel cells, is profound. Fuel cell power density is markedly lower than that of an ICE, inevitably leading to the requirement for large capacity, high cost, high pressure fuel cells of lower efficiency. This in turn requires a large capacity storage tank to deliver competitive range, necessitating the need for a large and heavy vehicle, compounding the need for a large capacity fuel cell stacks. As a consequence FCEVs are currently only offered in premium segments.

A focus on traditional vehicle architectures for FCEVs also severely limits the flexibility of manufacturing processes and importantly the creativity to deliver new, innovative and cost-effective vehicle designs more closely aligned to emerging customer needs for local and urban journeys. The consultancy , Strategy&, predict that 'shared-active' (rental, subscription) services will grow strongest in Europe achieving 10% of total person kilometers by 2025.

To address this issue necessitates a clean slate approach to both the vehicle architecture and the business model.

## A fundamental shift in vehicle architecture

A focus on lightweight vehicle architectures and mass-decompounding creates a virtuous circle for lower power, lower power density, increased efficiency, increased range and thereafter cost effectiveness.

The powertrain architecture in the Rasa decouples constant and transient demands - super-capacitors supporting acceleration/ hill climb demands combined with a small scale and light-weight fuel-cell system sized for constant speed operation. This further reduces power and power density need and matches powertrain design to duty cycle requirements rather than peak performance. Range is comparable to ICE without the cost of a heavy battery pack.

A lightweight vehicle and powertrain architecture furthermore enables the application of an air-cooled hub-motor traction system, which further reduces weight through elimination of drive/transmission components, whilst increasing flexibility of vehicle design solutions. Since the hub-motor can be low power (15kW max per wheel – 60kW total, providing a highly competitive power output for vehicles in these segments) in this application, it enables the system to achieve a small package size, integrating the brakes, whilst minimising cooling requirements. Air-cooling removes significant complexity, weight and cost and allows for manufacturing in high volumes

## Designing for VaaS

The issue of affordability of zero emission mobility solutions has already been raised.

Through designing the vehicle architecture for maximum efficiency and minimum total-cost-of-ownership (TCO) it is possible to align to the needs of future customers such as car-sharing services for whom cost of use is more important than initial purchase cost. Indeed, in a VaaS business model pricing is not based on build cost but lifetime cost and the shift to a comprehensive circular business model provides further TCO benefits through maximising value recovery at the end of life.

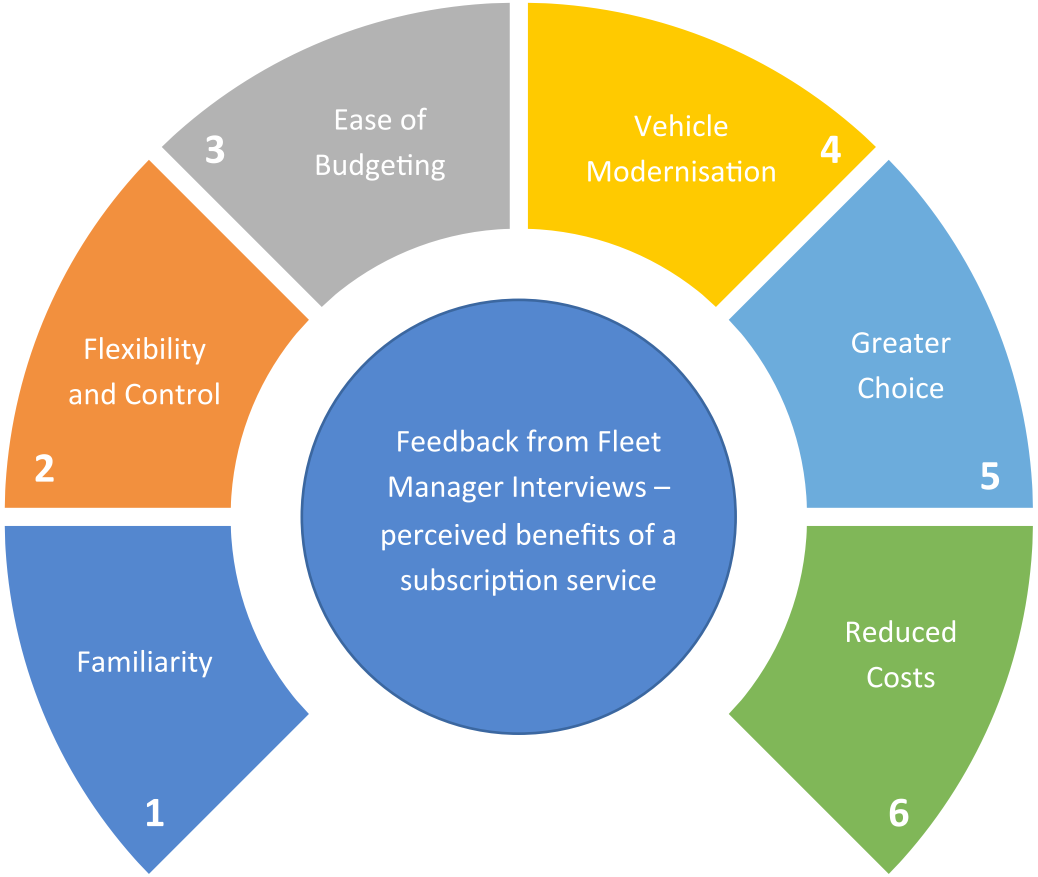
This is not only good business, but decouples revenue from resource extraction, future-proofing the UK economy against resource depletion and commodity price shocks, whilst supporting the development of 'stickier' manufacturing jobs within UK supply chains.

# Milford Haven Fleet Manager feedback – relevance for VaaS

## Benefits of a subscription service are recognised

The interviews carried out with Fleet Managers highlighted an existing recognition of a subscription service for vehicles, particularly amongst those who already leased or hired vehicles (50% of the group).

1. **FAMILIARITY**. VaaS has similar customer perception to lease or hire
2. **FLEXIBILITY AND CONTROL.** Greater flexibility vs ownership. Greater control vs traditional lease/hire agreements.
3. **EASE OF BUDGETING**. Predictable monthly payments, even for second hand users
4. **VEHICLE MODERNISATION**. Ongoing vehicle enhancements included within package.
5. **GREATER CHOICE**. Easier to change vehicle at the end of VaaS contract
6. **REDUCED COSTS**. Through keeping technology up to date, reducing running and maintenance costs



# Riversimple Rasa – technical approach and benefits

**Lightweight architecture is fundamental**

The whole Rasa architecture is focused on achieving minimum weight. This focus has significant benefits in terms of efficiency and ultimately affordability:

- The vehicle is carefully sized for local use requirements – no superfluous mass.
- Lightweight vehicle architecture necessitates smaller, light-weight and lower cost in-wheel motors. These can be air-cooled further reducing cost and weight.
- The fuel-cell stack, sized for constant speed requirements, can be 10% of the size required in a ‘traditional’ vehicle architecture – a significant cost reduction and a further weight reduction.
- Through a focus on high efficiency, competitive range can be delivered with a relatively small size (1.5kg) hydrogen fuel tank capacity receiving fuel at 350 bar. A smaller tank is again lower cost and weight, whilst the lower fuel pressure allows for common refuelling infrastructure to trucks/buses.

# Riversimple Rasa – designing for VaaS

## Benefits to the customer

The Arval survey highlighted reliability as a current barrier to adoption of battery electric vehicles. The technology is relatively new, and whilst high capacity motive batteries typically have an 8 year/100,000 mile warranty, ultimate cost of replacement is very high.

A vehicle as a service (VaaS) business model allows for entirely predictable monthly costs for potential customers – whether private or fleet. A single monthly payment covers use of the vehicle, servicing and maintenance, insurance and fuel costs. Through designing the vehicle from the ground-up for the VaaS business model (explained further in this section), monthly 'usership' costs can be minimized to be competitive with incumbent technologies. Furthermore, customers are isolated from the risks associated with the adoption of new technology – potentially accelerating the transition to ZEVs.

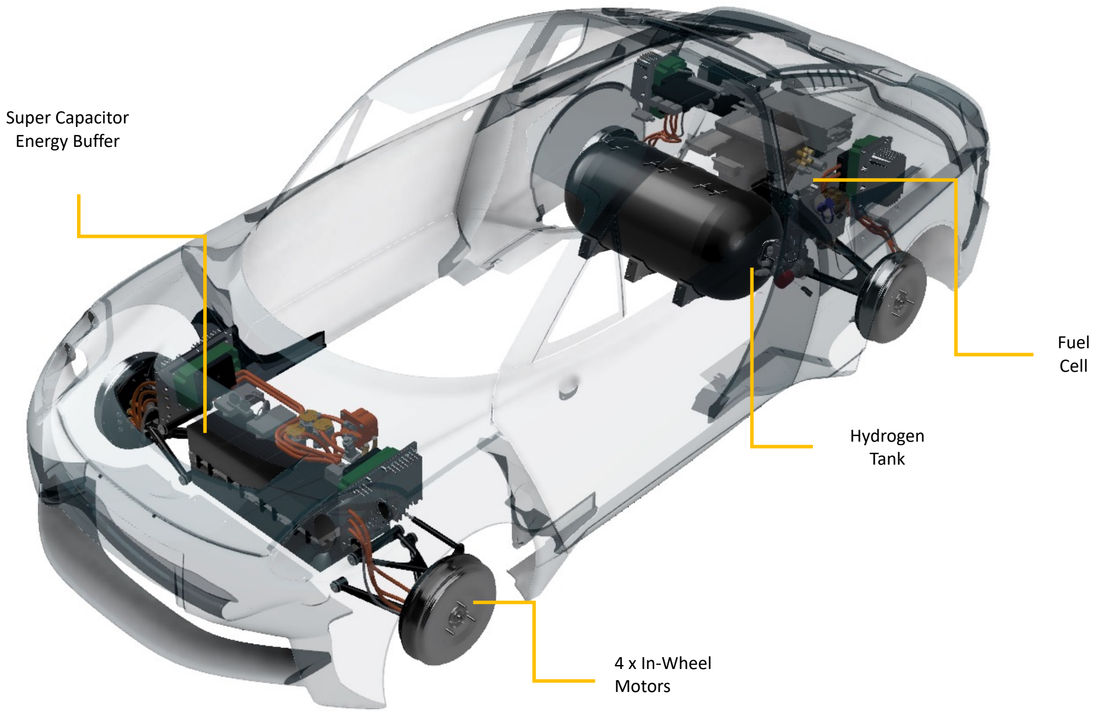
## Designing for VaaS

The adoption of a VaaS business model ideally requires the vehicle design approach to be fundamentally changed.

In a traditional vehicle, sold through a franchised dealer network, vehicle profitability at the point of wholesale is most important for the vehicle manufacturer, and by extension the potential revenues and associated costs (Cost of Goods Sold).

For a VaaS business model, total cost of ownership (TCO) is far more significant, since life-time profits are maximized through minimizing life-time TCO. Given that fuel costs are included within the monthly cost, there is an incentive to maximise the efficiency of the vehicle. This aligns the interests of the vehicle manufacturer with that of both the customer and the environment.

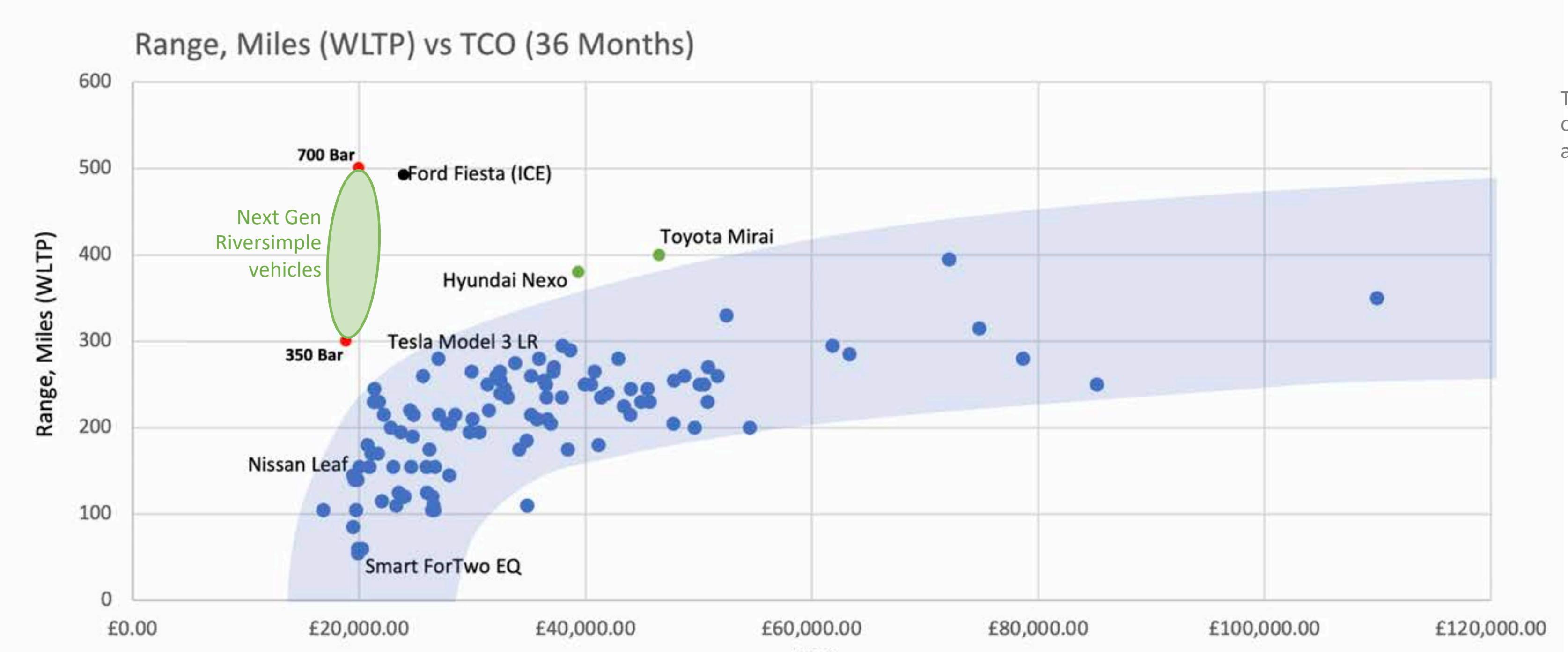
Through designing the VaaS architecture for maximum efficiency and minimum total-cost-of-ownership (TCO) it is possible to align to the needs of future fleet customers such as car-sharing services for whom cost of use is more important than initial purchase cost. Indeed, in a VaaS business model pricing is not based on build cost but lifetime cost and the shift to a comprehensive circular business model provides further TCO benefits through maximising value recovery at the end of life. This is not only good business, but decouples revenue from resource extraction, future-proofing the UK economy against resource depletion and commodity price shocks, whilst supporting the development of 'stickier' manufacturing jobs within UK supply chains.



# Riversimple Rasa – benefits of a lightweight architecture

**For widespread adoption of ZEVs, we need TCO to be competitive with current ICE vehicles for a similar user convenience**

Current ICE vehicles deliver high range at a competitive total cost of ownership. Over the last decade the Ford Fiesta has historically been the best-selling vehicle in the UK - to achieve an equivalent range with a BEV entails significantly higher cost. BEVs with a range of 300 miles (the range that most automotive OEMs are converging on as a target) are still ~200% of the annual TCO of the Fiesta. The Rasa powertrain architecture offers the potential to achieve 300 miles of range at a TCO approaching that of the ICE (with 350 bar hydrogen). The range of FCEVs can be increased without significant increases in mass (or reduction in efficiency).



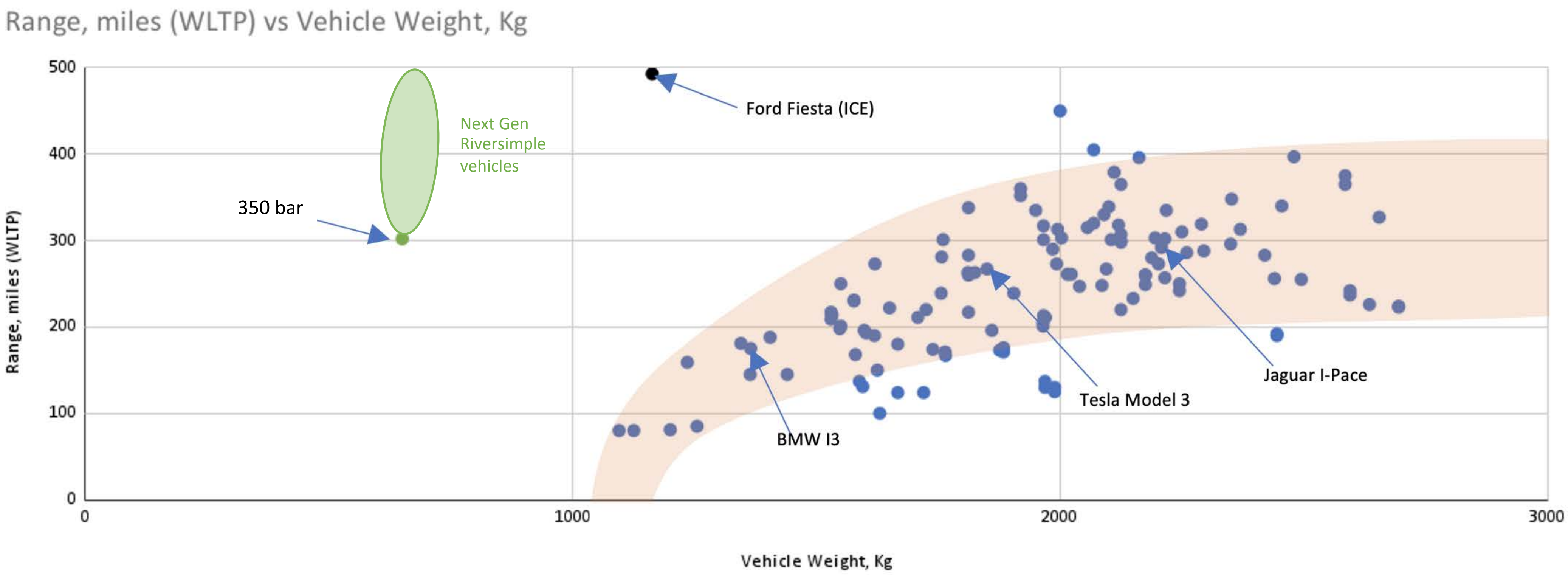
Source: Riversimple analysis

TCO calculated based on 10000 miles per annum, 3 years ownership on PCP, 2021 average petrol prices, hydrogen at £10/kg, rapid charging for BEVs (£0.50/kW).

# Riversimple Rasa – benefits of a lightweight architecture

**Vehicle weight is the key factor enabling the Rasa FCEV architecture to deliver competitive range at a competitive TCO**

A focus on mass reduction with a lightweight vehicle architecture allows for smaller, cheaper and lighter powertrain components. This ‘mass de-compounding’ effect allows for a competitive range and total cost of ownership to be achieved. High efficiency allows for smaller H2 storage requirements to achieve a competitive range. Additional range can be added to an FCEV through increases to H2 storage capacity with minimal change to vehicle mass. This contrasts strongly with BEV architectures whereby an increase in range requires heavier and more costly batteries to be installed.

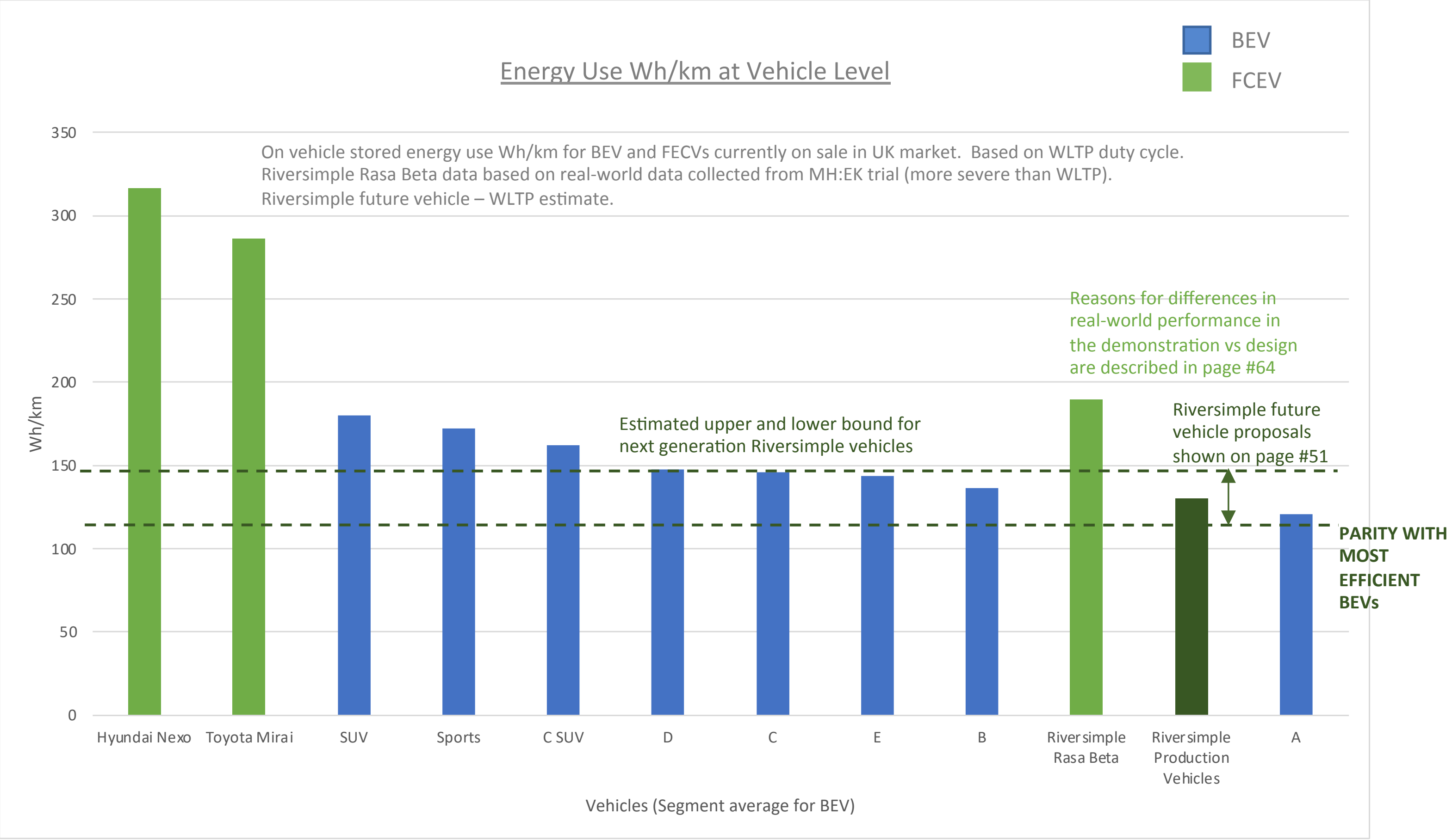


# Riversimple Rasa – benefits of a lightweight architecture

## Vehicle efficiency is important for FCEVs

A traditional vehicle architecture adapted for fuel cells entails a significantly higher energy use per km travelled than a typical BEV, which understandably attracts criticism. The lightweight Rasa vehicle and powertrain architecture* offers the potential to achieve parity in terms of operating efficiency with BEVs. The graph below shows vehicle level fuel efficiency, measured in Wh/km and compares how much of the energy stored onboard a vehicle, whether stored in batteries or hydrogen, is used per km.

A focus on efficiency allows for operating cost equivalence with BEVs when fuelled with hydrogen produced from grid electricity. This is important when we consider the transition to hydrogen passenger vehicles – a topic that will be discussed in more detail later. Furthermore, lightweight vehicle architectures offer benefits in terms of reduced material consumption and reduced emissions associated with tyre and brake wear.



On vehicle stored energy use Wh/km for BEV and FECVs currently on sale in UK market. Based on WLTP duty cycle.
Riversimple Rasa Beta data based on real-world data collected from MH:EK trial (more severe than WLTP).
Riversimple future vehicle – WLTP estimate.

