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PROJECT

# REPORT

## HyNTS Deblending for Transportation - Phase 2.

Final Report

17-12-2025

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***Document Revisions***

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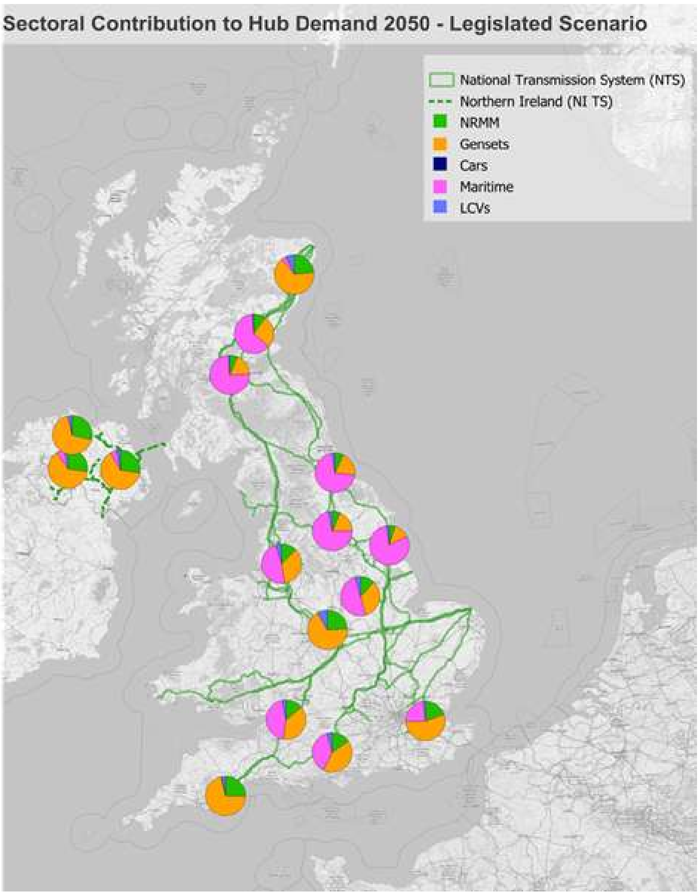
# Executive Summary

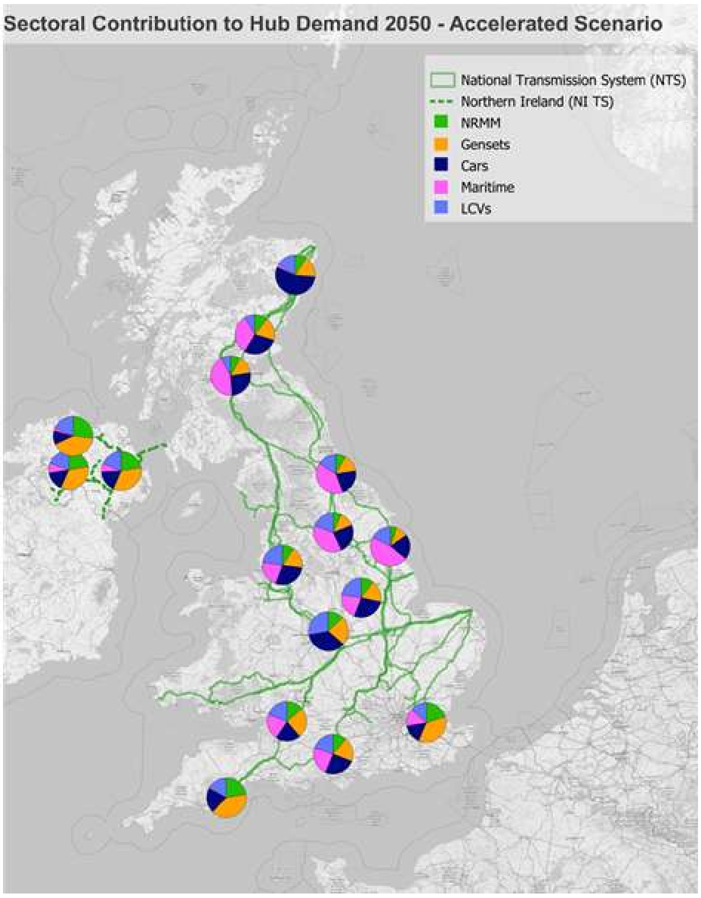
This report assesses the potential future demand for hydrogen from five sectors; cars, light commercial vehicles (LCVs), non-road mobile machinery (NRMM), maritime, and stationary generator sets (gensets). The analysis covers the whole of the UK, with regional resolution where data allows, and it includes multiple sectors, asset sizes, and fuel/powertrain options. Sector-specific results are presented in detail in chapters 4-8 of the report.

The approach taken was first to establish a 2024/25 baseline fuel demand for each sector, followed by modelling of low- and zero-emission technology uptake. Within each sector an estimate was made of what proportion of current diesel vehicles/generators will be difficult to replace with battery electric equivalents, taking into account available data on duty cycle, daily mileage and other relevant factors, and allowing for future battery technology development. It was then assumed that these 'hard to electrify' vehicles would make use of hydrogen, and the resulting hydrogen demand was projected out to 2050, in five-year increments.

Two rates of technology uptake were modelled. The Legislated uptake scenario assumes a slower uptake of hydrogen technologies resulting in demand for 541,000 tonnes per year by 2050. The accelerated uptake scenario assumes a more rapid hydrogen uptake across all sectors resulting in demand for 1,593,000 tonnes per year by 2050.

The final hydrogen demand was mapped and its relative proximity to the National Transmission System (NTS, the high-pressure backbone of the gas grid) was assessed. The maps below show the aggregate demand in 2050 relative to the NTS for the two scenarios considered.




The outputs of this report are intended to inform the commercial specification and demonstration activities within the HyNTS deblending project. The hydrogen demand estimates in this analysis are a complement to estimates of hydrogen demand for buses, coaches, Heavy Goods Vehicles (HGVs), trains and aviation made by Environmental Resources Management (ERM) in a previous report.

# Contents

***Introduction to Cenex***

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

Today, Cenex focuses on low emission transport & associated energy infrastructure and operates as an independent, not-for-profit research technology organisation (RTO) and consultancy, specialising in the project delivery, innovation support and market development.

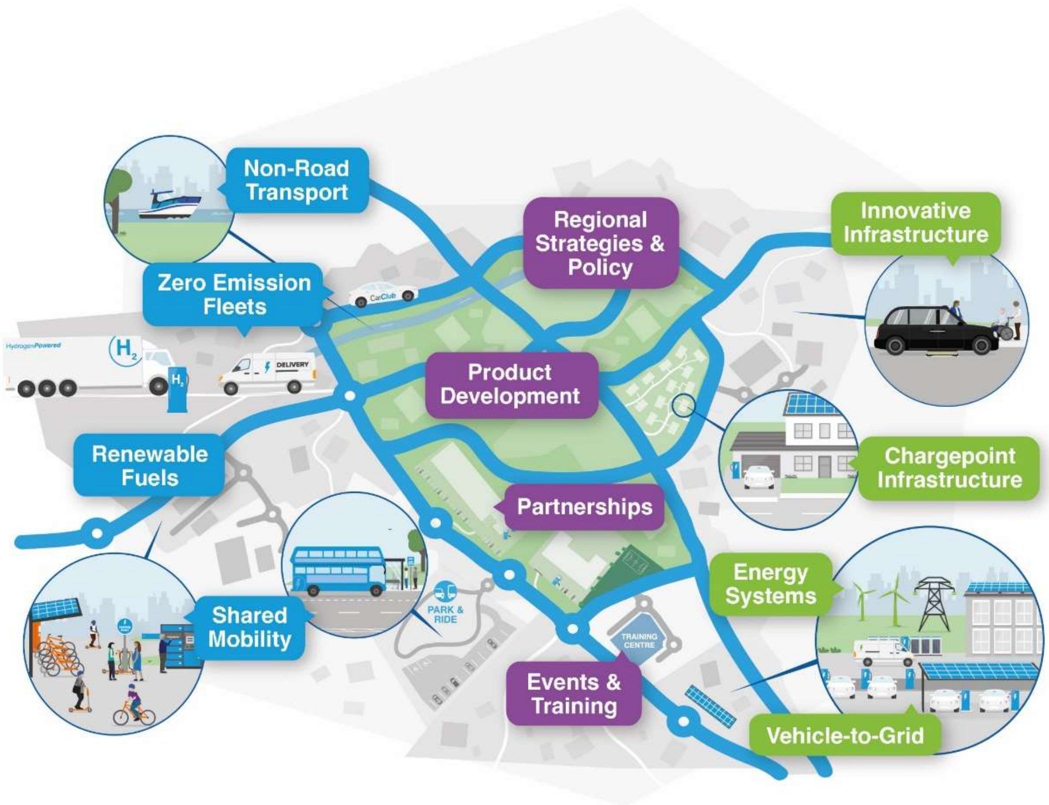
We also organise Cenex EXPO, the UK's premier low carbon vehicle event, to showcase the latest technology and innovation in the industry.

Our independence ensures impartial, trustworthy advice, and, as a not-for-profit, we are driven by the outcomes that are right for you, your industry and your environment, not by the work which pays the most or favours one technology.

Finally, as trusted advisors with expert knowledge, we are the go-to source of guidance and support for public and private sector organisations along their transition to a zero-carbon future and will always provide you with the insights and solutions that reduce pollution, increase efficiency and lower costs.

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

**www.cenex.co.uk**




# 1 Introduction

## 1.1 Background and objectives of this report

### *NGT's strategic aims*

National Gas Transmission (NGT) is responsible for the owning and operating the UK's National Transmission System (NTS). This includes approximately 7,800 km of high-pressure pipelines, 65 compressors and more than 500 above ground installations. Its role is to deliver gas from terminals and interconnectors to power stations, storage, distribution networks and industrial off-takers. With the continued goal of decarbonisation, National Gas is utilising a three-molecule strategy. This involves continuing the existing gas infrastructure while exploring ways to reduce carbon intensity, developing CCUS opportunities through repurposed pipelines for the movement of $CO_2$, and through the potential transition to Hydrogen. Hydrogen is being approached in two stages, a blending strategy of introducing Hydrogen up to 20% into the existing gas network, and a separate nominally 100% hydrogen network in the form of Project Union.

The HyNTS Deblending project aims to explore whether, if National Gas are operating hydrogen within the NTS, either as a blend or the nominally 100% Project Union; could it be extracted, 'deblended' and purified to supply fuel cell grade hydrogen for the use in transportation. This would potentially enable vehicle refuelling stations to secure low transportation cost hydrogen from low-cost,[1] large-scale production facilities in other parts of the country. If large-scale deblending experiments at Spadeadam[1] are successful, this could lead to a larger-scale rollout of this technology across the NTS.

### *This report*

This report is part of the work to establish both the likely future demand for hydrogen in transport and the geographical distribution of that demand. This information is required by NGT to build a business case for deblending stations, establishing the number needed and assessing the best locations. This report is Phase 2 of this research and builds on the previous Phase 1 report completed by Environmental Resources Management (ERM).[2] ERM's report estimated the hydrogen demand for buses, coaches, Heavy Goods Vehicles (HGVs), trains and aviation. The demand was mapped out across the UK to identify locations where demand could tie directly into the NTS. The report also provided estimated costs per kilogram for hydrogen at refuelling points, considering deblending costs.

The objective of Phase 2 is to identify additional demands for hydrogen in transport, which may benefit from the hydrogen provision occurring at the demand centres identified by ERM. It looks at demand from a further five vehicle segments – cars, Light Commercial Vehicles (LCVs, such as vans), Non-Road Mobile Machinery (NRMM), generator sets, and maritime demands. While all these segments are expected to have lower demand than those looked at in Phase 1, the additional demand they contribute improves the financial case for investment. Taken together, the ERM anchor sites and additional demands identified in Phase 2 may accelerate the creation and rollout of hydrogen refuelling centres (and the associated deblending technology) along the NGT network.

### *Scope*

This work focuses on the countries of the UK, providing regional breakdowns where appropriate and possible. Demand from Cars and LCVs is primarily based on publicly available annual mileage data. For the marine sector, results are largely based on UK statistics for total fuel use and equivalent Carbon Dioxide emissions ($CO_2e$). In the case of hydrogen demand from NRMM, the primary focus is on construction sites, mining, ports and airports. These three applications will form the bulk of energy demand in the NRMM sector (construction alone accounts for 56% NRMM sales in the UK, as discussed in section 6). Maritime demand includes both inland waterway and seagoing vessels.

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[1] As stated in the invitation to tender for this piece of work

[2] ERM (2024): HyNTS – Future Rollout Mapping: Final Report: Internal report

After establishing the baseline fuel use in each sector for 2024/25, the projected uptake of low- and zero-emission technologies is estimated, and the projected growth of hydrogen demand in each sector is mapped geographically out to 2050, in five-year increments.

With the expected future adoption of Hydrogen into the National Transmission System, either as a blend with natural gas, or as a nominal 100% hydrogen pipeline, this project will assess the demand, scale and geographical distribution of future hydrogen transport demands and how these may map across the existing NTS. The outcome of this report will help to inform the commercial specification and demonstration documents produced as part of the HyNTS Deblending project.

# 2 Technology trends and decarbonisation pathways

This section presents the market status of Zero Emission (ZE) fuels and technologies that could support the transition away from mineral diesel and other fossil fuels. Technologies are split into four categories: plug-in electric vehicles (PiV), hydrogen fuel cell electric vehicles (FCEV), hydrogen internal combustion engine (ICE) vehicles, and renewable biofuels. This report builds on an extensive literature review, publicly available databases, and interviews with experts, particularly for the construction NRMM and generator set sectors (see section 3.2.6 for interviewee details)

A detailed discussion of technologies is available in **Appendix B**. Similar principles can be applied in sectors analysed in this report, though the absolute size of power trains will vary. In terms of technology trends, the most complex sector covered in this report is NRMM, as it covers a wide variety of vehicle types (Generator Sets (gensets) are included in NRMM legislation, although covered separately later in this report).

## 2.1 Technology Roadmaps

The roadmaps below illustrate indicative scenarios of how the technology might develop from 2030 to 2050 for each Technology. Within each sector (or mode) of equipment, additional segmentation has been assigned based on the technical and operational suitability of the various technologies. Please see Appendix B for the technical discussion of the different power supplies (also referred to as 'powertrains').

- **For Cars and Light commercial vehicles** (LCVs), this has been split into two sectors: Small cars and LCVs below 2 tonnes (t) gross vehicle weight (GVW), and larger LCVs between 2.5t and 3.5t GVW.
- **For Non-Road Mobile Machinery** (NRMM), **including generator sets** (gensets), this has been split into two sectors: Below and above 100 horsepower (hp) or 75 kilowatt (kW), which are defined as 'compact' and 'large' engines, respectively. This division was selected due to the natural split in the technology capabilities for different fuel types (see Appendix B for more details). Non-road-going mobile machinery (NRMM), such as tractors and forklift trucks, is subject to different regulations than road-going vehicles. Regulatory foundations are in place to support and encourage a shift towards zero-emission NRMM. UK type-approval requires Stage V for NRMM engines, and 2025 regulatory changes now permit hydrogen-fuelled construction and agricultural machines to use public roads for site moves[3].
    - Specific municipal regulations are also coming into force. For example, London's NRMM Low Emission Zone is tightening standards toward Stage V by 2030 with a stated aim of zero-emission NRMM by 2040.
- **For maritime** applications, there is a slight change. Power train suitability is divided into auxiliary power unit and main propulsion. Maritime vessels include a broad scope of vessels from small leisure craft on inland waterways to large ocean liners and container ships. This means that the suitability of a given technology for a 20-meter, 15-ton leisure craft on a lake is not the same as that for a 400-meter, 20,000-ton container ship sailing global trade routes. The available data are limited, and the decarbonisation pathways across maritime sectors remain unclear. Therefore, this analysis focuses on total energy demand (based on existing Marine Fuel Oil (MFO) sales) rather than on the absolute number of vessels residing in or refuelling within UK waters.

Note that Generator sets (gensets) are included in Non-Road Mobile Machinery (NRMM) regulations, which means that the 2050 pathway is the same for both NRMM and gensets. Additionally, the duty cycle for gensets varies significantly, ranging from those that operate almost continuously to backup power units that may never be activated, except during scheduled maintenance. This variability

[3] JCB (2025) 'Historic day as hydrogen diggers get green light to use UK roads'. (Online). https://www.jcb.com/en-gb/news/2025/04/historic-day-as-hydrogen-diggers-get-green-light-to-use-uk-road (Accessed: 19 September 2025).

means that genset duty cycles naturally align with those of all other NRMM and achieve a similarly diverse energy profile.

The resulting roadmaps include the following themes:

- **Powertrain maturity**: This indicates how the maturity and market-readiness of the technology may change over time, what manufacturers' plans may be, and the likelihood of technology development and advancements.
- **Supporting technology**: This describes any supporting technology that is required to enable the deployment of each technology type. This section outlines the required infrastructure to support the vehicles and energy vectors, detailing both the availability of the fuel used and its associated environmental impact.
- **Economics, availability and deployment**: The economics and availability have a direct impact on the deployment of each vehicle type. If the economics are favourable but the availability is not, deployment will be low, and vice versa. For mass-market deployment, both factors will be required: good availability of product and a positive economic performance compared to diesel.
    - The economics account for the capital investment of the vehicle and the price of fuel to indicate the TCO.
    - Availability considers vehicle and fuel maturity, as well as the supply chain's likely ability to support mass-market adoption.

Commentary is provided under each roadmap to highlight key points, including future availability, cost performance, and emissions.

It should be noted that there is limited information available in some sectors, and therefore, we emphasise that these are indicative scenarios rather than forecasts. There are significant uncertainties around policy, technology performance, and cost models, which limit the confidence that should be placed in roadmaps of future technology uptake.

### *Cars and LCVs - Plug-in Vehicles*

Plug-in vehicles include battery electric vehicles (BEVs), plug-in hybrid electric vehicles (PHEVs), and range-extended electric vehicles (REEVs). PiVs store energy in a battery (usually lithium-ion) and deliver power through an electric motor.

This roadmap focuses on purely battery-powered vehicles and assumes that hybridisation (combining battery systems with other powertrains) will diminish as onboard battery technology improves and UK supply-side regulations lead to these vehicles being phased out.

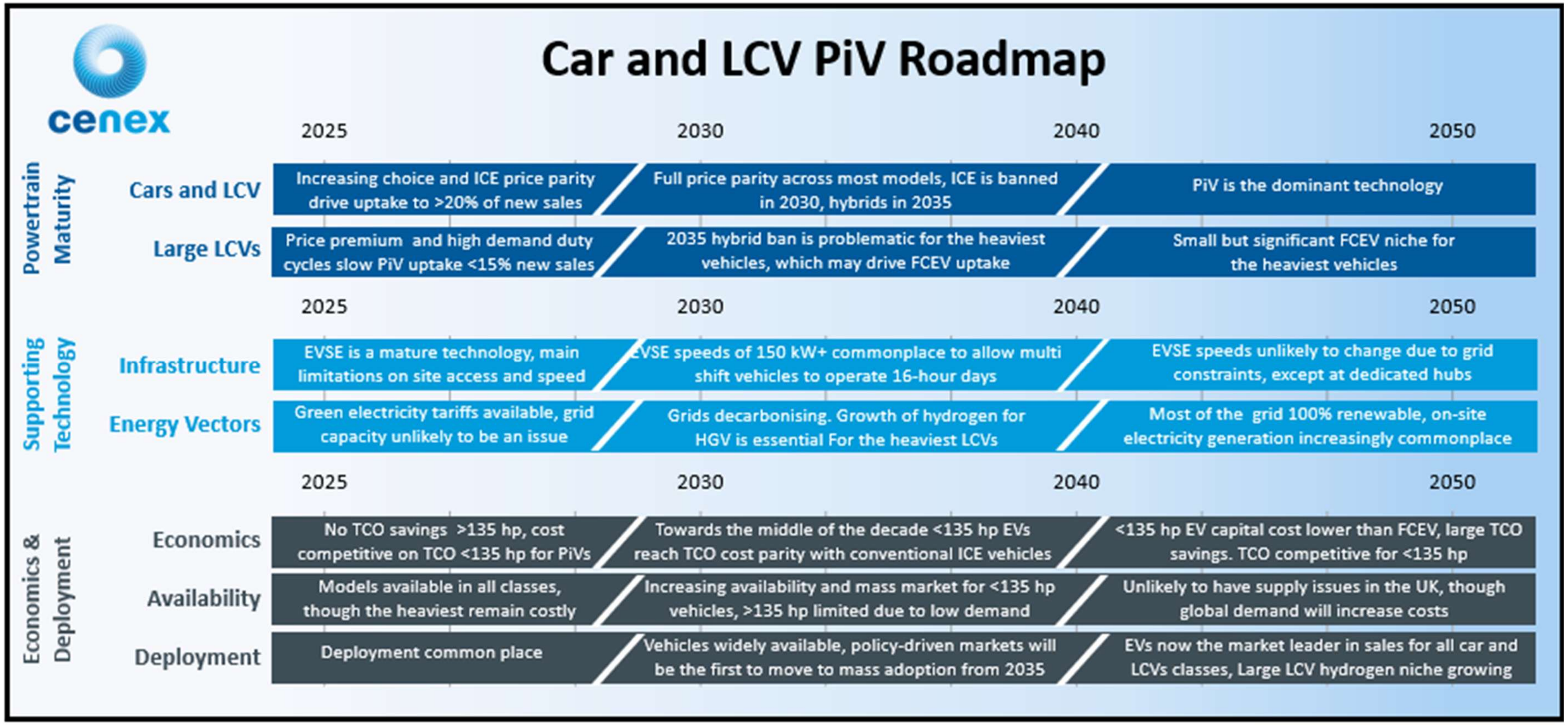


*Figure 1: Car & LCV Plug-in Vehicle Roadmap*

The main points from the roadmap are:

- There will be significant deployment of PiVs before 2030, comfortably in the 20% of new vehicle sales bracket, or even higher.
- Large LCVs (between 2.5 tonnes and 3.5 tonnes) are likely to see a lower uptake rate, in the order of 10 to 15% of new vehicle sales.
- Significant portions of the market are already cost-effective on a total cost of ownership (TCO) basis to convert to PiV, where low-cost home and depot-based charging are available.
- ICE and hybrid bans will see a dramatic spike in the uptake of new PiV sales in 2030 and 2035, respectively.
- Vans are subjected to the ICE ban from 2035 onwards.

### *Cars and LCVs - Hydrogen Fuel Cell*

Hydrogen is a safe, clean-burning energy source which is stored on vehicles in compressed hydrogen cylinders. In an FCEV, a small battery system is used to recover energy from regenerative braking systems and improve response times for power spikes.

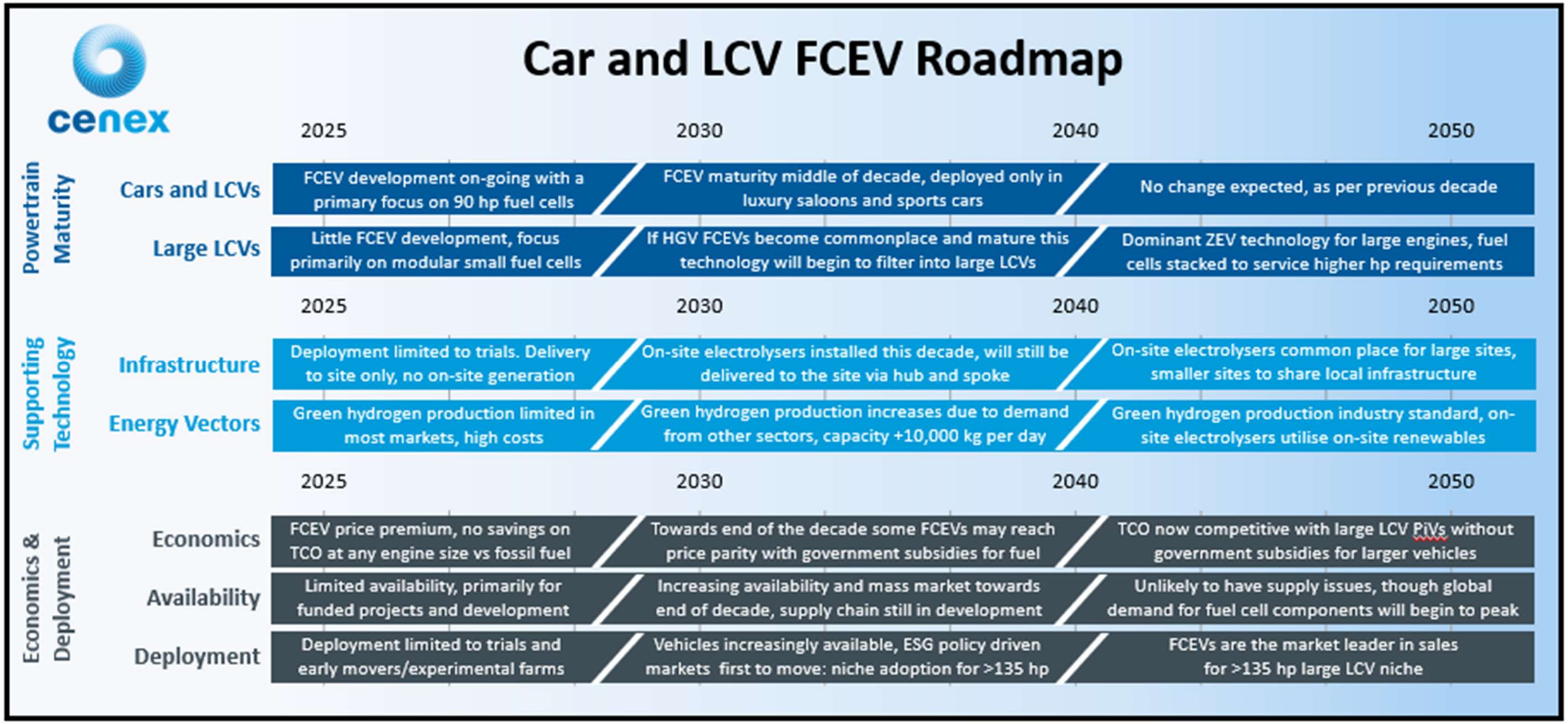


*Figure 2: Car & LCV FCEV Roadmap*

The main points from the roadmap are:

- There is likely to be limited unsubsidised deployment of FCEVs before 2030 due to a lack of product availability, lack of refuelling facilities and unattractive total cost of ownership (TCO) performance compared to PiVs.
- FCEVs are likely to cost more than diesel vehicles for some time to come and, without subsidies, are likely to be more expensive to fuel than PiVs. As such, it could be the late 2030s before a reasonable TCO performance, combined with policy drivers, leads to significant uptake.
- FCEVs can theoretically be used in all vehicle classes. However, they are most likely to be used in the larger LCV segments where PiVs are not operationally suitable.
- There may be niche FCEV demand in premium sectors, such as off-road vehicles, towing operations, luxury saloons, and sports cars.
- FCEVs can be considered a ZE technology if hydrogen is made from a renewable energy source, so-called ‘green’ hydrogen. Currently, most available hydrogen is produced through steam methane reforming without carbon capture, known as 'grey hydrogen’. This can still offer some limited CO2e emission savings in specific duty cycles, but not in all cases. Low (or very low) carbon hydrogen can also, at least in theory, be made through adding carbon capture and storage to the process of manufacturing hydrogen from methane, so-called ‘blue’ hydrogen.
- Infrastructure options may include a combination of on-site electrolysers on larger sites, though the power demand for this will be just as significant for equivalent PiV NRMM. However, the flexibility of power demand can make on-site electrolysis more attractive in specific sectors.
- ‘Hub and spoke’ delivery models are more likely to be the norm as time progresses.
- Uptake of FCEVs for cars and vans will be dependent on the successful rollout of hydrogen refuelling stations (HRS) for heavy goods vehicles (HGVs).

### *Cars and LCVs- Hydrogen Internal Combustion*

Hydrogen can also be used in an internal combustion engine. Hydrogen is stored in the same cylinders as for an FCEV, but is then burnt in a modified combustion engine. Hydrogen can be burnt neat or blended with other fuels (‘dual fuel’ systems).