Reasons for differences in real-world performance in the demonstration vs design are described in page #64

Estimated upper and lower bound for next generation Riversimple vehicles

Riversimple future vehicle proposals shown on page #51

**PARITY WITH MOST EFFICIENT BEVs**

*NOTE the two Riversimple vehicles in the chart. Rasa Beta calculation is based on real-world data from MH:EK demonstration ; next generation vehicle for volume production estimate (WLTP)

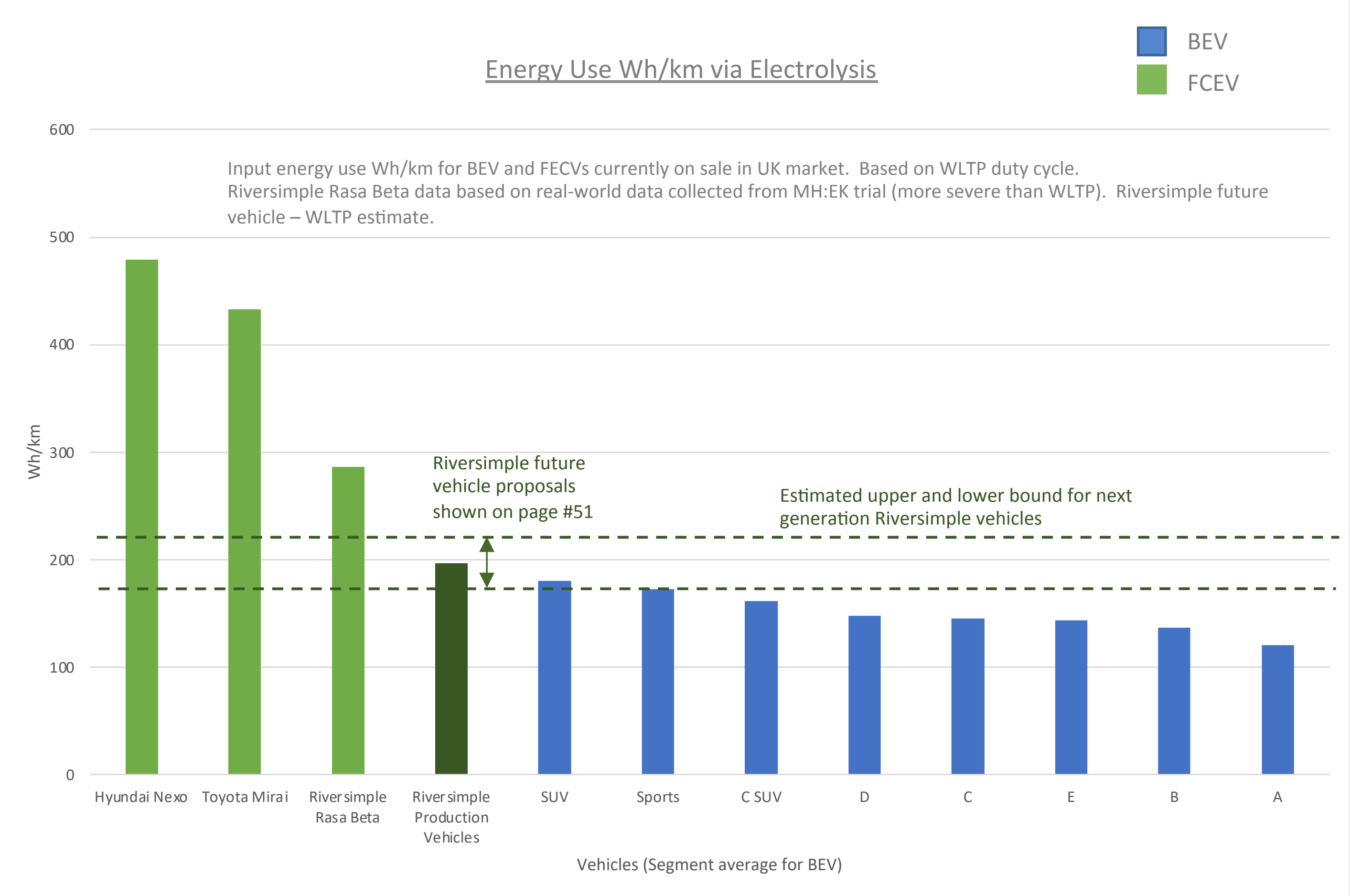
Source: Riversimple analysis

# Riversimple Rasa – benefits of a lightweight architecture

## Enabling the efficient use of electrolytic green hydrogen

The production of green hydrogen via electrolysis requires approximately 50 kWh of electricity per kg of hydrogen. Repeating the analysis shown on the previous page, but considering the input electricity required per km of vehicle use (rather than stored energy on the vehicle), further reinforces the importance of focusing on efficient vehicle architectures for fuel cell passenger vehicles – shown in the chart below.

The relative differences between the two analyses are associated with the losses in the electrolysis process, but this is offset by other factors. For instance, hydrogen is an important energy store for renewable electricity generation and so can be used to capture energy for subsequent use that would otherwise be curtailed. Furthermore, green hydrogen generation from biomethane is more efficient than electricity generation, so green hydrogen should not be evaluated exclusively through the efficiency of electrolysis. The analysis here shows the importance of maximizing efficiency to minimize use of this valuable resource.



Input energy use Wh/km for BEV and FECVs currently on sale in UK market. Based on WLTP duty cycle. Riversimple Rasa Beta data based on real-world data collected from MH:EK trial (more severe than WLTP). Riversimple future vehicle – WLTP estimate.

*NOTE the two Riversimple vehicles in the chart. Rasa Beta calculation is based on real-world data from MH:EK demonstration ; next generation vehicle for volume production estimate (WLTP)

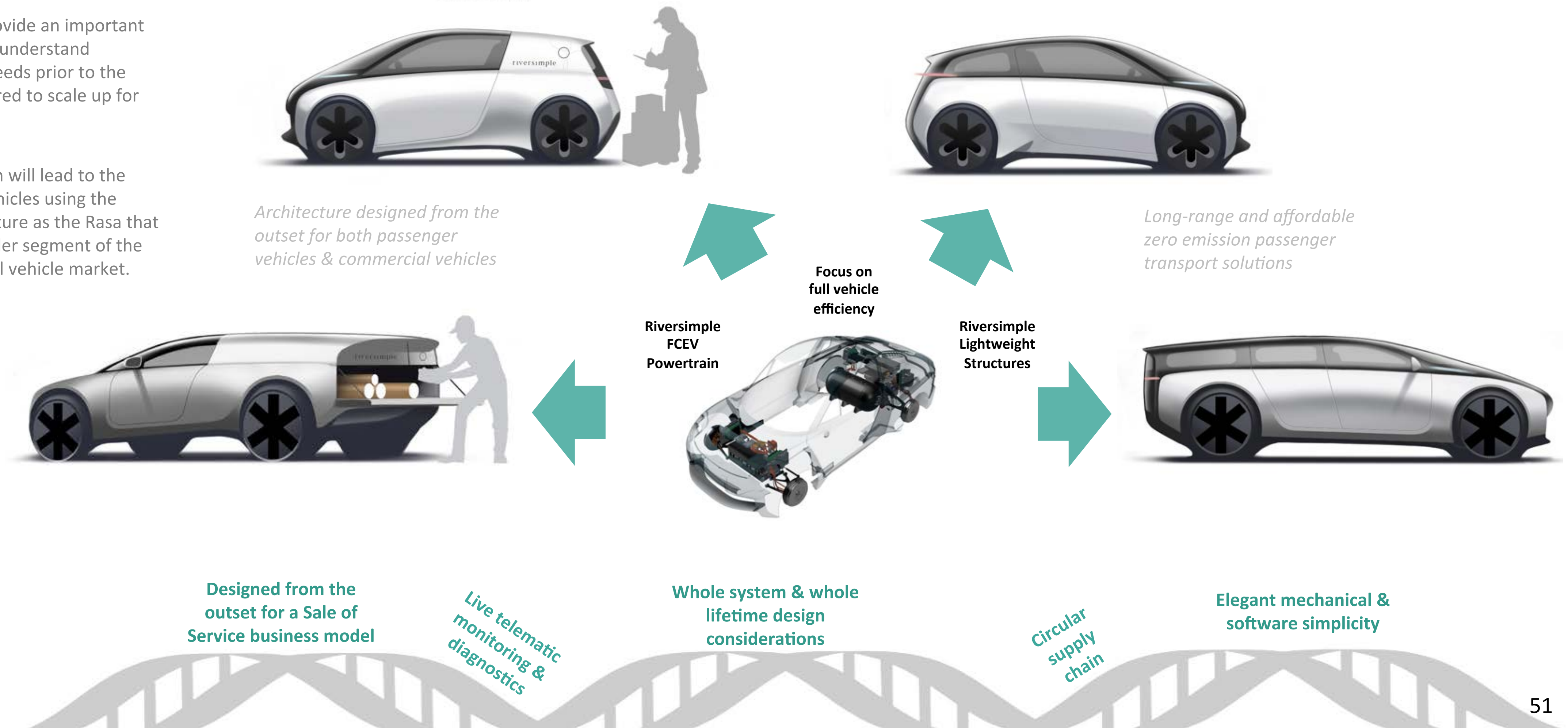
Source: Riversimple analysis

# Riversimple Rasa – future applications of the powertrain architecture

The Rasa Beta vehicles provide an important real-world opportunity to understand customer acceptance & needs prior to the sizeable investment required to scale up for mass production.

The vehicle demonstration will lead to the development of future vehicles using the same powertrain architecture as the Rasa that will be able to tackle a wider segment of the passenger and commercial vehicle market.

**Rasa Beta**



*Architecture designed from the outset for both passenger vehicles & commercial vehicles*

*Long-range and affordable zero emission passenger transport solutions*

**Focus on full vehicle efficiency**

**Riversimple FCEV Powertrain**

**Riversimple Lightweight Structures**

**Designed from the outset for a Sale of Service business model**

**Live telematic monitoring & diagnostics**

**Whole system & whole lifetime design considerations**

**Circular supply chain**

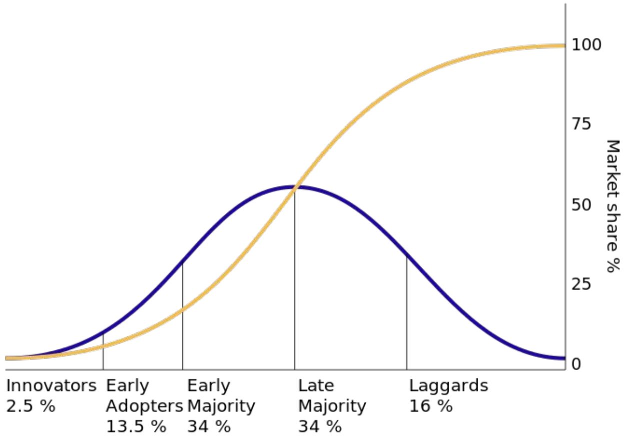
**Elegant mechanical & software simplicity**

# Short-term challenges and opportunities for zero emission personal transportation - summary

## Mapping the adoption of FCEVs

The Everett Rogers' Diffusion of Innovation Model is a useful reference in understanding the potential shift towards FCEVs, in particular the current barriers perceived by private users with regards to BEVs, these being:

- Lack of public charging and impact on range
- Vehicle price – affordability of use
- Vehicle model availability
- Home charging availability
- Workplace charging
- Reliability



Everett Rogers' Diffusion of Innovation Model

2022 viewpoint

| | Home Charging | No Home Charging |
|---|---|---|
| Above average household income | **EARLY MAJORITY for H2**<br>BEV is a convenient and economic choice enabling early adoption of ZEV transportation, but only if regular overnight charging is possible. BEVs available at a range of cost points associated with range/battery capacity. High cost market is supported through generous tax incentives, particularly for company car drivers.<br>FCEVs have widespread appeal once TCO is less than equivalent BEV and for drivers for whom maintaining convenience of ICE is important | **EARLY ADOPTERS of H2**<br>For low mileage customers BEV becomes more appealing once TCO equivalence with ICE achieved, accounting for higher cost of charging. Lack of convenience remains an issue.<br>For higher mileage customer, lack of convenience associated with long charging times will remain a block. FCEVs offer a convenient and economic solution once TCO equivalent to rapid charged BEV. For some customers environmental benefits and image will outweigh any cost penalty |
| Below average household income | **LAGGARDS for H2**<br>Lower cost BEVs with smaller battery capacities available to serve customers for whom large mileages are not important (TCO equivalence with new ICE vehicles).<br>Emerging second-hand BEV market offers higher range vehicles albeit with anxieties over battery life and reliability.<br>Higher mileage customers will stay with ICE for now. | **LATE MAJORITY for H2**<br>Lower cost BEVs (either via smaller battery capacities or second hand market) become appealing once TCO (including rapid charge penalty) has achieved equivalence with ICE.<br>Majority stay with ICE for now.<br>FCEVs offer a convenient solution, once TCO equivalence to ICE has been achieved. |

# Short-term challenges and opportunities for zero emission fleet transportation - summary

**The transition to ZEV for fleet vehicles is likely to be very different**

The challenges and barriers for ZEV adoption within vehicle fleets is quite different from personal/private vehicle users.

Fleet vehicles – company cars for business/commuting and personal use. Mainly parked at work.

Companies may wish to impose a faster transition towards ZEVs for ESG or financial reasons. In other respects, user behaviours could be expected to follow that of personal users.

Fleet vehicles – company vehicles used extensively for business activities during the day.

- Private businesses/organisations (such as taxi firms). Total cost of ownership will be a significant factor. The vehicle is a business tool, hence time spent charging is unproductive. For high mileage vehicles, the need for long-duration charging events during a working day will be an issue.
- Public businesses/organisations (such as County Councils, NHS). The constraints associated with private firms will equally apply. However, there will in many cases also be policy decisions mandating a more rapid shift towards zero emission transportation that needs to be taken into consideration.

| | Home/Workplace Charging | No Home/Workplace Charging |
|---|---|---|
| Daily Mileage > 150 miles | BEVs available are high cost – market is supported through generous tax incentives, particularly for company car drivers. Overnight charging a necessity to ensure that the vehicle has a full operational range each working day.<br>For daily mileages in excess of 250 miles, time to rapid charge during the day to sustain range is lost working time.<br>FCEVs offer similar user experience to ICE | BEV range theoretically serves need, but time, cost and inconvenience of rapid charging preclude wide adoption.<br>FCEVs enable range and fuelling convenience equivalent to ICE – potential to become prevalent if TCO equivalence to ICE can be achieved. |
| Daily Mileage < 150 miles | For lower mileage users BEV a convenient and economic choice enabling early adoption of ZEV transportation, but only if regular overnight or long duration charging is possible to allow a full daily charge.<br>TCO benefit supported via government grants/ incentives and particularly important in cases where ULEZ charges exist. | BEV range acceptable, but lack of convenience and high cost of charging is a barrier to adoption. Rapid charging would be required every 2/3 days – acceptable in some circumstances.<br>FCEVs offer a convenient solution, once cost equivalence to ICE has been achieved. |

*“There is potential for BEVs but more potential for hydrogen as BEVs are too range limited” – Milford Haven area Fleet Manager*

# Specific challenges for light commercial vehicles

## Understanding the UK van market

The Department of Transport has evaluated the van market across the UK to understand ownership and use. This analysis covers light commercial vehicles / light vans, being 4-wheel vehicles constructed for transporting goods with a gross weight of 3.5 tonnes or less.

Requirements for vans are very different than for passenger vehicles

Vans are predominantly a business tool and hence owned and used in a very different way.

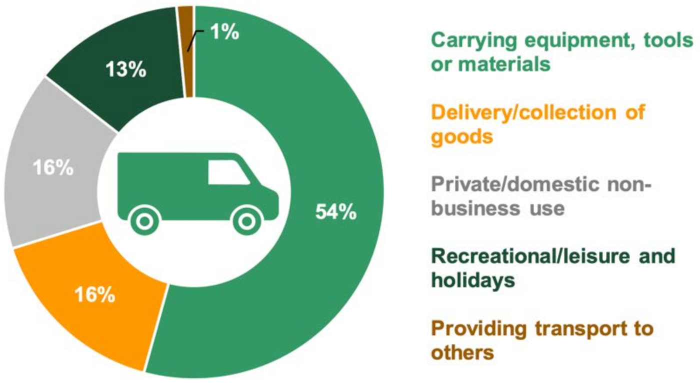
At the time of this study (based on 2019 data) there were 4.1 million vans in the UK market, covering a total of 55.5 biliion vehicle miles annually.

The primary uses are 1) carrying equipment, tools and materials, for which cargo volume and payload are important; and 2) delivery and collection of goods, for which range is important.

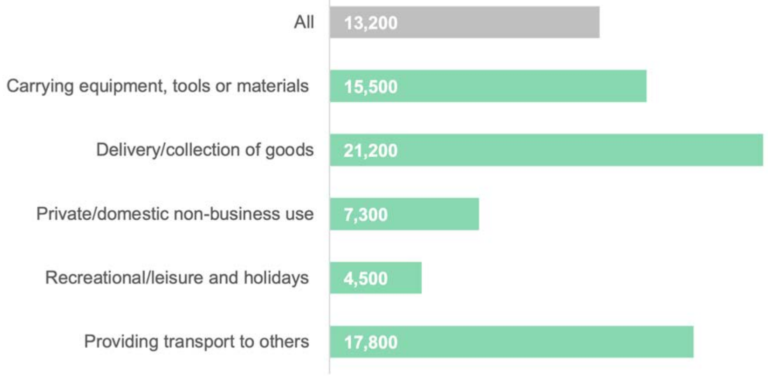
27% of the van fleet is less than 3 years old, but it is these newer vans that cover the highest mileages, averaging over 20,000 miles per year, significantly higher than that for an average passenger vehicle.

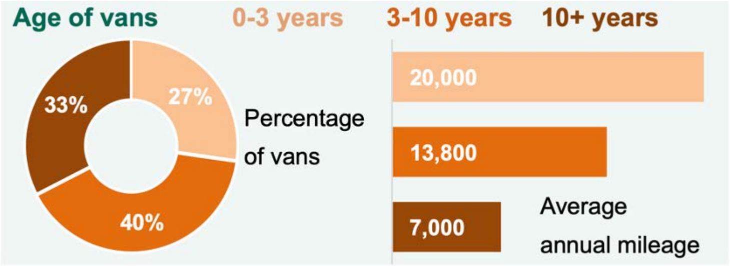
All of these factors have implications for the transition towards zero emission light commercial vehicles.

**Van Usage in Great Britain, 2019-20** (Table: VAN0201)

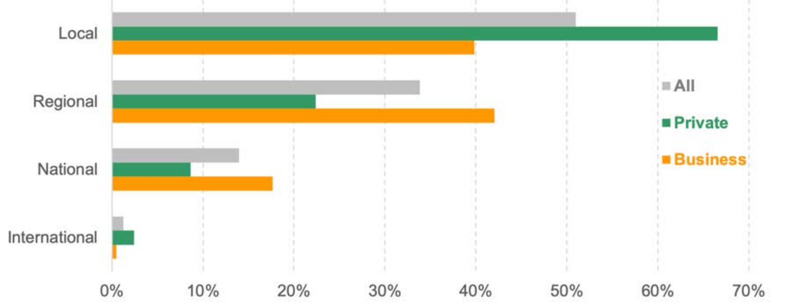


**Average Annual Van Mileage by Primary Usage** (Table: VAN0211)





**Proportion of Vans by Range of Typical Daily Van Journeys and Keepership** (Table: VAN0301)



Source: Department for Transport

# Specific challenges for light commercial vehicles

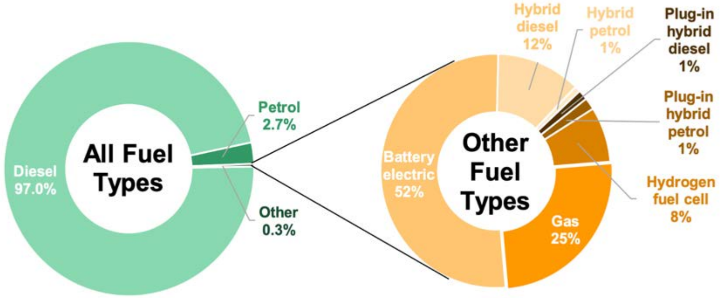
## The utility of the ICE is difficult to match

The chart shows a comparison of currently available (and soon to be released) light commercial vehicles within two vehicle categories. This compares vehicle range with payload, with annual TCO represented by the bubble area:

- Small vans (such as the Ford Transit Connect), with payloads of ~600kg
- Medium vans (such as the Ford Transit Custom – the highest selling vehicle of any type in the UK in 2021) with payloads in excess of 1000kg.

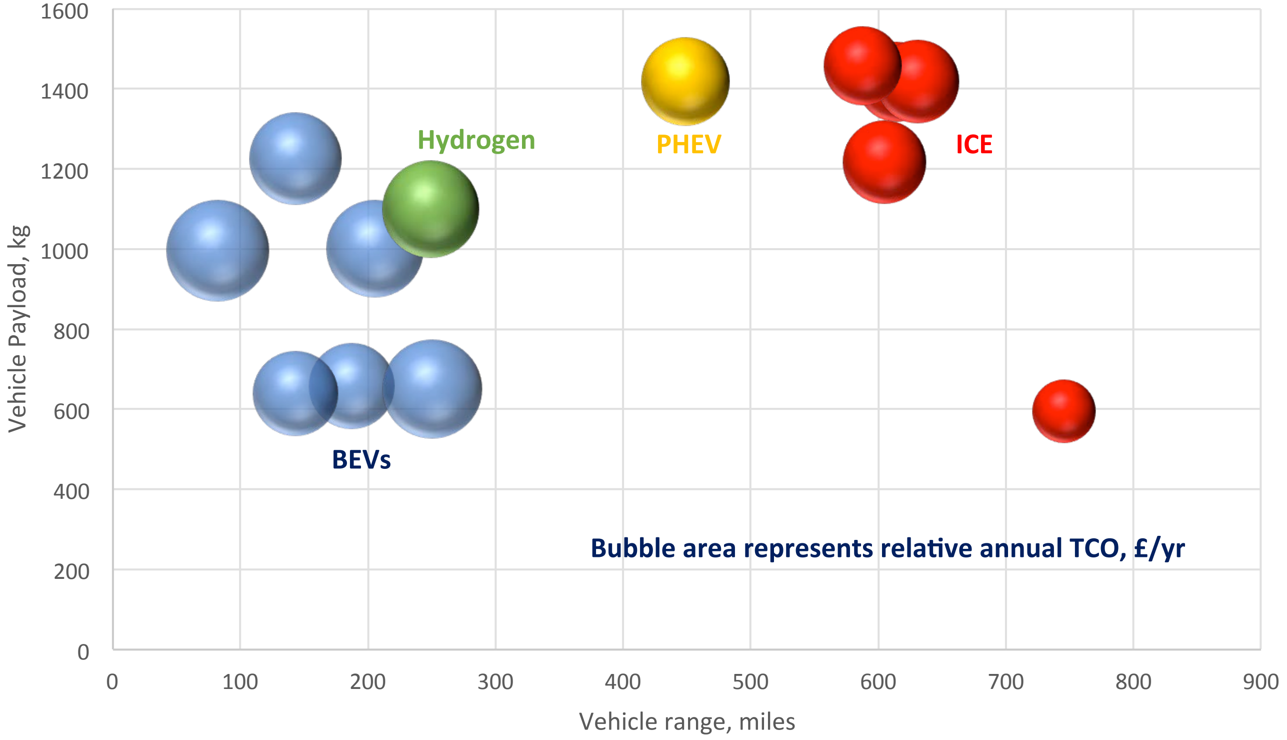
In all cases the BEVs are more expensive than their ICE equivalents, and yet offer either significantly lower range or payload, or both. Payload is compromised by the increased vehicle mass associated with the high-voltage motive battery. Range could be increased to a competitive level with ICE with increased battery size (and cost), but at the further expense of payload. It is a fine balance and illustrates why 97% of the current van fleet remains diesel. The PHEV vehicle (Ford Transit Custom PHEV) is a competitive offer, particularly for ULEZ charging zones, however it is not zero emission. Hydrogen does offer a potential solution, with the first volume production vehicle to be introduced in 2023 (Vauxhall Vivaro-e Hydrogen). It allows for competitive payload, the option of increased range without significant increases in vehicle mass and the convenience of refuelling times equivalent to diesel.