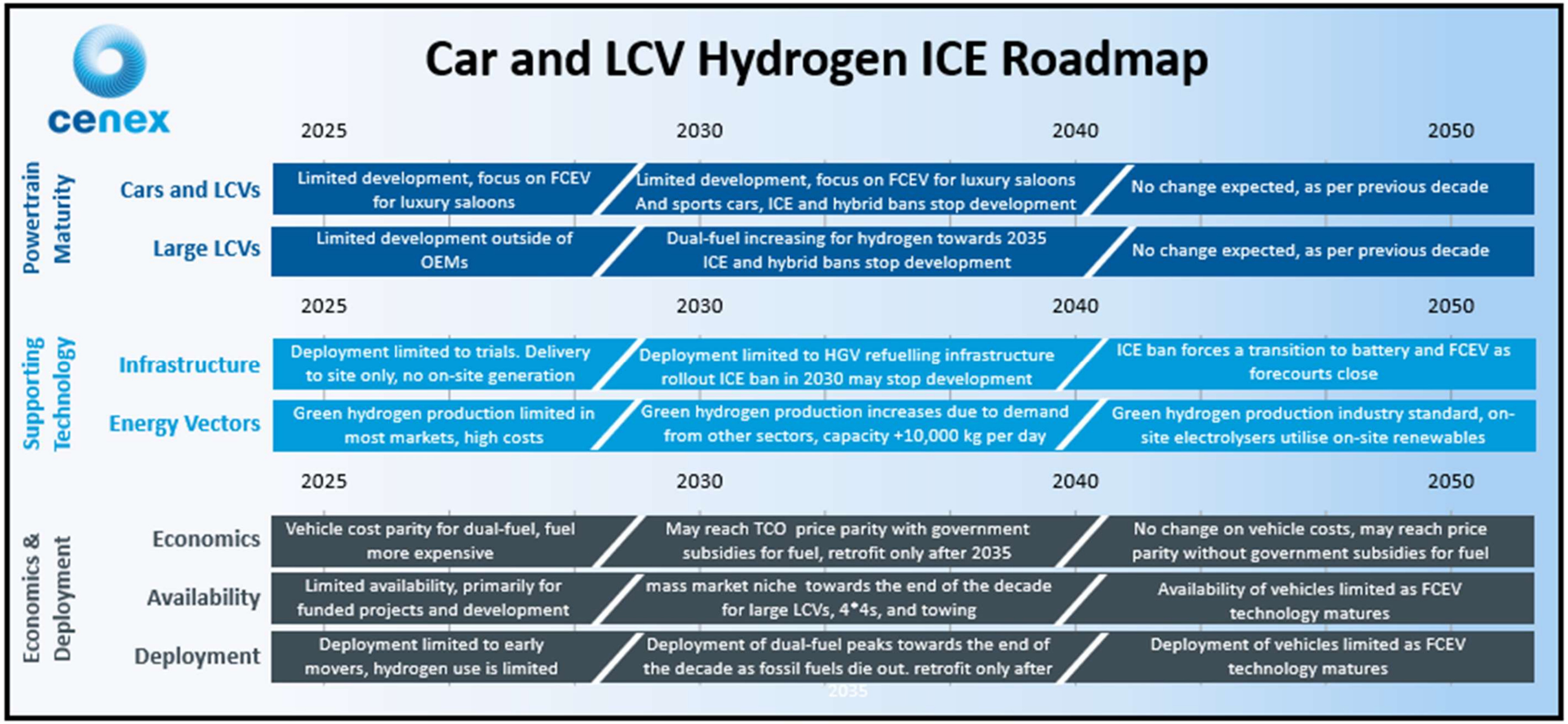


*Figure 3: Car & LCV H2ICE Roadmap*

The main points from the roadmap are:

- There is likely to be limited deployment of hydrogen ICEs before 2030 due to a lack of product availability, unattractive TCO performance compared to diesel, and a lack of hydrogen refuelling infrastructure.
- ICE and hybrid bans in 2030 and 2050, respectively, will prevent mass adoption of hydrogen ICE under existing legislation.
- There may continue to be a small niche for vehicles that will be permitted to run on ICE.
- The conversion of these vehicles (either through new vehicle sales or retrofit) will be highly dependent on the successful rollout of hydrogen refuelling infrastructure for HGVs.
- A small niche may develop in motor sport, the classic car market (for the proportion of classic car owners willing to convert to hydrogen ICE), and military vehicles. The total potential UK market for all these vehicles is estimated to be approximately one to two million units by 2050.
- Early hydrogen ICEs may be dual-fuel vehicles which can burn a blend of hydrogen and diesel (or other biofuels). Fuel costs are likely to increase in proportion to the quantity of green hydrogen used until the 2040s.
- Hydrogen ICEs can theoretically be used in all vehicle classes.
- Hydrogen ICEs can be considered a ZE technology if hydrogen is made from a renewable energy source, so-called ‘green’ hydrogen. Currently, most available hydrogen is produced through steam methane reforming without carbon capture, known as 'grey hydrogen’, which offers little to no carbon savings compared to diesel when used in a vehicle. Low (or very low) carbon hydrogen can also be made through adding carbon capture and storage to the process of manufacturing hydrogen from methane, so-called ‘blue’ hydrogen.
- Infrastructure options may include a combination of on-site electrolysers (or deblending stations) on larger sites, with smaller sites relying on tube trailer deliveries. Infrastructure could be a challenge for remote sites with low fuel demands or constrained footprints.
- Uptake of H2ICE will be dependent on the successful rollout of hydrogen refuelling stations (HRS) for heavy goods vehicles (HGVs).

### *Cars and LCVs - Renewable Biofuels*

Biodiesel can be used in blends with mineral diesel, typically at 20% or 30% concentrations, or neat as B100, although this requires some operational and infrastructure adjustments. HVO is a chemically identical fuel to mineral diesel and can be used in the same way. HVO should be made from certified waste feedstock such as used cooking oil. Extensive use of biofuels (both FAME and HVO) already occurs in conventional diesel supplies in the UK, with almost all diesels sold at the pump delivering up to 7% biofuel content ('B7').

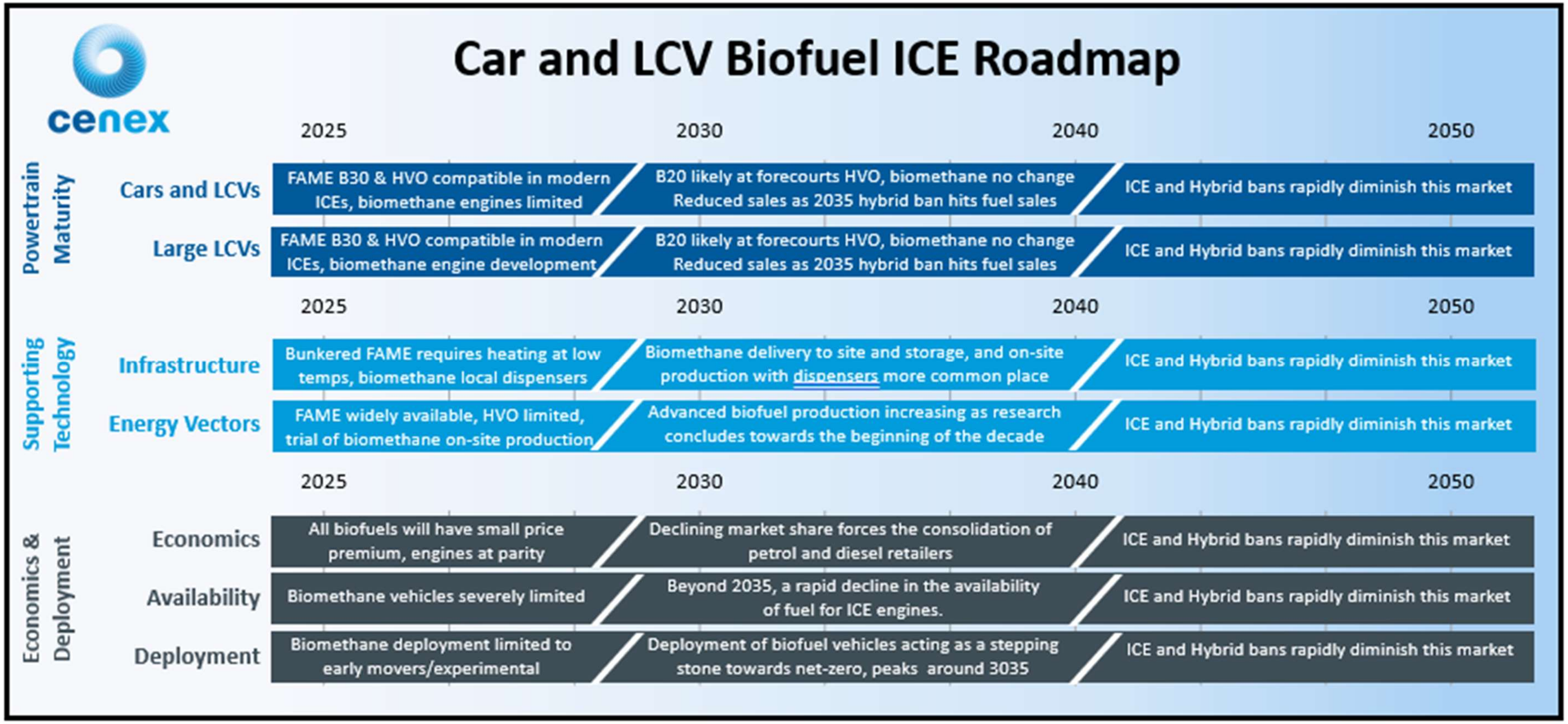


*Figure 4: Car & LCV Biofuel Roadmap*

The main points from the roadmap are:

- Deployment of biofuels is likely to increase up to 2035, and for a few years afterwards.
- ICE and hybrid ban in 2030 and 2050, respectively, will result in a rapid decline of biofuel sales after 2035, but there may continue to be a small niche for vehicles that will be permitted to run on ICE.
- The conversion of these vehicles (either through new vehicle sales or retrofit) will be highly dependent on the continued commercial viability of the UK's existing fossil fuel refuelling supply chains and networks.
- The loss of diesel sales to HGVs is likely to have a significant impact on these supply chains. A more rapid decline in biofuel is anticipated from 2040 onwards.
- A small niche may develop in motor sport, the classic car market (for the proportion of classic car owners willing to convert to hydrogen ICE), and military vehicles. The total potential UK market for all these vehicles is approximately one to two million units by 2050.
- Many biofuels can be, and are already, dispensed through the existing fuel distribution network.

***NRMM (including Generator Sets) - Plug-in Vehicles***

Plug-in vehicles include battery electric vehicles (BEVs), plug-in hybrid electric vehicles (PHEVs), and range-extended electric vehicles (REEVs). PiVs store energy in a battery (usually lithium-ion) and deliver power through an electric motor.

This roadmap focuses on purely battery-powered vehicles and assumes hybridisation (combining battery systems with other powertrains) will diminish as onboard battery technology improves and UK supply-side regulations cause these to phase out.

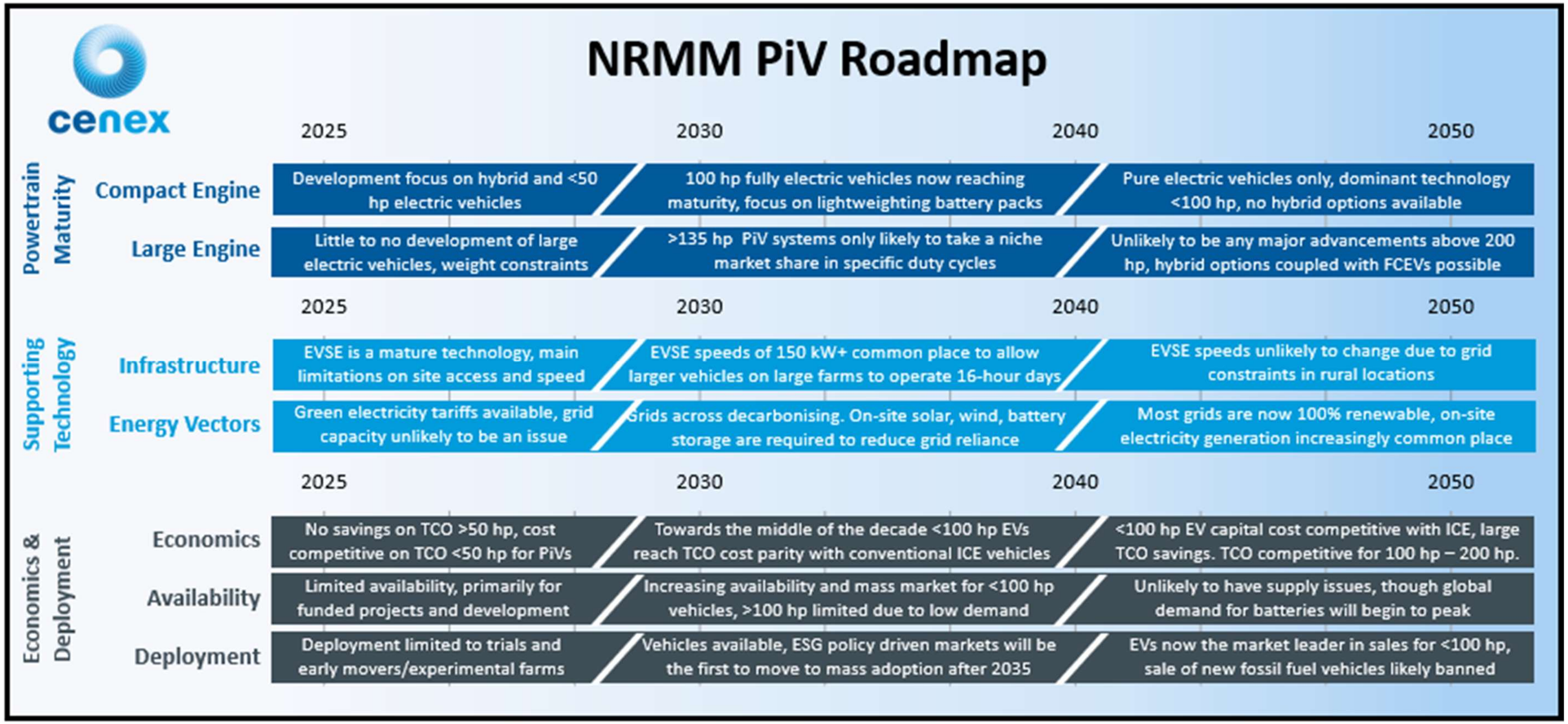


*Figure 5: NRMM Plug-in Vehicle Technology Roadmap*

The main points from the roadmap are:

- There will be limited unsubsidised deployment of PiVs before 2030 due to a lack of product availability and unattractive total cost of ownership (TCO) performance compared to diesel.
- Only the smallest NRMM (hand tools, mini-diggers and dumpers) are likely to achieve price-competitive deployment before 2030.
- Larger Prototype NRMM that are 100% battery powered are being developed and deployed in countries which heavily subsidise the infrastructure, vehicle purchase price, and running cost of these vehicles. (Norway is an example[4].)
- Larger PiV NRMM is finding a niche in some mining applications where the face of the mine is at a higher elevation than the processing and transport centre: The ability of the vehicles to travel uphill empty, and then downhill fully laden is ideal for battery regeneration, and it can significantly reduce, and in some cases eliminate, the need for refuelling and recharging.
- Battery costs have fallen steadily over the last few years as production has increased to meet demand in the road transport sector. If this trend continues, then PiVs with peak power of up to 100 hp (~75 kW) may be economically attractive in the 2030s, even without subsidies.
- PiVs will be better suited to lighter duty, lower-powered NRMM, which can be built with relatively small, lightweight batteries.
- PiVs can be considered a ZE technology if they are powered by local renewables or a fully decarbonised electricity grid.
- Charging infrastructure will be a significant challenge for PiV deployment, particularly for sites which are off-grid or already have a constrained supply or are of short duration (making the cost of installing infrastructure difficult to justify).

[4] Randall, C (2023): Norway to subsidize electric construction vehicles: Electrive.com (Online) https://www.electrive.com/2023/04/17/norway-to-subsidize-electric-construction-vehicles/#:~:text=By%20Chris%20Randall,use%20of%20electric%20construction%20machines.

### ***NRMM (including Generator Sets) - Hydrogen Fuel Cell***

Hydrogen is a safe, clean-burning energy source which is stored on vehicles in compressed hydrogen cylinders. In an FCEV, a small battery system is used to recover energy from regenerative braking systems and improve response times for power spikes.

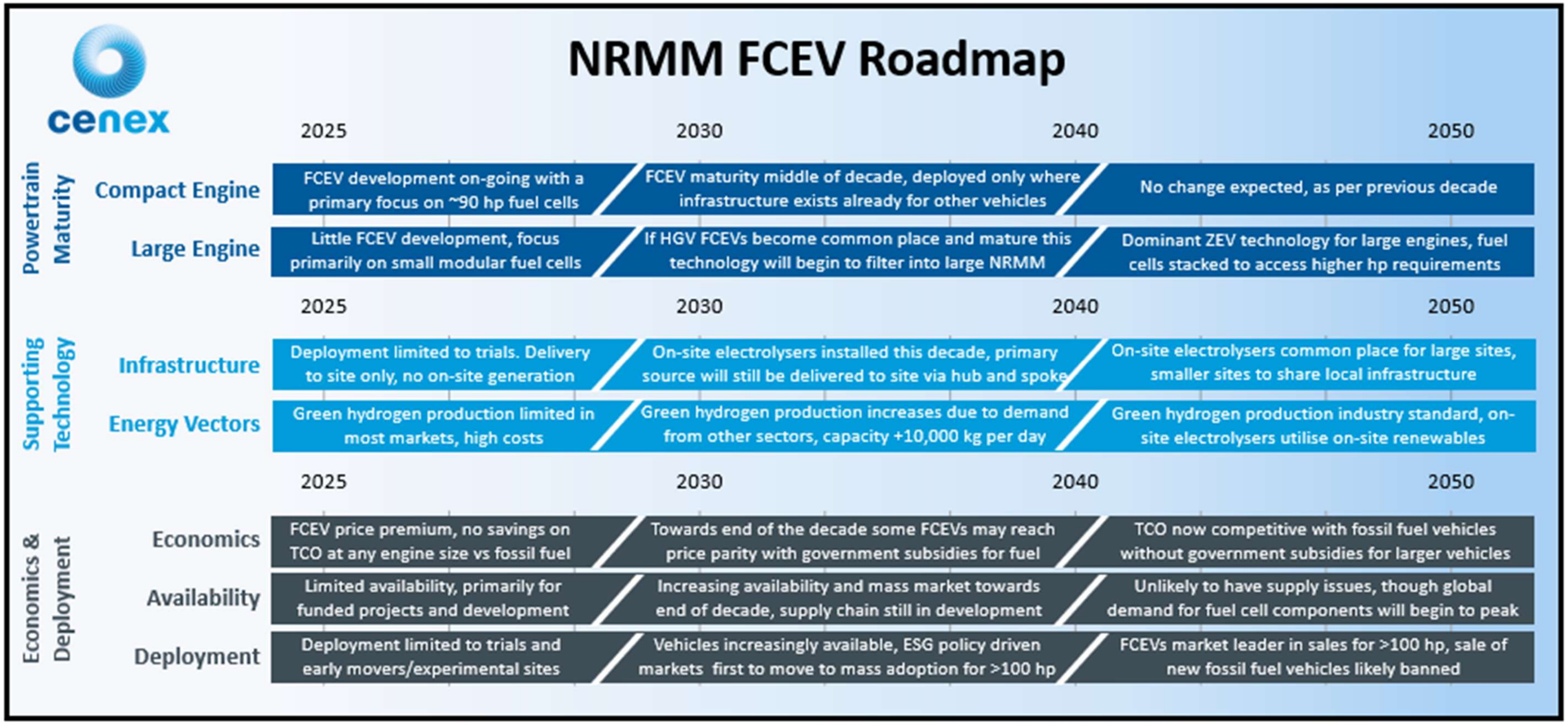


*Figure 6: NRMM Fuel Cell Electric Vehicle Roadmap*

The main points from the roadmap are:

- There is likely to be limited unsubsidised deployment of FCEVs before 2030 due to a lack of product availability and unattractive total cost of ownership (TCO) performance compared to diesel.
- FCEVs are likely to cost more than diesel vehicles for some time to come, and without subsidies are likely to be more expensive to fuel than PiVs. As such, it could be the late 2030s before a reasonable TCO performance, combined with policy drivers, leads to significant uptake.
- FCEVs can theoretically be used in all tractor classes. However, they are most likely to be used in the larger powered segments where PiVs are not operationally suitable.
- FCEVs can be considered a ZE technology if hydrogen is made from a renewable energy source, so-called ‘green’ hydrogen. Currently, most available hydrogen is produced through steam methane reforming without carbon capture, known as 'grey hydrogen’, which offers little to no carbon savings compared to diesel when used in a vehicle. Low (or very low) carbon hydrogen can also be made through adding carbon capture and storage to the process of manufacturing hydrogen from methane, so-called ‘blue’ hydrogen.
- Infrastructure options may include a combination of on-site electrolysers on larger sites, though the power demand for this will be just as significant for equivalent PiV NRMM.
- Smaller sites and short-term sites will rely on tube trailer deliveries from major hydrogen production centres (hub and spoke model). Infrastructure could be a challenge for remote locations with low fuel demands or constrained site footprints.
- Uptake of FCEVs may be dependent on the successful rollout of hydrogen refuelling stations (HRS) for heavy goods vehicles (HGVs).

***NRMM (including Generator Sets) - Hydrogen Internal Combustion***

Hydrogen can also be used in an internal combustion engine. Hydrogen is stored in the same cylinders as for an FCEV, but is then burnt in a modified combustion engine. Hydrogen can be burnt neat or blended with diesel.

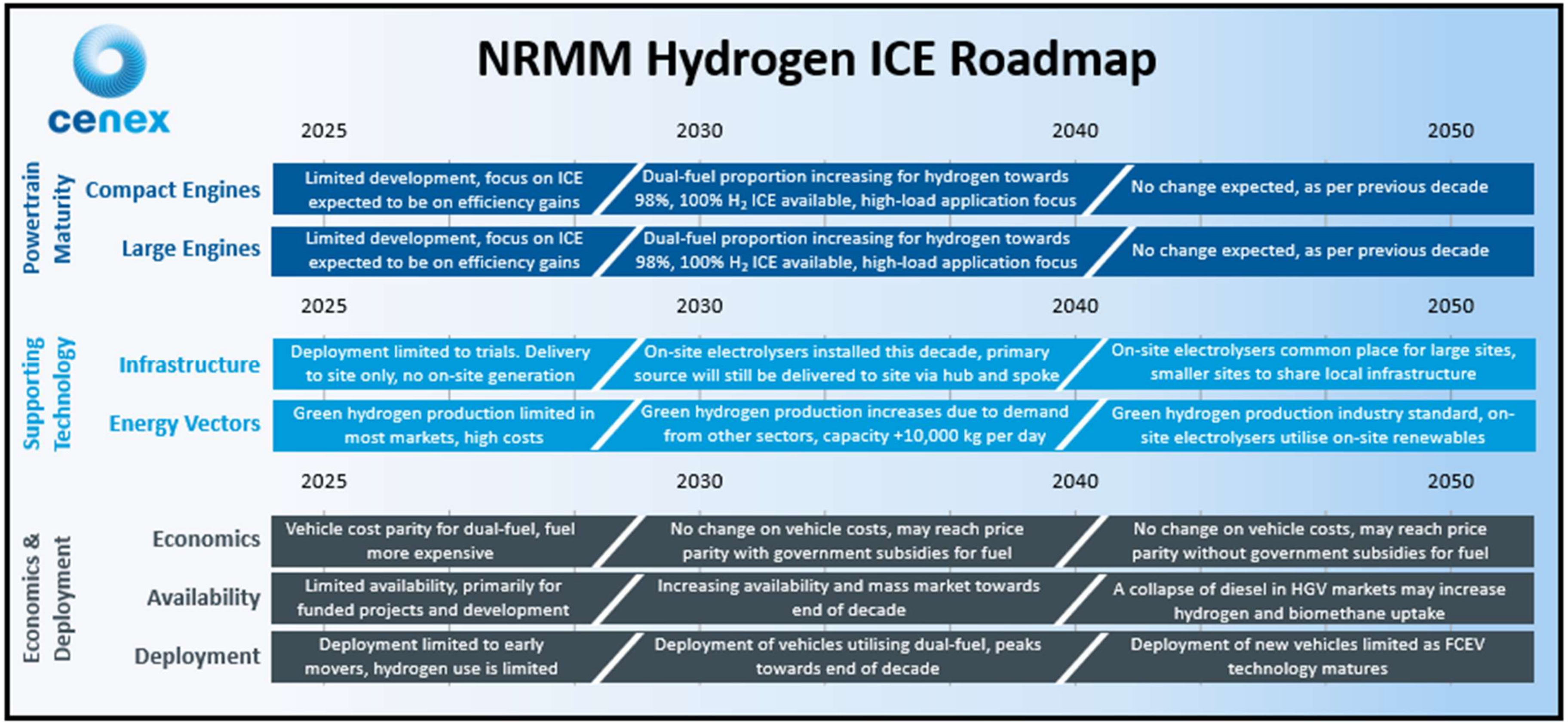


*Figure 7: NRMM H2ICE Vehicle Road map*

The main points from the roadmap are:

- There is likely to be limited deployment of hydrogen ICEs before 2030 due to a lack of product availability and unattractive TCO performance compared to diesel.
- Early hydrogen ICEs may be dual-fuel vehicles which can burn a blend of hydrogen and diesel (or other biofuels). Fuel costs are likely to increase in proportion to the quantity of green hydrogen used until the 2040s.
- Hydrogen ICE NRMM are likely to cost more than diesel vehicles for some time to come, and without subsidies are likely to be more expensive to fuel than PiVs. As such, it could be the late 2030s before a reasonable TCO performance, combined with policy drivers, leads to significant uptake.
- Hydrogen ICEs can theoretically be used in all NRMM classes. They are most likely to be used in larger powered segments where PiVs are not operationally suitable, in remote sites with constrained electrical supplies, and in vehicles with duty cycles that make electric charging difficult.
- Hydrogen ICEs can be considered a ZE technology if hydrogen is made from a renewable energy source, so-called ‘green’ hydrogen. Currently most available hydrogen is made through steam methane reforming without carbon capture, so-called 'grey hydrogen’, which offers little or no carbon savings vs diesel when used in a vehicle. Low (or very low) carbon hydrogen can also be made through adding carbon capture and storage to the process of manufacturing hydrogen from methane, so-called ‘blue’ hydrogen.
- Infrastructure options may include a combination of on-site electrolysers on larger sites, with smaller sites relying on tube trailer deliveries. Infrastructure could be a challenge for remote sites with low fuel demands, or constrained footprints.
- Uptake of H2ICE may be dependent on the successful rollout of hydrogen refuelling stations (HRS) for heavy goods vehicles (HGVs).

***NRMM (including Generator Sets) - Renewable Biofuels***

Biodiesel can be used in blends with mineral diesel, typically at 20% or 30% concentrations, or neat as B100, although this requires some operational and infrastructure adjustments. HVO is a chemically identical fuel to mineral diesel and can be used in the same way. HVO should be made from certified waste feedstock such as used cooking oil. Extensive use of biofuels (both FAME and HVO) already occurs in conventional diesel supplies in the UK, with almost all diesels sold at the pump delivering up to 7% biofuel content ('B7').

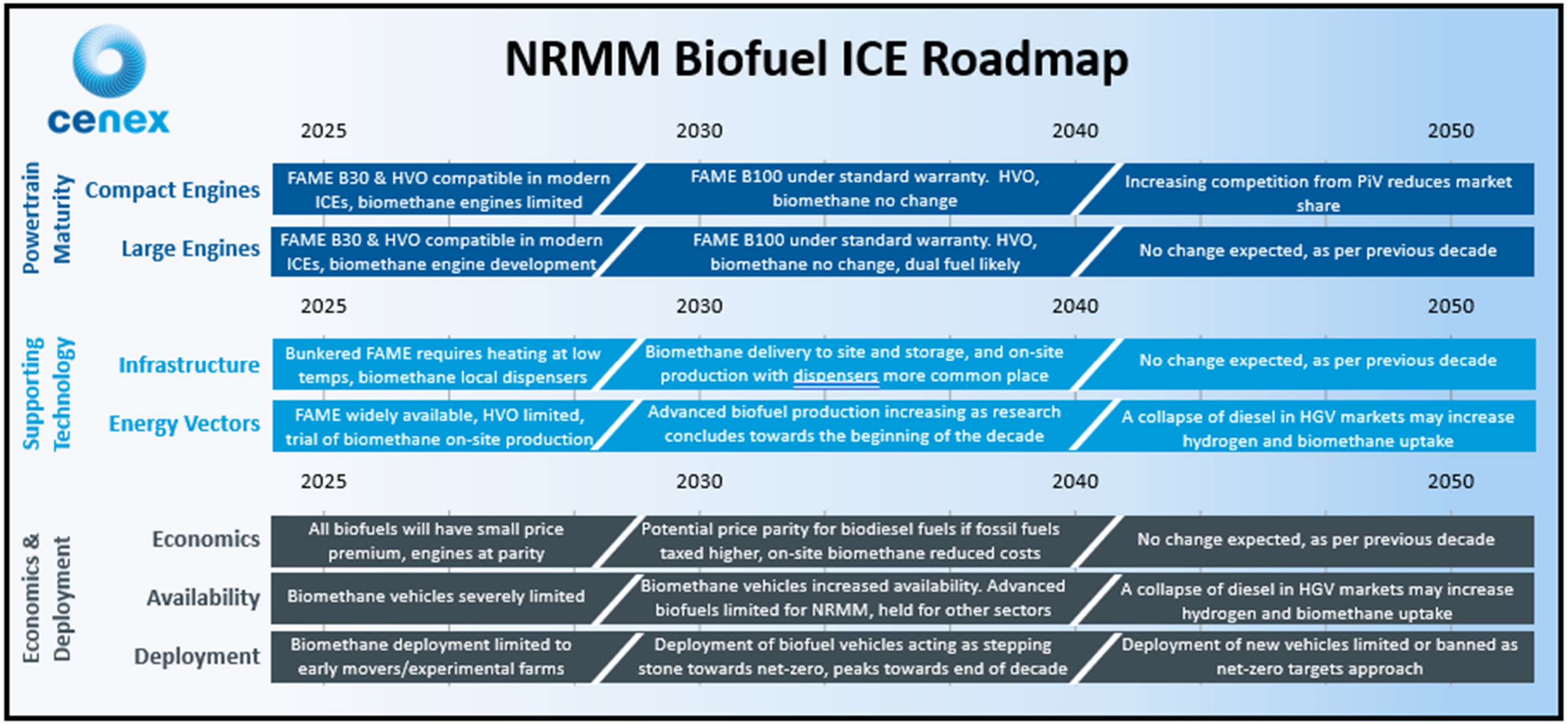


*Figure 8: NRMM Biofuels Roadmap*

The main points from the roadmap are:

- Biodiesel is a mature technology widely used in road transport and NRMM. Supply constraints limit its use, and in most markets, a price premium is applied compared to mineral diesel.
- There is typically a small price premium compared to mineral diesel. There are a few additional capital expenses, except when using very high concentrations of FAME, which may require changes to storage facilities and incur additional maintenance procedures.
- HVO is a drop-in fuel which can be used in place of mineral diesel. 100% HVO can be used in many existing diesel engines with modifications or changes to the warranty, although this must be confirmed with the manufacturer.
- Biodiesel and HVO are not long-term net zero solutions. Competition with other sectors, such as aviation, is expected to constrain supply and/or increase costs further.
- HVO is preferred over B100 as it is a drop-in fuel, chemically identical to mineral diesel. B100 may have additional requirements regarding storage in vehicles and bunkers, particularly in cold ambient temperatures and high-humidity environments.
- The development of increasingly effective zero-emission powertrains (PiV, FCEV, and arguably H2 ICE) will put significant pressure on biofuels combustion due to its continued Air Quality (AQ) and Greenhouse Gas (GHG) emissions[5].

- [5] In Dr McCarthy's opinion (lead author of this report), there is a risk that, driven primarily by AQ concerns, a ban on new biofuel-vehicle sales in the decades before 2050 is possible in the NRMM sector, especially for work undertaken in urban areas. However, this risk is difficult to quantify.

### *Maritime - Plug-in Vessels*

Plug-in vehicles include battery electric vessels (BEV), plug-in hybrid electric vessels (PHEV), and range extended electric vessels (REEV). PiVs store energy in a battery (usually lithium-ion) and deliver power through an electric motor.

This roadmap focuses on purely battery-powered auxiliary load systems and main propulsion units. We assume a degree of hybridisation (combining battery systems with other powertrains). It is essential to note that for smaller vessels, particularly leisure craft, full battery electrification may be a viable option. However, except for vessels with extremely well-defined routes that can install suitable charging infrastructure for each leg of the journey (for example, ferries), it is unlikely that larger commercial craft (over 1,000 gross tonnes) will use battery systems for main propulsion. There may still be significant battery electrification of auxiliary power systems, which can require very large amounts of power on the largest vessels.

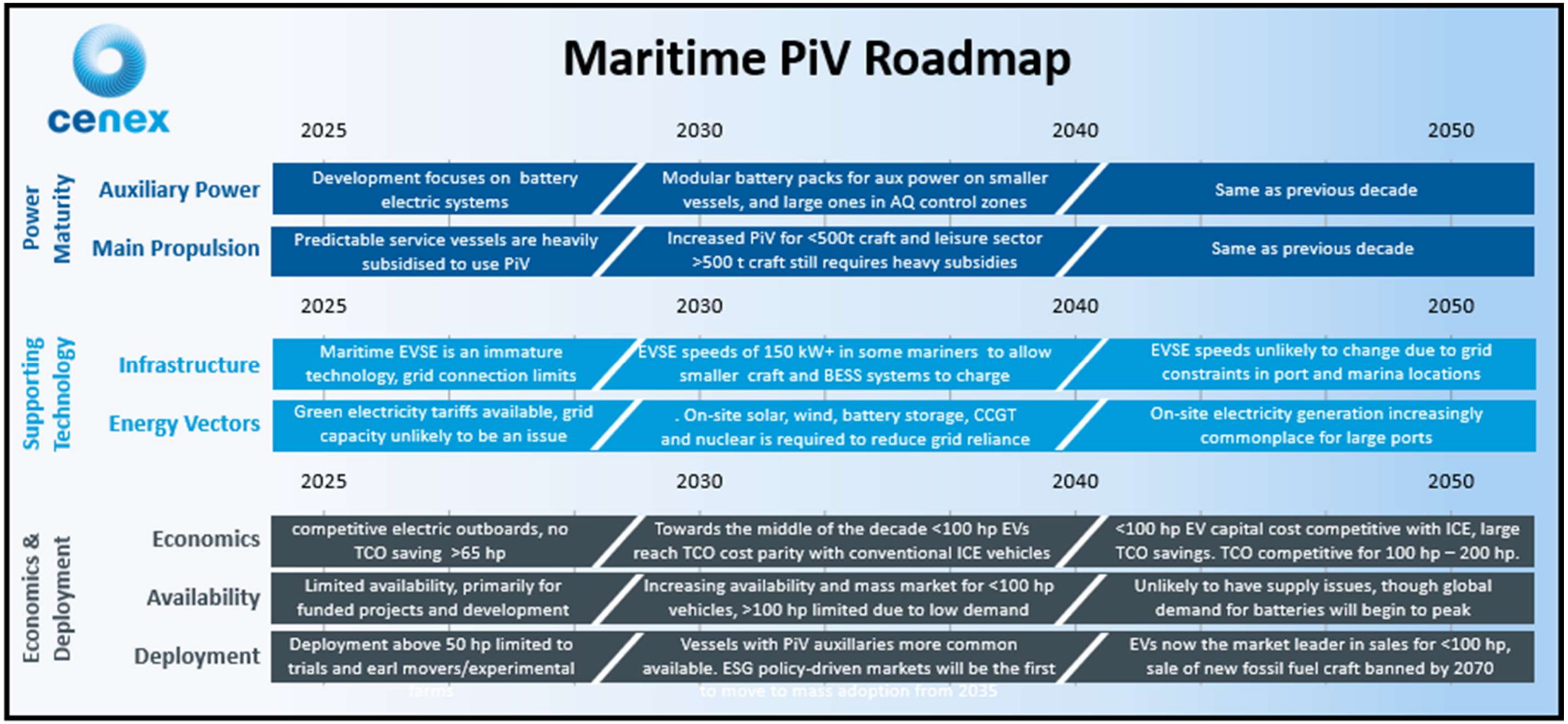


*Figure 9: Maritime PiV Roadmap*

The main points from the roadmap are:

- There will be limited unsubsidised deployment of PiVs for main propulsion before 2030 due to a lack of product availability, a lack of charging infrastructure, and unattractive total cost of ownership (TCO) performance compared to the wide variety of Marine Fuel Oils.
- Energy demands for the smaller leisure craft and some near-shore operations on the smallest of vessels will be able to convert to main propulsion PiV operation, over time.
- The adoption of car-based battery electrification and charging infrastructure for these smallest vessels is a likely route to market for the smallest PiV vessels.
- As vessel size increases to 500 gross tonnes (GT) and greater, full electrification becomes problematic. A certain portion of the total power demand for both propulsion and auxiliary power may be met by battery electric systems. Still, space will be a limiting factor on vessels in this size range.
- As vessel size increases, into the 500 to 5,000 GT bracket, there will be increasing scope for the adoption of auxiliary battery systems on board for hotel loads[6].
- Above 5,000 GT, the usefulness of PiV for main propulsion is increasingly diminished (outside of heavily subsidised ferry routes). However, the market for auxiliary power to supply hotel loads increases significantly.
- Larger PiV NRMM in port side operations will grow significantly, but grid constraints will limit uptake, unless dedicated infrastructure, including power generation, is put in place. (This is noted here as portside NRMM is considered within the 'maritime' section of this report.)

[6] The term to describe the essential power requirements not related to main propulsion and movements; for example, running refrigeration equipment on fishing vessels.

***Maritime - Hydrogen Fuel Cell***

Hydrogen is a safe, clean-burning energy source which is stored on vehicles in compressed hydrogen cylinders. In an FCEV, a small battery system is used to recover energy from regenerative braking systems and improve response times for power spikes.

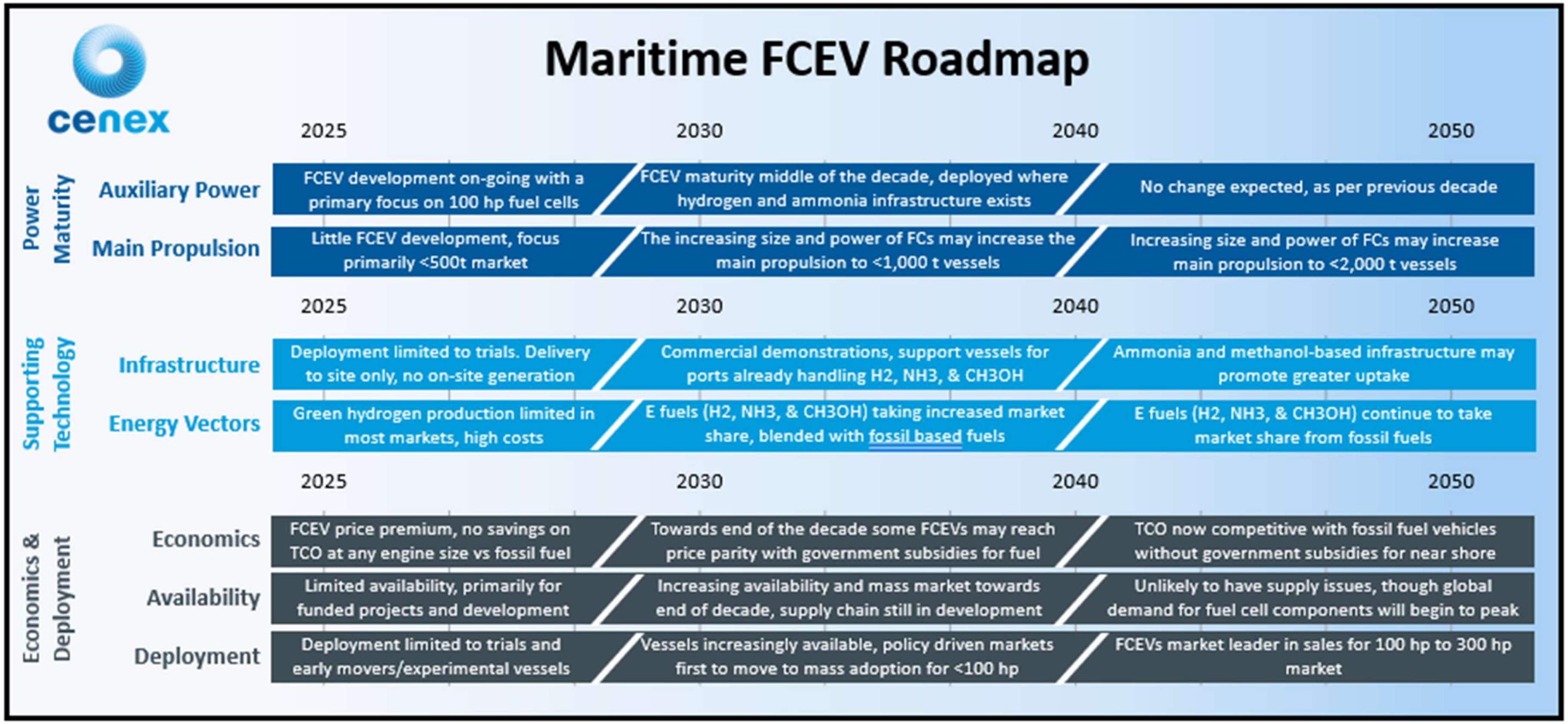


*Figure 10: Maritime FCEV Roadmap*

The main points from the roadmap are:

- There is likely to be limited unsubsidised deployment of FCEVs before 2030 due to a lack of product availability and unattractive total cost of ownership (TCO) performance compared to MFO.

- FCEVs are likely to cost more than MFO vessels for some time to come, and without subsidies are likely to be more expensive to fuel. As such, it could be the late 2030s before a reasonable TCO performance, combined with policy drivers, leads to significant uptake.
- FCEVs can theoretically be used in all vessel sizes. However, the stored energy density of hydrogen, whether as a gas or a liquid, limits the range of vessel sizes where hydrogen can be deployed. Vessels under 100 gross tonnes (GT) are unlikely to have room for hydrogen storage. As vessels increase in size, this may change, with vessels of 500 GT and above having sufficient storage space to consider hydrogen fuelling for some or all of their energy demands.
- Above 5,000 GT, vessel energy demands are so significant that the possible role of hydrogen is likely to diminish, as more energy-dense solutions are required. It is important to note that one potential solution to this issue is the ‘cracking’ of hydrogen-carrying liquids to power hydrogen propulsion.
- On ship cracking technology is a highly debated topic, and there is little evidence to base informed decisions on. For this reason, any vessel using ammonia or methane in a fuel cell, with or without cracking, is considered a separate energy vector, with its own supply chains, dispensing systems, quality controls and regulations. In this analysis, such vessels are classified as being powered by e-fuels (synthetic fuels derived from renewably or sustainably produced hydrogen, such as ammonia, methanol, or others).
- FCEVs operating on hydrogen can be considered a ZE technology if hydrogen is made from a renewable energy source, so-called ‘green’ hydrogen. Currently, most available hydrogen is produced through steam methane reforming without carbon capture, known as 'grey hydrogen’, which offers little to no carbon savings compared to diesel when used in a vehicle. Low (or very low) carbon hydrogen can also be made through adding carbon capture and storage to the process of manufacturing hydrogen from methane, so-called ‘blue’ hydrogen.
- Infrastructure options may include a combination of on-site electrolysers on larger sites, though the power demand for this will be just as significant.
- Smaller sites and short-term sites will rely on tube trailer deliveries from major hydrogen production centres (hub and spoke model). Infrastructure could be a challenge for remote locations with low fuel demands or constrained site footprints.

### *Maritime - Hydrogen Internal Combustion*

Hydrogen can also be used in an internal combustion engine. Hydrogen is stored in the same cylinders as for an FCEV, but is then burnt in a modified combustion engine. Hydrogen can be burnt neat or blended with diesel.

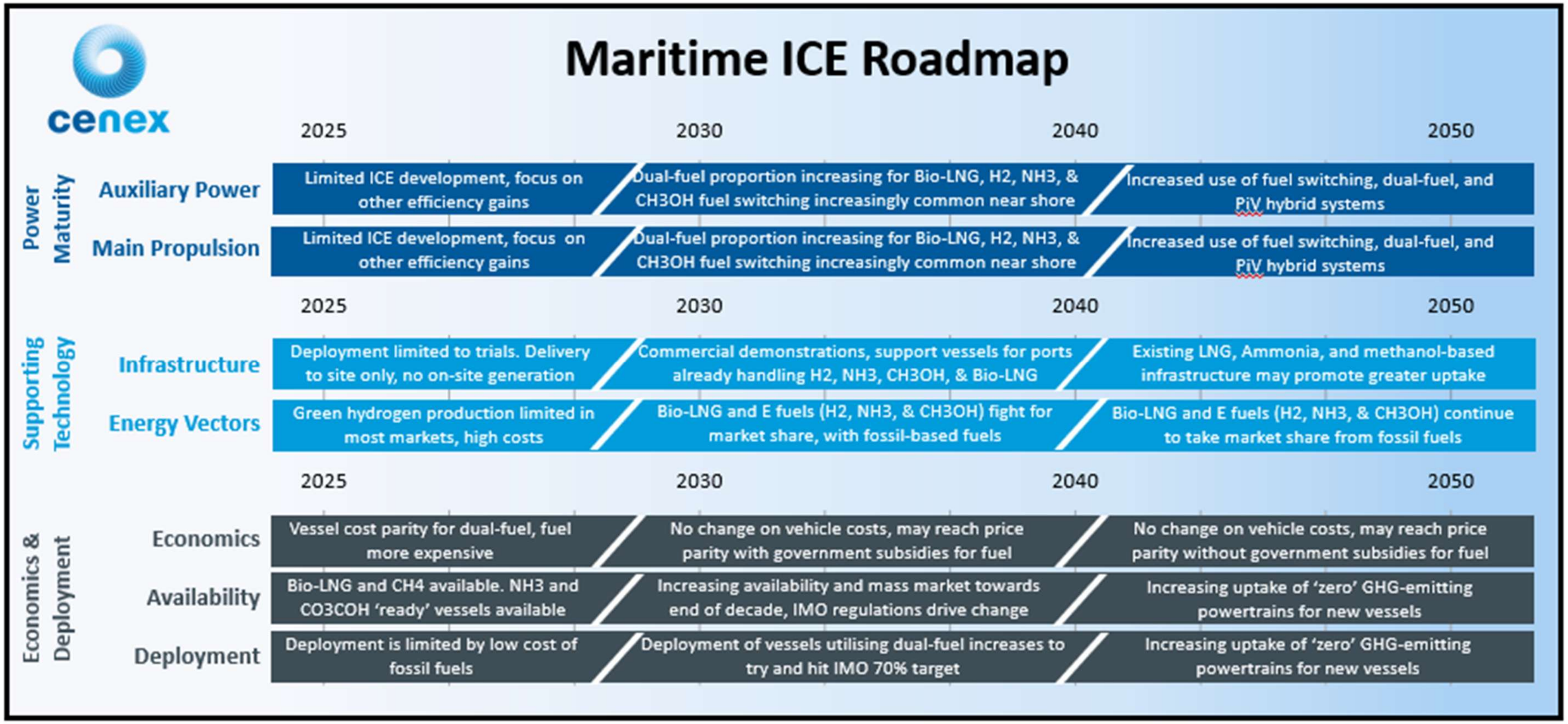


*Figure 11: Maritime ICE Roadmap*

The main points from the roadmap are:

- There is likely to be limited deployment of hydrogen ICEs before 2030 due to a lack of product availability and unattractive TCO performance compared to Marine fuel oils (MFOs).
- Early hydrogen ICE may be dual-fuel vessels which can burn a blend of hydrogen and diesel (or other fuels). Fuel costs are likely to increase in proportion to the quantity of hydrogen used until the 2040s.
- Hydrogen ICE vessels are likely to cost more than MFO vessels for some time to come, and without subsidies are likely to be more expensive to fuel than biofuel-based ICE. As such, it could be the late 2030s before a reasonable TCO performance, combined with policy drivers, leads to significant uptake.
- Dual fuel and 'fuel switching'[7] may promote the use of hydrogen.
- Hydrogen ICEs can theoretically be used in all vessel classes. Uptake will be driven primarily by fuel availability and legislative and ESG policy factors.
- The IMO does call for net zero compliance in international shipping by 2050, which may drive uptake of net zero emission fuels such as hydrogen.
- Hydrogen ICEs can be considered a ZE technology if hydrogen is made from a renewable energy source, so-called 'green' hydrogen. Currently, most available hydrogen is produced through steam methane reforming without carbon capture, known as 'grey hydrogen', which offers little to no carbon savings compared to diesel when used in a vehicle. Low (or very low) carbon hydrogen can also be made through adding carbon capture and storage to the process of manufacturing hydrogen from methane, so-called 'blue' hydrogen.
- Infrastructure options may include an on-site electrolysers or a deblending station on larger sites.
- From 2050, it is possible that bans on greenhouse gas-emitting vessels will come into force. However, many vessels can operate for 60 years or even longer with retrofits. ICE combustion is therefore likely to be a significant means of maritime propulsion and auxiliary power for the next 100 years.

[7] Running engines on different fuel mixes to comply with changing national fuel standards as vessels traverse the globe

***Marime - Renewable Biofuels***

Biofuels can be used in blends with marine fuel oil, typically at 20% or 30% concentration, or neat as B100, although this requires some operational and infrastructure adjustments. HVO is chemically identical fuel to mineral diesel and can be used in the same way; however, its price premium typically rules it out for all but the smallest vessels. Liquid natural gas is used in significant quantities today, primarily in the LNG transport fleet. There are also an estimated 600 LNG fuelled vessels[8] outside the LNG transport fleet, and this segment is growing rapidly.

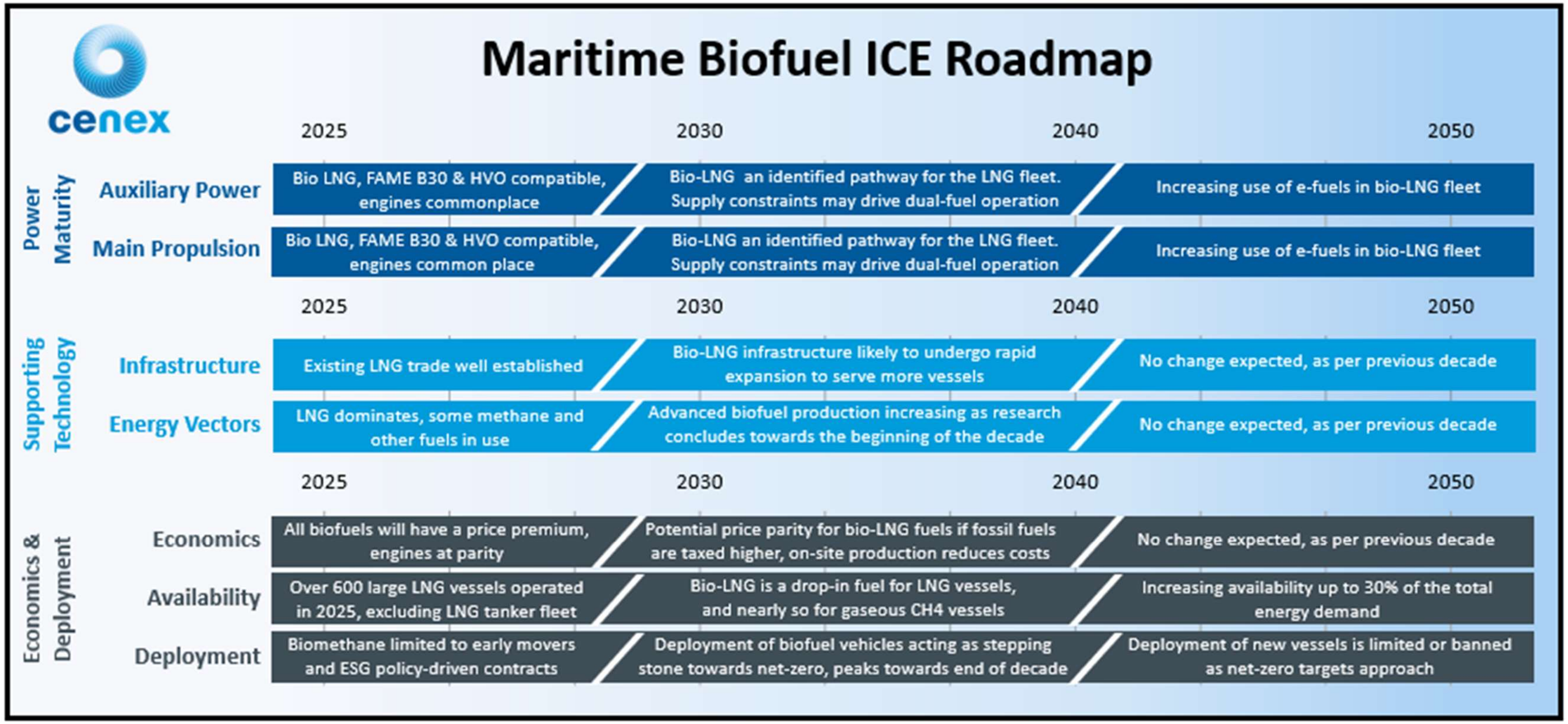


*Figure 12: Maritime Biofuel Roadmap*

[8] Bush, D (2025). Number of ships using LNG up 33% in 2024. Lloyds List. (Online) https://www.lloydslist.com/LL1152328/Number-of-ships-using-LNG-up-33-in-2024

The main points from the roadmap are:

- Biofuels are already entering the maritime sector, though primarily as technical proof of concept, or in sectors with strong ESG policy drivers (for example, support vessels for offshore wind farms), and not as a cost-competitive option with bio-LNG considered a likely pathway for larger vessels to decarbonise
- There is an expectation that shipping will adopt one of several 'net zero compatible' fuels, with Bio-methane (both gaseous and LNG), e-Ammonia, and e-Methanol often discussed in the literature, though with little agreement between the various supporters of each energy vector.
- Bio-Methane, e-ammonia, and e-methanol all offer the possibility of being close to a drop in fuel in terms of operational suitability for larger vessels (above 10,00 GT), with some relatively minor modification to engines, fuel storage bunkers, and operational practices.
- Early biofuel ICE may be dual-fuel vessels which can burn a blend of fuels (both fossil and net zero compatible). Fuel costs are likely to increase in proportion to the quantity of fossil MFO displaced until the 2040s.
- Vessels utilising any fuel other than MFO may have a small price premium. However, multi-fuel systems, up to and including fuel switching (for example, to switch from a standard MFO blend to low sulphur blends when operating in the North Sea) are already commonplace and considered to have acceptable impacts on operating costs.
- Dual fuel and 'fuel switching'[9] may promote the use of net-zero compatible fuels, particularly in North Sea operations, and in coastal and port-based operations. Hydrogen and ammonia offer the possibility of significantly reducing Air Quality pollution in cities. This may be yet another factor driving their uptake in certain settings.
- Biofuels ICEs can be used in all vessel classes. Uptake will be driven primarily by fuel price, availability, legislative and ESG policy factors.
- The IMO does call for net zero compliance in international shipping by 2050, which may drive uptake of net zero emission fuels such as Bio LNG.
- Infrastructure option may include bio methane production and liquification in some ports, but this is far from certain.
- From 2050, it is possible that bans on greenhouse gas-emitting vessels will come into force. However, many vessels can operate for 60 years or even longer with retrofits. ICE combustion is likely to be a significant means of maritime propulsion for the next 100 years.

[9] Running engines on different fuel mixes to comply with changing national fuel standards as vessels traverse the globe

### *Key Takeaways*

- There is a lack of information about technology pathways, so these roadmaps should be treated as indicative. National Gas will need to monitor the market and continue to engage with vendors and manufacturers to refine these scenarios continually.
- Additional discussion on powertrain technologies, estimated numbers of vehicles and vessels, and typical duty cycles is presented in Annexe B
- Prior to 2030, it is unlikely there will be significant deployment of NRMM ZE vehicles for vehicles above three tonnes in weight, without significant subsidies. However, these vehicles are entering the market, and subsidies are in place in many locations worldwide. (Norway in particular, is leading in this sector, and zero emission zones in cities such as London are fostering uptake of larger battery-powered NRMM[4].)
- Deployment must occur before 2050 for countries to achieve their national net-zero targets.
- Hydrogen uptake scenarios for this transition are presented in section 6.5.
- Total hydrogen demand for these scenarios (with legislated and accelerated sensitivity assessment) are presented in section 9.
- PiVs can be considered a ZE option in countries with a decarbonised grid. Countries with a net zero 2050 target will likely need to decarbonise their grid fully. Hydrogen vehicles are only ZE if the fuel is produced from renewable sources. Biofuels are not a ZE technology.
- The UK's existing policies are not sufficient to achieve net zero by 2050, or to achieve full grid decarbonisation[10]. Revised policies are due in October 2025. It remains to be seen if this third set of UK policy revisions will withstand judicial scrutiny.
- Low-power vehicles are more likely to switch to electric technology, while higher-power, heavier vehicles, are more likely to switch towards hydrogen in the long run. However, **there is significant uncertainty around this**. PiVs are likely to be deployed earlier than hydrogen-powered vehicles as the technology is more mature, and the running costs will be lower in most markets.
- The uptake of hydrogen will depend on the cost-effective and reliable delivery of hydrogen fuel through a national hydrogen refuelling network. At the time of writing, there is no national UK government policy in place to deliver such a network.
- Biofuels are likely to dominate in maritime sectors
- There may be a role for hydrogen fuel in the propulsion 500 GT to 5,000 GT range in the maritime sector for hydrogen.
- The role for hydrogen fuel beyond 5,000 GT, fuel switching is the most likely vector and will only account for a small percentage of near-shore movement.
- This range could expand if zero-emission fuel switching becomes standard practice in short sea waters (such as the North Sea).
- Grid constraints at ports could drive significant uptake of hydrogen power generation, even if hydrogen powertrains and auxiliary systems on ships do not materialise.

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[10] Burnett, N. & Stewart, I. (2025): Research Briefing: The UK's Plans and Progress to Reach Net Zero by 2050. (Online) https://researchbriefings.files.parliament.uk/documents/CBP-9888/CBP-9888.pdf

- **Based on the modelled results in previous work for clients in the financial sector,** and assuming governments remain committed to the net zero by 2050 agenda, **the market share for land-based fossil fuels can be expected to fall dramatically over the next few decades**
    - 2025 ~94% market share from fossil fuels
    - 2030 ~80% market share from fossil fuels
    - 2040 ~50% market share from fossil fuels
    - 2045 ~25% market share from fossil fuels
    - 2050 0% market share from fossil fuels

A global oil glut in fossil fuels is highly likely at one or more points in time between now and 2050, and it may occur as soon as the mid-2030s[11]. A significant oversupply of fossil fuels will drive down the price of fuel and make it harder for novel technologies to displace incumbent fossil ICE. Without further government intervention, the uptake of zero-emission powertrains is likely to stagnate.

### *Hydrogen generation, transport and fuelling infrastructure*

Hydrogen can be produced in several different ways. These include production from fossil fuels such as coal gasification or natural-gas steam-methane reforming ("grey" hydrogen), a process which can be made lower-carbon with carbon capture and storage ("blue hydrogen"), or hydrogen can be generated by electrolysis of water ("green hydrogen") using technologies such as alkaline, proton-exchange membrane, solid-oxide, or anion-exchange systems[12]. In the UK, early large-volume supply is expected from blue-hydrogen plants at industrial clusters, with green hydrogen expanding through the 2030s as costs fall and infrastructure scales.[13]

Hydrogen can be stored as compressed gas (including subsurface storage), as a cryogenic liquid, or as a chemical carrier (e.g., ammonia or other liquid organic hydrogen carriers, including methanol). The best option for a given use case will depend on transportation distance, storage duration, capacity, and response time. The energy stored in hydrogen can be recovered by combustion in boilers, engines, or gas turbines (including combined cycle), or via fuel cells. Today, most UK hydrogen production and use is integrated within steel, chemical, and refining sites (mainly grey hydrogen); as an energy-storage route, electricity produces hydrogen that is later reconverted to power or used as a transport fuel.

If hydrogen is to be used in vehicles, then it requires a refuelling infrastructure to distribute and dispense it. The state of hydrogen refuelling infrastructure is best summarised by looking at the stages of distribution and dispensing:

**On-site hydrogen dispensing**: Dedicated dispenser units provide hydrogen to vehicles. Historically, this has involved a range of dispensing pressures from 180 bar(g) to 900 bar(g). Most recently, two main dispensing pressures have been settled on as 350 bar(g) and 700 bar(g). The latest regulations require that all hydrogen refuelling stations (HRS) in the EU specify that they cater for HGVs refuelling at 700 bar(g)[14]. This will likely become a worldwide standard as the transport hydrogen market grows. It is important to note that the reverse Joule-Thomson effect of hydrogen means that when discharging hydrogen, temperature increases will occur as the gas experiences a pressure drop. H2 dispensers must either fill relatively slowly or include pre-cooling equipment to manage temperature increases.