**Proportion of Vans by Fuel Type (Table: VAN0502)**



Source: Department for Transport

Relationship between range, payload and TCO



Source: Riversimple analysis

# Specific challenges for light commercial vehicles – issues raised by Fleet Managers

### Feedback from Milford Haven fleets reflects the challenges raised

In the Fleet Manager interviews, questions regarding experience and attitude to battery electric vans and electrification of vans in general were raised, to understand current barriers. Four major issues were raised: range, payload, availability/utilisation and care/maintenance.

### Range

Many fleet vehicles travel several hundred miles per day, so range was identified as a major limitation for BEVs. Several fleets highlighted that whilst a theoretically acceptable range was now possible with some BEV vans, in cold weather or when the vehicle was loaded, the real-world range could be significantly lower, and less than the typical duty cycle for a day's activity. Utility fleets need reliable vehicles that work all year round and have high mileage even when it is cold. For one utility Fleet Manager that that was the reason they have almost no BEVs, quoting that they will be "late adopters" because they need to ensure they have suitably reliable vehicles to get the job done.

### Payload

For one utility company interviewed, a heavy payload was a must, essentially ruling out BEVs, since as explained previously maximum payload is compromised due to the weight of the battery. Furthermore, loading the vehicle to its maximum payload significantly reduces range. In their view, hydrogen was more likely to be a viable long-term solution.

### Availability/utilisation

Availability and utilisation was an issue also raised by fleet managers, with an expectation that vehicles are available for use whenever required. The need to wait for vehicles to be re-charged was considered unacceptable.

### Care/maintenance

Another big consideration for utility fleet vehicles is the care infrastructure. The vehicles have to be easily maintained, again because the utility companies need to be able to reach their clients at all times. Since one utility company had such specialist vehicles, they have their own garages so they can do their own maintenance. Local vehicle OEM dealerships are limited to one brand, that currently does not offer a full battery electric vehicle. The supply chain is considered by the Fleet Managers to be harder to manage with BEVs. There is also an issue with competency. To maintain an electric van, the utility company would need to update its own garages. A utility company Fleet Manager said that "finding the van is the easy bit. It's the after care which is the hardest bit."

***These are issues that can potentially be addressed with H2***

MILFORD HAVEN: ENERGY KINGDOM

# Outcomes from the Milford Haven Vehicle vehicle demonstration

MH2
ENERGY KINGDOM
DEYRNAS YNNI

# Hydrogen vehicle demonstration

## Objective – a reminder

UK manufactured, head turning H2 vehicles in use around the port of Milford Haven:

- demonstrating the potential of hydrogen as a transport fuel in the MH:EK locality
- inspiring end user demand in the MH:EK locality and beyond

## Vehicle build

Two Riversimple Rasas were specifically built for the MH:EK Project to be used in the vehicle demonstration: MH:EK 1 and MH:EK 2.

## Hydrogen refueller

A hydrogen electrolyser and hydrogen refuelling station was constructed by Fuel Cell Systems at Milford Haven Waterfront to refuel the Rasas for the duration of the vehicle demonstration. Since installation, there have been:

- 68 refills at the Milford Haven refuelling station
- >65kg H2 produced by the station at Mackerel Quay
- Average mass H2 delivered: 660g
- Average time to refill: 5 minutes

## User testing

MH:EK 1 and MH:EK 2 were used by locally based fleets:

- 4 trialists from Pembrokeshire County Council
- 5 trialists from Milford Haven Port Authority

The Rasas were used by the trialists for their day-to-day work around the Milford Haven region, including commuting and site visits. The Rasas were also used by the Council for educational outreach and visited several schools around the county.

## Use pattern and user experience analysis

Since the demonstration began, the trialists have driven 508 miles. Additionally, we have collected another 5,000+ miles worth of data:

•Riversimple data collection (replicating the council, local health board and Port Authority’s duty cycles: 1,243 miles
•Travel to and from Pembrokeshire: 3,517 miles
•Driver training: 224 miles
•School visits and project events: 277 miles

Following from the vehicle demonstration period, the trialists were asked for their feedback on the Rasa, what it was like to drive a hydrogen vehicle, what it was it like to refuel, and how well the Rasa/hydrogen fits into their working day.

## Business case design

The vehicle demonstration allowed for an assessment of real world fuel usage with non-Riversimple drivers. This, combined with data on the local fleets, and wider demographic and transport data, has been used to simulate the local demand for hydrogen for the region – required to develop the business case for a publicly accessible refueller.

*Handing over the keys of a MH:EK 1 to Pembrokeshire County Council.*

*MH:EK 2 at the hydrogen refuelling station at Milford Haven.*

# Hydrogen vehicle demonstration – educational outreach

## Educational outreach and community support has been at the core of the Rasa vehicle demonstration

Carew School visit to Carew Castle & Tidal Mill 28-03-22

*"My favourite workshop was the hydrogen car one because I enjoyed finding out about how much it will improve our environment" - Haverfordwest Highschool pupil*

"It was absolutely super, thank you. The children and staff really enjoyed learning about the cars!" Vicky Brown, Deputy Head, Redhill Preparatory School

# Hydrogen vehicle demonstration- local fleet participation

Project partners Pembrokeshire County Council and Milford Haven Port Authority agreed to take part in the vehicle demonstration.  This involved nominating 4-5 staff members to test drive the Rasa and share information on the types of journeys that they typically undertook.  This was assessed through the installation of a telemetry GPS tracker to their regular vehicles (not Rasa), the data being recorded and reported via the Quartix platform (explained further on the next page).  Although they did not test drive the Rasa, the local health board also shared information on their district nurses' duty cycles. Later in this report we will review these duty cycles in more detail, including the actual miles per kg of hydrogen achieved for each scenario.

Riversimple also spoke to representatives from five different organisations with a fleet based in the Milford Haven region and five others from outside the region (a summary of these fleet interviews is shown on page 65)

Each semi-structured interview lasted 30 - 45 minutes and included questions about the type of vehicles which make up the fleet and vehicle use, including miles travelled; the refuelling/recharging process; the procurement decision making process and expenditure; fleet maintenance; fleet insurance; driver training; and vehicle telemetry tracking.

The data from the Rasa test drives/ vehicle demonstration and the information gained from the semi-structured interviews were used to support the evaluation the potential demand for hydrogen from passenger vehicles in the Milford Haven region.

## Pembrokeshire County Council

- Fleet make up – 450 vehicles including HGV, vans, cars, tractors, tippers.
- Annual mileage: 10,000-30,000
- 8 BEVs in the fleet (+ 8 on order)
- Vehicle use: Operational uses are varied. HGVs used for refuse collection, highway maintenance, and traffic management. Vans are used for estates, maintenance and highways inspections. Cars are either used as pool cars or as departmental company cars.
- 4 trialists taking part in the demonstration

## Milford Haven Port Authority

- Fleet make up – 25 vehicles including pickup trucks, small vans, cars
- Annual mileage: 2,600
- 8 BEVs in the fleet
- Vehicle use: estates and maintenance
- 5 trialists taking part in the demonstration

## Hywel Dda University Health Board

- Fleet make up – 337 vehicles including HGV, cars, vans
- Annual mileage: 10,000 (based on pool car annual mileage only. Calculation from total pool car mileage for 2019-2020 )
- 0 BEVs in fleet (at time of interview)
- Vehicle use: estates, hotel services, support services, blood service, out of hours GP transport service, pool cars, mail runs, maintenance, and district nurse use.

# Understanding passenger vehicle use in Milford Haven – Telemetry data

### Telemetry data recorded

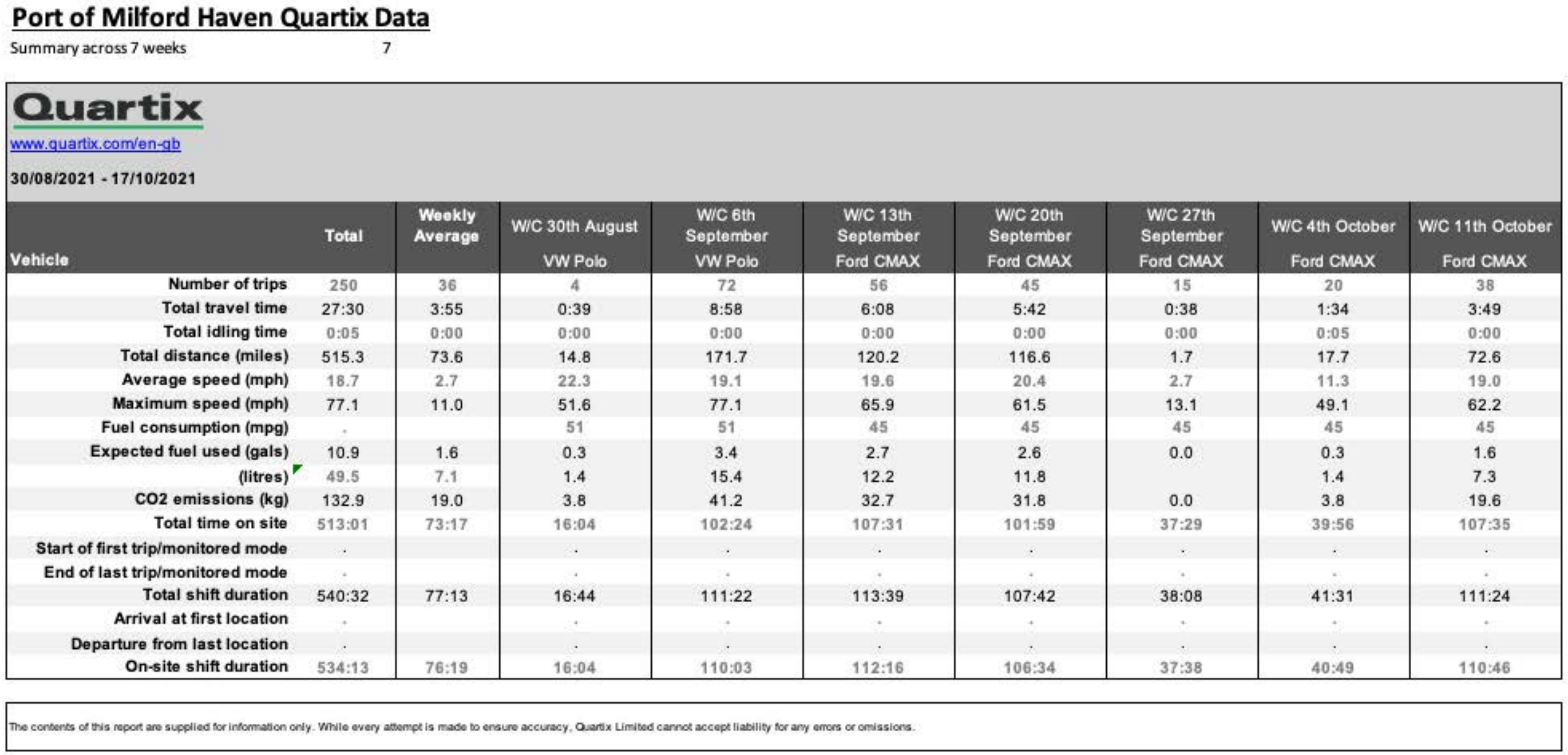
Telemetry equipment fitted to project partners' fleet vehicles enabled a detailed understanding of vehicle use to be recorded. This information allowed the planned demonstration driving routes for the Rasa to be aligned with real-world duty cycles, ensuring that the performance and efficiency data collected for the Rasa was representative of actual usage patterns in the Milford Haven area.

### Duty cycle replication

Riversimple engineers used this telemetry data to replicate the council, local health board and Port Authority's regular journeys in the Milford Haven region to collect data on how H2 consumption varied with the different duty cycles

### Trialists vs Riversimple engineer driving

The fleet duty cycles included different work trips around the Milford Haven region and a few local commutes. Duty cycle data was collected by Riversimple during spring/summer 2021. However, due to COVID-19 and other factors, the trialists did not behind the wheel of the Rasa until early 2022 and by that point some of their driving habits had changed. This was especially true for the council where the trialists were still mostly working from home. Therefore, the majority of journeys made by trialists for the demonstration included visits to schools and other community events, 'run-around' trips, commutes, and the odd work trip. Aside from the commuting journeys, the journeys made by the trialists were different to the duty cycles the Riversimple engineers replicated. That said, there was still much to be gained from the FCEV demonstration in terms of better understanding the impact of real-world usage on H2 consumption.



**Port of Milford Haven Quartix Data**

Summary across 7 weeks 7

**Quartix**

www.quartix.com/en-gb

**30/08/2021 - 17/10/2021**

| | Total | Weekly Average | W/C 30th August | W/C 6th September | W/C 13th September | W/C 20th September | W/C 27th September | W/C 4th October | W/C 11th October |
|---|---|---|---|---|---|---|---|---|---|
| **Vehicle** | | | VW Polo | VW Polo | Ford CMAX | Ford CMAX | Ford CMAX | Ford CMAX | Ford CMAX |
| **Number of trips** | 250 | 36 | 4 | 72 | 56 | 45 | 15 | 20 | 38 |
| **Total travel time** | 27:30 | 3:55 | 0:39 | 8:58 | 6:08 | 5:42 | 0:38 | 1:34 | 3:49 |
| **Total idling time** | 0:05 | 0:00 | 0:00 | 0:00 | 0:00 | 0:00 | 0:00 | 0:05 | 0:00 |
| **Total distance (miles)** | 515.3 | 73.6 | 14.8 | 171.7 | 120.2 | 116.6 | 1.7 | 17.7 | 72.6 |
| **Average speed (mph)** | 18.7 | 2.7 | 22.3 | 19.1 | 19.6 | 20.4 | 2.7 | 11.3 | 19.0 |
| **Maximum speed (mph)** | 77.1 | 11.0 | 51.6 | 77.1 | 65.9 | 61.5 | 13.1 | 49.1 | 62.2 |
| **Fuel consumption (mpg)** | . | | 51 | 51 | 45 | 45 | 45 | 45 | 45 |
| **Expected fuel used (gals)** | 10.9 | 1.6 | 0.3 | 3.4 | 2.7 | 2.6 | 0.0 | 0.3 | 1.6 |
| **(litres)** | 49.5 | 7.1 | 1.4 | 15.4 | 12.2 | 11.8 | | 1.4 | 7.3 |
| **CO2 emissions (kg)** | 132.9 | 19.0 | 3.8 | 41.2 | 32.7 | 31.8 | 0.0 | 3.8 | 19.6 |
| **Total time on site** | 513:01 | 73:17 | 16:04 | 102:24 | 107:31 | 101:59 | 37:29 | 39:56 | 107:35 |
| **Start of first trip/monitored mode** | . | | . | . | . | . | . | . | . |
| **End of last trip/monitored mode** | . | | . | . | . | . | . | . | . |
| **Total shift duration** | 540:32 | 77:13 | 16:44 | 111:22 | 113:39 | 107:42 | 38:08 | 41:31 | 111:24 |
| **Arrival at first location** | . | | . | . | . | . | . | . | . |
| **Departure from last location** | . | | . | . | . | . | . | . | . |
| **On-site shift duration** | 534:13 | 76:19 | 16:04 | 110:03 | 112:16 | 106:34 | 37:38 | 40:49 | 110:46 |

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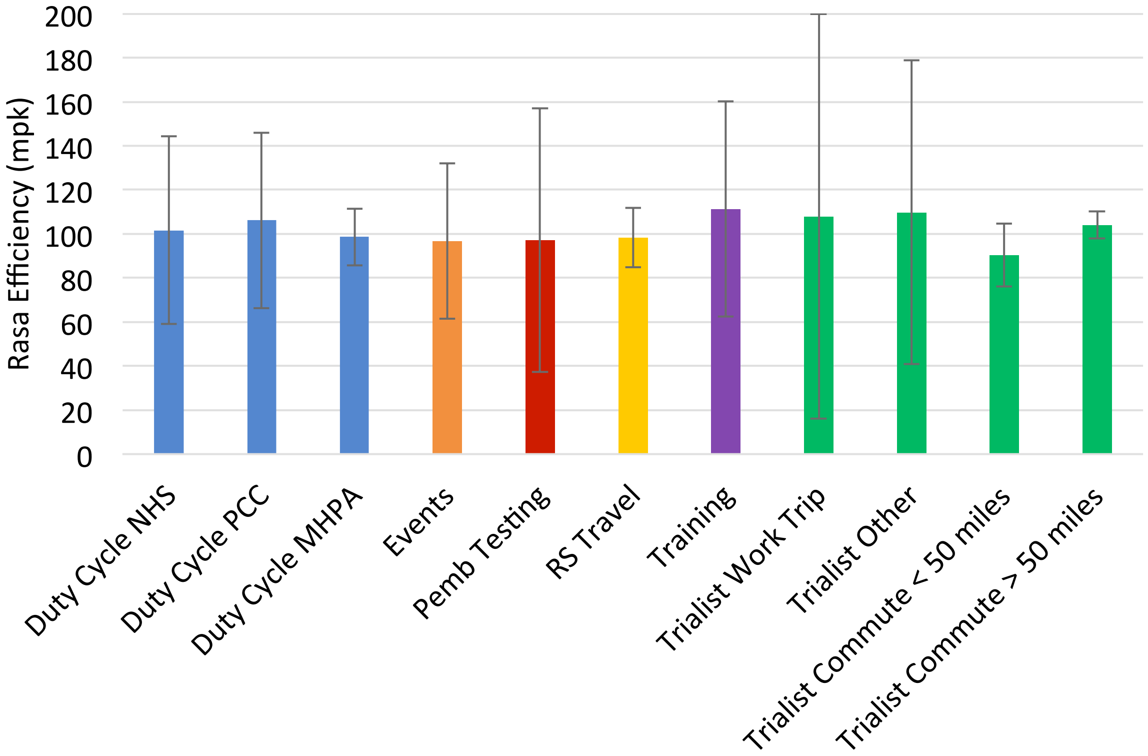
# FCEV Demonstration Data– what have we learnt?

As part of the FCEV demonstration, Riversimple Rasas drove over 5000 miles and each journey was categorised as one of the following:

- **Duty Cycle Replication** (further split into council (PCC), port (MHPA) or health board fleet (NHS)). This is where Riversimple engineers replicated the council, port, or health board's regular journeys.
- **Trialist** (further split into near/far commutes, work trips and other). This is where the different trialists took the Rasa for a set period of time.
- **Events**. This is where the Rasa was driven to schools or other community events either by trialists or Riversimple staff
- **RS Travel**. This is where Riversimple engineers drove the Rasa to/from Milford Haven from Riversimple's HQ in Llandrindod Wells.
- **Training**. This is when the Rasa was used for training purposes.
- **Pemb Testing.** This is when Riversimple engineers took the Rasa for test drives while carrying out maintenance in Milford Haven.



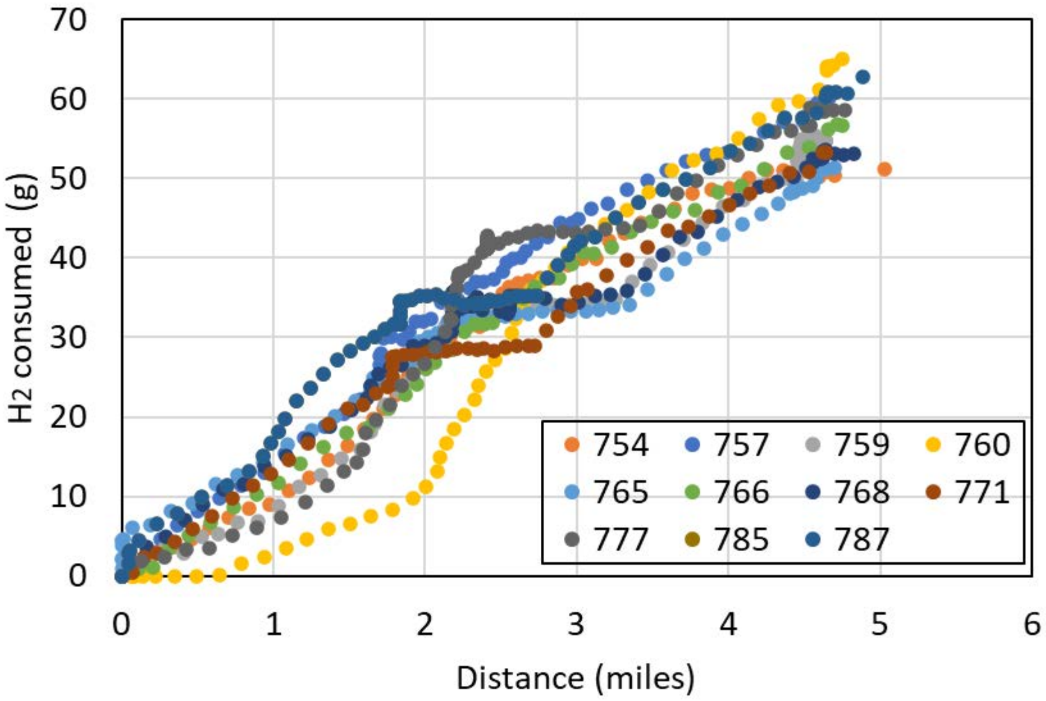
# FCEV Demonstration Data– what have we learnt?

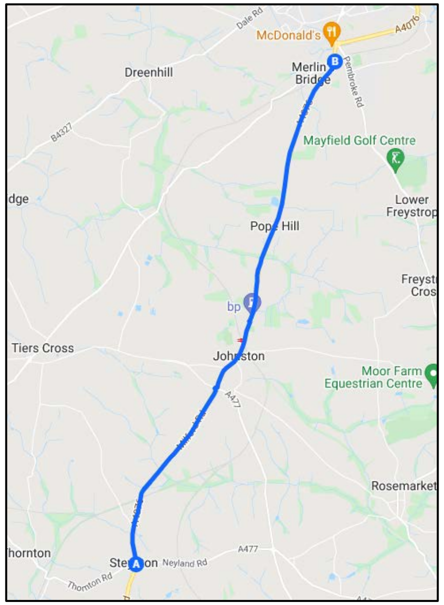
## Real world driving vs official testing

Production BEVs and FCEV range and efficiency figures come from official testing procedures such as the Worldwide Harmonised Light Vehicle Test Procedure (WLTP). During these tests, conditions are defined by EU law to measure fuel consumption and $CO_2$ emissions and the testing takes place in highly controlled laboratory environments. This is in stark contrast to the real world driving carried out as part of the hydrogen vehicle demonstration for MH:EK project where there were many different conditions which had an influence on the Rasa efficiency.

## Many factors impact $H_2$ consumption

Throughout the demonstration taking place at Milford Haven, the Rasa drove several different duty cycles, by different drivers at different times of the day/week/ month/year. Drivers included experienced Riversimple engineers who have been driving FCEV's for several years, and trialists who have only ever driven ICE vehicles. Duty cycles included hour long commutes including motorway driving, shorter commutes in rural regions, quick urban runaround trips, and journeys with and without passengers. Each of these different factors would influence $H_2$ consumption. For this reason it is difficult to directly compare the Rasa efficiency (mpk) values from the demonstration with the official BEV and FCEV efficiency values.





The graph above shows the Rasa $H_2$ consumption (g) by a Rasa travelling between Steynton and Merlin's Bridge in Pembrokeshire. In total 11 different journeys were made by 3 separate drivers. As the graph shows, Rasa $H_2$ consumption was different for each journey. $H_2$ consumption was impacted by topography, number of occupants, driving styles, and time of journey. As expected, $H_2$ consumption was greater when there were more occupants in the Rasa, when driving up an incline, and when the Rasa was been driven at a higher speed.