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[11] IEA (2024): Oil 2024, IEA, Paris (Online). https://www.iea.org/reports/oil-2024

[12] There is also so-called 'white' or 'gold' hydrogen, which consists of geological deposits of naturally occurring hydrogen which can be extracted using modern exploration and drilling techniques developed for natural gas. The extent and economic viability of this type of hydrogen is not yet fully confirmed.

[13] DNV (2023). *The Role of Hydrogen and Batteries in Delivering Net Zero in the UK by 2050.* The Faraday Institution. (Online). https://www.faraday.ac.uk/wp-content/uploads/2023/04/L2C231476-UKLON-R-01-F_Market-and-Technology-Assessment_FaradayInst_24Apr2023.pdf (Accessed 8 September 2025).

[14] European Union (2023) Alternative Fuels Infrastructure Regulation. Regulation (EU) 2023/1804. (online) (Accessed 8 September 2025).

- **Staged compression:** Today, virtually all HRS have staged compression for hydrogen delivery. Most hydrogen is stored as 180 bar(g) in large cylinders (sometimes delivered in tube trailers). Then the anticipated hydrogen demand for the next day is pressurised in a separate container at ~500 bar(g). This is sufficient to provide refuelling for 350-bar hydrogen tanks. If 700 bar(g) refuelling is required, a third stage of compression is used at 900 bar(g), though this is usually limited in size to meet the anticipated needs for the next few hours. Compressor failure has been the single largest flaw in hydrogen station equipment to date[15]. (Cenex advises National Gas to ensure that any proposed demonstration equipment for hydrogen dispensing keeps suitable replacement parts on hand to repair or replace failed compressor equipment.)
- **Liquid and gaseous hydrogen:** Most providers tend to design with gaseous hydrogen in mind. However, there is active research into the use of liquid hydrogen[16]. This has its own technical and economic challenges, but if the turnaround time for vehicles is fast enough, liquid hydrogen refuelling can be cost-competitive with gaseous hydrogen.
- **Off-site vs on-site hydrogen generation:** Off-site hydrogen generation requires delivery H2 to stations by tanker or pipeline (like conventional fuel deliveries today). It has the advantage of allowing large-scale production at low costs. On-site hydrogen generation involves installing an electrolyser at the same site as the HRS. When using renewable electricity, very low- or zero-carbon hydrogen can be produced. This solution eliminates the need for fuel deliveries (although such stations can be designed to accept delivered hydrogen), but it requires additional space. On-site electricity prices can vary and may be high relative to sites with co-located renewable electricity generators for off-site production processes.[17]
    - **Hydrogen deblending:** is a novel technology being developed by gas transmission companies like NGT with ambitions to blend hydrogen gas into natural gas supply networks. If deblending can achieve sufficient purity of supply, these deblending locations will be another vector for off-site hydrogen production.[18]
- **Mobile hydrogen dispensing:** A variety of small-scale mobile hydrogen dispensing providers have emerged in recent years. These companies provide either fully mobile (HGV-based) refuelling trucks, which decant stored hydrogen from deliverers to the chosen site, or semi-permanent containerised facilities, some of which can generate hydrogen on site, if sufficient electricity and water are available. It is also possible that hydrogen carrier liquids could be supplied in this fashion, and then 'cracked' into a hydrogen supply on site.

The UK's hydrogen infrastructure remains at an early demonstration stage, with a peak of ~20 publicly accessible hydrogen refuelling stations (HRS) a few years ago. This number has since declined as ageing demonstrator refuelling units proved unfit for commercial operation for many reasons (not least the lack of OEM-supplied hydrogen-powered vehicles). The few remaining HRS are clustered in London and southern England, Sheffield, Aberdeen, and Teesside (with refuelers in other locations not open to the public). See Figure 13 for more details.

Mobile HRS units (containerised or trailer-mounted) are increasingly deployed to support vehicle trials. These include buses, HGVs, and non-road mobile machinery (NRMM) on construction sites, where temporary fuelling avoids sunk costs before demand is proven. For maritime, UK ports (for example, Aberdeen, Teesport, Immingham, Milford Haven) are integrating hydrogen bunkering and hybrid onshore power supply in pilot schemes, often linked to regional industrial clusters and offshore wind.

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[15] ERM (2024): H2ME2: Emerging Conclusiosn Report. (Online) https://h2me.eu/wp-content/uploads/2024/04/D7.20-H2ME-emerging-conclusions-Final-Version.pdf

[16] Lister, M. (2024). Hydrogen trucks: €226 million funding for 100 liquid-hydrogen Mercedes trucks. Driving Hydrogen.com. (Online)

[17] H2ME2 (2023): Final Version of the Emerging Conclusions H2ME2: https://h2me.eu/publications/emerging-conclusions-2023-h2me-phase-2/

[18] Issac, T (2019): HyDeploy: The UK's First Hydrogen Blending Deployment Project: *Clean Energy*, Volume 3, Issue 2, June 2019, Pages 114–125, https://doi.org/10.1093/ce/zkz006

Overall, the network is highly fragmented. Coverage outside London is sparse, many stations are <350 bar or limited to 200–400 kg/day capacity, and long-term investment cases depend on scaling HGV/NRMM demand and maritime bunkering standards (ISO/IMO) that are still under development.

Figure 13 is adapted from the UK H2 Mobility hydrogen station map[19].


*Figure 13: 2025 UK public HRS*

[19] https://www.ukh2mobility.co.uk/stations/

## 2.2 UK policy, strategy and legislative landscape

The UK's policy on hydrogen is dominated by a small handful of documents, including hydrogen production and investment strategies[20], as well as key UK government policies on transport. It is important to note that Northern Ireland has an integrated electricity market with the Republic of Ireland, which means that the 'UK' policy documents are often Great Britain-focused and do not necessarily apply to Northern Ireland, such as the Ten Point Plan[21], and the more recent Clean Energy plan[22].

Alongside this, the UK Government has set an ambition for up to 10 GW of low-carbon hydrogen production by 2030[23], subject to affordability and value for money. That ambition is underpinned in law and institutions by the Energy Act 2023[24], the UK Infrastructure Bank Act 2023[25], and the launch of the National Energy System Operator (NESO) in October 2024[26], along with a wide variety of other market mechanisms and standards as detailed in the bibliography.

Each UK nation is developing its own approach. Scotland has moved fastest, building a practical governance and delivery platform to leverage its strong renewable resources and to advance real projects. Similar cross-regional alignment has yet to emerge across England, Wales and Northern Ireland.

Hydrogen developments cut across four main regulatory pillars applied differently by project type and scale. These are: health and safety, environmental permitting, land-use planning, and technical requirements (including digital security/cyber). Competent authorities are split by remit—for example the Environment Agency (EA) and Scottish Environment Protection Agency (SEPA) for environmental controls; the Health and Safety Executive (HSE) for safety; the Department for Transport for relevant transport law; and the Department for Levelling Up, Housing and Communities for planning and building control.

Parts of the framework originate in oil-and-gas law but now extend to hydrogen. Developers of hydrogen pipelines require a Gas Transporter Licence (it should be noted that, as of July 2025, the UK government is considering a temporary waiver on the need for a Gas Transporter licence for pilot and early-stage commercial projects that utilise 100% hydrogen pipelines[27]), and parties arranging conveyance require a Gas Shipper Licence, both regulated by Ofgem and adapted from the gas market. Technical and commercial code obligations can also apply (for example, Smart Energy Code, Retail Energy Code and Uniform Network Code).

Detailed guidance and standards are filling gaps. The UK has issued the Low Carbon Hydrogen Standard (with the latest version setting a maximum lifecycle emissions threshold for qualifying "low-carbon" hydrogen), while PAS 4445:2025 (BSI) provides a Code of Practice for large hydrogen-fired equipment and hydrogen conversions in industrial and commercial settings. Environmental regulators have also published Guidance for Emerging Techniques for hydrogen production by electrolysis of water to steer permitting. In parallel, work is underway in Scotland to clarify the planning and consenting routes for hydrogen projects, enabling developers to navigate approvals more predictably.

[20] DESNZ – Department for Energy Security and Net Zero (2024) *Hydrogen Net Zero Investment Roadmap*. London.
[21] UK Gov – UK Government (2020): Ten Point Plan for a Green Industrial Revolution: London.
[22] UK Gov – UK Government (2023) Clean Energy Industries: Sector Plan: London.
[23] UK Gov – UK Government (2021) UK hydrogen Strategy: London.

[24] UK Parliament (2023). Energy Act 2023 (c.52).
25 UK Parliament (2023). UK Infrastructure Bank Act 2023 (c.10). (Online). https://www.legislation.gov.uk/ukpga/2023/10/pdfs/ukpga_20230010_en.pdf (Accessed 9 September 2025)
26 National Energy System Operator (2024). National Energy System Operator launches today (1 October 2024). (Online). https://www.neso.energy/news/national-energy-system-operator-launches-today (Accessed 9 September 2025).
[27] UK Gov (2025): Hydrogen economic regulatory framework: developing an effective market framework for 100% hydrogen pipeline networks (online)

The key policies and regulations are summarised in Figure 14 below.

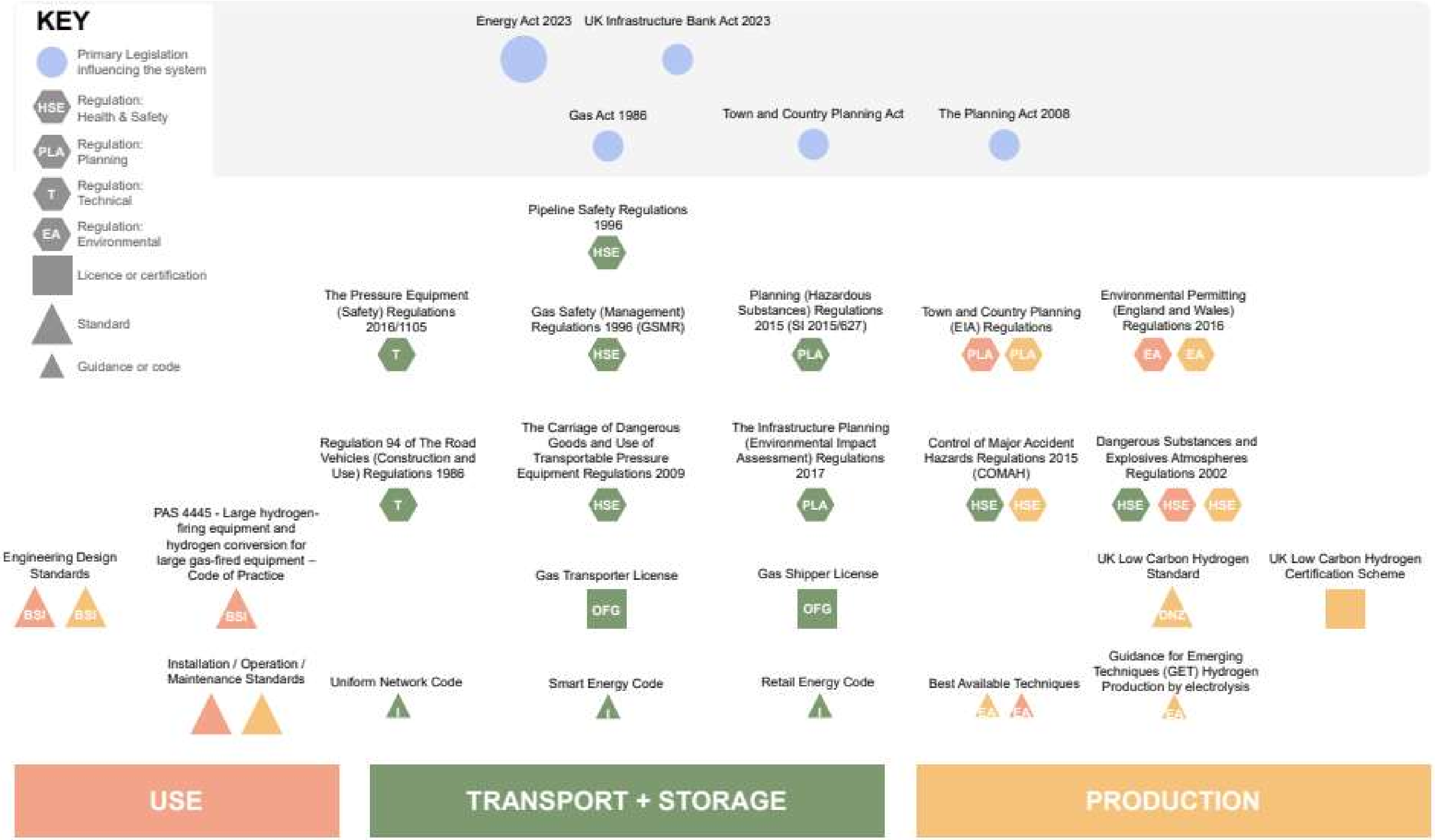


*Figure 14: Hydrogen policy and regulatory mapping (from Polina et al [28])*

[28] Polina, P, Reed, J. & Prokudina, A. (2025) *UK Hydrogen Economy - Policy and Regulatory Future Visioning.* OSF/UCL Department of Sci, Tech, Eng & Policy

# 3 Methodology

The following section outlines the steps taken to baseline energy demand and energy demands in each sector (and their previously defined market segments). This is followed by further discussion on the projected growth (or in many cases decline) in energy demand in each segment and how the future energy demands have been estimated.

## 3.1 Demand modelling methodological approach

The projected future energy demands are based heavily on assumptions from the literature review, and on the road mapping exercise outlined in Section 2. Once this initial assessment had been completed for each of the five sectors covered in this report, the following overall approach was taken[29]:

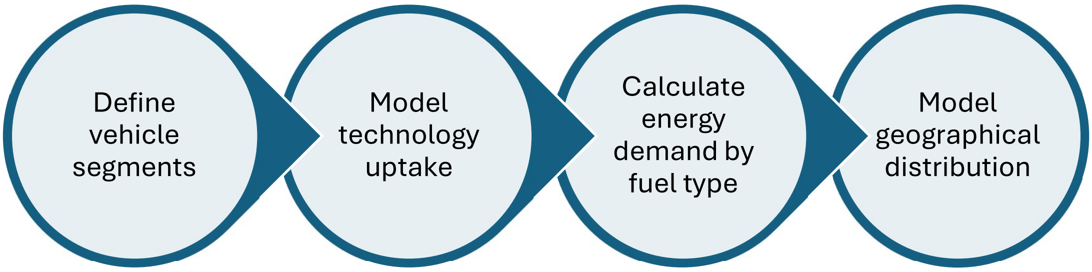


*Figure 15: Overall methodological approach*

### 3.1.1 Vehicle segmentation and technology uptake modelling

Modelling of the uptake of different powertrain technologies within the overall vehicle parc[30] has been completed for each combination of the following input factors:

*Table 1: Model input factors*

| Input factor | Type | Location | Size | Fuel market share |
|---|---|---|---|---|
| Options | Cars<br>LCVs<br>NRMM<br>Gen-sets<br>Maritime (different approach) | England<br>Scotland<br>Wales<br>N Ireland | Small<br>Medium<br>Large | Battery<br>Biofuel (FAME and Ethanol)<br>HVO<br>FCEV<br>$H_2$-ICE<br>Methane<br>ICE |

The uptake modelling was completed using an in-house model. Figure 16 shows the basic methodology of the model. Desk-based research of the existing number of vehicles of a given type in the markets of interest was used to establish the current vehicle parc ('parc' being the technical term for all vehicles within a group). The model then steps through each year to 2050 – at each step, vehicles are added to the parc (new vehicle sales), some are sold but remain as second-hand

[29] A different approach is taken for maritime due to lack of fleet and operational data. Data on port level fuel demand and current fuel mix was used to estimate future fuel mix under the two scenarios

[30] 'Parc' is the technical term for vehicles of a given category on the road, and is not usually reported. Most statistics and news reports focus on new vehicle sales within a period

vehicles, and some are scrapped and removed. The new vehicle parc is then calculated and fed back to the start of the next year.

Also shown in the figure, at each year there is an additional calculation of the energy used by that year's vehicle parc. This considers estimates of vehicle mileage and duty cycle, the fuel efficiency and the type of energy/powertrain (for example diesel, electricity, hydrogen, or similar).

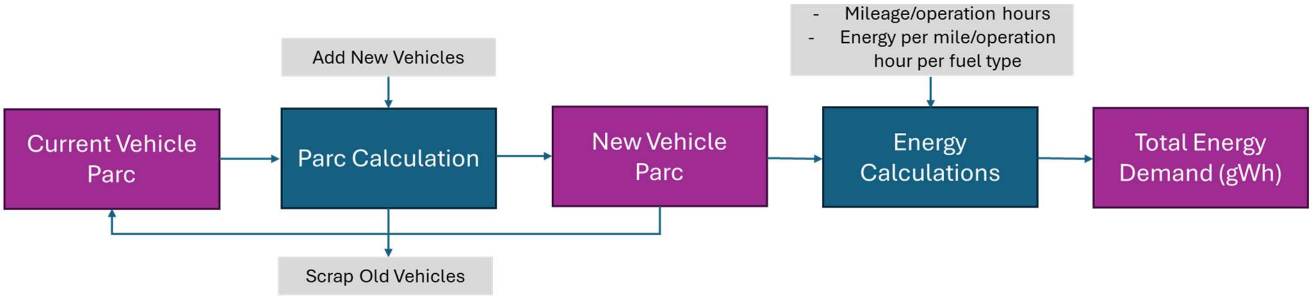


*Figure 16: Schematic of approach to uptake modelling*

The key point of insight for this project is how the vehicles entering and exiting the parc are split between the different powertrain/fuel types each year. Of particular interest is the proportion of vehicles that are BEV vs the proportion that adopt hydrogen as a fuel (either H2ICE or HFCV). This is based principally on an estimation of duty cycle, which is based on a variety of data sources detailed in the subsequent 'vehicle sector' sections of this report.

In the maritime sector, there is a lack of comprehensive fleet and operational data in the public domain, especially for smaller vessels that are more likely to witness significant hydrogen uptake. Therefore, the maritime fuel mix up is estimated to 2050 using a top-down approach. Public Global Port Optimisation fuel demand estimates by UK's major ports were used to estimate annual energy demand between 2024 and 2050[31], along with the IMO's Net-Zero Framework (NZF) and recent reports on the global maritime fuel mix outlook.[32,33]

### 3.1.2 Uptake scenarios

This section of the report draws heavily on the roadmaps and supporting information outlined previously in Section 2. This was then followed by seeking additional data to create baseline numbers for vehicles, equipment or energy demand (as appropriate). The roadmaps reported in the section 2 were then applied to the baseline figures, assisting in the creation of the scenarios.

In addition to the segmentation described above, for each vehicle sector, the model was run for two uptake scenarios – 'legislated uptake' and 'accelerated uptake'.

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[31] Salmon, Nicholas (2023), "Public-Global-Port-Optimisation", Mendeley Data, V2, doi: 10.17632/v4yz7778mh.2
[32] DNV, Maritime Forecast to 2050: A deep dive into shipping's decarbonization journey (Høvik, Norway: DNV, 2025).
[33] International Maritime Organization, "Net-Zero Framework (NZF)". The framework was approved in principle by the IMO's Marine Environment Protection Committee (MEPC) in April 2025 as a proposed new Chapter 5 in Annex VI of the MARPOL Convention.

Core assumptions regarding vehicle turnover rates and fuel efficiency were fixed across both scenarios. This allows estimated hydrogen demand to be compared based on uptake levels only. Main assumptions are as follows:

- **Fleet turnover:** the main driver of fleet growth is replacement of vehicles at the end of their lives. Therefore, the model assumes that total fleet for each mode remains almost the same. Table 2 shows detailed assumptions of lifespan and turnover rates.

*Table 2: Assumed lifespan and turnover rates per mode and vehicle size*

| Mode | Size | Turnover (%) | Lifespan |
|---|---|---|---|
| Cars | Small | 10% | 10 |
| Cars | Medium | 10% | 10 |
| Cars | Large | 10% | 10 |
| LCVs | Small | 10% | 10 |
| LCVs | Medium | 10% | 10 |
| LCVs | Large | 10% | 10 |
| Heavy Gensets | Small | 13% | 8 |
| Heavy Gensets | Medium | 7% | 14 |
| Heavy Gensets | Large | 5% | 20 |
| NRMM | Small | 10% | 10 |
| NRMM | Medium | 7% | 14 |
| NRMM | Large | 5% | 20 |

- **Mileage and energy use per mile for cars and LCVs:** the model employs average MOT mileage per fuel type and country. In the case of missing mileage data for a fuel type, Petrol and Diesel ICE average mileage is used (See Appendix E: Modelling Assumptions)
- **Operation hours and load factors for Gensets and NRMM:** To account for the wide variation of utilisation of NRMM and Gensets in various contexts, The model built on the National Atmospheric Emissions Inventory (NAEI) assumptions for load factors and hours of operations as follows:

*Table 3: Assumed annual hours of operation and load factors for NRMM and Gensets*

| Type | Size | Hours of operation per year | Load factor |
|---|---|---|---|
| Gensets | Small | 1000 | 0.4 |
| Gensets | Medium | 1000 | 0.4 |
| Gensets | Large | 600 | 0.55 |
| NRMM | Small | 1277 | 0.4 |
| NRMM | Medium | 1460 | 0.45 |
| NRMM | Large | 1825 | 0.5 |

### *Legislated uptake modelling*

The legislated uptake assumes that further policies are enacted at the last moment to accelerate net zero powertrain uptake and achieve legislated targets by 2050. The changes predicted for national policy will vary following each devolved nation's stated net-zero targets, and assumptions about the growth of new technologies in each sector.

In this scenario, the relatively low uptake of zero-emission vehicles will continue until legislation forces a change in purchasing behaviour. The legislated modelled uptake assumes little change in the rate at which BEV vehicles take market share from conventional ICE vehicles for cars, before the enforcement of the new regulation. For the LCV market, the market share is predicted to double ahead of enforcement, as more models become available and purchase prices approach parity with ICE equivalent vehicles. For certain market segments (based on region, sector, vehicle size sub-sector, projected vehicle working life, and segmented replacement rates for vehicle types), this 'forcing' point may arrive as early as 2030 for car, or 2035 for plug in hybrid ICE vehicles. (Fuel cell range extended plug in hybrids would still be permitted in theory, though no such models are available in the UK market at the time of writing.)

In other sectors, such as NRMM and gensets, a legally binding phase-out may not become an issue until 2050. For NRMM, there is no currently legislated phase-out, beyond the economy-wide net-zero by 2050 target. The legislative uptake model assumes that new purchases of ICE are phased out by then. However, this is inferred from the overall Net Zero target, not legislated explicitly. This phase-out assumption for NRMM should therefore be treated with caution.

Fossil fuel-combusting engines may be banned from UK roads and city centres at some point between now and 2050. Any such ban on fossil ICE powertrains could effectively become a de facto law, applying to any vehicle that cannot demonstrate a compelling reason to continue burning fossil fuels. There may be a classic car exemption for vehicles of historic significance, exempting ~1 million cars from zero emission compliance. However, this is not yet specifically mandated.

It is important to note that the legislated changeover from ICE to ZE fuels will have a huge impact on conventional fossil fuel and engine component manufacturers. Periods of highly volatile pricing for fuel and spare parts are likely to occur between now and 2050. Supply chains will inevitably be disrupted and rationalised by declining fuel demand (arguably, we may already be seeing the first signs of this in recent events[34]). Oversupply of fossil fuel and equipment will drive prices down and delay the uptake of zero-emission equivalent vehicles. Conversely, a shortage of fossil fuels and equipment may accelerate the adoption of zero-emission vehicles.

### *Accelerated uptake modelling*

Existing decarbonisation pathways are insufficient to meet the global climate commitment to stabilise global warming at 1.5°C above the agreed international baseline. The IEA has a 'Net Zero Emissions' (NZE) scenario that does meet this target, and our 'accelerated uptake' scenario assumes the NZE pathway will be adopted.

Our accelerated uptake scenario assumes that additional factors come into play to align the uptake of new technologies with the NZE pathway. These additional factors could include more aggressive legislation and/or more rapid improvements in low and net-zero technology (incentivising uptake beyond the regulated minimum).

The NZE scenario, as developed by the IEA, is a 'top-down' model based on total global fuel sales. It has minimal segregation by industrial sector (for example, all agricultural emissions are grouped,

[34] Ducket, A (2025): Lindsey refinery insolvency puts hundreds of UK jobs at risk: https://www.thechemicalengineer.com/news/lindsey-refinery-insolvency-puts-hundreds-of-uk-jobs-at-risk

regardless of source). However, it does suggest a pathway for the global energy sector to achieve net-zero $CO_2$ emissions by 2050, including sustainable development goals, universal energy access by 2030, and improvements in air quality. Advanced economies (such as the UK) are likely to reach net zero emissions ahead of other nations. The NZE trajectory claims a 50% probability of limiting global warming to 1.5°C above pre-industrial levels.[35]

The model used in this work is a 'bottom-up' calculation of vehicle replacement cycles for cars, LCVs, NRRM and Gensets. To align the outputs of the Cenex model to the NZE scenario, adjustments were made to the percentage sales of new low and zero-emission powertrains would occur, to adapt the model to align with the NZE scenario. NZE Assumptions for each mode are included in their respective sections (sections 3 to 5).

### 3.1.3 Geospatial modelling

The sectors evaluated in this report possess highly distinct operational geographies and energy consumption profiles across the UK. Recognising that a uniform analytical approach would fail to capture these critical variations, a bespoke, sector-by-sector methodology was developed for the geospatial modelling of hydrogen demand. This tailored approach ensures that the unique spatial characteristics and energy use patterns inherent to each sector are represented. The specific methods applied for each sector are detailed below:

#### *Cars and LCVs*

DfT's traffic count data was used to estimate traffic flow on Great Britain's Motorways and A roads. The authors then estimated potential energy use by cars and LCVs on road segments. Finally, modelled hydrogen demand per country is interpolated on road segments and subsequently on the hexagonal grid layer using area-based spatial interpolation methods (See Figure 17).

Due to a lack of quality traffic count data for Northern Ireland, the distribution of vehicle registrations on Super Output Area (SOA)[36] level was used for geospatial modelling of hydrogen demand for cars and LCVs.

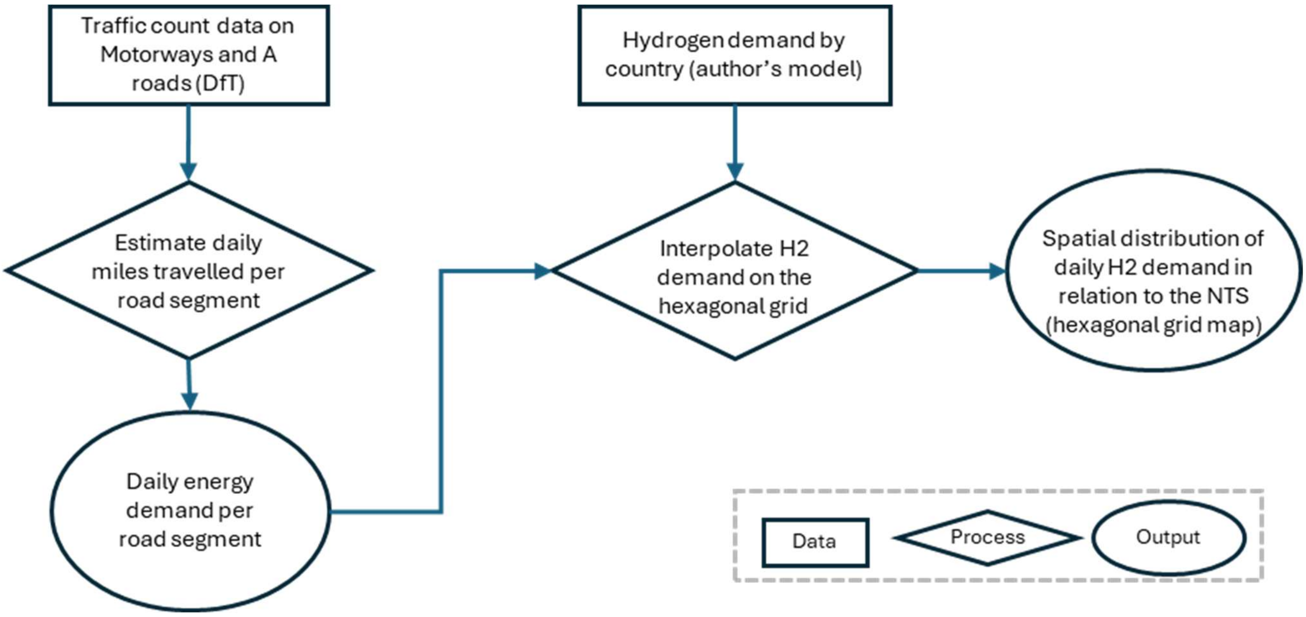



*Figure 17: Overview of the geospatial modelling process for hydrogen demand by cars and LCVs*

[35] IEA (2023): Net Zero Emissions by 2050 Scenario (NZE): International Energy Association (Online). https://www.iea.org/reports/global-energy-and-climate-model/net-zero-emissions-by-2050-scenario-nze

[36] A standard, small geographic unit used in Northern Ireland for presenting statistical data. SOA is an equivalent of Lower Super Output Area (LSOA) in England and Wales.

### *NRMM and Gensets*

Industrial activity locations have been mapped to a suitable resolution to allow for accurate interpolation of the country-level energy use. To obtain a granular estimate of energy demand, major active and planned construction projects in the UK were mapped. This was complemented by data from the Considerate Constructors Scheme (CCS) Construction Map, which offers insights into the location of many UK construction projects. The construction project map generated was used as a proxy for the spatial distribution of energy demand by NRMM and gensets.