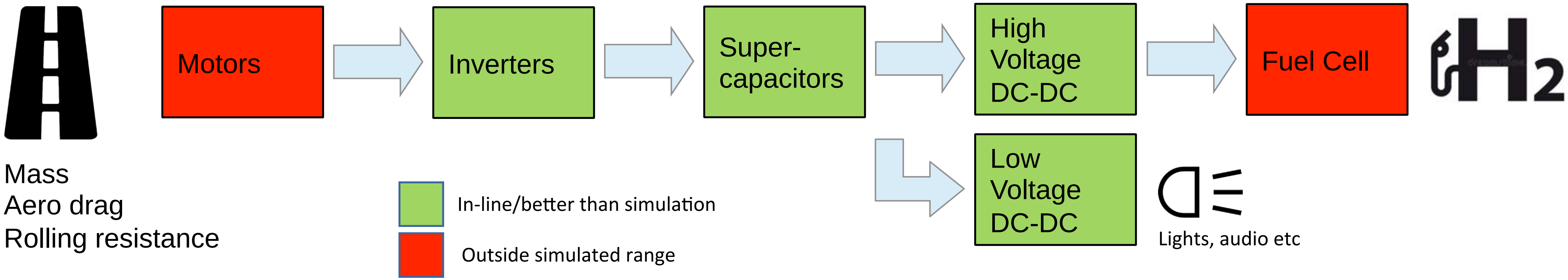
# FCEV Demonstration Data – what have we learnt?

**Assessing the differences between simulated fuel economy (mpk) and real-world fuel economy**

The Rasa Beta demonstration enabled real-world fuel economy data to be collected and assessed, the actual economy measured being 110 mpk (miles per kg of hydrogen) on average.  This compared to an expected fuel economy of 165 mpk based on a simulation using the WLTP duty cycle.

Through installing a Rasa Beta demonstrator on a vehicle dyno, it was possible to evaluate each of the components within the powertrain system to understand whether these were performing in line with quoted specifications.  This activity allows for future vehicle variants to be designed with further efficiency improvements.

This analysis showed that the majority of systems were operating in line with or better than simulated: the inverters, super-capacitors, high voltage DC-DC converters and low voltage DC-DC converters all performing well.  The key differences between the actual and simulated efficiency were associated with the 4 in-wheel motors and fuel cell, both running at lower efficiencies than expected.  Further work will be undertaken to evaluate the root cause of these efficiency drops to support design improvements for future Riversimple vehicles.



Motors

Inverters

Super-capacitors

High Voltage DC-DC

Fuel Cell

Low Voltage DC-DC

Lights, audio etc

Mass
Aero drag
Rolling resistance

🟩 In-line/better than simulation

🟥 Outside simulated range

# Hydrogen vehicle demonstration - other fleets

## Fleet interviews

Ten different organisations in the area were interviewed to gain a better understanding of the use of and attitude towards BEV vehicles within large fleets. These organisations included health boards, county councils, car clubs, utility organisations, a port authority, and a national park authority – summarised in the table to the right.

These organisations represent a wide variety of fleets, varying from fleets made up of thousands of vehicles covering 30, 000 miles annually to a fleet which comprised of only five vehicles.

## Main findings:

- Uptake of zero emission vehicles is generally low, particularly for those fleets that typically cover high mileages; an example being the utilities companies for whom none of the fleet were ZEVs. These fleets were dominated by vans and 4x4s, vehicles currently poorly served by competitive zero-emission (BEV) solutions, as discussed earlier.
- Both County Councils did have BEV vehicles within their fleets. However, they represented <1% of the total fleet size. Again, their vehicles could be expected to cover annual mileages significantly higher than average.
- The National Park Authority and both car clubs had >20% of BEVs within their fleets. It should be noted that these fleets in general covered a lower average mileage than the other fleet users interviewed.

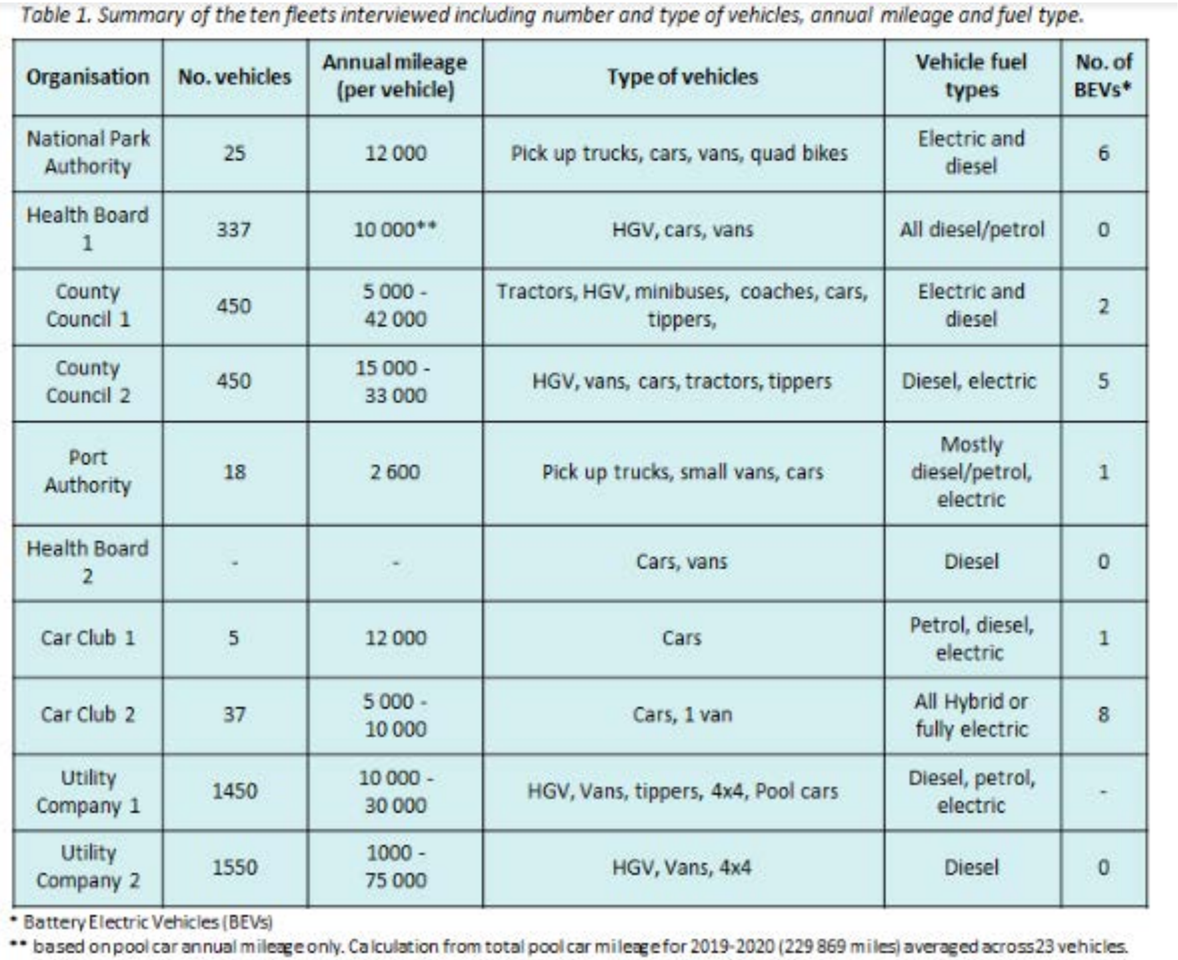


*Table 1. Summary of the ten fleets interviewed including number and type of vehicles, annual mileage and fuel type.*

| Organisation | No. vehicles | Annual mileage (per vehicle) | Type of vehicles | Vehicle fuel types | No. of BEVs* |
|---|---|---|---|---|---|
| National Park Authority | 25 | 12 000 | Pick up trucks, cars, vans, quad bikes | Electric and diesel | 6 |
| Health Board 1 | 337 | 10 000** | HGV, cars, vans | All diesel/petrol | 0 |
| County Council 1 | 450 | 5 000 - 42 000 | Tractors, HGV, minibuses, coaches, cars, tippers, | Electric and diesel | 2 |
| County Council 2 | 450 | 15 000 - 33 000 | HGV, vans, cars, tractors, tippers | Diesel, electric | 5 |
| Port Authority | 18 | 2 600 | Pick up trucks, small vans, cars | Mostly diesel/petrol, electric | 1 |
| Health Board 2 | - | - | Cars, vans | Diesel | 0 |
| Car Club 1 | 5 | 12 000 | Cars | Petrol, diesel, electric | 1 |
| Car Club 2 | 37 | 5 000 - 10 000 | Cars, 1 van | All Hybrid or fully electric | 8 |
| Utility Company 1 | 1450 | 10 000 - 30 000 | HGV, Vans, tippers, 4x4, Pool cars | Diesel, petrol, electric | - |
| Utility Company 2 | 1550 | 1000 - 75 000 | HGV, Vans, 4x4 | Diesel | 0 |

* Battery Electric Vehicles (BEVs)

** based on pool car annual mileage only. Calculation from total pool car mileage for 2019-2020 (229 869 miles) averaged across 23 vehicles.

# Assessing total vehicle hydrogen demand in Milford Haven

## All vehicle types

MH2
ENERGY KINGDOM
DEYRNAS YNNI

# Estimating hydrogen demand in Milford Haven

## Need to consider 7 user groups

The market analysis has shown that despite a major shift towards battery electrification of light duty passenger vehicles and to a lesser extent light commercial vehicles, there is a strong role for hydrogen to play in certain circumstances and use cases. Furthermore, the Advanced Propulsion Centre Fuel Cell Roadmap amongst other research (see Appendix) highlights the role that fuel cells may play in the decarbonization of heavy duty vehicle fleets, both on and off highway

In this section we will review each of these use cases with regards to the Milford Haven area, to evaluate the potential demand for hydrogen, initially focusing on full potential demand in 2050, prior to discussing the potential transition. This will later be used to inform the investment case for a publicly accessible refueller. Each of the demand cases is based on a series of defined assumptions and total demand is stated to the closest 10kg

**Total hydrogen demand**

Assessment of total vehicle hydrogen demand in the MH local area that would make use of a publicly accessible refueller

| | |
|---|---|
| **LIGHT DUTY PVs** | Passenger vehicles for personal/commuting use<br>2 cases shown: lower demand case based on 100% high efficiency vehicles (similar to Rasa); high demand case based on 50%/50% mix of Rasa type and conventional 4 seater vehicles. |
| **LIGHT DUTY FLEETS** | Passenger vehicles owned/used by fleets |
| **LIGHT COMMERCIAL** | Light duty goods vehicles (<3.5 tonnes) in private/public/business ownership |
| **BUSES** | Bus fleets local to Milford Haven |
| **HEAVY DUTY TRUCKS** | Heavy duty goods vehicles that frequent Milford Haven |
| **OFF-HIGHWAY** | Do forestry, agriculture, construction, mining, quarrying have demand for hydrogen? |
| **OTHERS** | Is there the potential for additional demand from a publicly accessible refueller in addition to the above? |

# Potential hydrogen demand from passenger vehicles – Group 1: vehicles travelling into the region

**Using Transport for Wales assessment of trips to determine potential hydrogen demand**

Transport for Wales have assessed the total weekday trips to and from the Milford Haven and Pembroke Dock area, with a breakdown of number of trips by destination. This represents a cumulative mileage of ~150,000 miles for weekday journeys.

As described earlier in this report, it is likely that there will in future be a mix of zero emission powertrain solutions for passenger vehicles – both full battery electric and fuel cell vehicles being suited to different customers and use cases. 37% of households in the Milford Haven area do not have access to off-street parking – a potential market for hydrogen fuelled vehicles. Assuming that 50% of this market is ultimately served by FCEVs (with the remainder either adapting to BEV use, or migrating away from vehicles altogether to public transportation) would imply that 18% of total weekday miles could be serviced via FCEVs – a total of 27,000 miles.

The Rasa vehicle demonstration has shown that in real-world use around the Milford Haven area, vehicles are achieving 110 miles/kg of hydrogen. Considering the full potential FCEV case of 27,000 miles per week, this would imply an H2 demand from passenger vehicles of approx. 245kg per working week or ~50kg per day. If 50% of the FCEV vehicles used were larger Hyundai Nexos achieving 65 miles/kg H2, then total demand would be 67kg/day.

*This data is based on a survey in Spring 2019, assessing trips into and out of the Milford Haven area. During the summer months there is a large influx of tourists within the wider Pembrokeshire area who would potentially have a further significant demand for hydrogen – this is not assessed here.*

Total incoming trips (midweek) to the MH/PD region: 15,931.

- ≤2,500 are coming from Haverfordwest (8 miles away)
- ≤1,500 from Broad Haven region (8 miles away)
- ≤1,000 from Tenby region (18 miles away)
- ≤500 from North Pembrokeshire (23 miles away)
- ≤500 from St Clears (30 miles away)

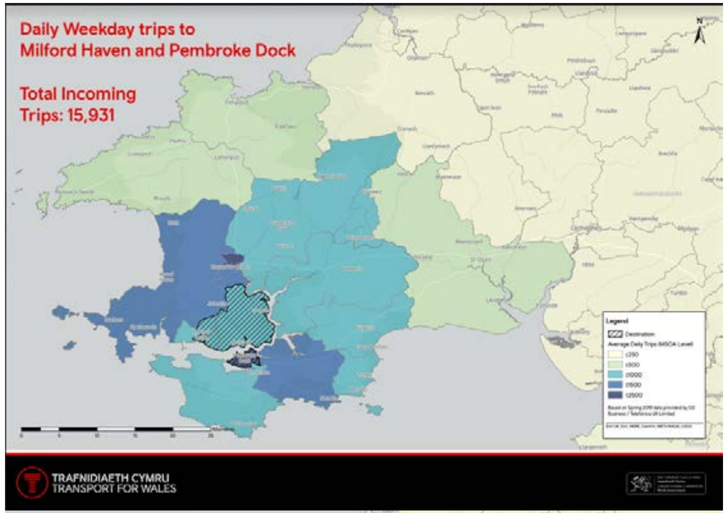
Total outgoing trips (midweek) from the MH/PD region: 15,977

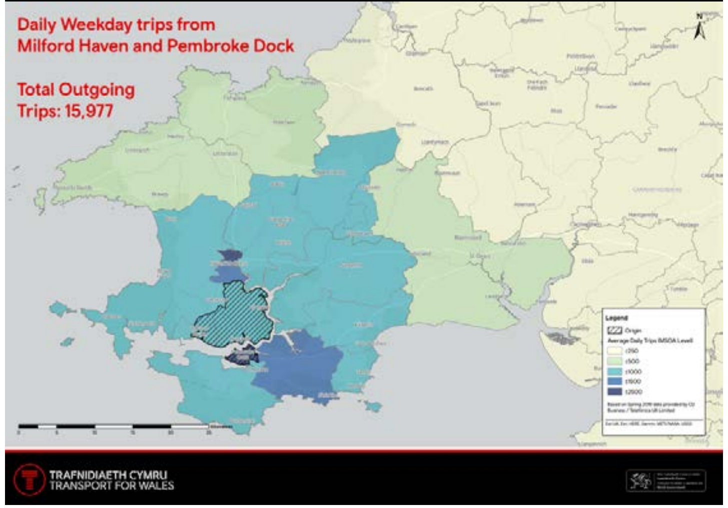
- ≤2,500 are going to Haverfordwest (8 miles away)
- ≤1,000 from Broad Haven region (8 miles away)
- ≤1,000 from Tenby region (18 miles away)
- ≤500 from North Pembrokeshire (23 miles away)
- ≤500 from St Clears (30 miles away)

**Analysis of passenger vehicle journeys to/from the Milford Haven and Pembroke Dock areas**

50 - 67 kg

**Total potential daily H2 demand from personal passenger vehicles – commuters**





Source: Transport for Wales

# Potential hydrogen demand from passenger vehicles – Group 2: Vehicles registered within the region

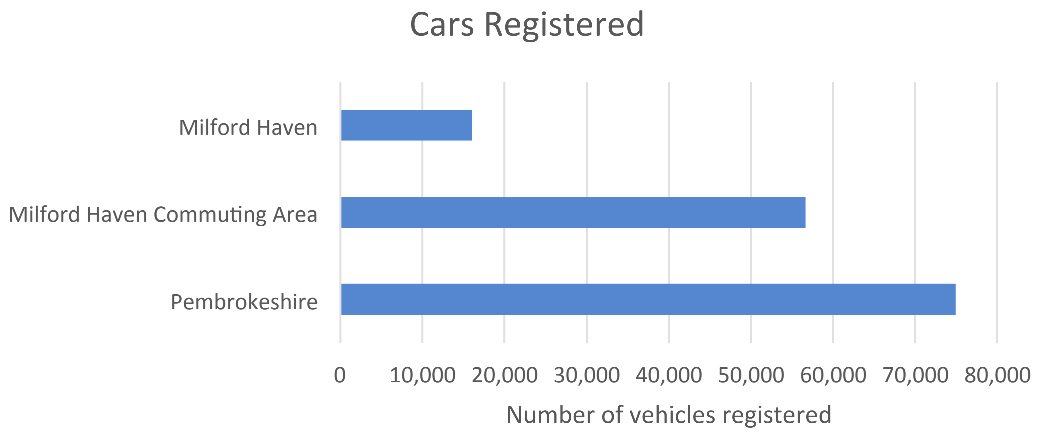
## Using vehicle ownership data to assess total potential hydrogen demand

Department for Transport data shows that there are ~75,000 cars registered within Pembrokeshire, ~57,000 within the commuting area of Milford Haven, and 16,000 within Milford Haven postcodes.

Considering the Milford Haven passenger vehicle parc alone:

- Based on a average mileage of 6,800 miles per annum (Department for Transport 2020 survey of 3,208 vehicles, analysing mean mileage between MOTs).
- The total passenger vehicle parc in Milford Haven will travel 108,800,000 miles per annum, or 298,000 miles per day.
- If similarly to the group 1 study, we assume that 18% of the vehicle parc will ultimately need H2, this equates to ~54,000 daily cumulative miles.
- At 110 miles/kg (Rasa demonstrator data), this equates to 487 kg of H2 per day assuming that 100% of the vehicles are light 2-seaters. At a mix of 50% Rasa—type vehicles and 50% Hyundai Nexo (or similar), total demand would increase to 656 kg/day.

*This figure is potentially conservative (although arguably as a result appropriate for this analysis). Rather than judging that due to customer need c.18% of the vehicle market cannot be served by a BEV, and hence hydrogen makes sense, as the cost of hydrogen reduces it can be argued that whilst BEVs can only cover 82% of potential customer needs, hydrogen vehicles can actually cover 100%, since the ownership proposition is much closer to current ICE.*



Source: Department for Transport registration data

490 – 655 kg

**Total potential daily H2 demand from personal passenger vehicles inside Milford Haven**

540 - 720 kg

**Total potential daily H2 demand from personal passenger vehicles inside Milford Haven + commuters**

# Potential hydrogen demand from passenger vehicles - fleets

**Several of the MHEK partners have passenger vehicle fleets**

Across the partners within the MHEK project there are ~250 passenger vehicles either within the company fleet, pool vehicles or provided to employees via a lease scheme.

**Other fleets to be assessed**

There is limited publicly available data with regards to other private fleets within the Milford Haven area. Given that there are 46 private hire/taxi firms listed in the Milford Haven area, this would imply a further ~50 vehicles within this category.

Under a scenario whereby 50% of these fleet vehicles were replaced with FCEVs, with an average annual mileage of 10,000 miles p.a., this would equate to a cumulative annual mileage of 1.5 million miles, or ~29,000 miles per week. Assuming again, hydrogen usage of 110 miles/kg, would imply a fuel demand of 37kg per day.

| | Cars | Light Vans | Medium duty/HGVs | Bus/Coach | Annual mileage (whole fleet) |
|---|---|---|---|---|---|
| Cyngor Sir Penfro · Pembrokeshire County Council | 49 | 193 | 155 | 30 | 15,000-30,000 |
| Port of Milford Haven | | 20 | | | 2,600 |
| GIG CYMRU NHS WALES Bwrdd Iechyd Prifysgol Hywel Dda University Health Board | ~200 | | 2 | | 10,000 |
| WALES&WEST UTILITIES | 220* | 1200* | 50* | | 10,000-30,000 |
| Dŵr Cymru Welsh Water | 200* | 5 | 175* | | 1000-75,000 (HGV) |

*full fleet – not MH specific

**~250 passenger vehicles within scope**

**40 kg**

**Total potential daily H2 demand from passenger vehicle fleets**

# Potential hydrogen demand from light commercial vehicles

**Several of the MHEK partners have passenger vehicle fleets**

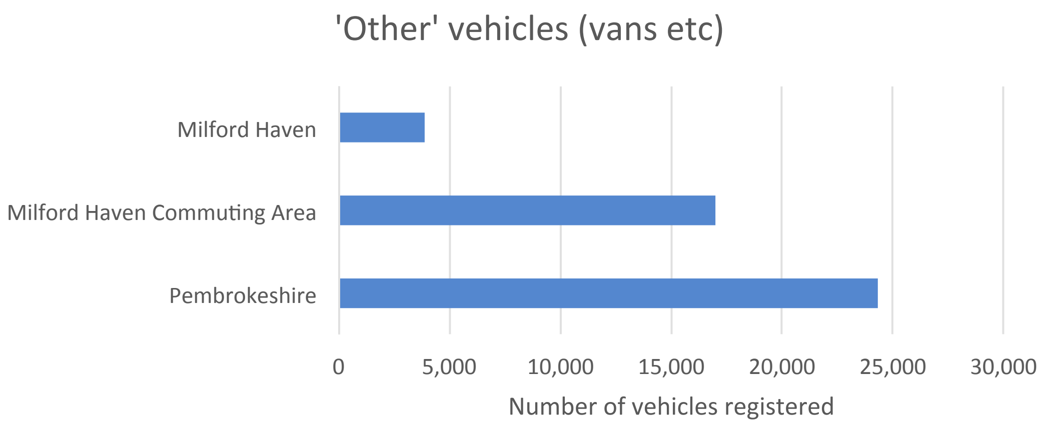
There are currently 4.2 million light commercial vehicles registered in the UK, of which 5.3% or 230,000 are registered in Wales.

Within Milford Haven there are 3,845 vehicles registered as neither cars nor motorcycles, so predominantly commercial vehicles of one form. Across the UK the total light commercial vehicle parc is 13% of the passenger vehicle parc – applying the same ratio here would imply approximately 2,000 light commercial vehicles registered within the Milford Haven region. The 213 LCVs identified as being part of the Pembrokeshire County Council, Port of Milford Haven and NHS fleets would be included within this figure (there is very limited registration data publicly available at the level of a town/district to be able to validate this).

So, for the purposes of assessing demand from light commercial vehicles, we could include 2,000 vehicles within scope. Given the inherent advantages of hydrogen vs BEV for light goods vehicles in terms of payload and range, at maturity, with equivalent TCO, for the purposes of this analysis we will assume that 50% of vehicles are FCEVs – high mileage/high payload vehicles being hydrogen fuelled, with shorter range/lower payload requirements being served by BEVs. The average UK van mileage of 13,800 miles would imply a total cumulative mileage for this van ‘fleet’ of 13.8 million miles per year, or ~265,000 per week.

There is limited information regarding the rate at which vans use hydrogen fuel; however, assuming a similar rate to the Hyundai Nexo (65 miles/kg) would necessitate a supply of ~580kg of hydrogen per day. If all LCVs identified as being associated with local fleets used hydrogen, this would equate to a demand of 124kg per day.

‘Blue light’ emergency services have vehicles that are more effectively served by FCEVs due to range, convenience of refuelling and power:weight ratios. This will be assessed later in the report.



Source: Department for Transport registration data

**580 kg** **Total potential daily H2 demand from all light commercial vehicles at maturity**

**120 kg** **Total potential daily H2 demand from local light commercial vehicle fleets**

# Bus electrification

## Buses are harder to electrify

The majority of the bus fleet across the UK (~32,000 buses) currently utilises diesel internal combustion engines, with limited trials of compressed natural gas. As has been widely reported, electrification of this fleet is more challenging than for passenger vehicles owing to the need for very large capacity, heavy and high-cost batteries in bus applications.