For each project, an Annual Energy Use Potential (AEUP) value as calculated using the following formula:

$$\boldsymbol{AEUP_i = B_i \frac{PTM_i}{D_i}}$$

Where:

- $\boldsymbol{AEUP_i}$ is the Annual Energy Use Potential for project i
- $\boldsymbol{B_i}$ is the total budget for project i
- $\boldsymbol{PTM_i}$ is the project type multiplier for project i.
- $\boldsymbol{D_i}$ **is the duration in years** for project i.

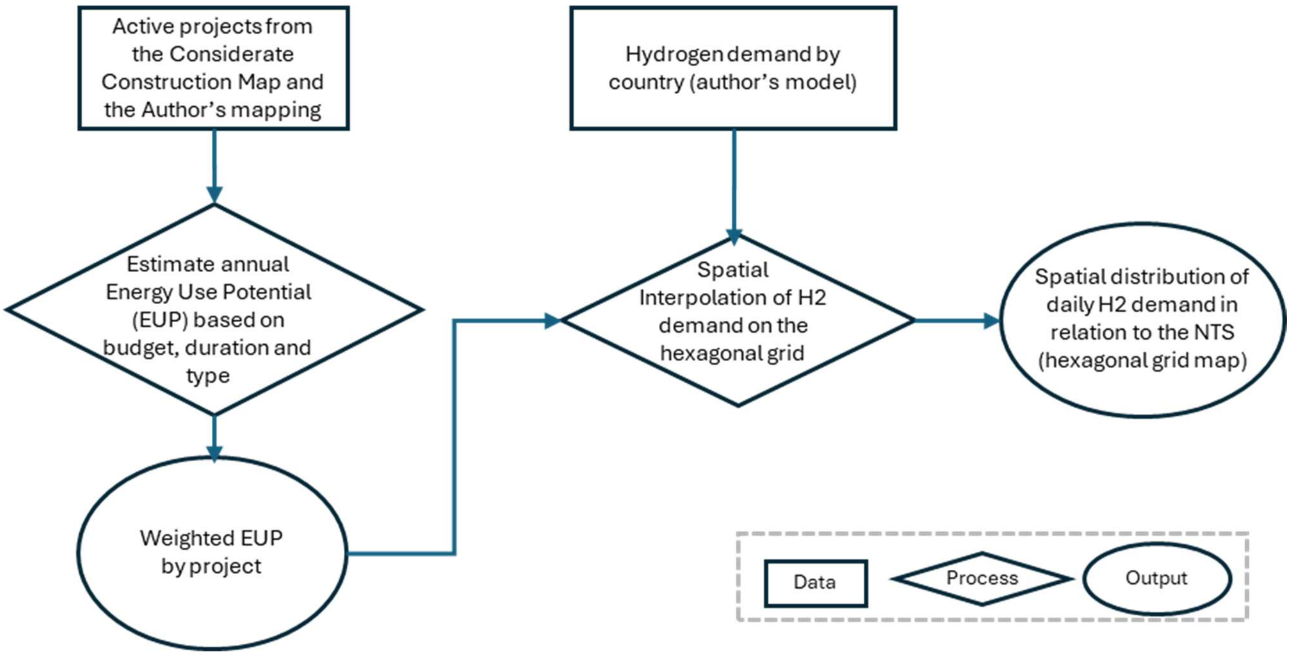
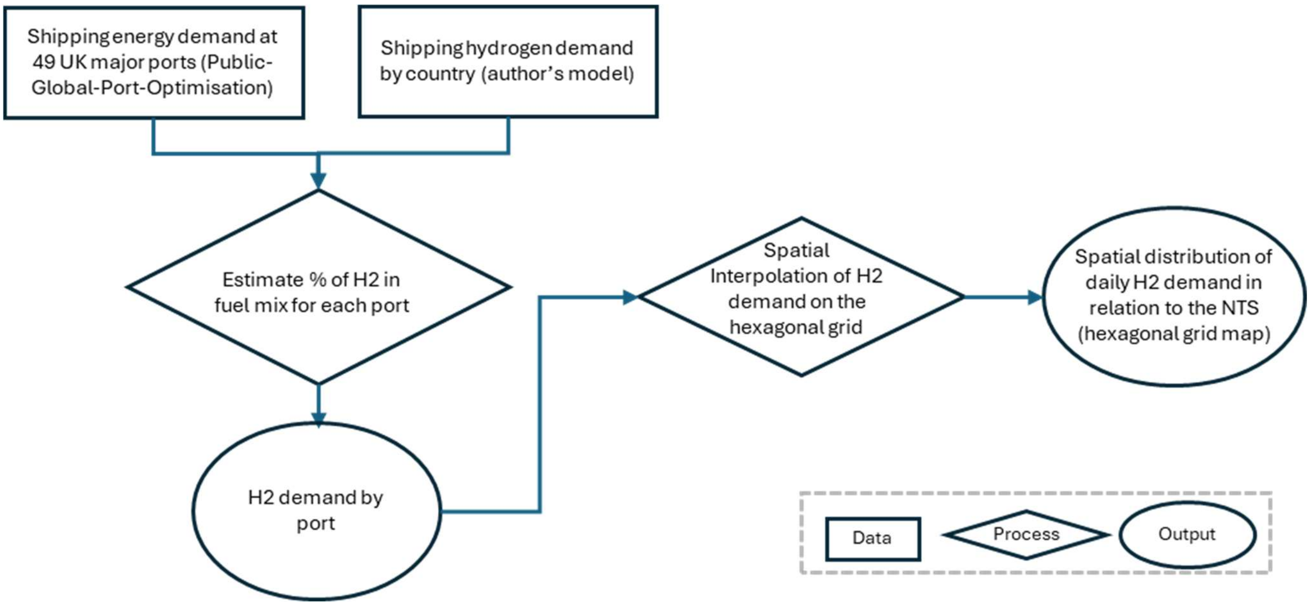



*Figure 18: Overview of the geospatial modelling process for hydrogen demand by NRMM and gensets*

### *Maritime*

To model maritime hydrogen demand, shipping energy demand data for 49 major UK ports, was combined with the authors' national-level shipping hydrogen demand model. [37] From these inputs, the percentage of hydrogen in the future fuel mix was estimated for each of the 49 ports to determine their specific hydrogen demand. This port-level demand data was then spatially interpolated onto the hexagonal grid layer to produce the final geospatial distribution of maritime hydrogen demand.




### *Aggregation of total hydrogen demand*

To ensure all potential demand is captured, two key adjustments were made during this aggregation process. Firstly, the hydrogen demand for Non-Road Mobile Machinery (NRMM) was multiplied by a factor of 1.79. This uplift accounts for the energy consumption from non-construction NRMM (e.g., in mining and agriculture), which constitutes 44% of the total NRMM energy demand but falls outside the scope of our primary model. This adjustment is applied consistently across both the legislated and accelerated scenarios.

Furthermore, a specific addition was made to the 2050 projections to reflect the decarbonisation of the UK's major ports. Industrial energy use within these ports that is considered difficult to electrify is expected to transition to hydrogen to meet net-zero targets. It is estimated that 32% of the ports' energy use will be hard-to-electrify[38]. This value was added to the overall maritime hydrogen demand totals for the year 2050 in both future scenarios, creating a more complete picture of demand in these industrial and logistical hubs.

Finally, the aggregated results were used to identify potential hydrogen hub locations along the National Transmission System (NTS) and Northern Ireland Transmission System (NI TS). Daily hydrogen demand was calculated for each hub using a catchment radius of 50 miles, which corresponds with the maximum working radius for a profitable tube trailer delivery system.

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[37] Salmon, Nicholas (2023), "Public-Global-Port-Optimisation", Mendeley Data, V1, doi: 10.17632/v4yz7778mh.1

[38] Based on previous work by ERM, Cenex, and the DFT on NRMM; 32% is the cross sectoral average estimate of the proportion fo NRMM that is 'hard to electrify' and is discussed in more detail in section 6.1

## 3.2 Data sources

This section of the report draws heavily on the road maps and supporting information outlined previously in Section 2. The approach in this work was to start with the initial roadmaps outlined in section 2. This was then followed by seeking additional data to create baseline numbers so for vehicles, equipment or energy demand (as appropriate) and then. The road maps reported in the section 2 were then applied to the baseline figures, assisting in the creation of the scenarios in section 3.1.2.

### *3.2.1 Hydrogen infrastructure and supply chains*

As already noted in Section 0, Hydrogen infrastructure and supply chains are underdeveloped in the UK in terms of their alignment with 2050 net zero ambitions. Key sources for this topic were a thorough review of UK infrastructure and deployments in multiple H2 sectors by Druganov and Lyden[39], the ICCT report on on-site electrolysis[40], and the H2ME emerging conclusion report[41].

### *3.2.2 Cars and LCVs*

The foundational data was derived from the Department for Transport and Vehicle Licensing Agency's (DVSA) licensed vehicles data tables[42]. These were used to both quantify the national vehicle parc of cars and Light Commercial Vehicles (LCVs) and to provide the make and model details necessary for their classification into size classes (e.g., small, medium, large). To determine real-world vehicle usage, the analysis relied on the MOT Anonymised Bulk data for 2023 and 2024[43], which was used for calculating average annual mileage broken down by fuel type and postcode area. Finally, to estimate energy use, the analysis relied on the energy per mile factors for different fuel types published in the Department for Energy and Net Zero's (DESNZ) Greenhouse gas reporting: conversion factors 2025[44].

### *3.2.3 Construction Non-Road Mobile Machinery (NRMM)*

The NRMM sector includes gensets, which are difficult to separate from NRMM completely. In addition, 'NRMM' encompasses a broad spectrum of equipment and working practices, making it challenging to categorise all NRMM under a single heading. For this report, construction equipment is the primary sector being considered, as it makes up the vast majority of the UK's NRMM market[45]. There is also an improved understanding of NRMM in the latest supporting notes for the National Atmospheric Emissions Inventory (NAEI)[46] which was therefore a key source. Lastly, the combined European Monitoring and Evaluation Programme and European Environment Agency and EMEP/EEA Guidebook 2023 proved a helpful point of reference for trends in NRMM (the UK is a tiny fraction of the NRMM market, and trends in the UK are dominated by trends in the EU due to our shared geography), as discussed previously in section 2. The work in this report attempts to segregate generator sets from aggregated NRMM data are dependent on the Office of National Statistics data sets[47] and expert interviews.

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[39] Tatyana Dergunova, Andrew Lyden (2024): *Great Britain's hydrogen infrastructure development*: Investment priorities and locational flexibility. Applied Energy. 375. https://doi.org/10.1016/j.apenergy.2024.124017
[40] ICCT white paper (2022): Cost of Renewable Hydrogen Produced Onsite at Hydrogen Refuelling stations in Europe
[41] H2ME (2024): Emerging Conclusions Report (online https://h2me.eu/publications/emerging-conclusions-2023-h2me-phase-2/ )
[42] Department for Transport & Driver and Vehicle Licensing Agency. Vehicle licensing statistics: data tables. (Online). https://www.gov.uk/government/statistical-data-sets/vehicle-licensing-statistics-data-tables
[43] Driver and Vehicle Standards Agency. Anonymised MOT tests and results. (Online). https://www.gov.uk/government/collections/anonymised-mot-test-data
[44] Department for Energy Security and Net Zero, "Greenhouse gas reporting: conversion factors 2025," GOV.UK, published June 10, 2025, https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2025.
[45] Department for Energy Security & Net Zero (2023). Industrial Non-Road Mobile Machinery: Decarbonisation Options – Techno-Economic Feasibility Study *(Final Report)*.
[46] National Atmospheric Emissions Inventory (2025) Improvement Report: Non-Agricultural NRMM (methods, hours, load factors).
[47] ONS (2023). UK regional electricity demand and industrial energy consumption datasets.

### 3.2.4 Maritime

Estimates for UK maritime shipping are largely based on the DUKES 2025 report[48], Public-Global-Port-Optimisation[49], and Port Freight Annual Statistics 2024[50]. Inland waterway energy consumption estimates are based on the 2011 report "*Greenhouse Gas Emissions from Inland Waterways & Recreational Craft in the UK*"[51], with more recent (but limited) data updates from other reports[52,53]. The estimation of shore-side power (so-called On-Shore Power (OSP) or sometimes referred to as cold-ironing) requirements is based on a small number of news reports[54,55,56].

### 3.2.5 Projections of improvements in battery technology

Battery pack pricing predictions often involve projecting a line-of-fit and an experience curve forward from historical cost to cumulative production. Historically (2010–2024), automotive Li-ion pack prices fell from ~$1,000/kWh to ~$115/kWh — ~90% reduction in 14 years. Extrapolating that same decay rate forward suggests another ~90% reduction by ~2050, with pack prices of $10–15/kWh[57,58,59]. A further 90% reduction in battery pack pricing by 2050 is theoretically possible under pure learning-curve/exponential decay modelling but the accuracy of this is doubtful when real-world commodity and processing constraints are considered. The simplistic 'cost-down curve model' approach ignores that the economic "easy wins" have mostly been achieved through:

- Manufacturing scale-up;
- Improved yield and automation;
- Reduction in cobalt content in NMC chemistries;
- Supply chain optimisation; and
- Commodity price floor.

Additionally, there are processing limits to the density of existing battery packs, as detailed in Table 4[60].

*Table 4: Limit to Reducing Foils, Current Collectors & Electrolytes*

| Component | Current Role | Reduction Limits |
|---|---|---|
| **Copper foil (anode current collector)** | Carries electrons from anode to external circuit | Can be thinned from ~8–12 µm to ~4–6 µm, but beyond that resistive losses & mechanical tearing during cycling rise sharply. |
| **Aluminium foil (cathode current collector)** | Carries electrons from cathode | Similar thinning limits (~12–15 µm → ~6–8 µm minimum) before conductivity and handling problems appear. |
| **Separator/ electrolyte** | Prevents shorting, allows Li-ion transport | Thickness already near 16–25 µm; further reduction risks puncture and thermal runaway. |

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[48] Department for Energy Security & Net Zero (2025) DUKES 2025, Chapter 3: Oil and oil products (Flow chart, 2024). Marine bunkers 1.9 Mt. UK Gov, Jul 2025.
[49] Salmon, Nicholas (2023), "Public-Global-Port-Optimisation", Mendeley Data, V1, doi: 10.17632/v4yz7778mh.1
[50] DfT (2025) Port Freight Annual Statistics 2024. UK Gov, Jul 2025.
[51] DEFRA (2011) Greenhouse Gas Emissions from Inland Waterways & Recreational Craft in the UK. Jun 2011.
[52] Canal & River Trust (2024) *National Boat Count*. May 2024.
[53] Broads Authority (2024) Recreation & Tourism Strategy 2024–29. 2024.
[54] ABP (2022) Shore power goes live at Southampton. ABP, Apr 2022.
[55] Safety4Sea (2023) Port of Southampton: 42 cold ironing ops in 2022. Jan 2023.
[56] Guardian (2023) Cruise ships plug in to greener power at Southampton. Nov 2023.
[57] Nykvist, B. et al., "Rapidly Falling Costs of Battery Packs for Electric Vehicles," Nature Climate Change, 2015.
[58] BloombergNEF, "Battery Pack Energy Density Trends," Dec 2024.
[59] IEA, Global EV Outlook 2024, International Energy Agency, May 2024.
[60] Wood, D. et al., "Technical and Economic Limits of Lithium-Ion Batteries," Nature Energy, 2019.

| | | |
|---|---|---|
| **Electrolyte volume** | Li-ion transport medium | Can only be reduced marginally; must fully wet electrodes. Dry-out or under-wetting impairs ion mobility. |
| **Graphite anode** | Stores lithium ions | Graphite density is already near theoretical optimum; small gains from Si-graphite blends but swelling and cycle life limit silicon content (~5–15% practical). |
| **Thermal management systems** | Keeps cells in safe operating range | Cannot be eliminated; some mass reduction is possible via better cell formats (e.g., structural batteries), but this is incremental. |

### *3.2.6 Stakeholder Engagement*

Unstructured interviews were conducted with key stakeholders in various fields. Typically, these calls involved presenting initial findings, discussing methodologies, and inviting the stakeholder expert to critique the approach. Occasionally, additional data was provided on a confidential basis.

**AMPS (Association of Manufacturers and Suppliers of Power Generating Systems)** - Alan Beech (Director General) was contacted and presented with our initial estimate of the annual sales and country-wide distribution of generator-sets. Following this conversation, key stakeholders in the AMPS network provided revised UK sales for generator sets in 2024 and supported the estimated distribution of UK generator sets used in this work (although no specific regional sales data was available to confirm this.)

**CEA (Construction Equipment Association)** - Dale Camshel (Senior Technical Consultant) was contacted and presented with our initial estimate of the NRMM UK annual sales. No data on country-wide distribution was available. This issue is exacerbated by the fact that hiring companies purchase 66% of UK NRMM, and this equipment could work anywhere in the country. To further complicate the problem, the exact location of these hire vehicles is considered commercially sensitive information. However, consultation with Mr Camshel established that mapping significant construction project investment and assigning equipment to those locations on a proportional basis would be the most reliable way to estimate the location of construction equipment today (assuming the hire company's data is not available). The proportion weighting of construction equipment to announced construction projects was, in Mr Camshel's opinion, probably the only way to assign construction equipment locations in future planning scenarios.

## 3.3 Modelling confidence

Each of the five modes of transport and energy use assessed has been analysed across multiple data sources where possible. Public data sets on energy use are usually ‘top down’ models based on total fuel sales in a sector, with limited segmentation by vehicle/vessel size. Additional data sources, such as publicly available MOT data, can be used to triangulate likely energy use within a segment.

Some segments are more detailed than others. In this case, the accuracy of the initial energy estimation for Cars and LCVs has high confidence, as this has been used and tested in a number of other projects over a long period of time. The assessment of NRMM as a whole is broadly correct, based on extensive experience in the sector.

However, disaggregating generator set data from overall NRMM data is challenging. Lastly, maritime and inland waterway data are extremely limited, making the analysis highly dependent on National Atmospheric Emissions Inventory (NAEI) collected across all inland waterways and maritime vessels. In-house datasets to further refine the maritime and land waterway data, although the sample size is extremely limited when compared to the entirety of UK shipping.

The confidence in the energy demand assessments are summarised on a red, amber, green basis, with green indicating high confidence, amber indicating moderate confidence (in the order of +/- 25%

of the initial energy demand assessment) and red indicating low confidence (in the order +/- 50% of the initial energy demand assessment).

*Table 5: Mode initial energy calculation confidence.*

| | RAG status | Notes |
|---|---|---|
| **Cars** | Green | Initial energy estimation relies on localised mileage by vehicle size and fuel type. Modelling followed a bottom-up approach |
| **LCVs** | Green | Initial energy estimation relies on localised mileage by vehicle size and fuel type. Modelling followed a bottom-up approach |
| **NRMM** | Amber | Assumptions around initial vehicle parc and operational patterns due to lack of data. Modelling followed a bottom-up approach |
| **Gensets** | Amber | Assumptions around initial vehicle parc and operational patterns due to lack of data. Assumptions were based on expert interviews for validation. Modelling followed a bottom-up approach |
| **Maritime** | Red | Modelling relied on port-level fuel demand projections rather than detailed vessel fleet and operational data. Energy modelling followed a top-down approach. |

# 4 Hydrogen demand potential: Cars

Hydrogen fuel-cell electric vehicles (FCEVs) in the United Kingdom are the most likely alternatively BEVs for zero-emission transport. Policy interest is driven by the need to decarbonise transport while diversifying energy pathways. FCEVs can be refuelled in a matter of minutes, offering operational advantages for fleet applications requiring long range, high utilisation, or rapid turnaround compared with BEVs.

Uptake of FCEV remains very limited in the UK, with fewer than 500 vehicles on the road as of 2024. Their use is constrained by the sparse hydrogen refuelling station (HRS) network (fewer than 10 publicly accessible sites, several of which are pilot or demonstration facilities) and the relatively high cost of both vehicles and hydrogen fuel compared with diesel or electricity.

Government strategies, including the Hydrogen Strategy[61] and the Hydrogen Production Delivery Roadmap[62] identify transport as an early demand sector to help scale hydrogen supply. Still, near-term deployment (before 2040) is expected to focus on buses, heavy goods vehicles (HGVs), and specialist fleets rather than private passenger cars.

## 4.1 Market segmentation

To segment the UK car fleet by size, we combined the anonymised MOT test records with the DVSA licensed vehicle data by make and model. Engine capacity (cc) and market classification (city car, SUV, and so on) were used as proxies for vehicle size (See Table 6). This approach provides a consistent and transparent framework for comparing vehicles across manufacturers and model years, while aligning with established market segmentation practices. By applying this classification to the combined MOT and DVSA datasets, we were able to estimate the distribution of the licensed fleet across size classes and high-level postcode areas.

*Table 6: Car market segmentation*

| Class | Engine capacity (and equivalent for EVs) | Typical Examples |
|---|---|---|
| **Small** | <1.400 cc | 1.0–1.2 L superminis & compact hatches (e.g., Fiesta 1.0, Polo 1.2) |
| **Medium** | 1,400 to 1,999 cc | 1.4–2.0 L family cars & crossovers (e.g., Golf 1.5/2.0, Corolla 1.8) |
| **Large** | ≥ 2,000 cc | 2.0 L+ saloons, SUVs, performance models (e.g., 320i/330i, XC60 2.0, 3.0 V6) |

## 4.2 Sector-specific technology status and trends

There are no commercially available OEM-manufactured hydrogen cars in the UK. Toyota and Hyundai have a small fleet of demonstration vehicles operating in the UK, and BMW plans to begin production of fuel cell vehicles in 2028[63]. However, it is unclear if any of BMW's vehicles will be in a right-hand drive configuration for UK roads. Production numbers for BMW are likely to be in the low thousands for the first few years.

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[61] HM Government (2021, updated 2024) UK Hydrogen Strategy. GOV.UK. (Online). https://www.gov.uk/government/publications/uk-hydrogen-strategy (Accessed: 19 September 2025).

[62] DESNZ (2023) Hydrogen Production Delivery Roadmap. GOV.UK. (Online). https://www.gov.uk/government/publications/hydrogen-production-delivery-roadmap (Accessed: 19 September 2025).

[63] Lister, M (2025): BREAKING: BMW puts a date on hydrogen – fuel-cell production confirmed for 2028: https://drivinghydrogen.com/2025/09/02/breaking-bmw-puts-a-date-on-hydrogen-fuel-cell-production-confirmed-for-2028/#newsletter

In terms of hydrogen refuelling for cars and LCV, it is assumed that most hydrogen refuelling will need to occur at a public hydrogen refuelling station (HRS). However, at present, there is no UK national target for creating an HRS network. In future, there is likely to be regulatory and economic pressure to align UK hydrogen refuelling infrastructure with European policy on hydrogen refuelling, to facilitate long-distance trucking with hydrogen-powered vehicles.

**Demand may create a need for deblending, which may, in turn, create a backbone for the national HRS network.** Deblending has the potential to become the foundation stone that determines whether the UK can meet its planned net-zero transport targets cost-effectively. See section 0 for more details on hydrogen infrastructure.

## 4.3 Evidence base and data gaps

The key data source for this segment is UK MOT test data, which enables the assessment of annual mileage and the subdivision of vehicles into size classes. All UK MOT certificates in 2023 and 2024 have been assessed, and annual mileage has been calculated to provide a baseline understanding of vehicle mileage and energy demand.

Cenex has extensive experience in monitoring and analysing road-going vehicles. As a ‘first pass’ on the entire UK car fleet (registered with MOT databases); an initial filter of 50,000 miles per year was applied. It was assumed that vehicles with an annual mileage higher than this would not be battery electric. In Cenex’s experience, this is the likely maximum annual mileage for cars where battery electrification becomes untenable within the current capabilities of BEV technology.[64]

*Table 7: Datapoints, sources and their roles in modelling for cars*

| Datapoint | Source | Role |
|---|---|---|
| **MOT Anonymised bulk records 2023 and 2024** | DVSA – Licensed vehicles data tables[65] | Calculate vehicle mileage by body type, size class and location |
| **Energy use and efficiency by fuel type** | DESNZ, Greenhouse gas reporting: conversion factors 2025[66] | Estimate energy use for vehicles based on their mileage, size and fuel type |

There are no publicly available national statistics on individual car-based data on refuelling behaviour. Annual millage alone is a very broad brush to select suitable vehicles for battery electrification. Some vehicles may complete far less than the 50,000-mile electric vehicle cut-off figure but are highly seasonal (and therefore unsuitable to complete daily mileage with standard battery equivalent vehicles). Some cars may have operational constraints, such as those used in the private hire sector that are shared between multiple drivers (a small but significant niche). Still other vehicles may complete far less than the 50,000 miles per year benchmark but complete many of those miles at high speeds whilst driving on motorways. Motorway speeds significantly reduce the effective battery range and would effectively lower the maximum mileage achievable per year.

[64] At the time of writing, Cenex also applies a lower mileage limit as a first-pass filter for fleet assessment, to mitigate the purchase price premium for BEV cars. Today, BEV cars are (on a like-for-like basis) approximately 12% to 40% more expensive to purchase in the BEV variant, compared to the equivalent ICE vehicle. Even with likely total cost of ownership savings over the life of the vehicle, this can still be off-putting to a significant section of the market, such as those that replace their vehicles every one to three years. However, this price gap is expected to close in the next two to five years and so has not been included when assessing the uptake of BEV cars out to 2050.

[65] Department for Transport and Driver and Vehicle Licensing Agency, "Vehicle licensing statistics data tables," GOV.UK, last updated August 13, 2025, https://www.gov.uk/government/statistical-data-sets/vehicle-licensing-statistics-data-tables.

[66] Department for Energy Security and Net Zero, "Greenhouse gas reporting: conversion factors 2025," GOV.UK, published June 10, 2025, https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2025.

To overcome these limitations in the annual mileage 'first-pass-filter', the baseline 'legislative scenario' applied the basic 50,000 miles per year to all cars. The accelerated uptake model used calculated values based on recent experience analysing over 19,500 vehicles across multiple fleets (including emergency service and operational 'response' vehicles). The factors governing uptake are:

- Lack of charging infrastructure
- Grid constraint (either locally or nationally) limiting power supply for charging infrastructure.
- Lack of vehicle supply due to increased global competition in battery and associated infrastructure supply chains.
- Deceleration in BEV uptake as innovators and early adopters are overtaken by the majority and late majority, revealing increasingly more challenging use-cases.
- A national alternative fuel supply chain is being rolled out successfully.
- Increased price competitiveness of alternative fuel (to BEV) power train solutions.

A detailed explanation of how these figures were determined is given in Section 4.4 .

## 4.4 Scenario modelling

**Scenario 1 (legislated model):** As detailed in the roadmaps in section 2, there are key legislative targets that are planned between now and 2050 that will drive technology change. In addition, a basic 'first pass' rules were applied to the entire UK car fleet (registered with MOT databases) and an initial filter of 50,000 miles per year was used for road-going cars. As of 2025, there remains a price premium for battery electric cars and LCVs in the order of 15% to 40% depending on the size and specification of the vehicle. However, this additional CapEx for purchasing BEV model variants of vehicles is widely assumed to reduce to zero on or before 2030. To model uptake out to 2050 in five-year increments, purchase price parity is assumed between BEV and ICE equivalent models of vehicles over this period.

The Legislated model assumes that recent trends in battery electrification continue, and that the 2030 phase-out of the sale of new diesel and petrol cars remains in place. Projections for new vehicle sales were based on projections for the maximum borrowing allowance under the Zero Emission Vehicle Mandate (ZEV mandate)[67], which allows manufacturers to sell fewer ZEV vehicles in interim years and pay back in more vehicles towards the 2030 date. Diesel and petrol ICE and hybrid vehicles were assumed to be replaced by battery electric cars as part of a natural ten-year replacement cycle for cars.

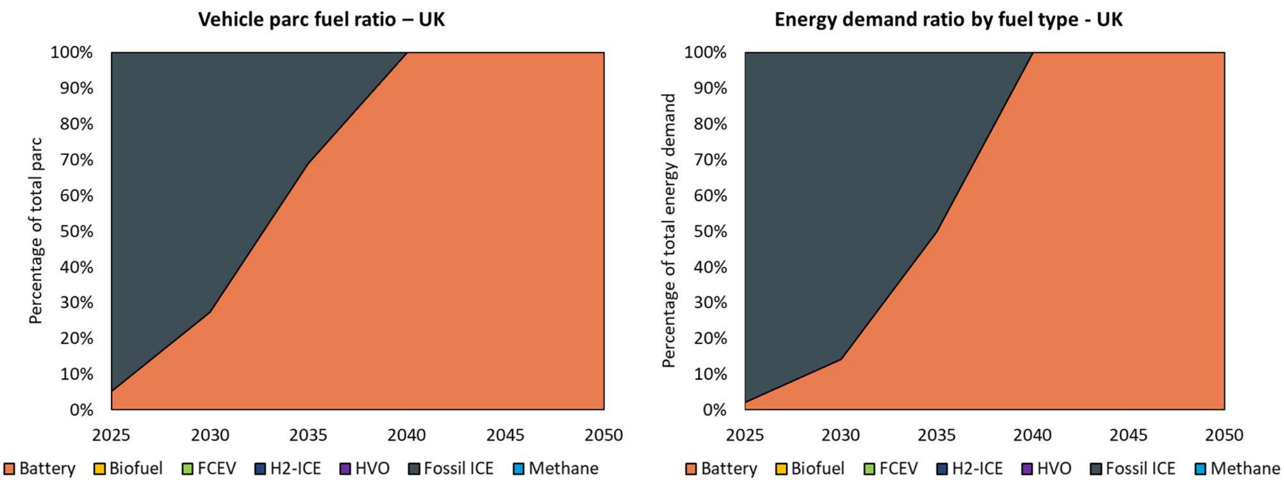


*Figure 19: Vehicle parc and energy demand for the UK's car fleet by fuel type 2025-2050 – Legislated Scenario*

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[67] The Zero Emission Vehicle Mandate Order 2024, SI 2024/1394, https://www.legislation.gov.uk/uksi/2023/1394/contents.