Full battery electrification of buses can be suited to certain locations and drive cycles. For example, data from TfL shows that across the total fleet of 9,068 vehicles the average bus in 2020/21 covered 33,800 miles per year, or just under 100 miles per day. This at an average speed of 10.27 miles per hour. These intercity duty cycles are well suited to battery electric vehicles.

## Specific challenges for Milford Haven

There are 17 bus routes covering Milford Haven, Pembroke Dock and Haverfordwest, operated by a mix of local and national service providers. As the table on the right shows, these bus routes cover a range of duty cycles/average daily mileages. 65% of the routes cover a daily mileage of over 100 miles, 53% greater than 144 miles – higher than for an intercity bus, and at higher average speeds. These duty cycles are less well suited to full battery electrification. Hydrogen fuel cell buses offer a potential solution.

| Bus | Location | Est. daily mileage | Est. no. buses | Days per week (Currently) | Est. total weekly Mileage |
|---|---|---|---|---|---|
| 300 | Milford Haven | 62 | 1 | 5 | 310 |
| 356 | Milford Haven/P.Dock | 137 | 2 | 6 | 1644 |
| 315 | Milford Haven | 165 | 1 | 5 | 825 |
| 342 | Haverfordwest | 32 | 1 | 1 | 32 |
| 311 | Haverfordwest | 21 | 1 | 5 | 105 |
| 308 | Haverfordwest | 85.1 | 1 | 5 | 425.5 |
| 301 | Haverfordwest | 40 | 1 | 5 | 200 |
| 302 | Haverfordwest/Milford | 191 | 3 | 6 | 3438 |
| 313 | Haverfordwest | 35 | 1 | 5 | 175 |
| 349 | Haverfordwest/P.Dock | 172 | 4 | 6 | 4129.2 |
| 381 | Haverfordwest | 152 | 3 | 6 | 2739 |
| 322 | Haverfordwest | 210 | 1 | 5 | 1050 |
| 360+361 | Pembroke/Pembroke Dock | 139 | 1 | 5 | 695 |
| 387/8-S | Pembroke/Pembroke Dock | 144 | 1 | 7 | 1008 |
| 387/8-W | Pembroke/Pembroke Dock | 144 | 1 | 2 | 288 |
| T5 | Haverfordwest | 252 | 3 | 6 | 4536 |
| T11 | Haverfordwest | 234 | 3 | 6 | 4221 |
| | | Totals | 29 | | 25820.7 |

Source: Pembrokeshire County Council and Geopunk.co.uk

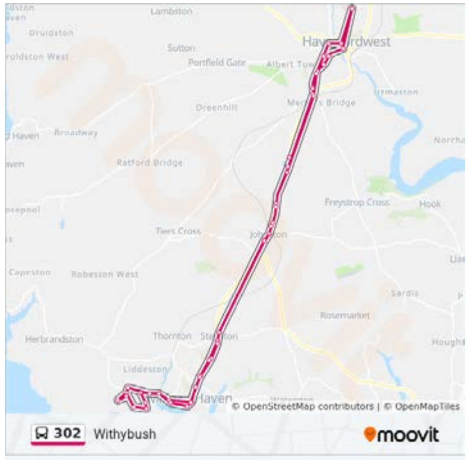
# Potential Hydrogen demand from buses travelling through Milford Haven

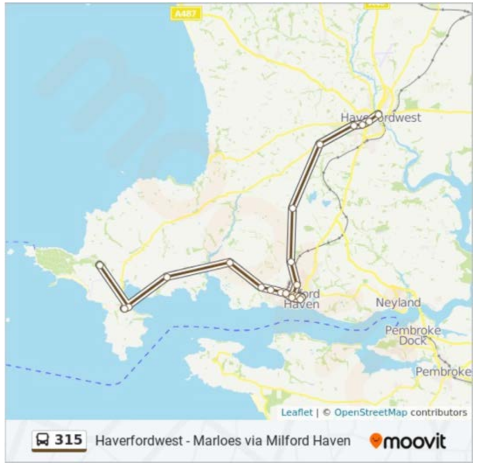
## Estimating H2 demand from buses in Milford Haven

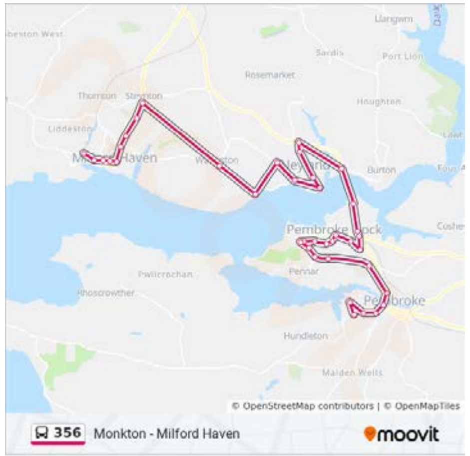
The Clean Hydrogen in European Cities (CHIC) trial deployed 56 fuel cell electric buses with associated refuelling infrastructure across 8 cities in Europe from 2010 to 2016. This trial demonstrated that:

- An operating range similar to a diesel bus could be achieved (greater than 350km)
- Short refuelling times of less than 10 minutes minimized service disruption
- Demonstrated high fuel efficiency with a consumption of 9kg of hydrogen per 100km.

Bus route numbers 300, 302, 315 and 356 pass through Milford Haven on a regular basis. The 7 buses serving these routes cover 6,217 miles per week (over a 6 day working week), or 1,036 miles per day (1,658km). Assuming a similar fuel economy to the CHIC trial of 9kg/100km would equate to a total daily demand of 150kg from these 4 bus routes.







Source: Moovit (https:moovitapp.com)

**150 kg** **Total potential daily H2 demand from 7 local buses**

# Trucks in Milford Haven

### Electrification of heavy duty trucks is challenging

Heavy goods vehicles in the UK covered a total of 17.8 billion miles in the year to September 2021, an increase of 4.7% over 5 years. This represents ~6% of all vehicle miles travelled from a fleet that represents only 1% of all vehicles. Average mileages and utilization rates are much higher than for other modes of transport.

The electrification of heavy duty trucks is challenging due to a number of factors:

- The average heavy duty vehicle covers around 2,500 miles per week, or 500 miles per working day. A typical 6 axle articulated truck used for longhaul deliveries has a maximum gross vehicle weight of 44 tonnes and would be expected to cover around 400-500 miles per working day. The battery capacity required to support both range and GVW requirements would be several hundred kWh in capacity – very high cost, and importantly high weight, reducing the available payload of the vehicle by between 19% and 87% (Roland Berger, 2017). Whilst full BEV heavy goods vehicles are now available, they are normally in lower classes (in terms of GVW) and have ranges limited to 250 miles – hence suitable for a specific range of tasks.
- To avoid 'dead-legs' most HGVs do not simply transport goods from a depot to their destination, and then return empty, so reliance on depot charging is not possible. To maximise profitability it is normal for HGVs to move from their first destination to a secondary pick-up point, such that that the truck is also full (and earning revenue) for the majority of its return journey.

### Charging en-route is unproductive

The need for full battery electric trucks to re-charge en-route is unproductive for a number of reasons:

- Unproductive miles associated with travelling away from the optimum route to a re-charging station.
- Unproductive hours associated with time to recharge. Given the potential size of HGV batteries, this equates to several hours. It is sometimes assumed that given that HGV drivers are mandated to stop and take rest breaks that these could coincide with the need to re-charge. However, in practice this is very unlikely to be the case – most drivers being forced to stop and rest wherever they may be once their tachometer has reached its limit.

The economics of heavy duty haulage are challenging, with margins as low as 5% reported. Whilst BEVs offer lower running costs, the higher cost of purchase, combined with a 20% loss in revenue associated with unproductive hours and miles, makes the economic case challenging.

### Hydrogen offers a potential solution

Series hybrid trucks with a primary power source using hydrogen allow for high mileages to be achieved combined with competitive payloads. Refuelling times are equivalent to that with current diesel vehicles. In combination this enables an economic business case for hauliers once the TCO for hydrogen vehicles reaches that of ICE.

Using data from the smaller Hyundai XCIENT vehicle already under trial, a future 44 tonne HGV could be expected to achieve 8 miles per kg of hydrogen and by 2030 with improvements in powertrain efficiency a range of 11 miles/kg is forecast. Companies such as Daimler are working on fuel cell HGVs with ranges in excess of 600 miles, so it is reasonable to assume that HGVs local to Milford Haven would be able to re-fuel once per day. An HGV covering an average of 400 miles per day would require 50kg of hydrogen per vehicle.

There is limited data available regarding the total HGV fleet in, or regularly transiting through the Milford Haven area, however, traffic survey data from Transport for Wales shows that between 3% and 4% of all trips across a number of measurement points within Milford Haven related to HGV traffic (survey carried out in September 2019). This approximates to ~10 HGVs per day travelling across Milford Haven – potentially a significant underestimate. If 80% of these trucks ultimately moved to hydrogen, then hydrogen demand could reach 400kg per day.

400 kg **Total potential daily H2 demand from 10 HGVs**

# Agricultural and off-highway

The agricultural and off-highway sectors are considered difficult to fully electrify – the reasons for which are explained in the table below. In these sectors, currently fuelled by red diesel, it is common for the fuel to be bunkered on-site rather than use a publicly accessible re-fueller. Hence, whilst these vehicles may long term be a significant user of hydrogen, this demand has not been embedded in our demand simulation

| Vehicle Sector | Challenges associated with electrification | Implications for Milford Haven |
|---|---|---|
| Agricultural | Wide range of vehicles covering multiple needs.<br>• High power demand, including need for power take-off<br>• High utilisation rates<br>• Working in remote areas (away from grid connections) limits recharging capability.<br>• Farm-sites often lacking 3 phase power necessary for large battery packs/multiple vehicles<br>• Mass associated with battery packs increases vehicle weight with detrimental impact on soil structure.<br>• Challenging economic conditions for many farmers – cost of electrified vehicle prohibitive | Pembrokeshire is a rural region for which agriculture is an important economic activity. There are an estimated 2,279 active farms in Pembrokeshire, with 1,700 full time principal farmers and 2,086 part time principal farmers. The area farmed is approximately 140,000 ha, with 12% of this land used for crops and horticulture. The remainder is grassland: permanent pasture (86,000 ha), rough grazing (8,000 ha), and rotational grassland (21,000 ha). The grassland supports 308,000 sheep and 175,000 cattle. |
| Construction | Wide range of vehicles covering multiple needs.<br>• High power demand<br>• High utilisation rates<br>• Working in undeveloped areas (away from grid connections) limits recharging capability. | Construction forms a relatively high proportion of the economy in Pembrokeshire (1.52x the national average) |
| Forestry | • High power demand<br>• High utilisation rates<br>• Working in remote areas (away from grid connections) limits recharging capability. | Forestry has long been an important industry in Wales for which the Welsh Assembly has developed the Woodlands for Wales (2009) strategy, the three principal objectives of which are to:<br>• Bring more woodlands into management<br>• Expand woodland cover<br>• Increase the resilience of Welsh woodlands and trees so that they deliver more benefit to the public |
| Mining/Quarrying | • Very high power demand<br>• High utilisation rates<br>• Working in remote areas (away from grid connections) limits recharging capability. | Whilst mining in Wales provided a significant source of income to the Welsh economy in the 19th and early 20th century, only 0.2% of the current Welsh economy is made up of mining and quarrying |

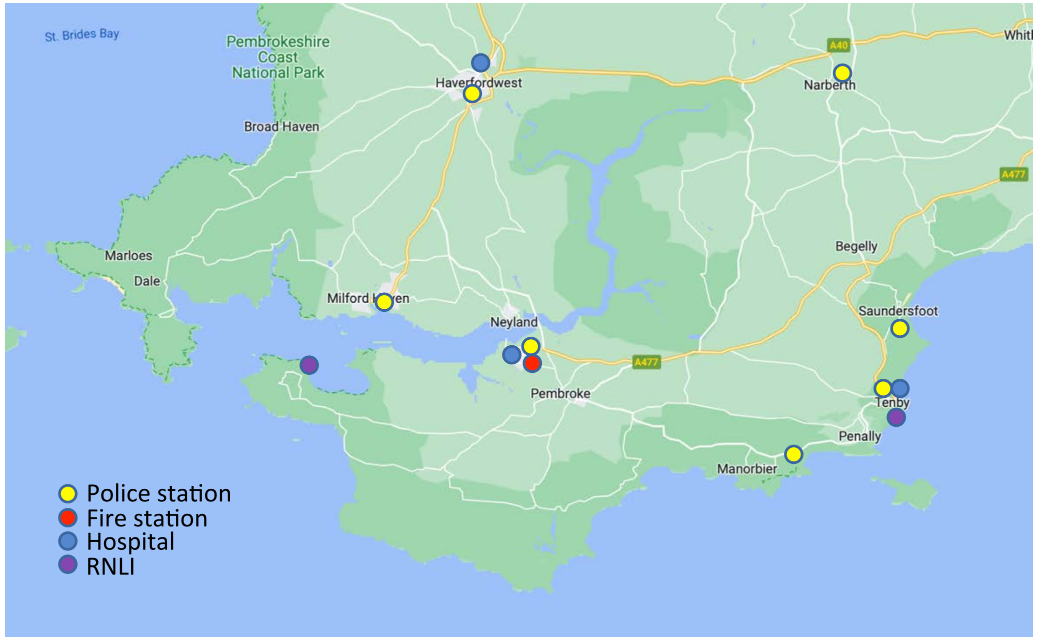
0 kg

**Total potential daily H2 demand from a publicly accessible refueller – assumption being that supply is at a depot/agricultural site**

# Wider applications of H2 – emergency service vehicles

## Electrification of emergency service vehicles

The electrification of emergency service vehicles is also very challenging, with a need to be available 24/7 (no down-time due to charging), reliable in all weather conditions (no reduction in range or performance due to cold weather) and the need to be able to support sometimes significant ancillary loads. There is limited information available on the specific duty cycles of blue light service vehicles in the Milford Haven area but it is possible to create a demand simulation based on a number of scenarios and research/reports from other regions of the UK. From this analysis we have assessed a potential daily demand of ~30kg. Further work with the emergency services would be required to investigate further. Other emergency services in the Milford Haven area such as RNLI have not been included due to lack of vehicle duty cycle information.



**30 kg** **Total potential daily H2 demand from emergency vehicles**

### Simulation of potential hydrogen demand from blue light services

| Vehicle Sector | Ambulance Services | Police Service | Fire Service |
|---|---|---|---|
| Number of vehicles within scope | 4 (300 NHS vehicles across 90 stations in Wales + St. John's and other services | 4 (assume mix of FCEV and BEV) | 5 pumps/tankers<br>1 light duty vehicle |
| Average Daily Mileage for Fleet | ~100 (estimate based on research from similar rural service - YAS) | ~50 (based on ~15000 miles per year) | ~10 miles a day average across the HGVs. 25 miles/day for light vehicle |
| Fuel Use, Miles/kg | ~30 miles per kg (estimate based on typical ICE performance) | 65 miles per kg (based on Hyundai Nexo) | 8 miles per kg (for HGV). 65 miles/kg for light duty |
| Potential daily H2 Demand | 13 | 6 | 8 |

Source: Riversimple correspondence with local emergency services

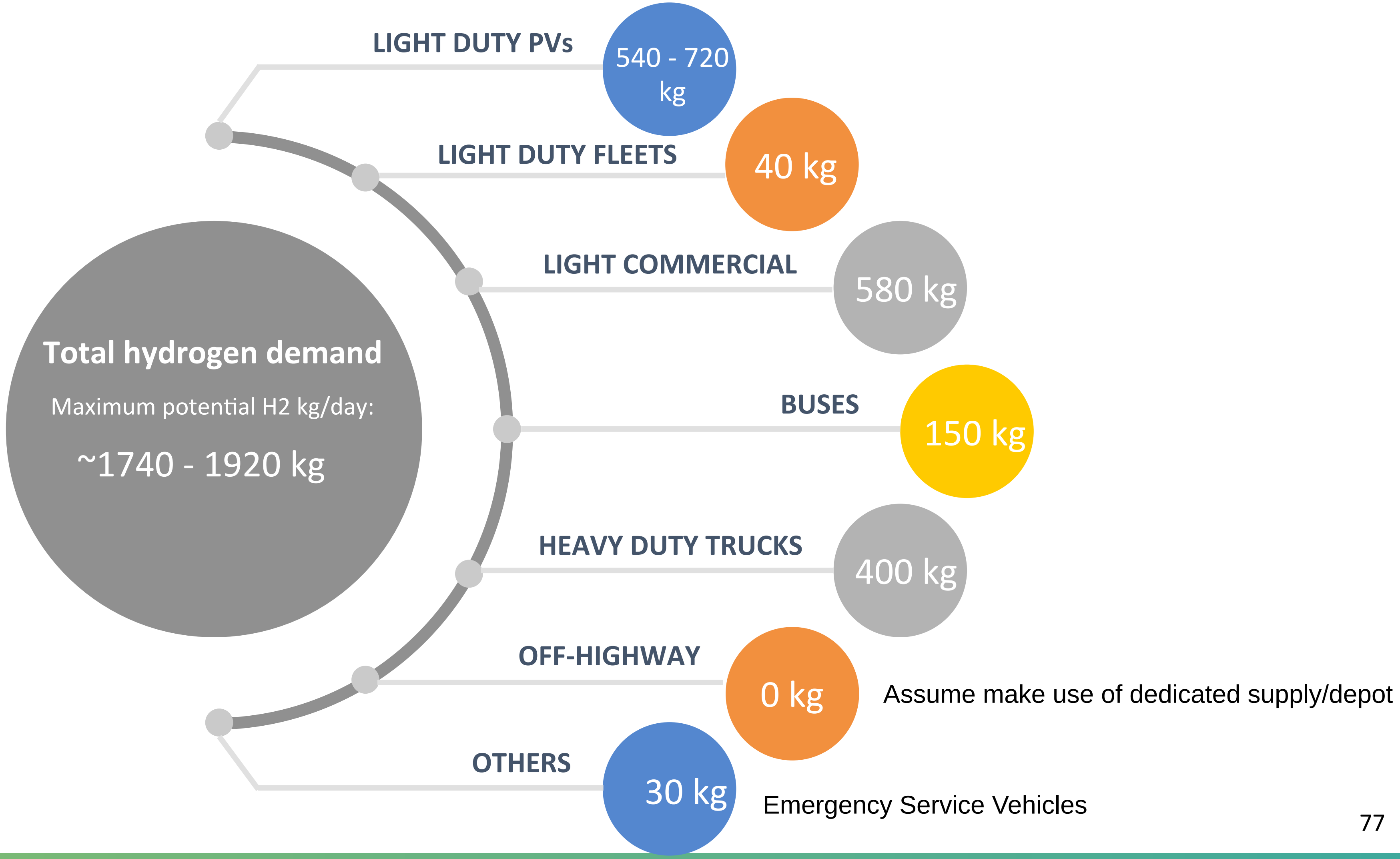
# Conclusion - Estimating hydrogen demand in Milford Haven – 2050 case

At a time when all vehicles will need to be zero emission, given the very different characteristics of each vehicle type, there is likely to be a strong need for hydrogen, particularly across commercial vehicles.

Passenger vehicle demand is approximately 1/3 of the total demand profile for Milford Haven. Whilst the majority of current zero emission passenger vehicles are battery electric, affordability and convenience are likely to remain significant barriers to adoption particularly for those households in Milford Haven without access to home charging – an issue that could be addressed with a high efficiency fuel cell powertrain architecture.

**An important conclusion is that given there are several discrete sources of demand, it is essential that any installed refuelling infrastructure is publicly accessible. With public accessibility, as demand cases evolve and at different rates, it will maximise the potential for the refueller to make a positive financial return. The majority of vehicles ( light duty passenger vehicles, fleets, light commercial and HGVs) would naturally refuel in publicly accessible locations vs depots.**

This analysis represents a viewpoint in 2050. In the next section, we will explore how this transition may occur to determine the point at which it becomes economically viable to commence installation of this infrastructure.



**Total hydrogen demand**

Maximum potential H2 kg/day:

~1740 - 1920 kg

**LIGHT DUTY PVs** 540 - 720 kg

**LIGHT DUTY FLEETS** 40 kg

**LIGHT COMMERCIAL** 580 kg

**BUSES** 150 kg

**HEAVY DUTY TRUCKS** 400 kg

**OFF-HIGHWAY** 0 kg

Assume make use of dedicated supply/depot

**OTHERS** 30 kg

Emergency Service Vehicles

MILFORD HAVEN: ENERGY KINGDOM

# Modelling the transition to H2

## The tipping point for H2 use

ENERGY KINGDOM
DEYRNAS YNNI

# Modelling the transition to H2 – what about 2025/2030?

## Modelling the transition

Our analysis has shown the full potential demand for hydrogen at a time where all vehicles need to be zero emission – there is clearly a role for this fuel across multiple vehicle sectors, reinforcing the need to publicly accessible infrastructure. However, demand from each of these sectors is likely to develop at different rates. In order to analyse when there is a business case for a publicly accessible refueller, we will need to understand the potential transition from ICE to hydrogen across each of these sectors.

## Passenger vehicles

Whilst new fully ICE vehicles will be banned from sale in 2030, and hybrid vehicles from 2035, as we have shown earlier, given the average age of vehicles in the UK, the transition to ZEVs may take several years.

Government policy continues to evolve with a recently announced consultation to investigate the potential to mandate that 50% of vehicle sales by 2028 are zero emission. If introduced this will accelerate the transition to ZEV, with hydrogen within that mix.

Vehicle manufacturers are responding to these policy announcements, with several volume OEMs already announcing a phase out of pure ICE vehicles between 2025 and 2030.

## Consumer behaviour is important

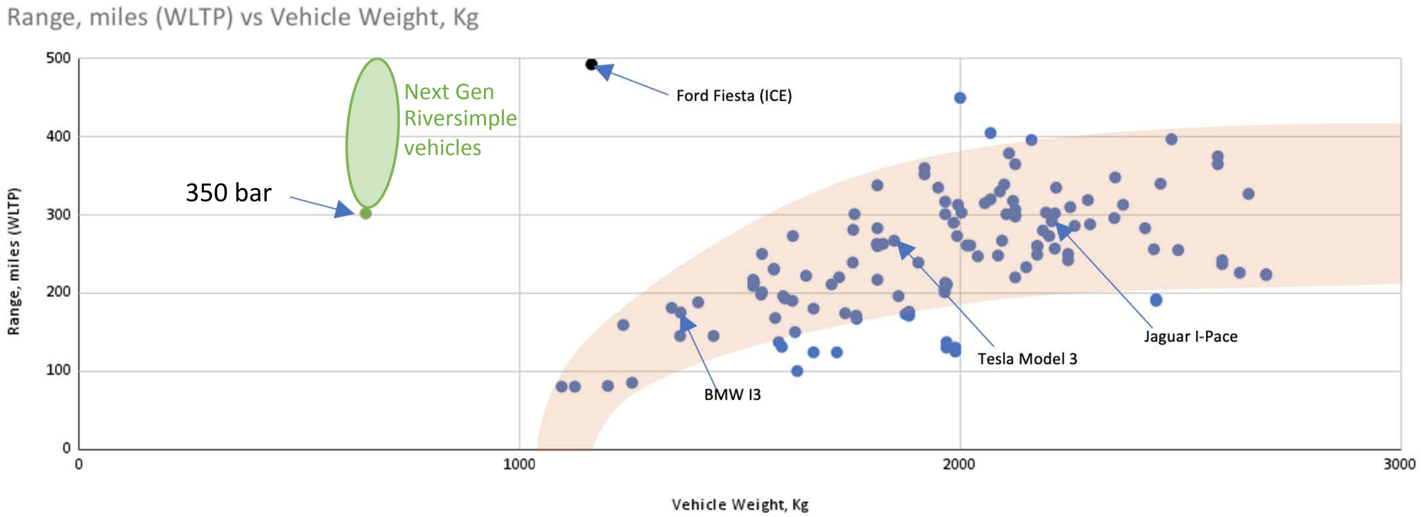
Government legislation will guide vehicle manufacturers towards reducing the mix of new ICE vehicles on sale. However, the actual transition of the vehicle parc towards ZEVs will arguably be achieved when consumers perceive that ZEVs are not inconvenient or expensive to use vs current ICEs.

As covered earlier, TCO will be an important factor. Affordability being particularly important for those households least likely to have access to home charging. In this respect the proposed Riversimple powertrain architecture has distinct advantages.

## Hydrogen cost is a tipping point

Significant demand for hydrogen in passenger vehicles may be triggered once the running costs are equivalent or lower than for a battery electric equivalent, or for an equivalent ICE vehicle. This tipping point is influenced by the efficiency of the vehicles themselves and the costs of the alternative fuels.

The TCO analysis shows that there are already several ZEV vehicles that are approaching the annual total cost of ownership of a typical high volume ICE vehicle, albeit offering much lower range. As battery and fuel cell costs reduce, this will continue to improve – many vehicle OEMs expecting BEVs to achieve cost equivalence by 2030.



# Understanding the tipping point - Real cost competitiveness of H2 passenger vehicles – comparator fuel cost

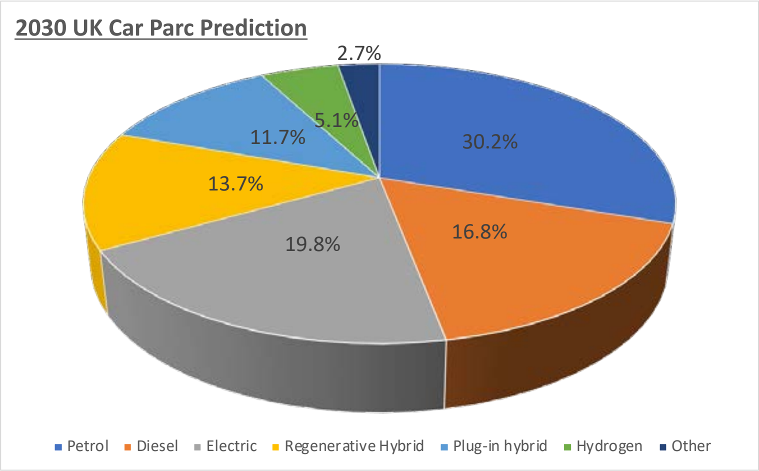
## Recent and rapid rises in the cost of ‘legacy fuels’

The appeal of hydrogen passenger vehicles to potential users is related to convenience and cost. As already discussed, hydrogen offers a similar user experience to current ICE vehicles, particularly for those who have limitations in terms of home charging capability, or regularly cover long distances and need to be able to quickly and conveniently refuel on a regular basis.

In 2021, the AA carried out research which concluded that in 2030, 24.9% of the UK car parc would be zero emission (BEV or hydrogen), with 30.2% still petrol, and 16.8% diesel, with hybrids totalling 25.7%. Hydrogen passenger vehicles represent over 20% of the total zero emission fleet.

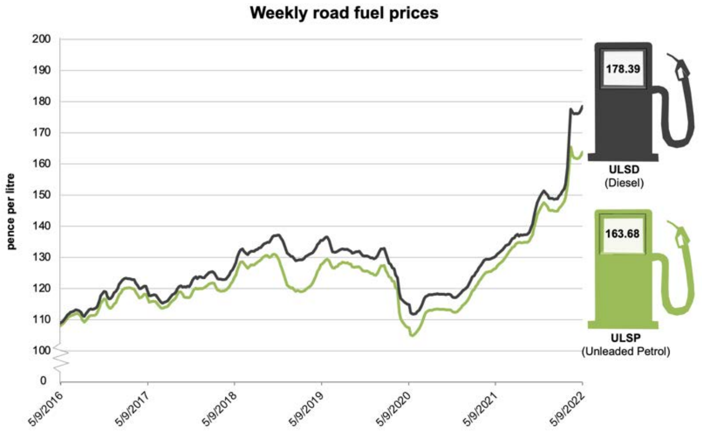
As cited earlier, surveys have shown that cost is currently a major barrier to ZEV vehicle adoption. However, research has also shown that customer buying behaviour for EVs is closely linked to the cost of alternatively fuelled vehicles. The National Bureau of Economic Research in the US reported in March 2022 that using data for California they could establish that EV sales respond both to electricity prices (falling as they rise) and to petrol prices (rising as pump prices increase). Sales responded to petrol prices at between four and six times the rate of electricity prices.

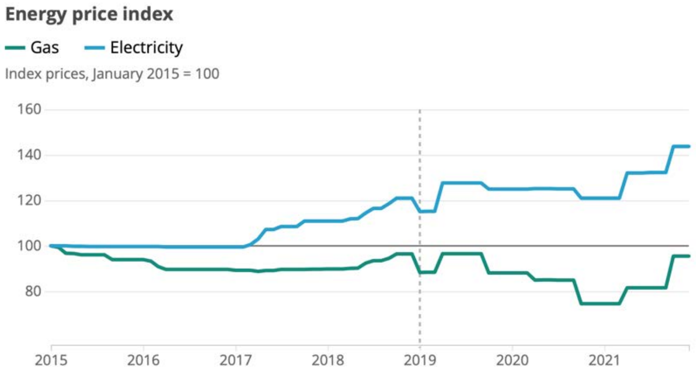
2022 has already seen dramatic increases in both pump prices of petrol and diesel, and home electricity costs in the UK. Both have the potential to increase the transition to zero emission vehicles at a rate faster than the AA analysis from 2021. It is interesting therefore to understand how hydrogen costs may influence this transition.



Source: AA survey, Feb 2021

*Prior to current fuel and electricity cost increases, in 2030 already forecasting that 25% of the vehicle parc would be ZEV, of which 25% would be H2.*





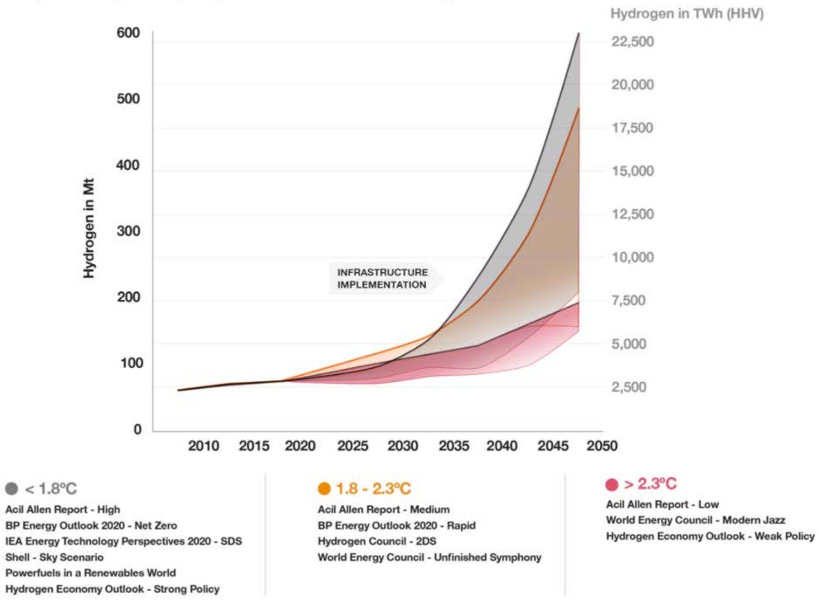
Source: Ofgem, Office for National Statistics – Consumer price statistics

# Understanding the tipping point - real cost competitiveness of H2 passenger vehicles – H2 cost

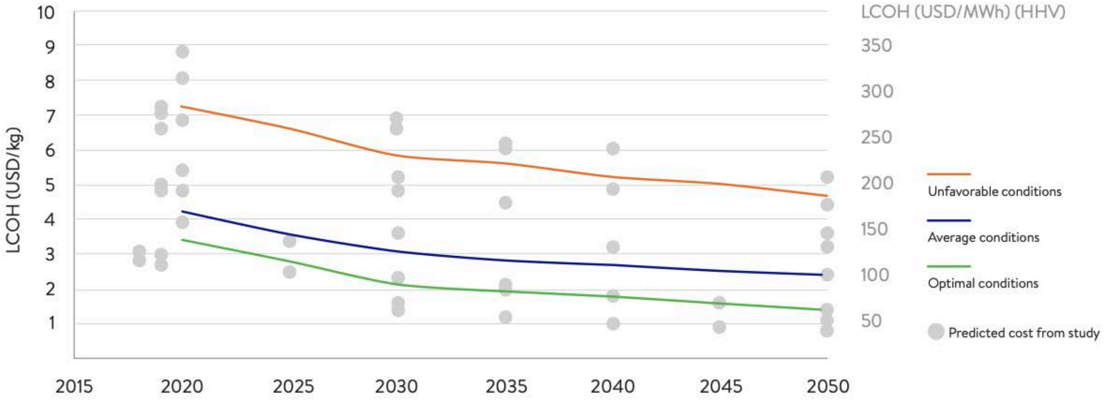
## Predicting future global demand scenarios and costs for green hydrogen

PwC and the World Energy Council have conducted extensive research into future global demand and potential costs of green hydrogen. They conclude that '*hydrogen produced through renewable resources such as wind and solar hold significant promise in meeting the world's future energy demands*'. GHG emissions results for hydrogen production pathways vary widely, from 75-100 gCO2e/MJ for grid electrolysis in 2020 or unabated natural gas pathways, to around 10-45 gCO2e/MJ for abated natural gas pathways, to 0-5 gCO2e/MJ for renewable and nuclear electricity (source: Options for a UK low carbon hydrogen standard, published by BEIS, May 2021).

Without a price on carbon emissions, grey hydrogen from natural gas is currently inexpensive (<€2 per kg). However, the World Energy Council/PwC research suggests that green hydrogen could be produced for €3 to €8/kg in Europe today - the low end of this range being achieved most easily in locations with access to low-cost renewable energy. This supports research carried out in Wales which demonstrated that a positive business case could be achieved now for the production of green hydrogen for the transport sector, from curtailed onshore wind, with a cost of £5/kg. Longer term, the EU has already stated a goal of achieving €1.8/kg for green hydrogen by 2030 (reference European Hydrogen Week keynote address by President von der Leyen)



**Source: PwC**

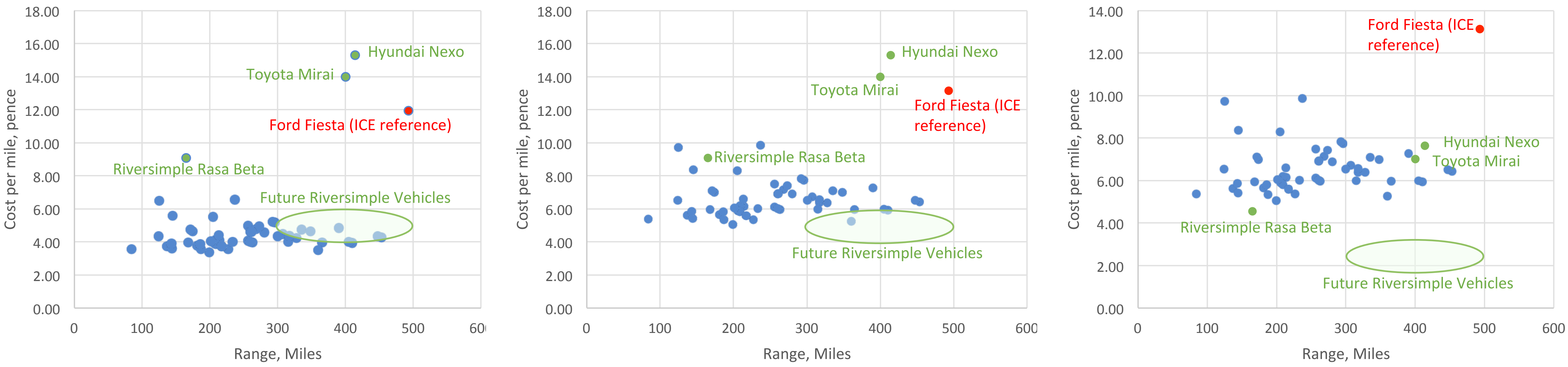


***Source: World Energy Council****

Source: Hydrogen on the Horizon: ready, almost set, go? Working paper – hydrogen demand and cost dynamics, World Energy Council

# Understanding the tipping point - real cost competitiveness of H2 passenger vehicles – fuel cost

Cost per mile, pence vs range in miles for 3 scenarios



Scenario 1: 2021 average petrol and home electric prices, H2 at £10/kg

Scenario 2: 2022 average petrol and home electric prices, H2 at £10/kg

Scenario 3: 2022 average petrol and home electric prices, H2 at £5/kg

## Hydrogen cost is a tipping point

The trial data for the Rasa shows that this tipping point could be achieved much sooner with the use of a lightweight and efficient vehicle architecture. As a reminder, the vehicle demonstration in Milford Haven used the Rasa Beta, representing a first iteration of the powertrain and vehicle architecture to support technical validation of the concept. In the demonstration the Rasa Beta achieved 110 miles/kg of H2. Under these conditions, to achieve running cost parity with a BEV at 2021 average electricity prices, hydrogen costs would need to achieve £5.48/kg for a customer who could home charge, £13.76/kg for a customer who could only rapid charge. Considering 2022 home electricity costs, hydrogen becomes economic for a customer who can home charge at £10/kg. A future Riversimple Rasa vehicle, further optimized for range (range of 300+ miles forecast) and efficiency would be expected to improve the economic benefit vs BEV.

The Rasa VaaS business model could further accelerate this transition since fuel costs are included within the fixed monthly charge. This completely de-risks the shift to hydrogen mobility for consumers. Longer term, an efficient hydrogen vehicle architecture could offer significantly cheaper running costs. With hydrogen at £5/kg, costs per mile are <50% of that for a typical BEV. Assuming achievement of the EU target of €1.8/kg for green hydrogen, running costs would be <20% of a typical BEV.

# What about the rate of transition for other vehicle sectors?

## Light Commercial Vehicles

Battery electric vans are currently compromised in terms of payload, range and overall cost. Limited sales are being stimulated by the introduction of ultra-low emission zones across many cities. Daily charges for ICE vehicles, combined with central government support in the form of grants, means that BEVs are achieving TCO parity in these circumstances.

For van users that can cope with the inherent vehicle constraints they are an appropriate choice. However, as we have already seen, 97% of the van fleet remains diesel.

Hydrogen fuel cells offer a compelling solution. Vehicles from high volume OEMs (Vauxhall) will enter the UK market in 2023, so vehicle availability will no longer be an impediment.

For Milford Haven, local government policy could then be a tipping point – through a combination of positive action (shifting captive vehicle fleets to hydrogen), and legislation (for example introduction of ULEV zones).

## Buses/coaches

Hydrogen offers compelling advantages for buses in rural areas where daily mileages are higher – allowing for higher range/ reduced re-fuelling times, similar to ICE. Annual running costs are already approaching parity with ICE. Capital costs, however, remain significantly higher.

Similarly to light commercial vehicles, local government policy is likely to be an important factor in promoting the shift towards hydrogen in advance of the central government imposed timetable for the phase out of new ICE vehicles. The Zero Emission Bus Regional Area Scheme (ZEBRA) is an example of how government funding can accelerate the transition to zero emission public transportation

## Heavy Duty Trucks

As discussed earlier, this sector remains challenging to electrify due to challenging economics for hauliers. Whilst hydrogen offers a long-term solution, significantly higher capital costs mean that most hydrogen fuelled heavy duty trucks currently in operation are part of vehicle trials, rather than in commercial use – examples being the trials underway since 2021 in Europe conducted by Daimler, Hyundai and Scania.

The Advanced Propulsion Centre's 2020 Automotive Fuel Cell Roadmap forecasts a reduction in system cost of >50% by 2025 and >80% by 2030 for heavy duty vehicles (compared to a 2020 baseline), with improvements in efficiency and durability. This has the potential to accelerate the transition from ICE.

Furthermore, HGV vehicles are assets with a 15 year life, hence buying decisions are based on confidence in securing full utilisation over their entire life. Current lack of availability and uncertainty regarding refuelling infrastructure is arguably holding back vehicle demand. Once a roadmap for infrastructure development is clear, however, there may be a disincentive to continue with ICE if future costs and availability of fossil fuels are in doubt. In the meantime, incentives will be required to stimulate demand.

The high hydrogen demand from an individual HGV means that converting a small local haulage fleet to hydrogen may be enough to seed the infrastructure investment. This will be explored further later in this report.

***These difficult to electrify vehicle sectors will be explored in more detail in the next pages.***

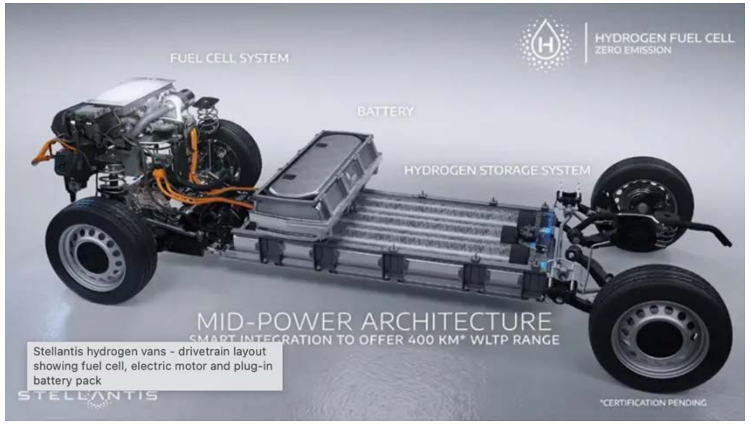
# The Transition to hydrogen vans has already started

## Hydrogen Light Commercial Vehicles are now available

Vehicle OEMs recognise the challenges associated with the electrification of vans with major launches planned for hydrogen vehicles in the next 12 months:

- Stellantis (the parent company of Peugeot, Citroen, Fiat, Opel, Vauxhall and Chrysler) have already started to introduce a plug-in-hybrid electric van supplemented with a hydrogen fuel cell in some markets. This vehicle combines a 45kW fuel cell stack and capacity of 4.4kg of hydrogen with a 10.5kWh battery pack offering a total range of 248 miles. Whilst the range is not significantly greater than the full battery version of these vans which can travel 211 miles (WLTP), the critical advantage is the shorter time required to re-fuel. Refilling the hydrogen tank takes only 3 minutes, vs at least half an hour for a meaningful recharge for a BEV (and even then not achieving 100% charge).
- Vauxhall are planning to introduce the hydrogen fuelled Vivaro-e in early 2023. The left-hand drive Opel version has already gone into service with some business customers in Germany.
- Hyvia, a union of Renault Group and Plug Power is now offering mobility solutions including green hydrogen production, storage, supply and a range of commercial vehicles based on the Renault Master light commercial vehicle platform
- Ford, the manufacturer of the largest selling vehicle in the UK (the Ford Transit Custom) are working with AVL Ltd to produce an FCEV demonstrator.

Vauxhall Vivaro-e hydrogen van (launch 2023). Image courtesy of Vauxhall UK



Stellantis Hydrogen fuel cell architecture. Image courtesy of Stellantis

Hyvia vehicle ecosystem

# Hydrogen bus trials are now well established across the UK

Since 2020 there have been an increasing number of trials across the UK with hydrogen fuel cell buses, evaluating their use against legacy diesel fleets. The challenges associated with more widescale adoption are associated with both infrastructure roll-out and current capital costs for fuel cell vehicles in comparison with existing diesel vehicles. The bus trials, however, have consistently shown that fuel cell electric buses can support similar duty cycles and operating patterns to current ICE buses.

## Aug 2020

In August 2020 trials were completed with the Wrightbus Streetdeck FCEV in Brighton and Hove. Brighton and Hove and Metrobus was the first UK bus operator to publicly set a goal to be zero emission by 2030.

## July 2021

Unveiling of the first of 20 Wrightbus FCEVs purchased as part of Birmingham City Council's Clean Air Hydrogen Bus Pilot. Refuelling infrastructure provided by ITM through the re-fuelling hub at Tyseley Energy Park.

## Oct 2021

A combined initiative between HITRANS, Protium Energy Limited and Opportunity Cromarty Firth to trial a Caetano FCEV bus in Inverness on bus routes operated by Stagecoach Highlands

## Nov 2021

Announcement of hydrogen transport pilots in the Tees valley including the retrofit by Ricardo PLC of a Stagecoach double decker diesel bus with a hybrid fuel cell system. The trial includes 10 rapid response H2 passenger vehicles for Cleveland Police and NHS patient support, plus hydrogen vans operating in collaboration with a leading supermarket chain.

## Jan 2022

A total order of 54 FCEVs to be integrated into the Go-Ahead fleet serving Metrobus routes across Surrey and Sussex. Europe's largest fleet of hydrogen buses to date.

# Hydrogen buses a potential solution for MH

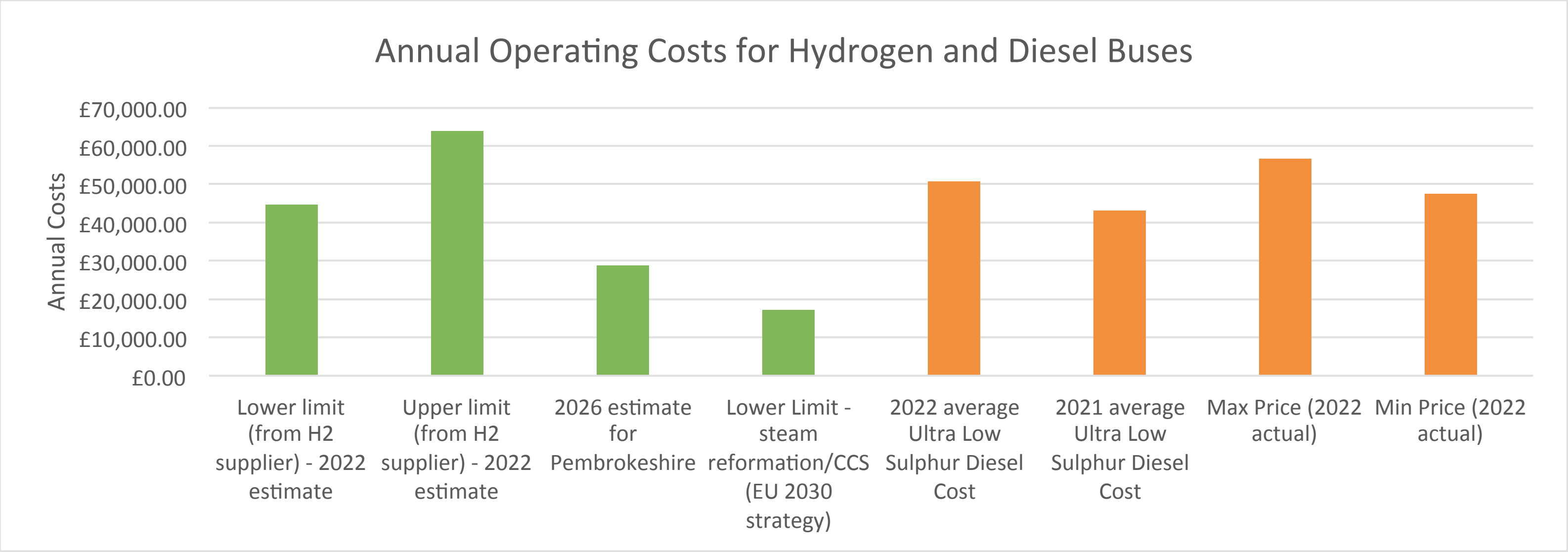
## Similar operating experience to diesel

Hydrogen buses offer long range (300-400km), quick refuelling (10-20mins), zero tailpipe emissions, improved air quality and the potential for reduced fuel costs. In rural areas where longer range is required this offers an attractive solution for decarbonisation vs battery electric vehicles. The much faster refuelling times ensure that the vehicle is out of operation for a similar time to the current diesel fleet.