**Scenario 2 (accelerated uptake model):** The accelerated uptake model assumes a faster rate of BEV uptake ahead of 2030, **but also a much higher rate of FCEV uptake, up to 22%. This is based primarily not on modelling but on detailed observations taken from analysis of 20 different fleets over the last two years**, comprising 19,500 vehicles and covering a mix of local authority, emergency response, utilities, and facilities management service provider vehicles.

Real world analysis of working fleets suggests that if and when fleets move strongly to zero-emission vehicles, a range of factors will limit the suitability of BEV for a significant proportion. The primary constraint is range, but other factors come into play that prevent fleets making other operational changes to accommodate the more limited range of BEVs. These include grid constraints, market factors that may limit the development of longer range BEVs and even overall power generation.

Across all these vehicles, a range of data was available. This included per-vehicle annual fuel use and a stakeholder assessment of seasonality and extreme daily mileage events. For 50% of the fleets analysed, representative vehicles were monitored in real-time data to assess second-by-second energy demand and understand operational constraints. High-level assessments of grid connectivity were also completed on the same 50% of fleets. On an individual basis, some fleets experienced extremely high suitability for battery electrification (in line with the assumptions of the legislated model). Other fleets varied widely from the legislative model assumptions and could not achieve anywhere near the level of battery electrification indicated in the legislative model.

Across all 19,500 vehicles, the following trends were identified:

- Cars for public sector users are highly likely to transition to BEV
- Blue light fleets have far more complex operational constraints, and at the time of writing, only 32% of blue light fleet cars and LCVs can directly convert to BEV operation today.
  - Extrapolating forward to 2050, with a 13% increase in battery range by 2037, this increases to 36% (see technical appendix B for further discussion on battery film processing limits).
  - It is important to note that blue light operators are actively researching novel dispatch and vehicle assignment operational software to increase this figure.
- Utilities companies could have 83% of their car and LCVs (=< 3.5t) converted to BEV operations by 2050 based on their high-level analysis, and ignoring battery pricing issues. This may be a somewhat optimistic assessment
- Facilities management companies could achieve up to 91% BEV electrification in ideal conditions, though without ready access to top-up charging through the day, that figure falls dramatically to only 61%

These data and observations were used to inform the accelerated uptake model. Overall, the model assumes that for cars, the overall uptake will be 78% BEV, with the remainder of vehicles (22%) requiring an alternative powertrain. In the absence of other options, this alternative powertrain is assumed to be FCEV.

It is acknowledged that this is a much higher estimate of FCEV uptake in this segment than many other analysts would suggest, and we would regard it as very much an upper bound estimate. However as noted above this is based on detailed real-world engagement with fleets and comprehensive analysis of their data. This perhaps suggests the extent to which more abstract models may underplay the practical difficulties that many fleets may face once the ‘low hanging fruit’ for simple electrification have been transitioned to BEV.

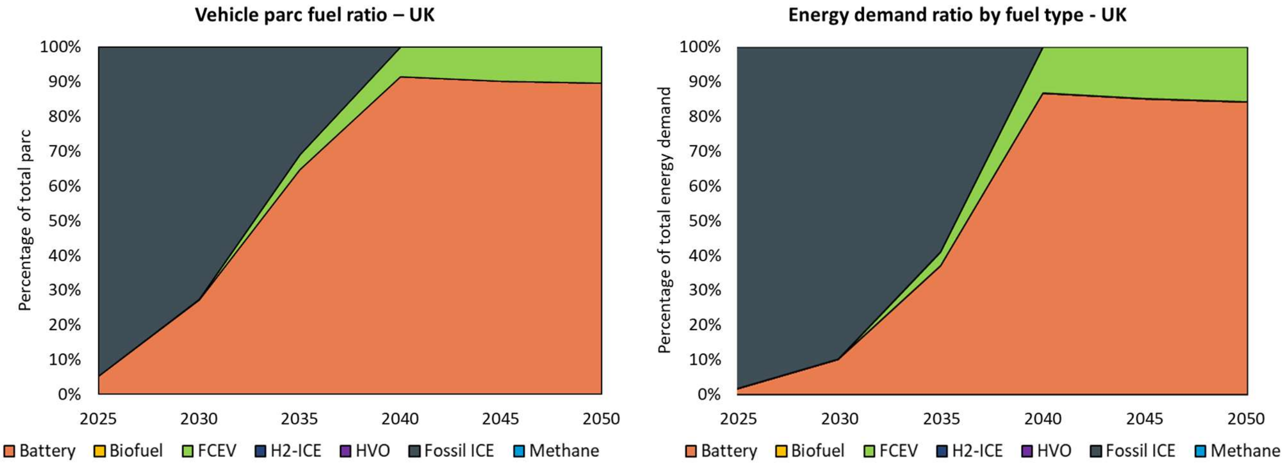


*Figure 20: Vehicle parc and energy demand for the UK's car fleet by fuel type 2025-2050 – Accelerated Scenario*

- Total number of cars on UK roads is assumed to remain at around **32,590,500 vehicles**.
- Table 8 shows total energy demand estimates for cars in both scenarios (to three significant figures)

*Table 8: Total energy demand in gigawatt hours (GWh) for the UK car fleet under the legislated and accelerated scenarios*

| Year | Legislated scenario (GWh) | Accelerated Scenario (GWh) |
|---|---|---|
| 2025 | 295,000 | 295,000 |
| 2030 | 248,000 | 248,000 |
| 2035 | 159,000 | 161,000 |
| 2040 | 92,900 | 97,120 |
| 2045 | 92,900 | 97,800 |
| 2050 | 92,900 | 98,100 |

## 4.5 Location-specific demand estimates

UK-level projections for technology uptake and energy demand presented in this report were derived from a foundational modelling approach. UK aggregates were modelled using a detailed breakdown of the national vehicle fleet combined with country-level average mileage statistics (see Figure 21).

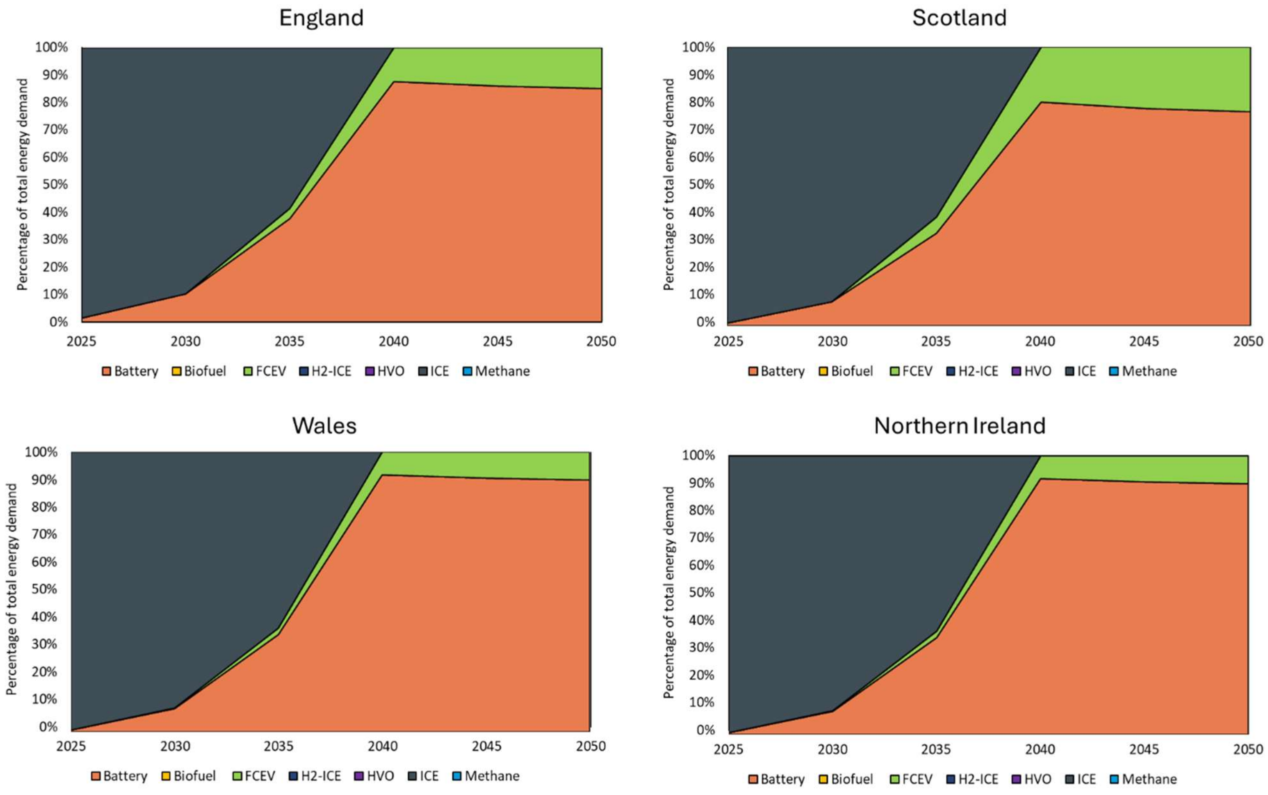


*Figure 21: Car energy demand ratio by fuel type for countries 2025-2050 – Accelerated Scenario*

Table 9 shows country-level energy demand by cars in the accelerated uptake scenario (to three significant figures)

*Table 9: Energy demand in GWh for car fleet under the accelerated scenario – breakdown by country*

| Year | England | Scotland | Wales | Northern Ireland |
|---|---|---|---|---|
| 2025 | 251,000 | 37,700 | 3,500 | 2,570 |
| 2030 | 212,000 | 31,200 | 2,800 | 2,120 |
| 2035 | 138,000 | 19,600 | 1,700 | 1,280 |
| 2040 | 84,200 | 11,400 | 914 | 681 |
| 2045 | 84,600 | 11,600 | 912 | 680 |
| 2050 | 84,800 | 11,600 | 911 | 679 |

Subsequent modelling provides a more granular breakdown of demand on a hexagonal grid.

### 4.5.1 Legislated scenario

Under the legislated scenario, electrification is anticipated to be the predominant decarbonisation pathway for the car sector. This trajectory, driven by existing and planned policy trends, strongly favours battery electric vehicles as the primary technological solution. Consequently, our analysis did not identify any significant clusters of hydrogen demand emerging from cars within the projection years of 2030, 2040, and 2050. The infrastructure and market are expected to develop in alignment with widespread electrification, limiting the potential for a significant hydrogen-fuelled passenger vehicle fleet in this timeframe.

### *4.5.2 Accelerated Scenario*

Under the accelerated scenario, significant hydrogen demand clusters from cars are projected to emerge by 2040. **These are primarily concentrated within the UK's major metropolitan areas and along key transport corridors, showing a strong correlation with the routes of both the primary motorways and the National Transmission System (NTS).** High demand of more than 10 tonnes per day can be seen in Glasgow (M8, M74 and M77) and southern areas in Manchester (M56 and M60). The most substantial clusters of consistent demand, with many areas requiring 5 to 10 tonnes per day, is centred on London and the M25 orbital motorway, with high demand extending outwards along arterial routes such as the M1 and M4. Further distinct clusters, reaching between 5 and 10 tonnes per day, are evident in the West Midlands, particularly around the strategic intersection of the M6 and M42 motorways near Birmingham and Coventry, and across the Northwest, following the M62 corridor between Liverpool and Manchester. In Scotland, a continuous cluster of demand (3 to 10 tonnes per day) can be seen on the section of the M9 between Stirling and Edinburgh (Figure 22).

By 2050, the hydrogen demand from cars is forecast to intensify and expand considerably, creating a more widespread and interconnected network of high-demand clusters. The clusters identified in 2040 become significantly more pronounced, with a substantial increase in the geographical area exceeding 10 tonnes of demand per day, especially in Greater London Area, Northwest and Glasgow. The footprint of demand also grows, with the previously distinct clusters expanding and merging along the primary motorway network to form near-continuous corridors of high demand of 3 to 10 tonnes per day, particularly along the M1, M6 and M8 (Figure 23).

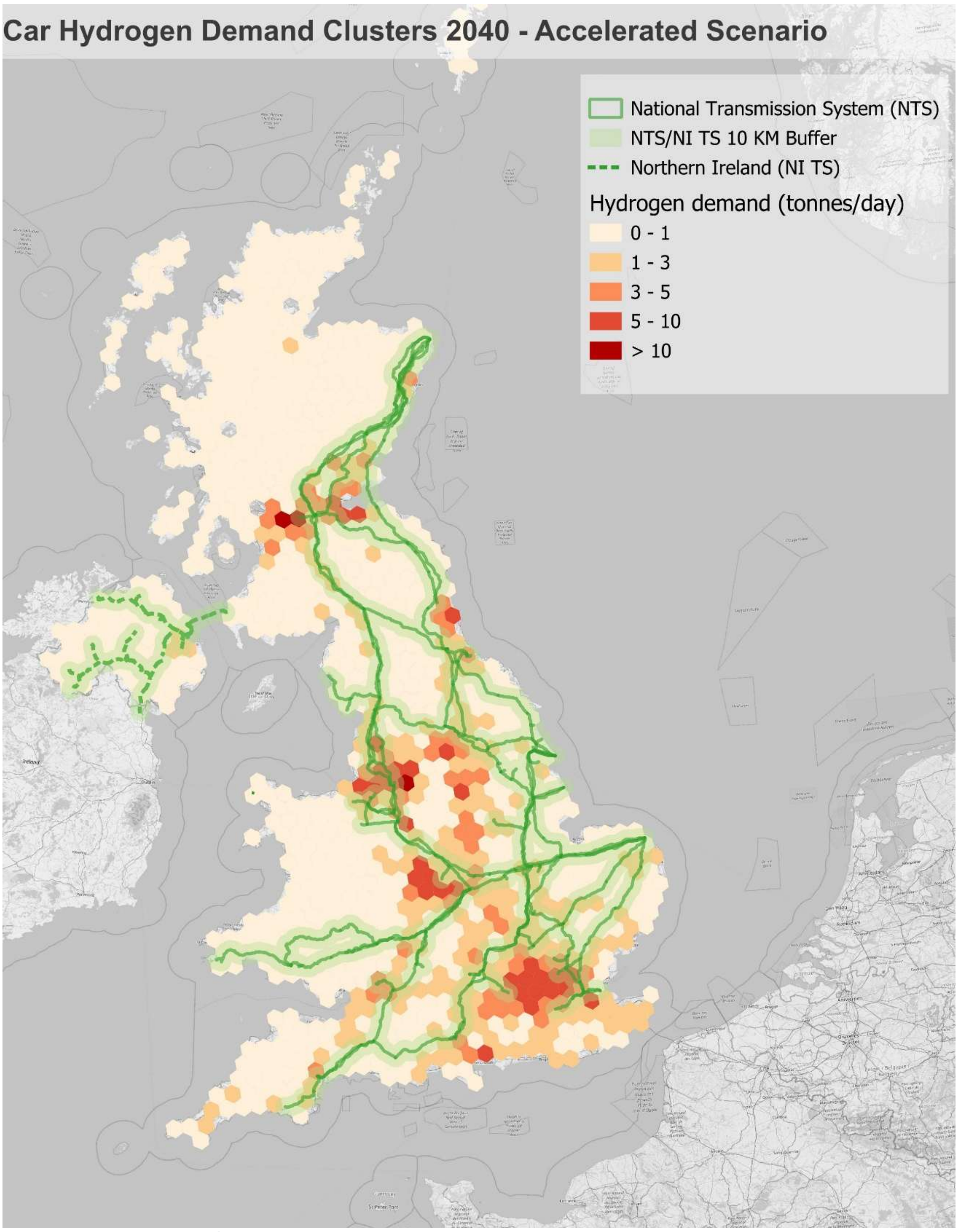


*Figure 22: Cars hydrogen demand clusters in 2040 under the accelerated scenario*

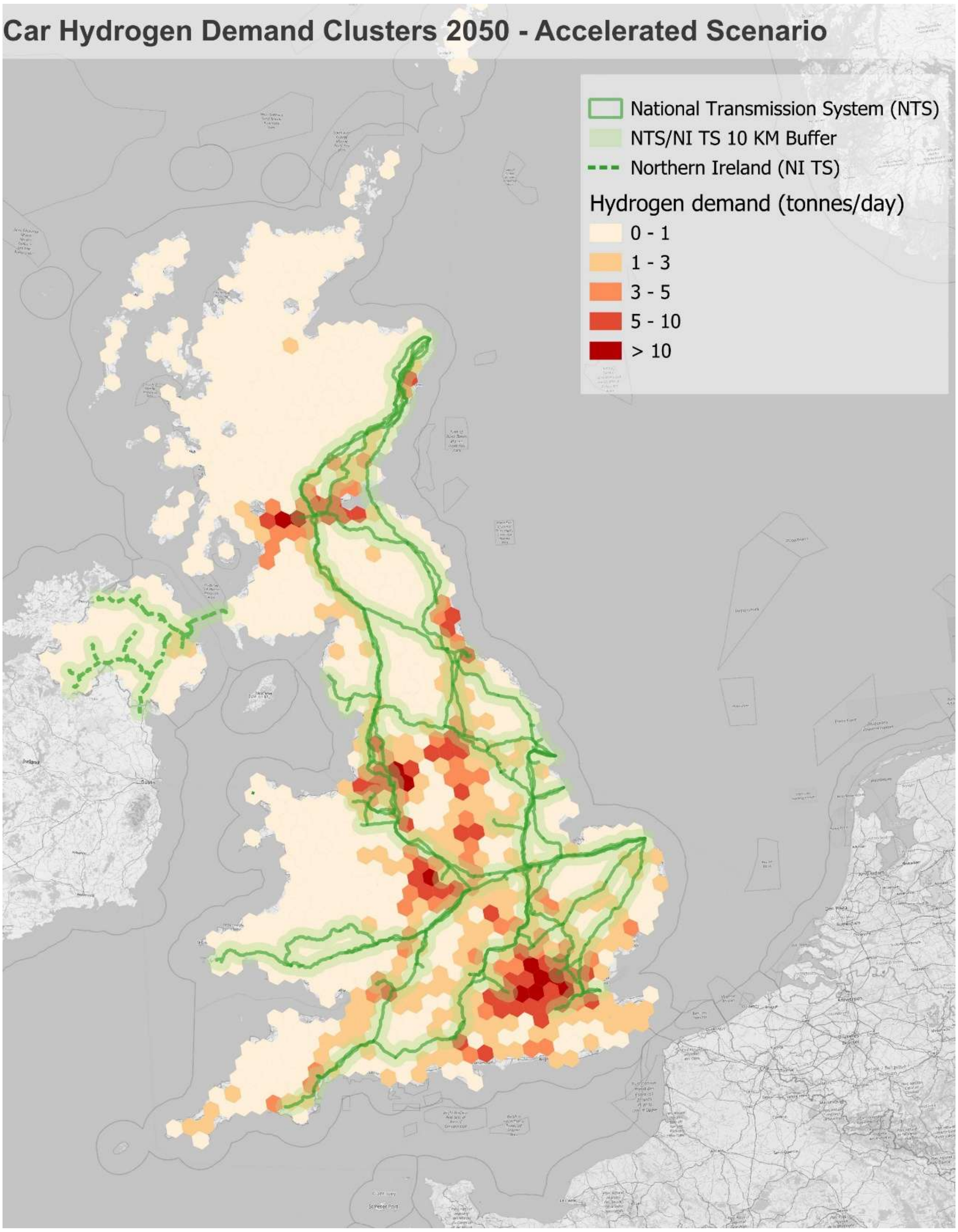


*Figure 23: Cars hydrogen demand clusters in 2050 under the accelerated scenario*

# 5 Hydrogen demand potential: Light Commercial Vehicles

Hydrogen-powered light commercial vehicles (LCVs) in the UK are in early pilot deployment. They are aimed at high-utilisation, time-critical use cases where fast refuelling and long range can offset today's higher costs and scarce infrastructure. Recent trials include Ford's fuel-cell E-Transit programme[68] (2023–2025) and Vauxhall's UK customer pilots of hydrogen vans in 2024, often paired with depot-based or partner refuelling solutions, while European offerings such as the Renault Master H2-Tech are targeting production from 2025.

Despite these trials, the near-term outlook remains uncertain as public refuelling remains limited to roughly half a dozen accessible sites and manufacturer plans have shifted. Most notably, Stellantis indicated in July 2025 that it would discontinue its hydrogen fuel-cell van programme, citing a lack of hydrogen refuelling infrastructure roll-out across Europe[69].

UK activity is expected to remain small-scale, fleet-led, and clustered around private or mobile hydrogen supply and emerging multi-energy hubs planned for mid-decade.

## 5.1 Market segmentation

To segment the UK LCV fleet by size, a similar approach was followed to that for cars. LCVS were classified based on Design Gross Weight (DGW) as a proxy for vehicle size (see Table 10). By applying this classification to the combined MOT and DVSA datasets, the distribution of the licensed fleet across size classes and high-level postcode areas was estimated.

*Table 10: LCV market segmentation*

| Class | Design Gross Weight (DGW) | Typical Examples |
|---|---|---|
| **Small** | < 2,000 kg | Car-derived vans, microvans (Ford Fiesta Van, Renault Kangoo, Citroën Berlingo) |
| **Medium** | 2,000 – 2,999 kg | Mid-size panel vans, crew vans (VW Transporter, Ford Transit Custom, Vauxhall Vivaro) |
| **Large** | 3,000 – 3,500 kg (4,250 kg for EVs) | Long-wheelbase panel vans, high-roof vans (Mercedes Sprinter, Iveco Daily, Ford Transit LWB) |

## 5.2 Sector-specific technology status and trends

There are no commercially available OEM-manufactured hydrogen LCVs. There are a small number of demonstration vehicles being trialled (notably by Wales and West Utilities), and the HyLUX project seeks to produce an initial test fleet of 10 hydrogen-powered Toyota Hilux prototypes for demonstration trials. The Stellantis group (Abarth, Alfa Romeo, Chrysler, Citroën, Dodge, DS Automobiles, Fiat, Jeep, Lancia, Maserati, Opel, Peugeot, Ram, and Vauxhall) originally intended to release a series of small panel vans with hydrogen power. However, this project has been

[68] Ford Motor Company (2023) Ford announces three-year hydrogen fuel cell E-Transit trial. Ford Media. (Online). https://media.ford.com/content/fordmedia/feu/gb/en/news/2023/05/09/ford-announces-three-year-hydrogen-fuel-cell-e-transit-trial.html (Accessed: 19 September 2025).

[69] Reuters (2025) Stellantis discontinues hydrogen fuel cell programme and van production. (Online). https://www.reuters.com/technology/stellantis-discontinues-hydrogen-fuel-cell-programme-van-production-2025-07-16/ (Accessed: 19 September 2025).

mothballed due to a lack of hydrogen infrastructure throughout the UK and the EU[70]. See section 3.2.1 for more details on hydrogen infrastructure.

## 5.3 Evidence base and data gaps

Annual mileage has been recorded as a baseline understanding of vehicle energy demand, derived from assessing all UK MOT certificates for 2023 and 2024. A basic 'first pass' rule was applied to the entire UK LCV fleet (registered with MOT databases); an initial filter of 30,000 miles per year to road-going vehicles. This is assumed to be the likely maximum annual mileage for LCVs where battery electrification becomes untenable. As noted above, price parity between BEV and ICE equivalent models was assumed in line with industry predictions of price parity being achieved before 2030.

*Table 11: Datapoints, sources and their roles in modelling for LCVs*

| Datapoint | Source | Role |
|---|---|---|
| **MOT Anonymised bulk records 2023 and 2024** | DVSA – Licensed vehicles data tables[71] | Calculate vehicle mileage by body type, size class and location |
| **Energy use and efficiency by fuel type** | DESNZ, Greenhouse gas reporting: conversion factors 2025[72] | Estimate energy use for vehicles based on their mileage, size and fuel type |

There is no individual LCV-based data on refuelling behaviour. Annual millage alone is a very 'broad brush' to select suitable vehicles for battery electrification. Some vehicles may complete far less than the 30,000-mile electric vehicle cut-off figure but may be highly seasonal. Some LCVs may have operational constraints, such as those used in the private hire sector, which are shared among multiple drivers (a small but significant niche). Still other vehicles may complete far fewer than the 30,000 miles per year benchmark but complete many of those miles at high speeds whilst driving on motorways. Motorway speeds significantly reduce the effective battery range and would effectively lower the maximum mileage achievable per year.

To overcome these limitations in the annual mileage 'first-pass-filter', the baseline 'legislative scenario' applies the basic 30,000 miles per year to all LCVs.

The 'accelerated uptake' scenario uses calculated values based on Cenex' recent experience analysing over 19,500 vehicles across multiple fleets (including emergency service and operational 'response' vehicles). These uptake factors are:

- Lack of charging infrastructure
- Grid constraint (either locally or nationally) limiting power supply for charging infrastructure.
- Lack of vehicle supply due to increased global competition in battery and associated infrastructure supply chains.
- Deceleration in BEV uptake as innovators and early adopters and are overtaken by the majority and late majority, revealing increasingly more challenging use-cases.

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[70] Stellantis (2025): Stellantis Discontinues Hydrogen Fuel Cell Technology Development Program. (Online) https://www.stellantis.com/en/news/press-releases/2025/july/stellantis-discontinues-hydrogen-fuel-cell-technology-development-program

[71] Department for Transport and Driver and Vehicle Licensing Agency, Vehicle licensing statistics data tables, GOV.UK, last updated August 13, 2025, https://www.gov.uk/government/statistical-data-sets/vehicle-licensing-statistics-data-tables.

[72] Department for Energy Security and Net Zero, Greenhouse gas reporting: conversion factors 2025, GOV.UK, published June 10, 2025, https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2025.

- A national alternative fuel supply chain being rolled out successfully.
- Increased price competitiveness of alternative fuel (to BEV) power train solutions.

For a detailed explanation of how these figures were determined, please see section 4.4.

## 5.4 Scenario modelling

**Scenario 1 (legislated model):** As detailed in the roadmaps in section 2, there are key legislative targets that are planned between now and 2050 that will drive technology change. Similar to cars, a basic 'first pass' rule has been applied to the entire UK car fleet (registered with MOT databases) – an initial filter of 30,000 miles per year to road-going LCVs. In our experience, this is the likely maximum annual mileage for cars where battery electrification becomes untenable. At the time of writing, Cenex currently operates a lower mileage limit as a first-pass filter for fleet assessment, to mitigate the purchase price premium for BEV LCVs

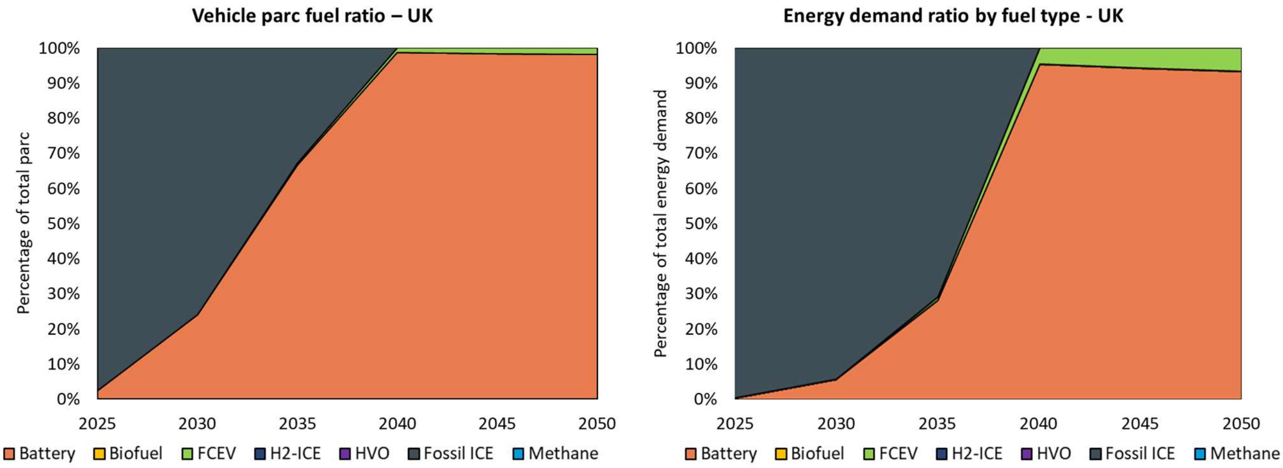


*Figure 24: Vehicle parc and energy demand for the UK's LCV fleet by fuel type 2025-2050 – Legislated Scenario*

The Legislated model assumes that recent trends in battery electrification continue, and that the 2030 ban on the purchase of new diesel and petrol LCVs remains in place. Diesel and petrol ICE and hybrid LCVs are replaced by battery electric vehicles as part of a natural ten-year replacement cycle for LCVs, with a small percentage transitioning to hydrogen due to their high mileage.

**Scenario 2 (accelerated uptake model):** The accelerated uptake model assumes a faster rate of BEV uptake ahead of 2030, **but also a much higher rate of FCEV uptake, up to 22%. This is based primarily not on modelling but on detailed observations taken from analysis of 20 different fleets over the last two years**, comprising 19,500 vehicles and covering a mix of local authority, emergency response, utilities, and facilities management service provider vehicles.

Real world analysis of working fleets suggests that if and when fleets move strongly to zero-emission vehicles, a range of factors will limit the suitability of BEV for a significant proportion. The primary constraint is range, but other factors come into play that prevent fleets making other operational changes to accommodate the more limited range of BEVs. These include grid constraints, market factors that may limit the development of longer range BEVs and even overall power generation.