Operating costs have the potential to be significantly lower than for the diesel-fuelled equivalent. Current (2022) hydrogen prices have the potential to offer lower operating costs vs diesel – considering both 2021 and 2022 average prices for diesel. In the chart below, four hydrogen cost scenarios have been simulated: 1) £7/kg (lower estimate for supply in 2022); 2) 10/kg (upper estimate for supply in 2022); 3) £4.50/kg (estimate for Green Hydrogen in Pembrokeshire in 2026) and £2.69/kg (EU 2030 lower limit from steam reformation/CCS). In the long-term there is an expectation that green H2 costs will reduce significantly, offering considerable savings vs fossil-fuelled equivalents.

Whilst capital costs for FCEV buses and heavy duty trucks are currently much higher than ICE, there is an expectation in some markets to achieve cost parity with ICE by 2027 and with BEV by 2028. (Deloitte/Ballard, 2020).

Image source: Wrightbus



Source: Riversimple Analysis

# Introduction of hydrogen Heavy Duty Vehicles

**The Roadmap for introduction of hydrogen heavy duty trucks is becoming clearer**

Major manufacturers of heavy duty trucks have already commenced trials of hydrogen fuel cell heavy duty trucks since 2021, with plans for first production vehicles to be delivered to customers in the 2024/2025 timescale. Large scale adoption of H2 trucks is expected to follow establishment of refuelling infrastructure, with several of the vehicle trials planned including refuelling station installation. Daimler Trucks are collaborating with Shell and Scania/Cummins with HyTrucks to ensure that refuellers are in place. Shell's plan includes 150 refuellers and 5,000 Daimler trucks by 2030.

| | | >2021 | 2022 | 2023 | 2024 | 2025 | 2026-30 |
|---|---|---|---|---|---|---|---|
| Daimler Truck AG |  | Joint project with Shell. Testing commences | | Initial commercial trials | | First customer vehicles | Series production vehicles (2027) |
| Hyundai XCIENT |  | Commercial trial in Switzerland (2020 start) | | | | Sales of 1,600 XCIENT fuel cell trucks achieved | |
| Scania/Cummins collaboration |  | 4 trial vehicles in Norway with ASKO (2020) | | | 20 fuel cell electric trucks delivered to HyTrucks Netherlands | HyTrucks plan to deploy 1,000 fuel cell trucks | |
| MAN Truck & Bus |  | | | | Customer trials in Bavaria | | Production once infrastructure widespread |

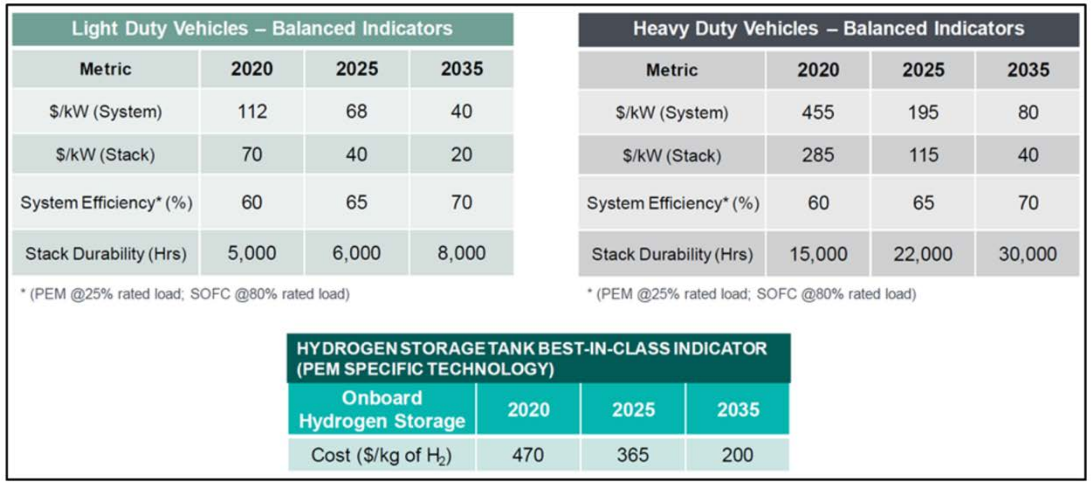
Source: public announcements of future fuel cell heavy duty truck trials/production plans

# Cost reduction roadmap for fuel cells and high capacity batteries

## A roadmap for future fuel cell cost and efficiency improvements has been defined

The Advanced Propulsion Centre has defined a roadmap for fuel cell stack and system cost reduction, together with expected efficiency and durability improvements. Improvements in the use of expensive metals such as platinum within the latest fuel cells means that raw material cost is no longer the limiting factor to achieving significant cost reduction. Economies of scale through mass production are expected to deliver the majority of savings.

A system level cost of $40/kW in 2035 is competitive with ICE. In an efficient, lightweight vehicle such as the Riversimple Rasa, the fuel cell is only 12kW – fuel cell costs therefore become a relatively insignificant part of the total vehicle cost.



**Light Duty Vehicles – Balanced Indicators**

| Metric | 2020 | 2025 | 2035 |
|---|---|---|---|
| $/kW (System) | 112 | 68 | 40 |
| $/kW (Stack) | 70 | 40 | 20 |
| System Efficiency* (%) | 60 | 65 | 70 |
| Stack Durability (Hrs) | 5,000 | 6,000 | 8,000 |

* (PEM @25% rated load; SOFC @80% rated load)

**Heavy Duty Vehicles – Balanced Indicators**

| Metric | 2020 | 2025 | 2035 |
|---|---|---|---|
| $/kW (System) | 455 | 195 | 80 |
| $/kW (Stack) | 285 | 115 | 40 |
| System Efficiency* (%) | 60 | 65 | 70 |
| Stack Durability (Hrs) | 15,000 | 22,000 | 30,000 |

* (PEM @25% rated load; SOFC @80% rated load)

**HYDROGEN STORAGE TANK BEST-IN-CLASS INDICATOR (PEM SPECIFIC TECHNOLOGY)**

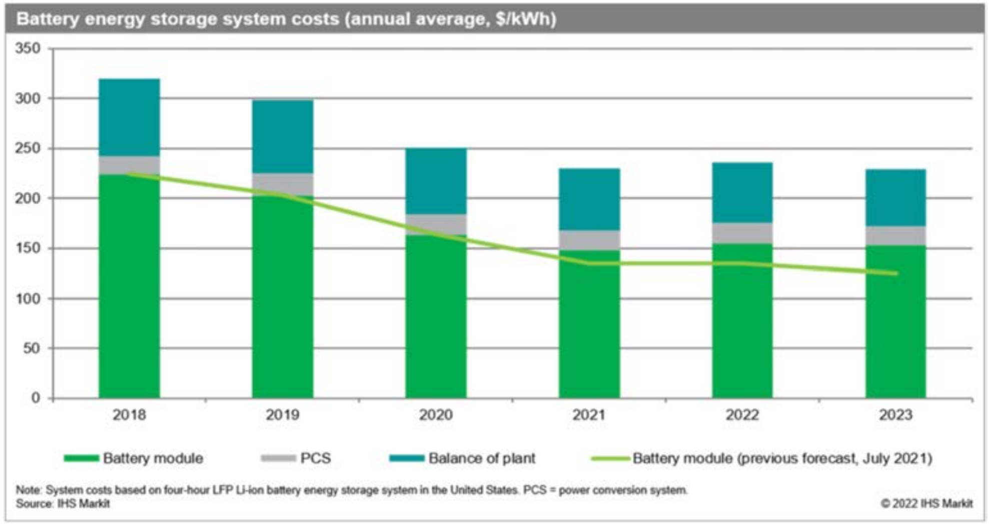
| Onboard Hydrogen Storage | 2020 | 2025 | 2035 |
|---|---|---|---|
| Cost ($/kg of $H_2$) | 470 | 365 | 200 |

Source: Advanced Propulsion Centre UK, 2020 Automotive Fuel Cell Roadmap

## Battery costs are strongly influenced by the availability of raw materials

High capacity motive battery design, chemistry, manufacturing and packaging has improved enormously over the last decade, such that the latest BEVs have real-world ranges many times greater than the first vehicles to market.

The introduction of new battery technologies such as solid state offers the future potential for higher energy density and faster charging rates. IHS Markit reported in January 2022 that cost reduction of these batteries has recently stalled, however, due to increasing raw material costs. Lithium, nickel and cobalt are the key metals used in BEV batteries for which there remains uncertainty whether there is enough global mining capacity to deliver the raw materials required to meet projected EV demand – total demand for batteries expecting to increase from 200GWh in 2019, to between 2600 GWh (EU forecast) and 5700GWh in 2030 (iClima report). This is likely to maintain an upward pressure on prices, at least in the short term.



Note: System costs based on four-hour LFP Li-ion battery energy storage system in the United States. PCS = power conversion system.
Source: IHS Markit

Source: IHS Markit, 2022

# Potential demand scenarios: short-term to long-term

As we have described, at the point when ICE vehicles have been phased out, the role for hydrogen is likely (at least at first) to be different for differing vehicle types/sectors. This is as a consequence of customer demands, vehicle usage patterns and economics. Some vehicle sectors are difficult to electrify, which reinforces the need for an alternative such as hydrogen. Through studying the total number of vehicles in operation within these sectors, and their current use patterns we have been able to simulate total hydrogen demand across Milford Haven at maturity for which we estimate ~1740 to 1920 kg/day depending on the mix of passenger vehicles.

The transition in demand from today, where the majority of vehicles are ICE, is much more difficult to predict. However, through focusing initially on captive fleets (both cars and light commercial vehicles) and buses (potentially supported via incentives) it is possible to build total demand to the level required to justify infrastructure investment. With respect to passenger vehicles, those with high efficiency (such as the Riversimple Rasa) already offer competitive running costs vs current BEV vehicles and a competitive total cost of ownership proposition compared with both BEV and ICE. This offers the potential to stimulate market growth for passenger vehicles. **Public access to the hydrogen refueller is critical, since we cannot rely on one transport mode to seed the market on its own and this would accommodate from the outset the majority of the potential hydrogen vehicle parc.**

Potential demand scenarios – H2 demand kg/day

| | Cars | Cars-Fleet | Light Vans | Buses | Heavy Goods | Off-highway | Other | TOTAL |
|---|---|---|---|---|---|---|---|---|
| Seeding (short-term) | 50<br>Affordable FCEV | 20<br>Focus: captive fleets | 120<br>Focus: captive fleets | 150 | 0 | 0 | 15 | 335 |
| Building (mid-term) | 100 | 40 | 270 | 150 | 80 | 0 | 30 | 670 |
| Mature (long-term) | 540 - 720<br>Full range of FCEVs | 40 | 580 | 150 | 400 | 0 | 30 | 1740 - 1920 |

# Potential HRS Locations

A detailed evaluation of potential locations for a hydrogen refuelling station is outside of the scope of this report, however, it is useful to consider in broad terms locations that may be appropriate.

As we have seen, buses and captive fleets are likely to be important vehicle sectors to seed the market for hydrogen demand in the Milford Haven area, so any future HRS location needs to be able to conveniently serve this market. Furthermore, given that FCEV passenger vehicles could in future be the single largest demand source, it is also important to consider areas of highest passenger traffic density.

The map to the right addresses the main sources of initial demand:

- Fleet and bus routes are shown in purple
- Council depots are located in Milford Haven and Haverfordwest
- Traffic count data (from a 2 week survey in Sept 2019) shows two locations with the highest number of journeys: location 1, in Milford Haven (7873 journeys in a 24 hour period), and Location 2 in Pembroke Dock (6499 journeys in a 24 hour period). These locations are already served by several existing petrol filling stations.

Based on these considerations, either location 1 or location 2 could be of interest, with **location 1 being a priority given the proximity to an existing council depot**

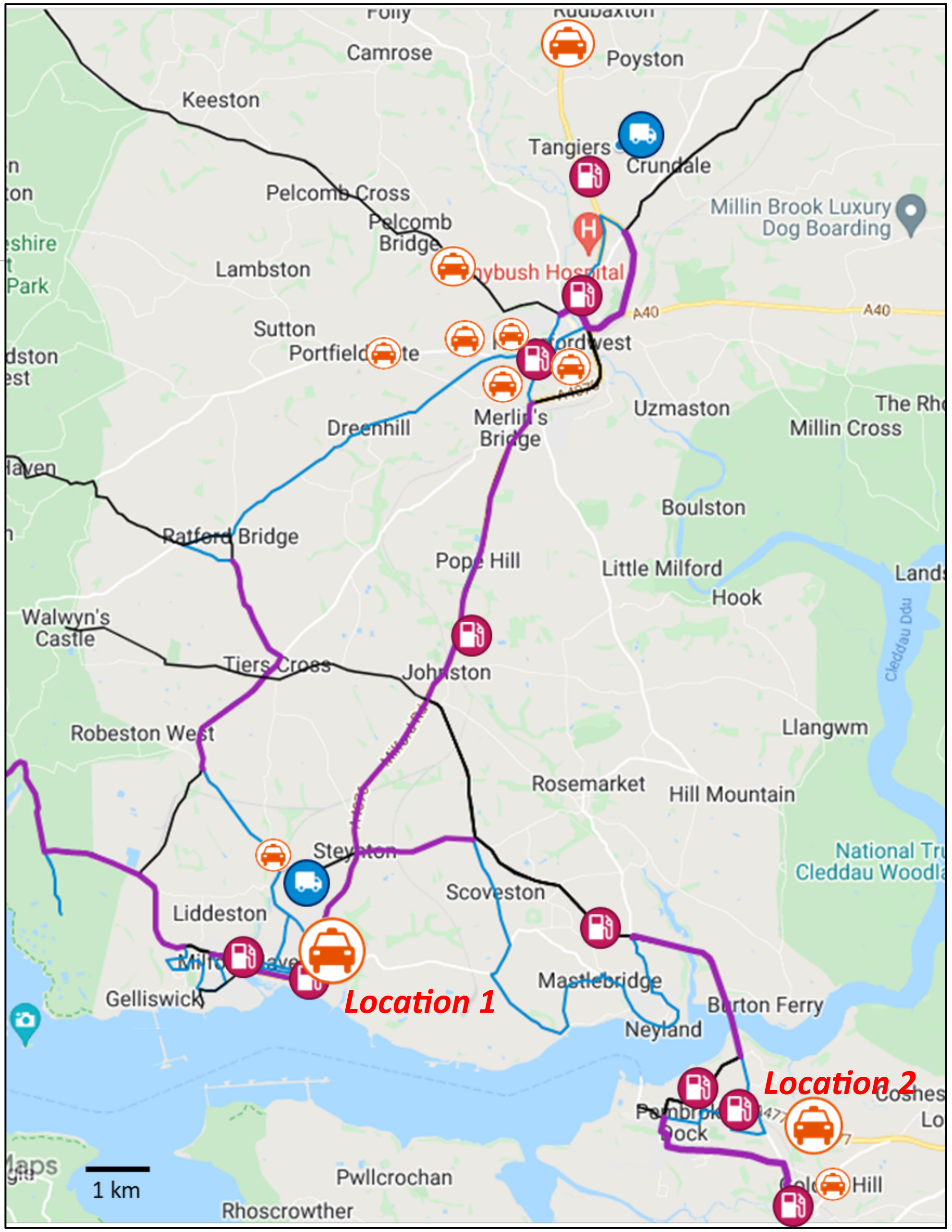
— Local fleet routes
— Bus routes
━ Local fleet & bus routes
● Existing petrol/diesel stations
● Council depots
● Traffic count*

*Traffic count data from TfW 14 day survey 7-9 September 2019. The bigger the icon, the more vehicles. For more information see Table below.

| ACT Site | Date | Town | Vehicles in 24 hour period | | |
|---|---|---|---|---|---|
| | | | Direction A | Direction B | Average |
| 1322 | 09/09/2019 | Haverfordwest | 593 | 3354 | 1974 |
| 1225 | 07/09/2019 | Haverfordwest | 2884 | 1663 | 2274 |
| 1224 | 09/09/2019 | Haverfordwest | 871 | 858 | 865 |
| 1259 | 09/09/2019 | Haverfordwest | 1235 | 1231 | 1233 |
| 1261 | 09/09/2019 | Haverfordwest | 3390 | 3455 | 3423 |
| 1222 | 09/09/2019 | Haverfordwest | 1658 | 2389 | 2024 |
| 1320 | 09/09/2019 | Haverfordwest | 100 | 2107 | 1104 |
| 1251 | 09/09/2019 | A40 | 4757 | 4647 | 4702 |
| 1229 | 08/09/2019 | Milford Haven | 7500 | 8246 | 7873 |
| 1285 | 09/09/2019 | Pembroke Dock | 6365 | 6632 | 6499 |
| 1324 | 09/09/2019 | Pembroke Dock | 1220 | 1164 | 1192 |
| 1324 | 09/09/2019 | Pembroke Dock | 1220 | 1164 | 1192 |
| 1327 | 09/09/2019 | Thornton | 598 | 658 | 628 |

***Location 1***

***Location 2***



# Investment cases for H2 production

## Small, medium and large scale

MH2
ENERGY KINGDOM
DEYRNAS YNNI

# Available technologies for the production of green hydrogen - overview

**There are several approaches for the electrolysis of green hydrogen**

The discovery that the application of an electric current to water produced hydrogen and oxygen, termed 'electrolysis' was first made by Nicholson and Carlisle in 1800.

Since that first discovery several alternative approaches to the production of hydrogen by electrolysis have been proposed, each with relative strengths in terms of efficiency, durability, cost and suitability for use with intermittent renewable electricity sources.

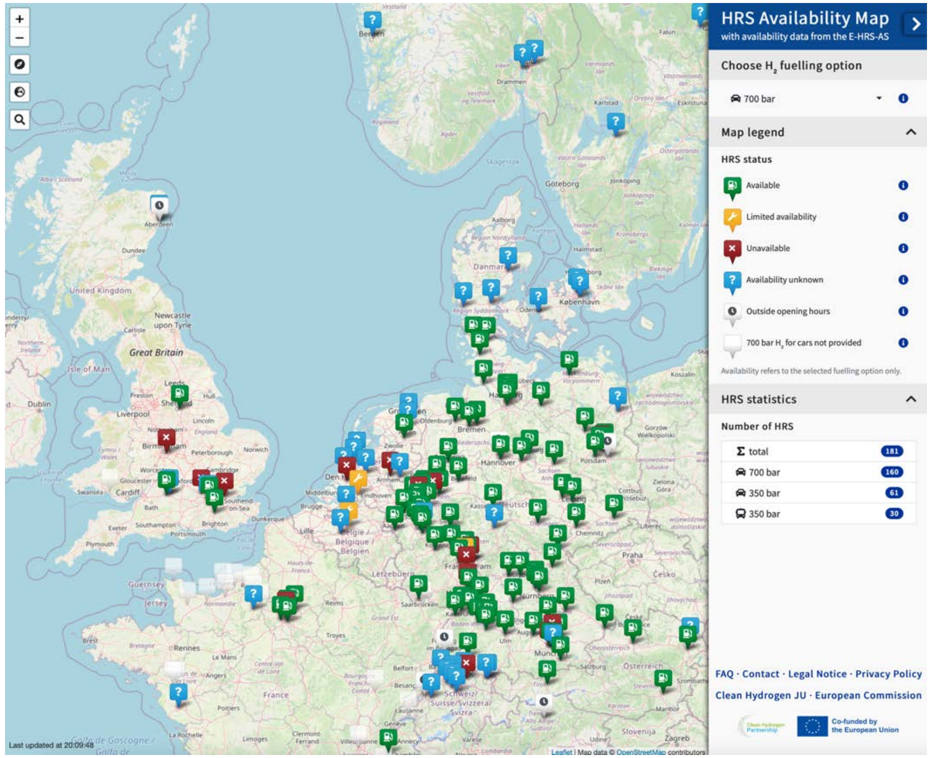
The Milford Haven Energy Kingdom project features an AEM electrolyser producing 14kg of hydrogen per week. This will be explained in more detail on page 94.

| Technology | Description | Maturity |
|---|---|---|
| Alkaline | Alkaline water electrolysis is considered to be the most technologically mature. These electrolysers have the potential to use low cost materials, are durable and tolerant to impurities. Disadvantages are associated with a high lower limit of minimum load which prevents coupling with some types of renewables. | MATURE |
| Anion Exchange Membrane (Alkaline Polymer) | AEM aims to overcome the disadvantages of conventional alkaline electrolysis. **This technology is employed in the Fuel Cell Systems refueller used in the Milford Haven trial.** Whilst AEM electrolysers offer greater efficiency than conventional alkaline electrolysers, they are currently less efficient than PEM | EARLY STAGE |
| Acidic | These can be subdivided into acid electrolysers and acid polymer electrolysers, the latter represented by Proton Exchange Membrane (PEM) electrolysers. PEM electrolysers are considered to be more efficient than AEM and better suited to renewables, however are impeded by significantly higher costs. | LATE STAGE |
| Acidic/alkaline amphoteric | Combine both acidic and alkaline environments allowing for the potential of lower energy use and higher H2 output than AEM electrolysers, without the high costs associated with the use of Pt-group metals in PEM electrolysers. | VERY EARLY STAGE |
| Solid Oxide | Potential to significantly increase the efficiency of water electrolysis through the use of high temperatures. Very high efficiency and low level of minimum load allows for operation with variable generation. Use of inexpensive catalysts reduces costs. However, high temperatures currently creates durability issues | EARLY STAGE |
| Microbial | Microbial Electrolysis Cells (MECs) utilise the chemical energy from biomass to allow for lower temperature (and lower energy) electrolysis. This offers the potential for reduced operating costs. However, the use of precious metal catalysts keeps CAPEX costs high | VERY EARLY STAGE |
| Photoelectrochemical | Utilises semi-conductor materials to enable electrolysis using solar energy. Use is restricted by limited efficiency and lower durability | VERY EARLY STAGE |

# Current H2 refuelling network – UK and Europe

**Lack of hydrogen refuelling infrastructure is often cited as the main barrier to Fuel Cell EV adoption**

Within the UK the majority of hydrogen refuelling stations currently open and available for passenger vehicles are located close to London, with two future locations proposed in the Midlands and the North East. This compares to Germany where there is already an extensive countrywide network of hydrogen refuelling stations now available – 95 stations accessible via the H2.LIVE refueller card. The limited refuelling network in the UK has been linked to the lack of vehicles – a chicken-and-egg situation, not dissimilar to the early roll-out of BEVs for which incentives and support was required. The remainder of this report will assess the opportunities for deploying hydrogen refuelling infrastructure, and based on the demand profile developed for Milford Haven, whether these may be commercially viable.



HRS Availability Map

with availability data from the E-HRS-AS

Choose $H_2$ fuelling option

700 bar

Map legend

HRS status

- Available
- Limited availability
- Unavailable
- Availability unknown
- Outside opening hours
- 700 bar $H_2$ for cars not provided

Availability refers to the selected fuelling option only.

HRS statistics

Number of HRS

| | |
|---|---|
| Σ total | 181 |
| 700 bar | 160 |
| 350 bar | 61 |
| 350 bar | 30 |

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Clean Hydrogen Partnership

Co-funded by the European Union

Source: UKH2 Mobility

# Small scale hydrogen refuellers – Fuel Cell Systems trial in Milford Haven

## Fuel Cell System installation in Milford Haven

The hydrogen refuelling station installed in Milford Haven for the vehicle demonstration has been installed by Fuel Cell Systems, using technology built around the Enapter AEM electrolyser, a winner of the inaugural Earthshot Prize in 2021.

This modular system allows for refuellers to be scaled to up to 1MW (using 420 of the EL 4.0 AEM electrolysers).

Key headlines for Milford Haven:

- Produces 2kg of hydrogen per day, 14kg per week.
- Total installation costs ~£250k of which ~£175k relates to the refueller, with the remainder covering site preparation.

Enapter EL 4.0 AEM (1 module)

Enapter EL 4.0 AEM (multi-module)

## Economic viability at very small scale appears challenging

Data from existing petrol filling stations suggest that the net yield averages 4.5%, although this can be expected to decline over time with the reduction in ICE vehicles on UK roads. Assuming a similar profit margin is required for HRS, based on the actual costs incurred for the Milford Haven refueller would require a gross profit, £/kg of H2 of £16. This is significantly higher than the target selling price for H2 in passenger applications (<£10/kg).

However, if we consider a short term learning curve effect for AEM electrolyser cost reduction of 16% per year (mid range based on Oxford Institute for Energy Studies report Jan 2022), this would imply that a 40kg system in 2025 would need to achieve a gross profit, in terms of £/kg of H2 delivered, of £3-£4/kg, in order to cover investment costs. Electricity supplied via curtailed wind at nominal cost would potentially allow a price of hydrogen to be set that would successfully stimulate a local mobility market. Enapter quote that for their current electrolyser the CAPEX cost to produce hydrogen is 6.67 Euro/kg, with a goal of reducing this to 1.5 Euro/kg (CAPEX) by 2023. Further work is required to evaluate this potential, including validation of the learning curve effects for the underlying technology.

A concern with this approach relates to scale – at small scale one HGV could be enough to use 24hrs worth of capacity. However, it does offer the potential to seed the market and scale across multiple sites.

# Medium scale approach

**National roll-out of hydrogen refuelling infrastructure has been announced.**

Established fuel distribution companies such as Shell have already commenced the installation of hydrogen refuellers at a limited number of their existing petrol forecourts across the UK.

More recently new entrants to the refuelling market, Element 2, have announced its intention to roll-out a UK-wide network of hydrogen refuellers across the UK, aiming to achieve 800 pumps onto the UK network by 2027 and 2000 by 2030. The company has declared that it expects cost per mile driven to reach parity with diesel by 2024.

Element 2's business model is a demonstration of an approach interesting in the context of the outcomes from the Rasa vehicle demonstration and our investigation into total hydrogen demand in Milford Haven for three reasons:

- Mobile refuellers have been demonstrated, enabling refuelling locations to be established quickly – seeding the market
- Total daily hydrogen delivery per site is within the demand range identified in this report.
- The refuelling system is designed to be technology agnostic – taking hydrogen produced from whichever source offers the most competitive solution for local customers.

**Trials already underway in Aberdeen and Tees Valley**

The Tees Valley Hydrogen Hub included mobile hydrogen refuelling infrastructure capable of providing up to 300kg/day across 3 regional locations.

In Aberdeen, Element 2 supported the provision of refuelling infrastructure for the HITRANS, Opportunity Cromarty Firth hydrogen bus trial, demonstrating successful delivery of hydrogen sourced from a distributed network of producers.

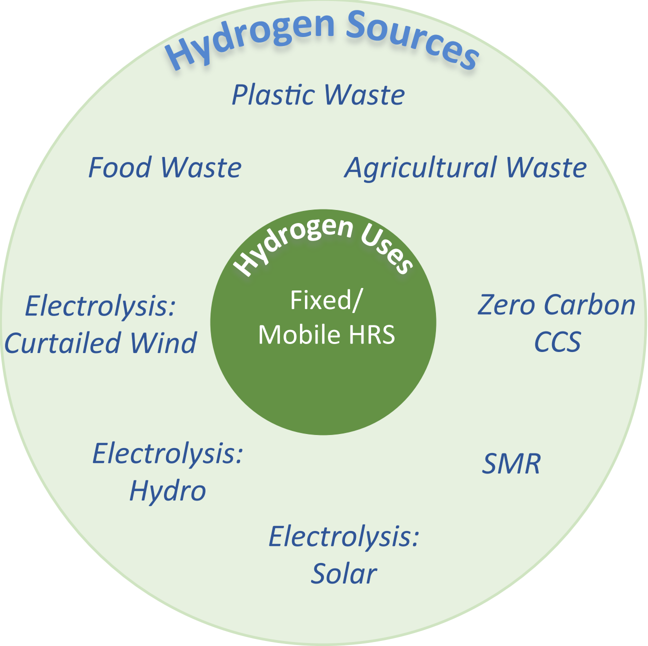
**Technology agnostic hydrogen sources allows for local flexibility**

The flexibility to source hydrogen from multiple producers allows for the most cost effective supply to be sourced, and for an ecosystem of small to medium scale producers to develop tailored to the local market. Through this approach it is expected to be able to achieve a current (2022) price of between £7 and £10/kg for a minimum of 300kg/day supply (estimate from commercial operator). At this scale the capital investment costs for the refueller could be expected to be around £1.5M (excluding hydrogen production costs – source FCH 2 JU).

With regards to Milford Haven sources of hydrogen could include:

- Given that the area is rural, opportunity for hydrogen from bio-mass (agricultural wastes and residues)
- Electrolysis from solar
- Onshore wind. A case study in North Wales has shown that a 9 turbine site can profitably supply hydrogen for the transportation sector from curtailed wind.

Utilisation of curtailed off-shore wind for hydrogen production offers strong potential, although at a much larger scale, as we will discuss next.


Hydrogen Sources
Plastic Waste
Food Waste
Agricultural Waste
Electrolysis: Curtailed Wind
Hydrogen Uses
Fixed/ Mobile HRS
Zero Carbon CCS
Electrolysis: Hydro
SMR
Electrolysis: Solar

Hydrogen sources and uses: technology agnostic approach to hydrogen sourcing (reference, Element 2)

| | *Delivery Scale* | *Capital Investment* |
|---|---|---|
| **Refuelling stations (without hydrogen production)** | Small (200 kg/day) | €950k |
| | Medium (400 kg/day) | €1.8M |
| | Large (1000 kg/day) | €3M |
| | Industrial (5000 kg/day) | €6M |

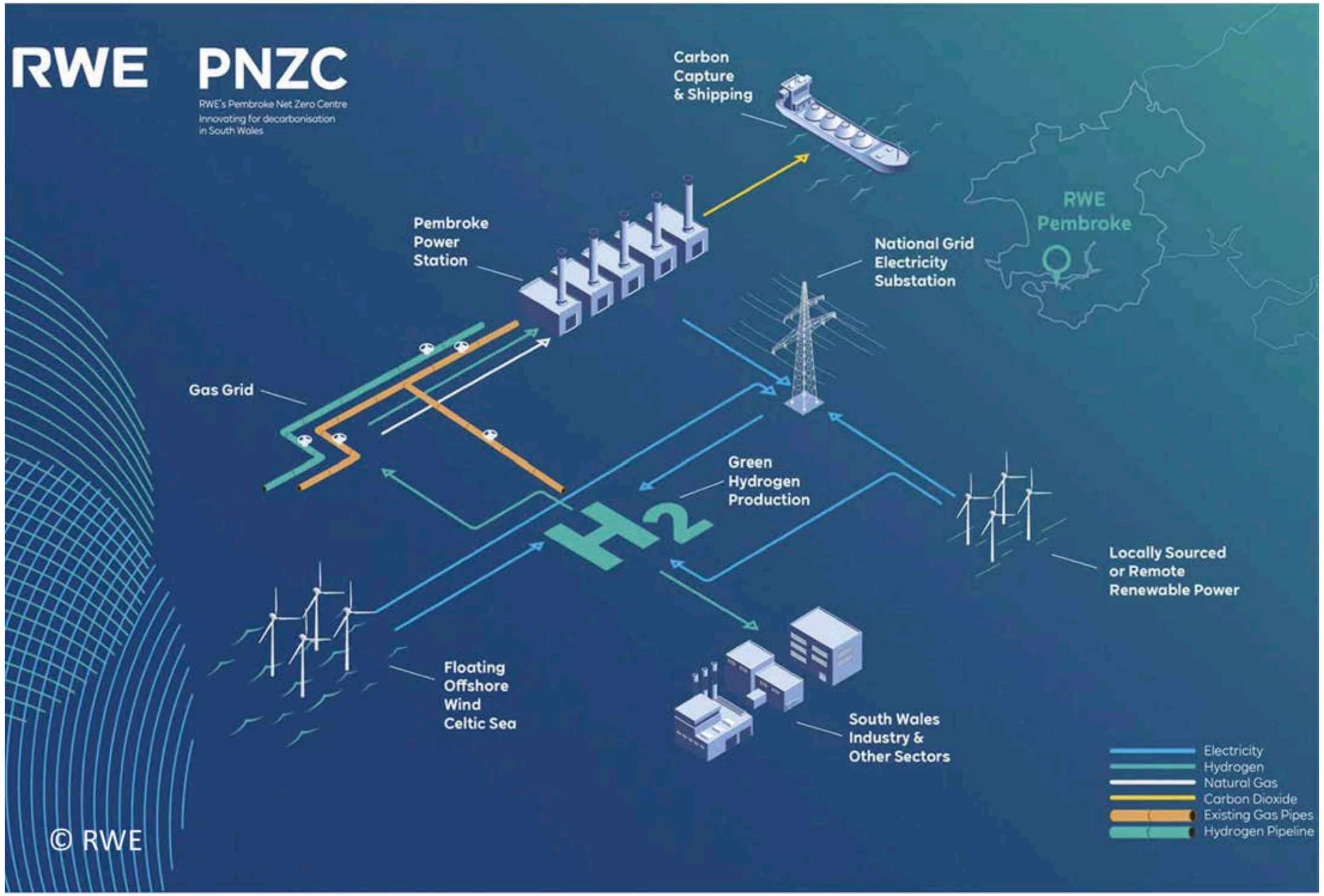
Hydrogen Refuelling Station Cost (without hydrogen production) - from FCH 2 JU)

# Large scale approaches possible in Pembrokeshire

A recent proposal to Pembrokeshire County Council from a company looking to build out a 50 MW solar farm and 10 MW electrolyser has stated a likely green hydrogen sale price of £4.50/kg in 2026.

RWE is a key industrial player on the Haven waterway, owning and operating the Pembroke natural gas-fired power station. To transition to carbon neutrality, RWE is looking at wide-scale investment in decarbonisation technologies which includes transforming the Pembroke power station to the Pembrokeshire Net Zero Centre (PNZC) – a decarbonisation hub linking innovative low carbon technologies such as hydrogen production, CCUS and floating offshore wind. Feasibility studies for the decarbonisation of the Pembroke power station with CCS and hydrogen production have commenced and RWE have now started FEED (Front End Engineering Design) study for a green hydrogen production project using a 100-110 MW electrolyser. RWE has plans to scale hydrogen production to the Gigawatt (GW) scale in the longer term and develop floating offshore wind farms in the Celtic sea. RWE sees the PNZC as an enabler to unlock the route to net zero in South Wales and is working with the MH:EK project and the SWIC projects to further understand decarbonisation plans and ensure projects and plans are aligned.

> “RWE is looking to deliver 2GW of hydrogen projects by 2030, including a green hydrogen project in Pembrokeshire. Key to this is the economic viability of projects producing hydrogen for use across a wide variety of sectors such as transport, power and industry. RWE welcomes the work of MH:EK in helping to make the storage, use and distribution of hydrogen cost effective.”
>
> Jeremy Smith, RWE



© RWE

# The cost of electrolysis is forecast to significantly reduce

### Volume and learning curve effects are important factors

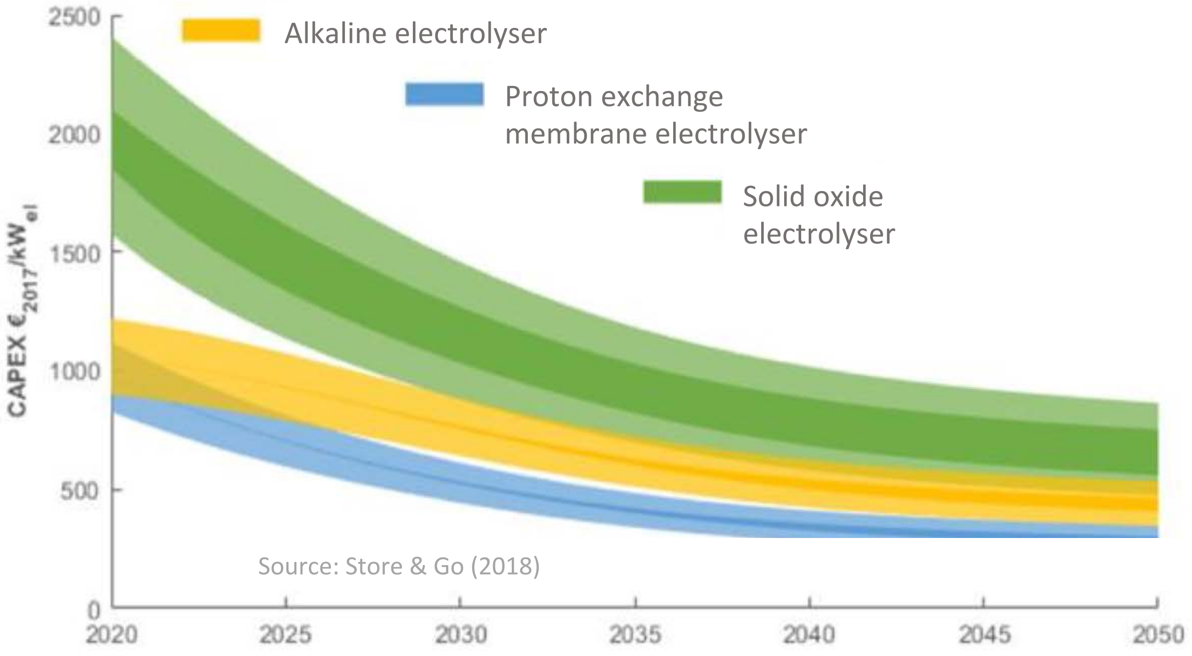
Elsewhere within the Milford Haven Energy Kingdom project there is research being undertaken into potential future costs of green hydrogen, produced via off-shore wind in the Celtic Sea. The Offshore Renewable Energy Catapult has reported that reductions in electrolyser costs of between 54% and 80% (from 2020 costs) could be expected with significant increases in production volumes (54% reduction quoted for an increase to 50,000 units of 1MW electrolysers). This view is shared by the Oxford Institute for Energy Studies, who expect significant cost reductions across all electrolyser technologies, with the largest proportion of that reduction in the period to 2035. The chart on the right shows expected learning curves for alkaline, proton exchange membrane and solid oxide electrolysis systems. It should also be noted that the CHANNEL project underway as part of the EU Horizon 2020 programme is aiming to develop novel, cost efficient electrolyser stacks based on anion exchange membranes. These use low-cost materials but aim to achieve the efficiency and current density operation close to that of proton exchange membrane electrolysers.

Electrolyser cost reductions in turn allow for a dramatic reduction in green hydrogen costs, the ORCA report expecting £2 to £3.50/kg for green hydrogen produced from offshore wind to be possible in the timescale 2025 to 2032.

As a reminder, it was shown earlier that operating cost parity for lightweight efficient passenger vehicles, such as the Riversimple Rasa could be achieved at £10/kg and for mainstream passenger vehicles at £5/kg (both vs BEV), whilst for buses, operational cost equivalence vs diesel was achieved at £7/kg. Rapid scaling of electrolyser volumes combined with competitive off-shore wind, therefore offer the potential for operating costs of transport in the Milford Haven area to be a fraction of competitor fuels.

The Fuel Cells and Hydrogen 2 Joint Undertaking (FCH 2JU) published June 2018 has reviewed hydrogen production from renewable energy via electrolysis and concluded that a 50% reduction in cost (vs 2017 levels) would be required by 2030. This report also identified the specific levers that could be used to achieve this cost reduction target.

Learning curves for alkaline, proton exchange membrane, and solid oxide electrolysis systems with an uncertainty of +15% on initial CAPEX (light-coloured areas) – from 'Cost-competitive green hydrogen: how to lower the cost of electrolysers?'
Oxford Institute for Energy Studies, Jan 2022,



Source: Store & Go (2018)

# Conclusion - The business case for a publicly accessible hydrogen refueller

**Fuel supply and demand strategies need to be considered together**

It is critical that both demand and supply are managed in tandem. Commercial operators are already proposing installation of HRS facilities that can supply hydrogen at between £7 and £10/kg, but dependent on achieving volumes of at least 300kg/day. Our analysis of the different modes of transportation in the Milford Haven area show that this demand should exist based on competitive operating costs. However, given current differences in capital costs for FCEVs vs both ICE and BEV equivalents, incentives will potentially be required to stimulate this demand and kick-start the market. This is not dissimilar, however, to the early strategies for BEVs relating to both vehicle purchase and infrastructure deployment.

Given that demand from several vehicle types is needed to support the business case for a refueller in the short-term it is critical that the refueller is publicly accessible, and also sited carefully to maximise access.

| | HRS Fuel Supply Strategy | Source of demand | Key Enablers |
|---|---|---|---|
| SHORT-TERM (2022-25) | Business case already exists for delivery of hydrogen at £7 to £10/kg at a scale of 300 kg/ day based on source agnostic approach, sourcing fuel from most competitive local supply. | With a hydrogen price of £7-£10/kg operating costs are competitive for lightweight efficient passenger vehicles such as the Riversimple Rasa and buses. Comparable customer experience (range/refuelling) vs ICE will stimulate fleet and light commercial vehicle market. Initial demand of >300kg/day exists | Incentives potentially necessary to encourage transition to ZEV for these user groups.<br>Local Government Policy to encourage bus and captive fleets to move to H2.<br>Disincentives for continued use of ICE in MH and port area. |
| MEDIUM-TERM (2026-30) | Proposals already exist to deliver green hydrogen from renewables at scale (10MW electrolyser capable of ~4000 kg/day) at £4.5/kg<br>Small-scale hydrogen refuellers potentially competitive, subject to electrolyser cost reduction achievement. | At £4.50/kg fuel cost allows for competitive operating cost for passenger vehicles vs battery electric (BEV). Significant operating cost savings for other modes of transport. Total transport demand in MH will be less than total local supply. | Roll-out of additional HRS across Pembrokeshire<br>Need confidence in non-transport fuel uses to justify investment for large scale electrolysis.<br>Roll-out of small scale HRS to support more localised demand |

# Community centric roll-out as a business model for infrastructure development

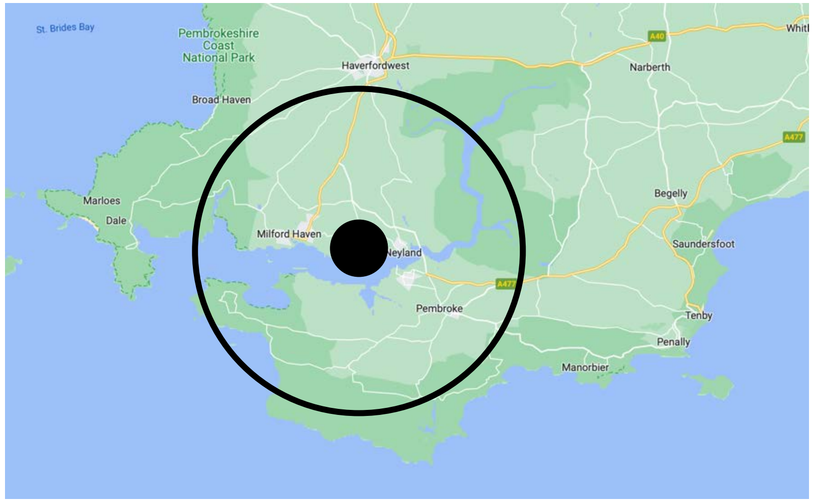
**Building national hydrogen refuelling infrastructure from the bottom up**

The Milford Haven study is an example of how it is possible, through a detailed understanding of local demand characteristics it is possible to build a business case for a hydrogen refueller serving a communities needs.

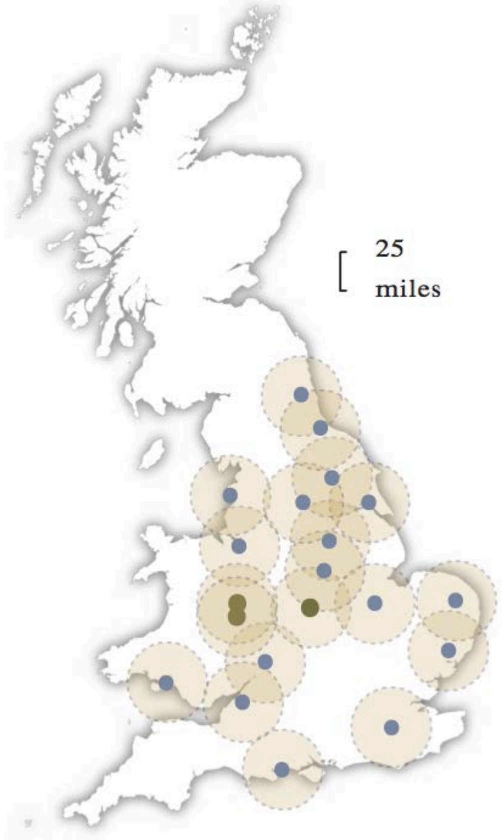
Given the distinct advantages of hydrogen vehicles in terms of refuelling convenience and range, it may appear logical to develop a nationwide HRS strategy based on positioning refuelling stations along major arterial routes – to serve long distance travel. However, in the absence of a large number of vehicles, it is very unlikely that these would be commercially viable.

Through taking a community centric approach, a commercial business case can be built for a publicly accessible refueller:

- A city-by-city, town-by-town strategy
- Through developing partnerships with hydrogen suppliers, local councils and communities to develop hydrogen refuelling stations that can serve all local transport sectors.
- Groundswell of local support the key factor for early market roll-out
- The 'skeleton' of a nationwide network emerges as the commercial viability of refuelling grows
- 'Viral replication' of community refuelling hubs creates nationwide refuelling corridors



*Through careful assessment of local hydrogen demand requirements, and an understanding of specific local hydrogen supply opportunities, a commercial case can be built for a hydrogen refueller serving a local community. Replicating this approach nationally forms the skeleton of a national network.*



# Next steps

## Refinement of the demand profile

Whilst the hydrogen demand profiles for this study have been developed for each transport mode based an analysis of vehicles currently in use in the Milford Haven area, this will require ongoing refinement:

- With regards to passenger vehicles and light vans, the technology landscape is rapidly evolving. Vehicle manufacturers are now transitioning at speed to electrified powertrains, some brands already announcing plans to retire the internal combustion engine within their line-ups from 2028. Once vehicles are universally driven by an electric motor and the underlying powertrain architecture has been developed, there may become some flexibility with regards to how that electricity is delivered: batteries or fuel cells, or a combination of both.
- Through discussions with public bodies and utility companies further refine the 'captive fleet' demand that could transition quickly to hydrogen - covering fleet passenger vehicles, light commercial, buses and heavy goods vehicles. Build a year-by-year demand roadmap for these users.

The work carried out to estimate demand at a community level will enable the creation of a calculation tool that can be used across other communities in the UK to estimate their potential hydrogen demand from each mode of transport.

## Identification and recommendation of a site in Milford Haven for a refueller.

This report has taken a high level view of potential locations for a publicly accessible hydrogen refueller, predominantly considering passenger vehicle traffic and public transportation routes. As a next step it will be necessary to refine this, working with HRS suppliers:

- Strategic site. The site will need to consider access from all transport modes, refining the passenger vehicle traffic density data, and considering medium and heavy duty vehicle routes.
- Sufficient space with ease of access for both fuel delivery and FCEVs.
- Ease of installation.
- Access to utilities (power, water particularly important if electrolysis on-site).
- Safety and security.
- Whether a standalone HRS, hosted/non-integrated (for example alongside an existing forecourt), or integrated into an existing forecourt.

## Refinement of the business case

The MH:EK project has shown in broad terms that the economic case for a very small scale electrolyser based solution is currently challenging, whilst medium scale delivery using a flexible sourcing approach could be economically viable according to feedback from commercial suppliers. We have relied on commercial operators to provide estimates for hydrogen costs to end users.

The data available for this report has not allowed us to carry out a detailed bottom-up estimation of the CAPEX investment required for differing hydrogen refueller delivery capacities and associated OPEX, so that we can independently validate these cost estimates. As a next step it would be useful to do this, so that a year-by-year roadmap for hydrogen delivery costs could be estimated.

MH2

ENERGY KINGDOM

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MILFORD HAVEN: ENERGY KINGDOM

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