Across all these vehicles a range of data was available. This included per-vehicle annual fuel use and a stakeholder assessment of seasonality and extreme daily mileage events. For 50% of the fleets analysed, representative vehicles were monitored with real-time data to assess second-by-second energy demand and understand operational constraints. High-level assessments of grid connectivity were also completed on the same 50% of fleets. On an individual basis, some fleets experienced extremely high suitability for battery electrification (in line with the assumptions of the legislated model). Other fleets varied widely from the legislative model assumptions and could not achieve anywhere near the level of battery electrification indicated in the legislative model.

Across all 19,500 vehicles, the following trends were identified:

- By 2050, for local authority LCV users, with a single daily top-up charge, up to 80% of LCVs could be fully BEV. Without access to daily top-up charging, that figure drops to 53%.
- Blue light fleets have far more complex operational constraints, and at the time of writing, only 32% of blue light fleet cars and LCVs can directly convert to BEV operation today.
    - Extrapolating forward to 2050, with a 13% increase in battery range by 2037, this increases to 36%
    - It is important to note that blue light operators are actively researching novel dispatch and vehicle assignment operational software to increase this figure
- Utilities companies could have 83% of their car and LCVs (=< 3.5t) converted to BEV operations by 2050 based on their high-level analysis, and ignoring battery pricing issues. This may be a somewhat optimistic assessment
- Facilities management companies could achieve up to 91% BEV electrification in ideal conditions, though without ready access to top-up charging through the day, that figure falls dramatically to only 61%

Overall, the accelerated uptake model assumes that for cars and LCVs, the overall uptake will be 78% BEV, with the remainder of vehicles (22%) requiring an alternative powertrain. In the absence of other options, this alternative powertrain is assumed to be FCEV.

It is acknowledged that this is a much higher estimate of FCEV uptake in this segment than many other analysts would suggest, and we would regard it as very much an upper bound estimate. However as noted above this is based on detailed real-world engagement with fleets and comprehensive analysis of their data. This perhaps suggests the extent to which more abstract models may underplay the practical difficulties that many fleets may face once the ‘low hanging fruit’ for simple electrification have been transitioned to BEV.

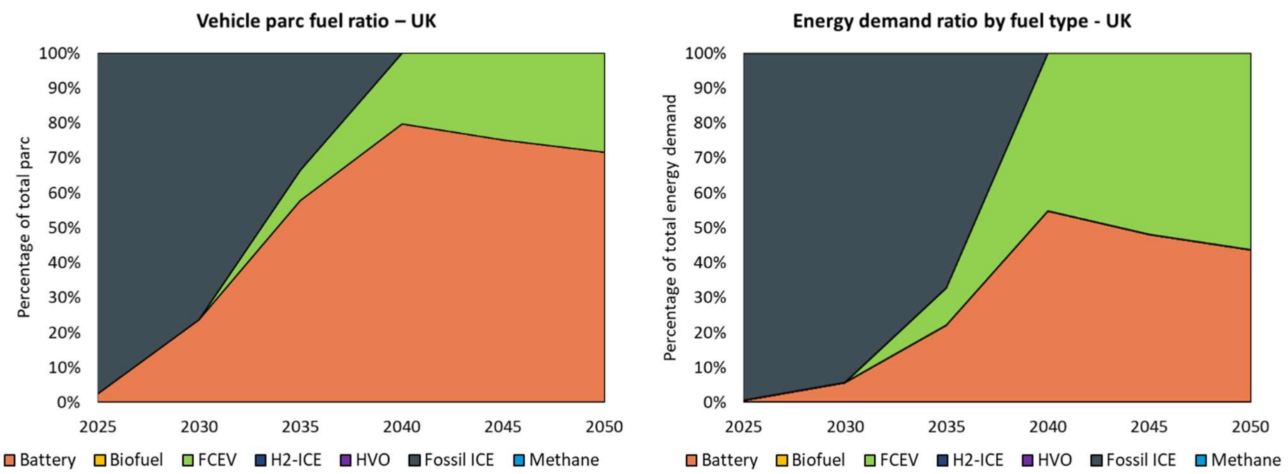


*Figure 25: Vehicle parc and energy demand for the UK’s LCV fleet by fuel type 2025-2050 – Accelerated Scenario*

- Total number of LCVs on UK roads is assumed to remain at around **4,713,500 vehicles.**
- Table 12 shows total energy demand estimates for LCVs in both scenarios (to three significant figures)

*Table 12: Total energy demand in gigawatt hours (GWh) for the UK LCV fleet under the legislated and accelerated scenarios*

| Year | Legislated scenario (GWh) | Accelerated Scenario (GWh) |
|---|---|---|
| 2025 | 64,000 | 64,000 |
| 2030 | 52,600 | 53,100 |
| 2035 | 30,200 | 33,200 |
| 2040 | 13,300 | 18,600 |
| 2045 | 13,400 | 19,900 |
| 2050 | 13,500 | 20,800 |

## 5.5 Location-specific demand estimates

### *5.5.1 Legislated Scenario*

As with cars, electrification is anticipated to be the predominant decarbonisation pathway for the LCV sector under the legislated scenario. While a small percentage of LCVs will be hard to electrify, our analysis did not identify any significant clusters of hydrogen demand emerging from LCVs within the projection years of 2030, 2040, and 2050.

### *5.5.2 Accelerated Scenario*

For Light Commercial Vehicles (LCVs) under the accelerated scenario, the geographic distribution of hydrogen demand in 2040 mirrors that of cars, though with a slightly lower overall intensity. The most significant cluster, with demand reaching between 5 and 10 tonnes per day, is centred around London and the M25 and in Greater Manchester particularly on the M62 and M56. Other continuous clusters of moderate demand, typically between 1 to 3 tonnes per day, are identifiable along the M1, particularly in the Midlands around the M1/M6 interchange, and along the M5 corridor between Bristol and Birmingham. In Scotland, a smaller but distinct demand cluster is visible along the M8 corridor near Edinburgh (Figure 26).

By 2050, the demand for hydrogen from LCVs is projected to increase substantially in both intensity and geographic scope. The clusters identified in 2040 become more pronounced, with a particular area requiring over 10 tonnes per day north of London at the intersection of the M25 and M1. The overall footprint of demand also expands as the existing clusters grow and begin to merge along the main logistical arteries of the motorway system, indicating a maturing market for hydrogen-fuelled LCVs, with demand growth remaining anchored to the primary urban, economic, and logistical corridors (Figure 27).

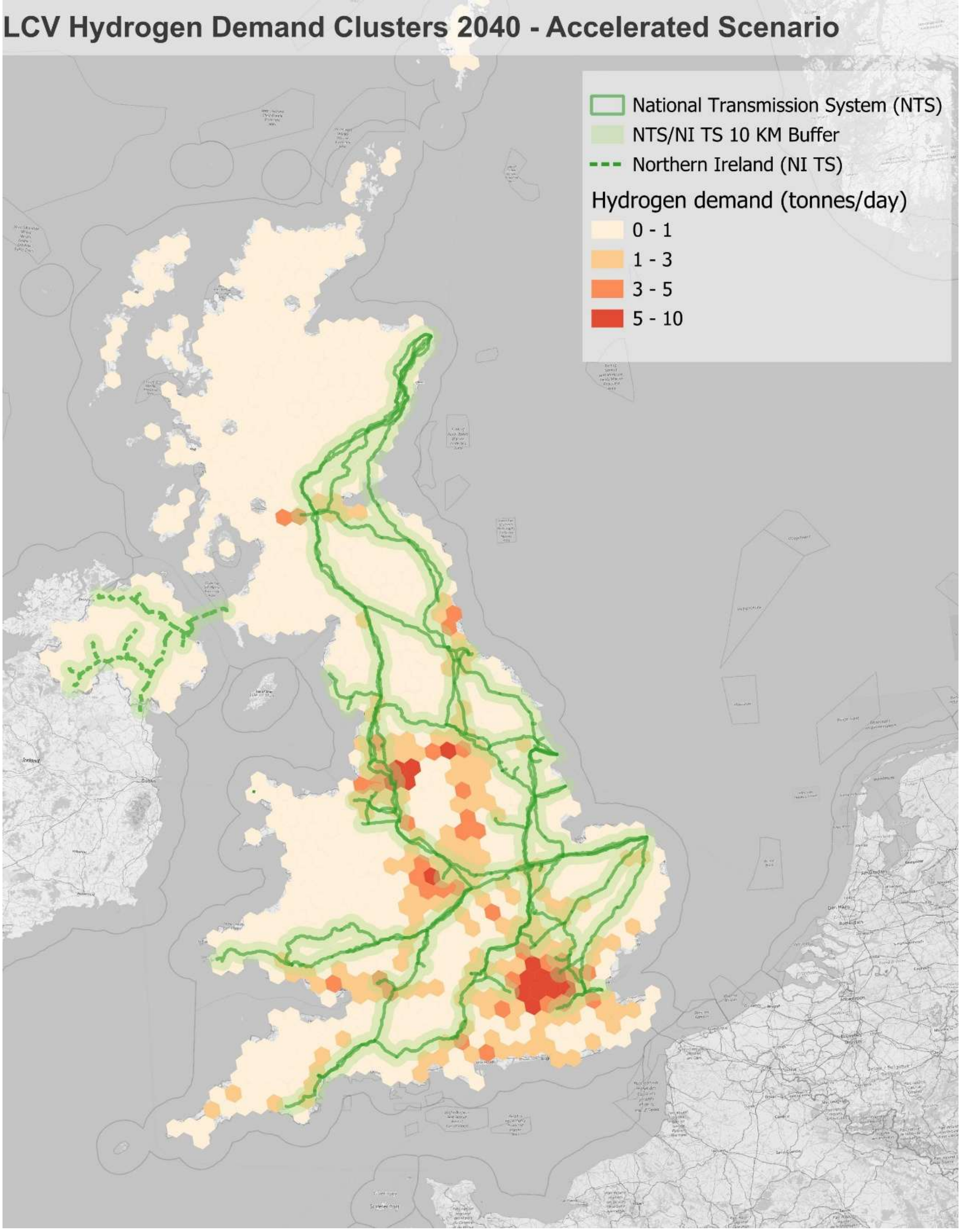


*Figure 26: LCV hydrogen demand clusters in 2040 under the accelerated scenario*

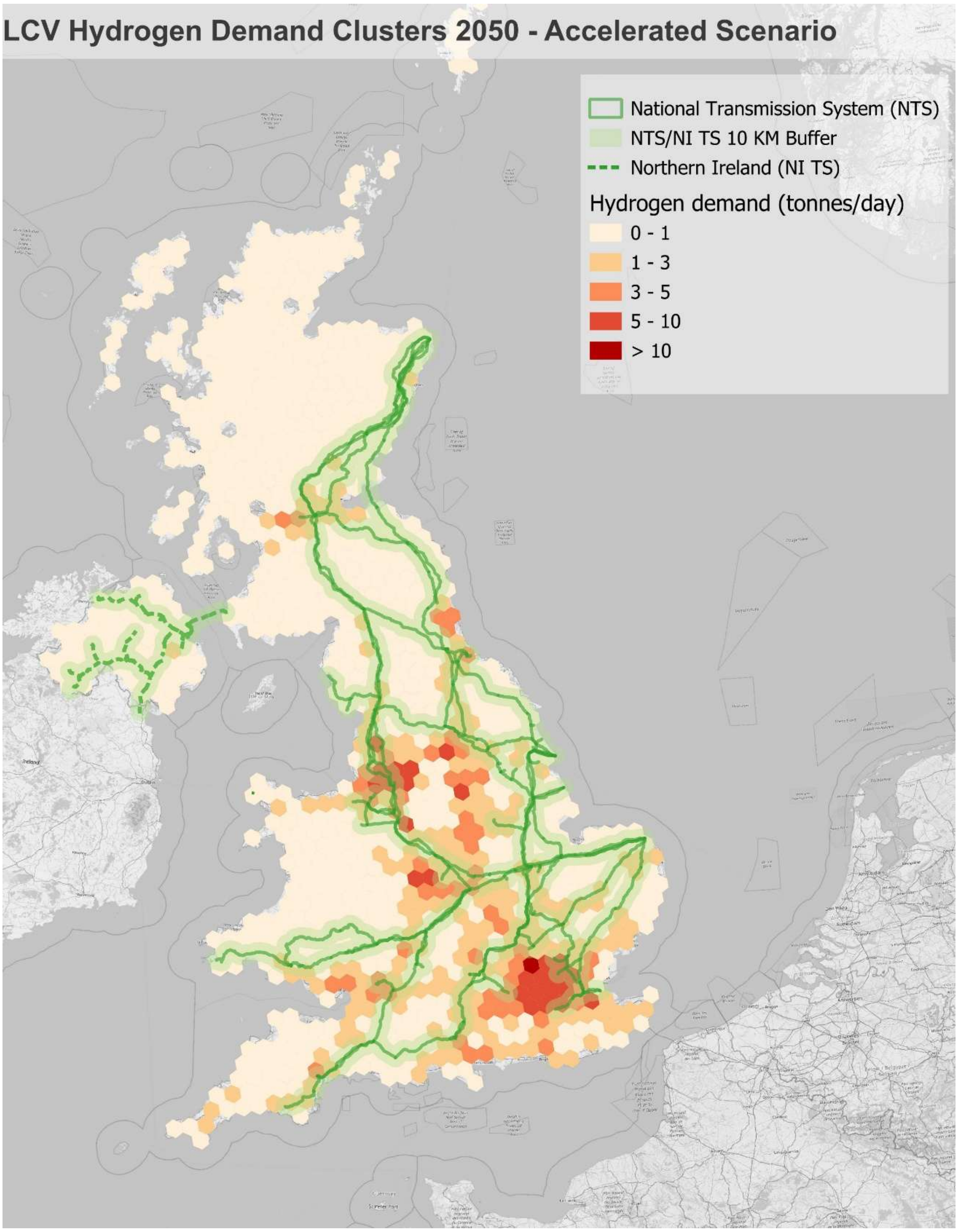


*Figure 27: LCV hydrogen demand clusters in 2050 under the accelerated scenario*

# 6 Hydrogen demand potential: Non-Road Mobile Machinery

As previously discussed in Section 2, hydrogen in non-road mobile machinery (NRMM) in the UK is moving from concept to targeted pilots across construction, agriculture, and ports. This transition is being led by two technical routes: hydrogen internal-combustion engines (H2-ICE) and hydrogen fuel cells.

Non-road-going mobile machinery (NRMM), such as tractors and forklift trucks, are subject to different regulations than road-going vehicles. Regulatory foundations are in place to support and encourage a move towards zero emission NRMM. UK type-approval requires Stage V for NRMM engines, and 2025 regulatory changes now permit hydrogen-fuelled construction and agricultural machines to use public roads for site moves[73].

Specific municipal regulations are also coming into force. For example, London's NRMM Low Emission Zone is tightening standards toward Stage V by 2030 with a stated aim of zero-emission NRMM by 2040.

Manufacturers such as JCB have secured full EU type-approval for H2-ICE intended for NRMM[74]. At the same time, EU port demonstrations (for example, the H2Ports programme in Valencia) have deployed fuel-cell reachstackers and terminal tractors, illustrating how hydrogen can decarbonise high-duty, tightly scheduled off-highway operations where long duty cycles and fast refuelling are valuable.

Many construction sites are short-term and cannot justify additional charging infrastructure. Some construction and mining sites have a rolling workface, where the work is required to move as the mine face or motorway (for example) is constructed. In both cases, fixed refuelling infrastructure is not a viable solution. In some cases, a construction site may be installing significant amounts of electrical power, and the required grid construction and upgrading is prioritised to facilitate the use of battery-powered and other NRMM. However, the initial construction phase still requires other fuels in advance of the electrification works. Other structures (such as the motorway example) may never require the type of electrical connection required to power plant equipment. A significant construction site such as Hinkley Point C nuclear power station can be so power-intensive (or cost-intensive) during the construction phase that even with the highest rated electrical connections to the grid, it is not feasible to electrify all the required plant equipment fully.

## 6.1 Market segmentation

NRMM are typically subdivided into three sectoral categories: agricultural, materials handling and construction (of which mining is a subset). Of these, the construction sector dominates UK NRMM, accounting for 56% of all NRMM sales and energy demand (see Figure 28), outweighing all other categories combined. Therefore, this analysis focuses on construction NRMM and extrapolate energy use for the rest of the sectors based on these modelling results (this is the basis for the road maps shown in Figure 5 through Figure 8).

Original Equipment manufacturers (OEMs) design and manufacture NRMM with the construction market at the forefront of their minds, including gensets. This market pull of the construction sector is further strengthened by the relatively short 'first-working-life' of many pieces of construction equipment. Newly purchased NRMM in the construction sector is primarily purchased by hire companies (approximately 66% of the UK market) and is worked at very high utilisation rates. This leads to rapid turnover and replacement of equipment. Therefore, any powertrain technologies

[73] JCB (2025) 'Historic day as hydrogen diggers get green light to use UK roads'. (Online). https://www.jcb.com/en-gb/news/2025/04/historic-day-as-hydrogen-diggers-get-green-light-to-use-uk-road (Accessed: 19 September 2025).

[74] JCB (2025) 'JCB secures full EU type-approval for pioneering hydrogen engine'. (Online). https://www.jcb.com/en-gb/news/2025/05/jcb-secures-full-eu-type-approval-for-pioneering-hydrogen-engine (Accessed: 19 September 2025).

adopted in the construction or equipment hire markets (powered by either battery or hydrogen) will, in all probability, force the adoption of the same powertrain solutions in other markets.

While the legislation that applies to them is the same, not all NRMM sectors are the same. Deploying low and zero-emission powertrains in all NRMM sectors can be difficult. The UK government recently referred to these 'hard to deploy' [ZEV] NRMM and, from a purely UK context, identified the following trends[75]:

"*Machines were classified as 'hard-to-deploy' [ZEV] if they satisfied at least two of the following four criteria:*

***(1) they regularly change sites,***

***(2) they are used on smaller sites,***

***(3) they are used intensively, or***

***(4) they are used on remote sites.***

*Based on* [UK] *stakeholder feedback, it is estimated that 32% of all industrial NRMM is hard-to-deploy."*

This suggests that it may never be practical to make all NRMM battery electric. Initially, biofuels, and later hydrogen, are likely to be required (to a greater or lesser extent) for almost all makes of vehicle.

One of the more comprehensive, cross-sector studies on NRMM was conducted by ERM with assistance from Cenex. This study was completed to inform the UK government's enquiries into the red diesel tax rebate, before its subsequent removal from the majority of NRMM users in 2022.

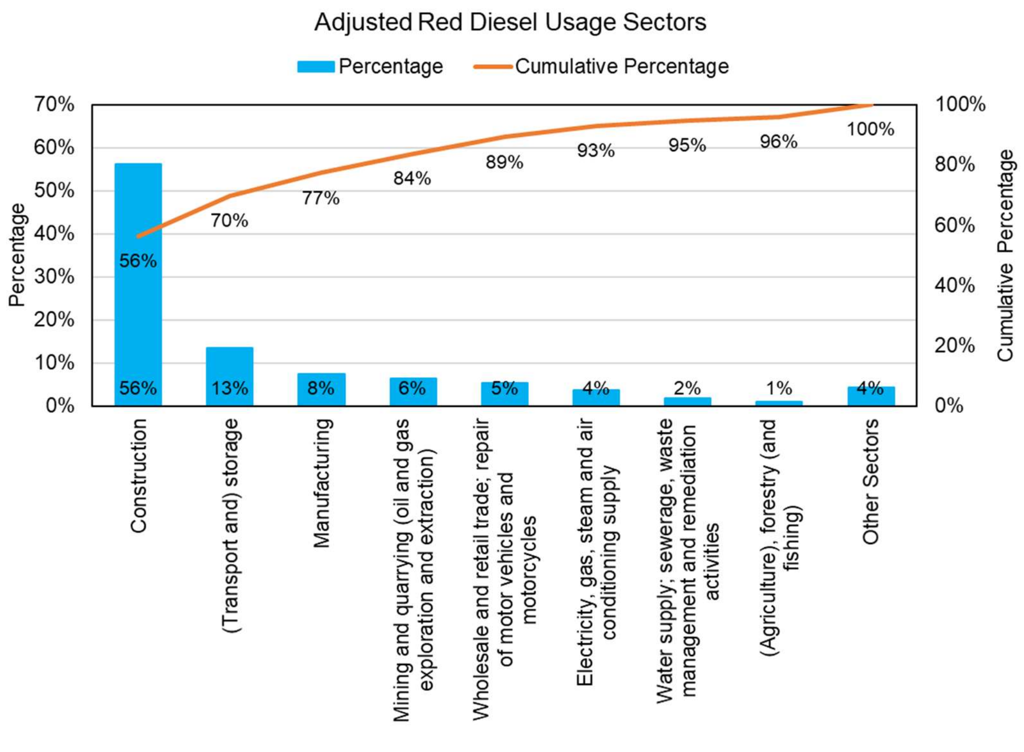


*Figure 28: NRMM fuel consumption by sector*

[75] ERM (2023): Industrial Non-Road Mobile Machinery Decarbonisation Options: Techno-Economic Feasibility Study: The Department for Energy Security and Net Zero (Online). https://assets.publishing.service.gov.uk/media/658443f3ed3c3400133bfd4d/nrmm-decarbonisation-options-feasibility-report.pdf

As shown in Figure 28 above, diesel use is heavily influenced by a handful of sectors, especially construction. When combined with storage (e.g. warehousing), manufacturing and mining and quarrying, these sectors account for 84% of usage. Note that ports are to be considered in the maritime section for this project, and as a generalisation, warehouse-based NRMM is less likely to require hydrogen, as its work patterns are often well-suited to battery electrification[76].

**Sub-sector breakdown**

A further level of sector breakdown is included in the Standard Industrial Codes (SIC) used in national statistics. Key sub-sectors for the high-priority areas are shown in the table below. Specifically of interest is the high percentage of red diesel use in crude petroleum and natural gas extraction and the defence sector.

*Table 13: 2018/2019 likely NRMM diesel usage by subsector*

| SIC Code | Sector | Supply % | Priority for review | Key sub-sectors |
|---|---|---|---|---|
| F | Construction | 56.3% | High | Civil engineering (75%), Buildings (17%), Other (8%) |
| H | (Transport and) storage | 13.5% | High | Warehousing includes transport support e.g. airports, harbours, ports (100%) |
| C | Manufacturing | 7.5% | High | e.g. petroleum, vehicles, building materials, machinery, food, drinks |
| B | Mining and quarrying (oil and gas exploration and extraction) | 6.5% | High | Mining and quarrying, excluding offshore oil and gas exploration and extraction. |

## 6.2 Sector-specific technology status and trends

Hydrogen vehicle development in this sector covers both plant and forklifts, using both FCEV and H2ICE. Major suppliers for plant equipment, including JCB, Fendt, Mahle, Volvo Construction Equipment, Case-New Holland, and their tier one suppliers such as Cummins, and Johnson Mathey are actively developing hydrogen technology prototypes (both ICE and Fuel Cell), with demonstration vehicles beginning to see field test in some cases, primarily aimed at the construction market. Several companies, most notably Plug Power, Toyota Materials Handling and Mingu, all offer hydrogen-powered forklifts.

## 6.3 Sector-specific policy and regulatory context

The design and manufacture of NRMM is a global market and original equipment manufacturers (OEMs) seek to work toward a common design across the world to increase economies of scale. This means that technology available in the UK is not primarily driven by UK policy and regulation. A series of key guidance, policy, and regulatory documents has been reviewed for the EU, USA (which can be considered "legislatively closer" to the UK than other key markets such as India and China), alongside several 'global' summary documents that have also been considered. These guidance, policy and regulatory documents will likely shape new technology's future global adoption landscape between now and 2050[77].

[76] There is a potential business case for very large warehousing operations, with 80 or more medium to heavy forklifts operating over multiple shifts, to switch to hydrogen-powered forklifts in some cases.

[77] See appendix E for the bibliography the summary of global hydrogen policy by the World Energy Council, although the report does not capture the most recent developments since 2021.

**UK national policy**

The UK does not yet have a fully established, binding policy specifically mandating the decarbonisation of non-road mobile machinery (NRMM) by 2050. However, there are significant steps underway indicating that a specific NRMM policy is forthcoming.

A "Call for Evidence" on NRMM decarbonisation (also referred to as "off-road machinery") was published in December 2023, with responses collected through March 2024. A techno-economic feasibility study was published alongside the call for evidence. In the summary of responses, it was noted that stakeholders generally view existing and planned UK policies as insufficiently specific for NRMM. Respondents emphasised the need for tailored intervention.

In the "Powering up Britain: Net Zero Growth Plan" (March 2023), the UK government said it would publish a cross-government strategy to decarbonise NRMM. However, as of now, that strategy has not yet been finalised or released. This process is explicitly to inform future policy, meaning no binding requirements have yet been set. [78,79,80,81,82]

## 6.4 Evidence base and data gaps

In the absence of a comprehensive inventory for the NRMM fleets, the authors relied on policy and academic reports to estimate the volume of NRMM in the construction sector. The National Atmospheric Emissions Inventory data were used to estimate operational patterns and fuel consumption for NRMM.

*Table 14: Datapoints, sources and their roles in modelling for NRMM*

| Datapoint | Source | Role |
|---|---|---|
| **Number and types of construction NRMM in the UK** | Desouza et al, 2024 [83] | Calculate vehicle mileage by body type, size class and location |
| **Load factor, energy use and efficiency for fuel types and machine sizes** | NAEI - Emissions Factors Data Selector[84] | Estimate energy use for machinery based on their size, duty cycle and fuel type |

## 6.5 Scenario modelling

### *Legislated uptake modelling*

As detailed in the road maps in Section 2, there are key legislative targets that are planned between now and 2050 that will drive technology change. The legislative modelled uptake assumes little

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[78] Department for Energy Security and Net Zero (DESNZ). (2023) *Non-road mobile machinery: decarbonisation options – Call for evidence*. London: UK Government. (Online). https://www.gov.uk/government/calls-for-evidence/non-road-mobile-machinery-decarbonisation-options (Accessed: 5 September 2025).

[79] Ricardo Energy & Environment. (2023) *Non-road mobile machinery decarbonisation options: Feasibility study*. London: UK Government. (Online). https://www.gov.uk/government/publications/non-road-mobile-machinery-decarbonisation-options-feasibility-study (Accessed: 5 September 2025).

[80] Department for Energy Security and Net Zero (DESNZ). (2024) *Summary of responses: Non-road mobile machinery decarbonisation options call for evidence*. London: UK Government. (Online). https://assets.publishing.service.gov.uk/media/67a4941d4dd52dddeb16a7fb/nrmm-decarbonisation-options-cfe-summary-of-responses.pdf (Accessed: 5 September 2025).

[81] Department for Energy Security and Net Zero (DESNZ). (2023) *Powering up Britain: Net Zero Growth Plan*. London: UK Government. (Online). https://www.gov.uk/government/publications/powering-up-britain/powering-up-britain-net-zero-growth-plan (Accessed: 5 September 2025).

[82] Greater London Authority (GLA). (2024) *Non-road mobile machinery (NRMM) emissions and standards*. London: GLA. (Online). https://www.london.gov.uk/programmes-and-strategies/environment-and-climate-change/pollution-and-air-quality/nrmm (Accessed: 5 September 2025)

[83] Desouza, C., Marsh, D., Beevers, S. et al. Emissions from the Construction Sector in the United Kingdom. Emiss. Control Sci. Technol. 10, 70–80 (2024). https://doi.org/10.1007/s40825-023-00237-w

[84] National Atmospheric Emissions Inventory. (n.d.). Emissions Factors Data Selector. Retrieved September 19, 2025, from https://naei.beis.gov.uk/emissions-factors-data-selector/

change in the uptake of BEV or other zero-emission equipment in the NRMM sectors, until the market approaches the point where vehicles purchased will become subject to likely decarbonization laws in 2050. The point at which this applies will vary depending on the estimated replacement cycles of the NRMM in question.

Modelling of the construction NRMM market is underpinned by the following key assumptions, which reflect the influence of legislation, technology readiness, and the unique operational demands of the sector.

1. **Legislative and Regulatory Pressure:** The primary driver for the transition is the UK's legally binding Net Zero by 2050 target. In the absence of specific and binding NRMM decarbonisation legislations, this is assumed to be enforced through several mechanisms including:
   - Fuel Taxation: The April 2022 reform, which removed the entitlement for most of the construction sector to use subsidised red diesel.
   - Emissions Standards: It is assumed that national emissions standards for non-road mobile machinery will continue to tighten beyond the current Stage V regulations.
   - Local Air Quality Schemes: The expansion and enforcement of Clean Air Zones (CAZs) in cities across the UK, alongside London's Ultra Low Emission Zone (ULEZ), will increasingly restrict or penalise the use of combustion-engine machinery on urban construction sites
2. **Dominance of HVO as a Transitional Fuel:** Hydrotreated Vegetable Oil (HVO) is assumed to be the most critical bridging solution for the sector, particularly for medium and large machinery. As a "drop-in" fuel, it allows fleet owners to significantly reduce net $CO_2$ emissions using their existing and newly purchased diesel-engine assets.
   - This approach requires that combustion of carbon-based fuels continues to be permitted for the foreseeable future. It is very possible that electrification and hydrogen fuel cells will prove successful and cost-effective in road transport in the coming years, which will in turn increase pressure to ban the combustion of carbon-based fuels, particularly in urban construction, freight and logistics handling sites.
3. **Segment-Specific Technology Pathways:** The forecast assumes that there is no single solution for decarbonising construction machinery. The optimal technology is dictated by machine size and application:
   - Small Machinery (<8 tonnes): This segment is expected to electrify rapidly. Battery electric technology is considered viable and operationally effective for smaller machines that work fewer continuous hours and can return to a depot for overnight charging.
   - Large Machinery (>20 tonnes): Hydrogen is assumed to be the only viable long-term, zero-emission solution for heavy-duty machinery requiring high energy density and fast refuelling. Hydrogen Internal Combustion Engines (H2-ICE) are expected to lead adoption over Fuel Cells initially, owing to their greater robustness in difficult site conditions and lower capital cost.
4. **Role of Hybridisation:** Diesel-electric hybrid powertrains are considered likely to be adopted as an interim technology, especially in the medium and large machine categories. They are accounted for within the "ICE" fuel class for now and are expected to form a growing proportion of those sales.

Figure 29 below shows the results of the legislated uptake model for NRMM.

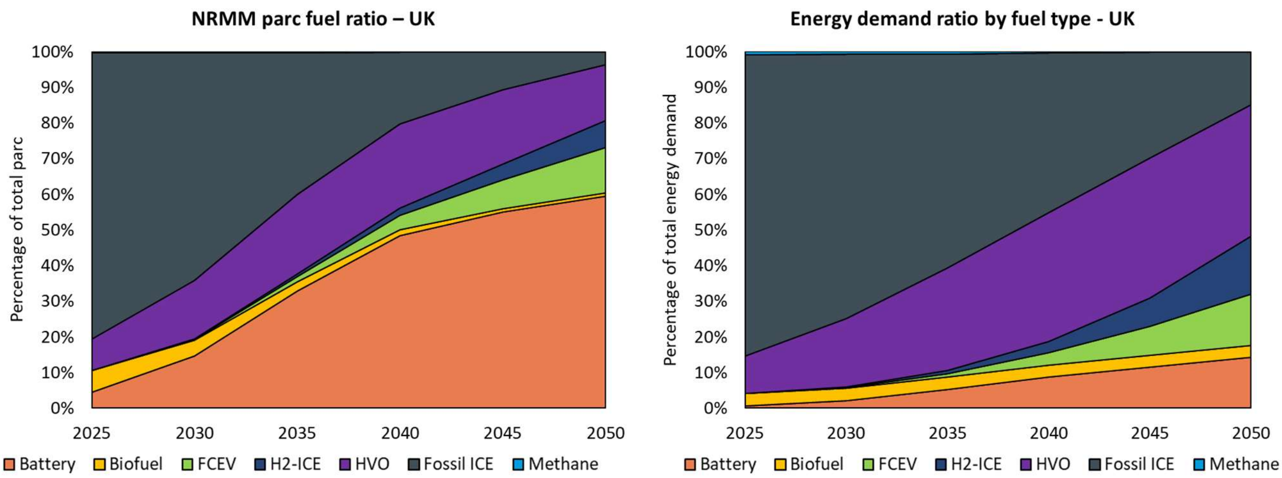


*Figure 29: Vehicle parc and energy demand for the UK's construction NRMM fleet by fuel type 2025-2050 – Legislated Scenario*

### Accelerated uptake modelling

Existing decarbonisation pathways are insufficient to meet the global climate commitment to stabilise global warming at 1.5 degrees C above the agreed international baseline. The International Energy Agency (IEA) has a 'Net Zero Emissions' (NZE) scenario that does meet this target, and this scenario assumes the NZE pathway will be adopted.

Our accelerated uptake scenario assumes that additional factors come into play to align the uptake of new technologies with the NZE pathway. These additional factors could include more aggressive legislation and/or more rapid improvements in low and net-zero technology (incentivising uptake beyond the regulated minimum).

The NRMM model is a mixture of top-down national sales figures and proprietary in-house data accrued over several years of NRMM stakeholder engagement. The 'bottom-up' estimate seeks to align national data with our understanding of the market and follow similar principles of calculating NRMM replacement cycles.

To align the outputs of the model to the NZE scenario, it was necessary to project where the most likely increases in percentage sales of new low and zero-emission powertrains might occur..

Technology trends in roadgoing vehicles offer some insight into likely developments in NRMM, but the picture is complex and requires evaluation of multiple factors. On one hand, many of the technologies and tier one supply chains in the NRMM sector overlap with those of the road going sector, hence the presence of household automotive names such as Volvo, Toyota, and others in the NRMM sector. More fuel-efficient engines, improved exhaust gas management, and battery–ICE hybridisation have all started in the automotive sector and now make up an ever-increasing market share in the NRMM sector.

Despite this, NRMM continues to lag in terms of technology development. Profit margins in the NRMM sector are often lower than those in automotive, which can discourage new technology experimentation. In addition, NRMM emission legislation is at least five years behind that of road-going traffic. However, it is becoming increasingly strict, with Stage V emission limits for engines in nonroad mobile machinery, which significantly impacts the majority of new NRMM sales across the EU (and therefore the UK). Stage V regulation does not currently set Green House Gas (GHG) emission standards. Still, NRMM manufacturers widely recognise that it is only a matter of time before stricter controls on NRMM GHG emissions are enforced in legislation.

Figure 30 below shows the results of the accelerated uptake scenario for NRMM.

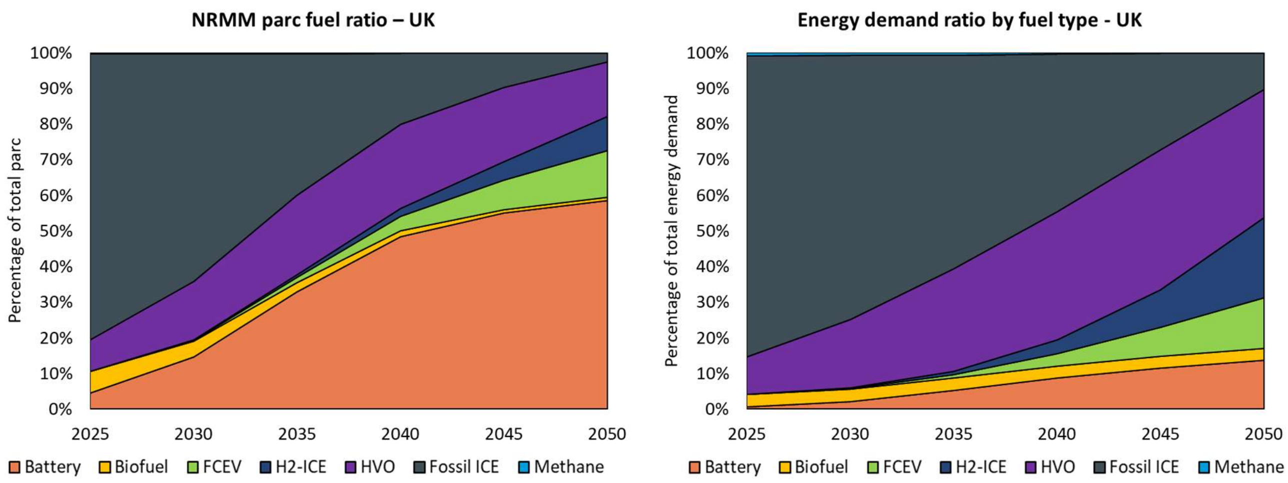


*Figure 30: Vehicle parc and energy demand for the UK's construction NRMM fleet by fuel type 2025-2050 – Accelerated Scenario*

- Total number of NRMMs in the UK is assumed to remain at around **141,370 machines.**
- Table 15 shows total energy demand estimates for LCVs in both scenarios (to three significant figures)

*Table 15: Total energy demand in GWh for the UK NRMM fleet under the legislated and accelerated scenarios*

| Year | Legislated scenario (GWh) | Accelerated Scenario (GWh) |
|---|---|---|
| 2025 | 11,600 | 11,600 |
| 2030 | 11,300 | 11,300 |
| 2035 | 10,800 | 10,800 |
| 2040 | 10,000 | 10,000 |
| 2045 | 9,400 | 9,400 |
| 2050 | 8,700 | 8,770 |

## 6.6 Location-specific demand estimates

### 6.6.1 Legislated Scenario

Under the legislated scenario, the 2040 hydrogen demand for NRMM is concentrated in specific industrial and urban centres. The Greater London area emerges as the principal demand centre, with clusters requiring over 10 tonnes of hydrogen per day. A significant secondary cluster is located in East Suffolk, driven by the Sizewell power generation complex, with demand projected to be between 5 and 10 tonnes per day. Clusters of moderate demand, generally under 5 tonnes per day, are scattered across the country in key industrial regions, including the Southwest near Bristol, the West Midlands, the Northeast, and Glasgow (Figure 31).

By 2050, the demand from the NRMM sector is projected to intensify and expand geographically. The demand in the Greater London area intensifies further, while the clusters in East Suffolk, the Southwest, and the West Midlands are all expected to grow to exceed 10 tonnes of hydrogen per day. The overall geographic footprint of demand also broadens, with new clusters (under 5 tonnes per day) emerging in Yorkshire and within the central belt between Glasgow and Edinburgh in Scotland (Figure 32).

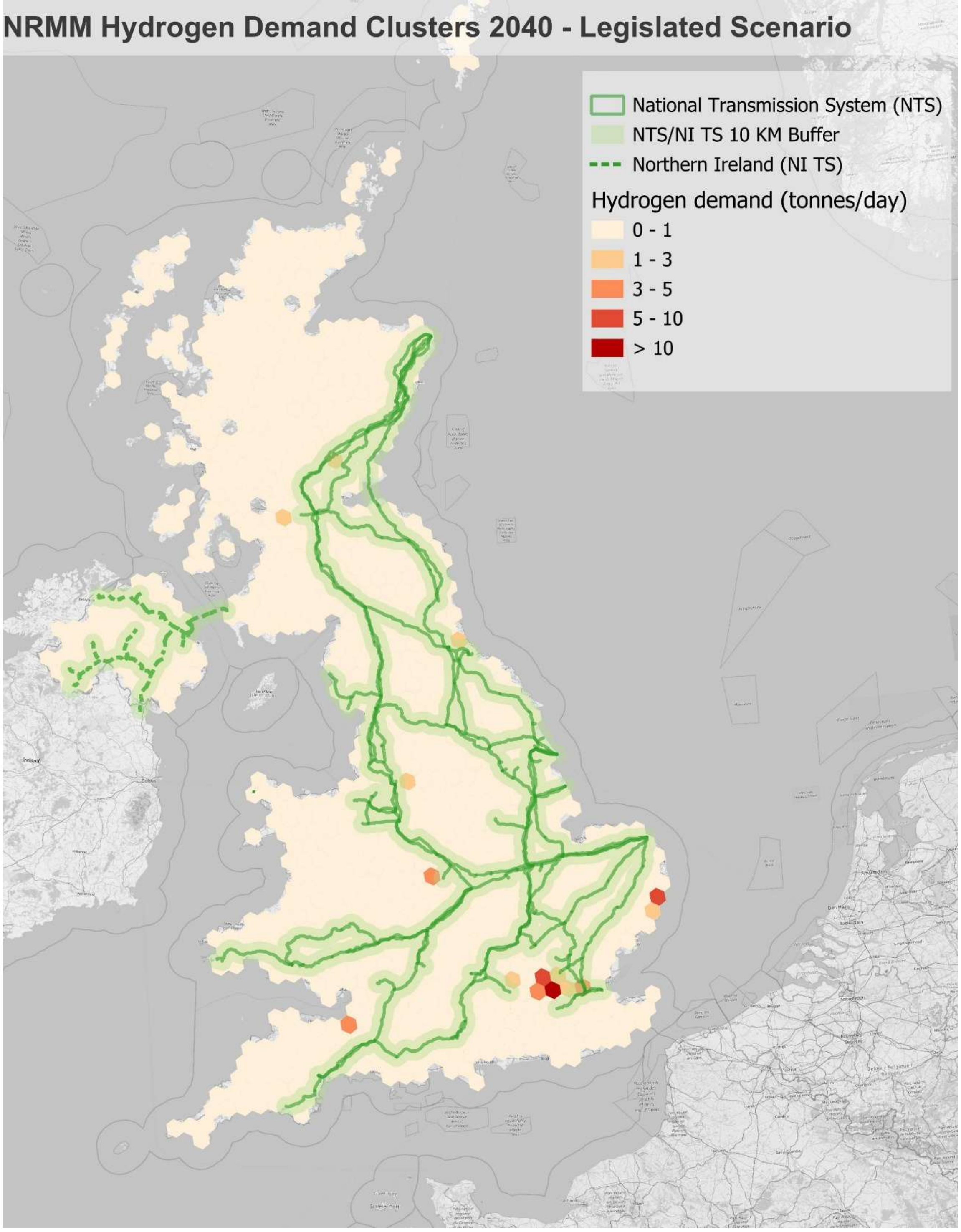


*Figure 31: NRMM hydrogen demand clusters in 2040 under the legislated scenario*

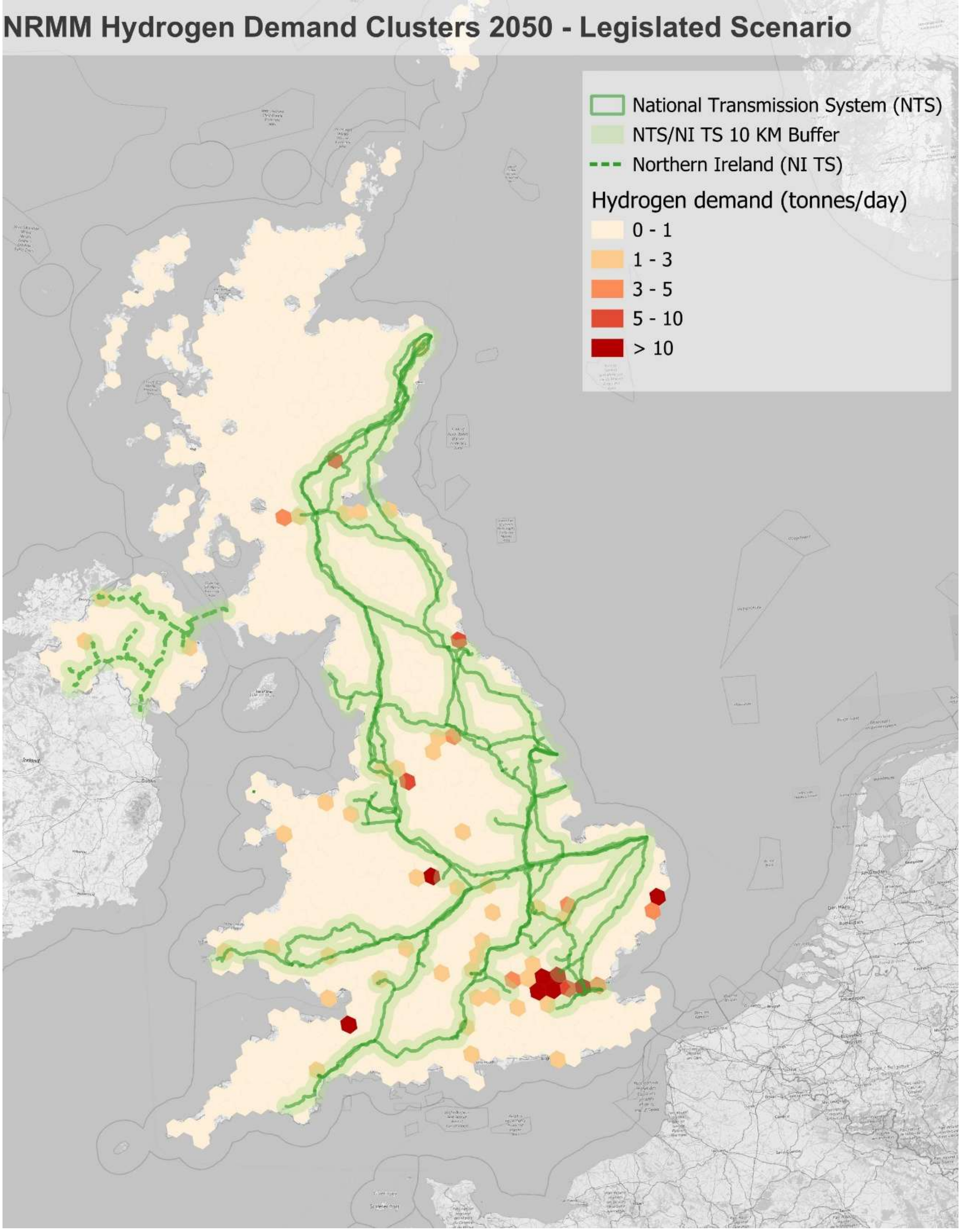


*Figure 32: NRMM hydrogen demand clusters in 2050 under the legislated scenario*

### 6.6.2 Accelerated Scenario

Under the accelerated scenario, the 2040 hydrogen demand for NRMM follows the same core geospatial patterns as the legislated scenario, though with a significantly greater magnitude. The primary demand clusters are concentrated in the Greater London area and East Suffolk, reflecting the industrial and construction activities in these regions (Figure 33).

By 2050, this trend continues with demand intensifying in line with the legislated scenario's geographic evolution. The clusters in the Greater London area grow more intense, while new major demand centres requiring over 10 tonnes per day emerge in East Suffolk, West Midlands, the South West, and the Northeast. The geographic footprint of demand also becomes more expansive, with a notable increase in moderate clusters across the Midlands, the Northwest, and Yorkshire (Figure 34).

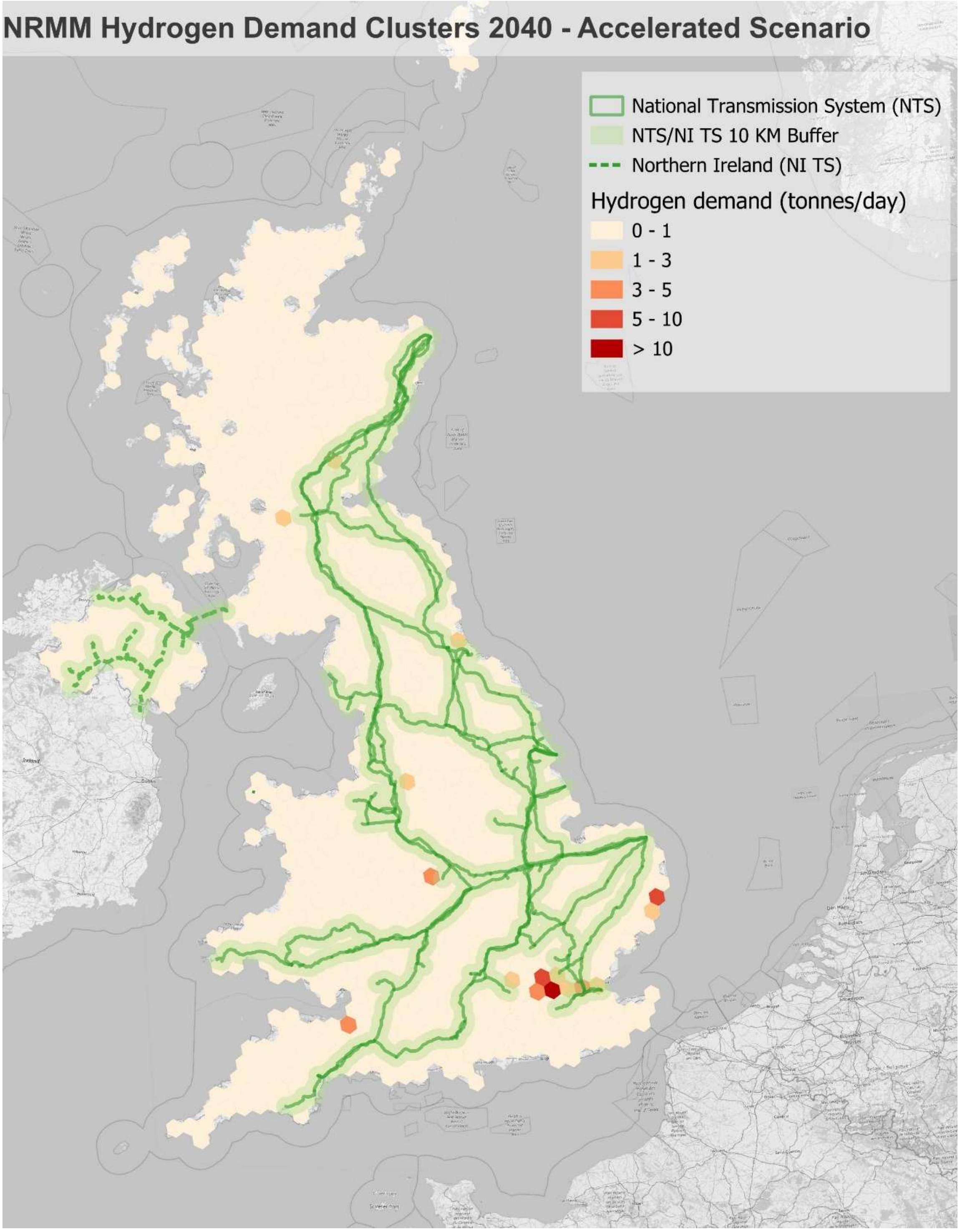


*Figure 33: NRMM hydrogen demand clusters in 2040 under the accelerated scenario*

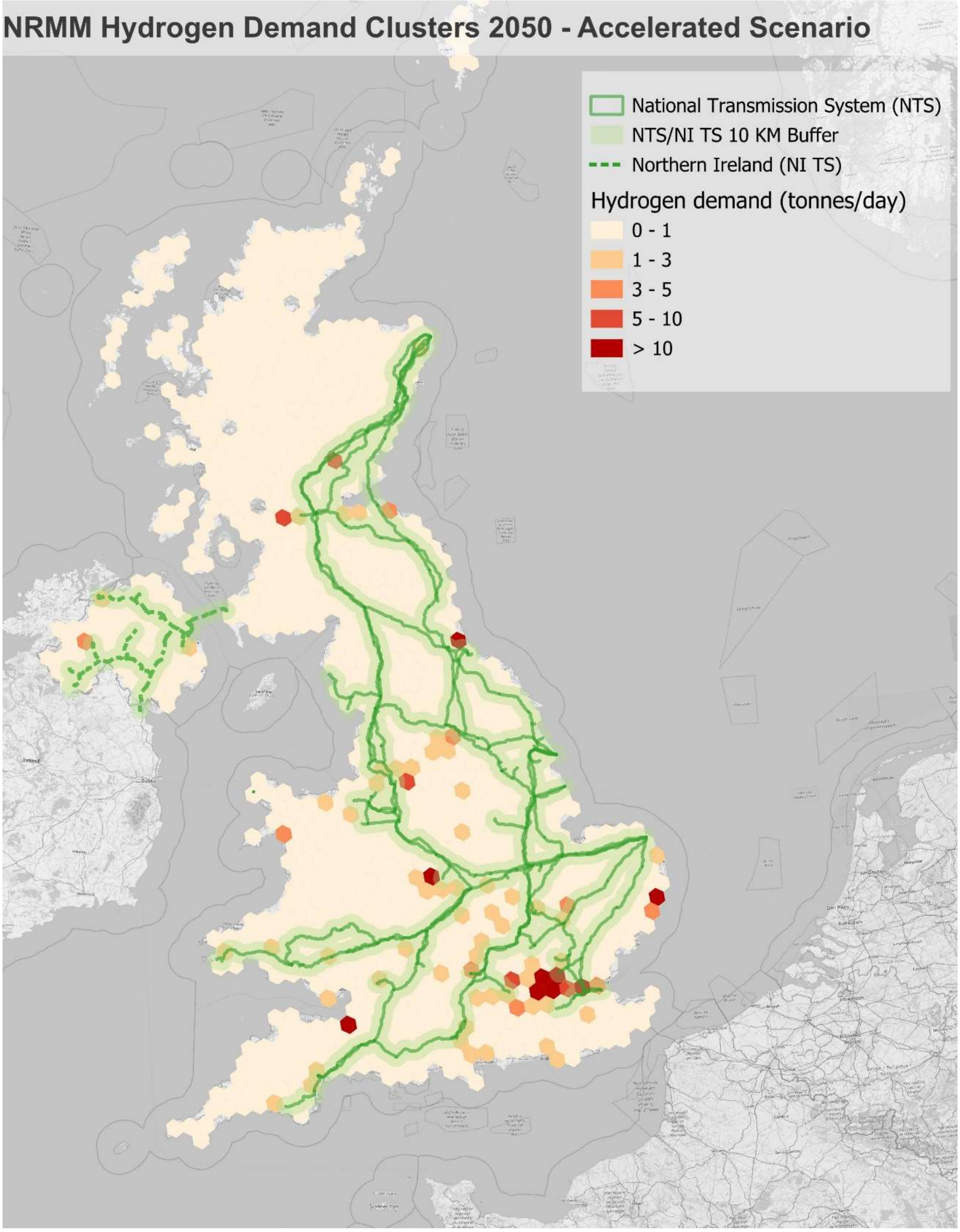


*Figure 34: NRMM hydrogen demand clusters in 2050 under the accelerated scenario*

# 7 Hydrogen demand potential: Gensets

Hydrogen generator sets (gensets) are emerging as a zero-emission alternative for temporary and off-grid power in the UK, serving construction, utilities, events, and maintenance outages. Commercial fuel-cell gensets from UK suppliers now deliver tens to hundreds of kilowatts—typical units integrate a battery for load-following and provide around 250 kW three-phase output— and have been deployed by National Grid at substations[85], on HS2 compounds, and at major events.

In the hire market, Speedy Hire's joint venture with AFC Energy is rolling out modular H-Power fuel-cell generators[86] to replace diesel on sites, complementing larger trailer-mounted systems[87] from GeoPura used for higher-power, longer-duration applications.

## 7.1 Market segmentation

Table 16 below shows UK sales of gensets in 2024. The figures and the size segments selected are based on available data and liaison with expert stakeholders at the Association of Manufacturers and Suppliers of Power Generating Systems (AMPS).

*Table 16: New 2024 UK sales of the UK-produced Gensets*

| Size Class | Small (7.5 to 75 kVA, portable & site) | Medium (75 to 375 kVA, construction & standby) | Large (376 to 750 kVA, industrial & datacentre) | Utility-scale (>750 kVA, CCGT/backup) | Total Units (est.) | Notes |
|---|---|---|---|---|---|---|
| **2024 sales** | ~4,200 | ~3,200 | ~750 | ~1,120 | ~9,270 | Decarbonisation pressures start shifting demand to HVO-ready gensets |

**Assumptions:**

- Rental dominance means turnover rates are higher in NRMM (~5–8 years for mini excavators) compared to gensets (~10–15 years depending on duty cycle).
- For energy modelling, the assumptions are laid-out in Table 17. In battery storage and methane generators, Efficiency increases with size is due to technological advancements and better thermal efficiency.

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85 National Grid (2023) 'National Grid goes carbon-free with hydrogen-powered substation trial'. (Online). https://www.nationalgrid.com/national-grid-goes-carbon-free-hydrogen-powered-substation-trial (Accessed: 19 September 2025).

86 AFC Energy (2025) 'Full Year 2024 results and strategic update' (Speedy Hydrogen Solutions roll-out). (Online). https://www.afcenergy.com/news/press-releases/full-year-2024-results-and-strategic-update/ (Accessed: 19 September 2025).

87 GeoPura (2025) 'HS2 case study (EKFB)'. (Online). https://www.geopura.com/wp-content/uploads/2025/03/GeoPura-EKFB-Case-Study.pdf (Accessed: 19 September 2025).

*Table 17: Assumptions used to estimate energy demand by gensets of different classes and fuel type*

| Size Class | kVA Range | Assumed class average | Assumed Efficiency |
|---|---|---|---|
| **Small** | 7.5 - 75 kVA | 45 kVA (63 kW) | Battery: 89%<br>Fuel Cell: 55%<br>H2-ICE: 36%<br>Diesel: 34%<br>Methane: 31% |
| **Medium** | 76 - 750 kVA | 400 kVA (320 kW) | Battery: 91%<br>Fuel Cell: 60%<br>H2-ICE: 38%<br>Diesel: 38%<br>Methane: 36% |
| **Large** | More than 750 kVA | 1,400 kVA (1,120 kW) | Battery: 93%<br>Fuel Cell: 63%<br>H2-ICE: 41%<br>Diesel: 42%<br>Methane: 43% |

- The model uses the NAEI estimates for annual utilisation of Gensets. The NAEI's figures are generally more conservative than industry-specific reports as they account for the entire fleet of generators in the UK. This includes the thousands of units installed in buildings like hospitals, data centres, and commercial offices for standby or emergency backup power.
  - Small generators: 1,000 hours annually at 0.4 load factor
  - Medium generators: 1,000 hours annually at 0.45 load factor
  - Large generators: 600 hours annually at 0.55 load factor
- Based on regional electricity usage or non-grid backup needs
- Based on earlier estimate of ~31,850 total units sold (for portable, commercial gensets) across the UK.
- Regional shares mirror those of construction activity or data centre concentration. Scotland and NI have lower volumes, while England dominates.
- The combustion of carbon-based fuels continues to be permitted.

**Approximate Genset Sales by UK Nation (2024)**

Based on UK national statistics covering the value of announced construction work, the geographic distribution of UK NRMM has been estimated, including Gensets (see Table 18). NRMM energy use is highly concentrated in England, broadly in line with economic activity.

*Table 18: National distribution of UK NRMM (2024 data)*

| UK Nation | Proxy Metric | Approximated Share |
|---|---|---|
| England | ~85% of UK non-grid electricity or data centres | 85% |
| Scotland | ~7% of UK non-grid electricity or manufacturing | 7% |
| Wales | ~5% of UK volume (similar assumptions) | 5% |
| Northern Ireland | ~3% of UK volume | 3% |
| Total (UK) | — | 100% |

## 7.2 Sector-specific technology status and trends

There are a handful of commercially available OEM-manufactured hydrogen generator sets. Those that are available are primarily focused on providing electrical power in confined spaces, or when silent operation (with fuel cell-powered gen-sets) is required and direct electrification or battery systems are not suitable. Typically, these units are configured as either dedicated power to a single system (for example, lighting towers[88]), or for more general power applications[89] where a variety of tools and equipment can be run from a single generator, including battery charging for battery-powered NRMM, if required.

## 7.3 Sector-specific policy and regulatory context

Generator sets fall under NRMM regulations, and the comments in section 6.3 apply equally to Generator sets.

## 7.4 Evidence base and data gaps

It is difficult to find specific data on the sales of generators. Many OEMs don't disclose unit counts or market share in annual reports, and generator sales, when mentioned separately from NRMM sales at all, are presented as total sales figures with little or no segregation by sector, type, or size. Cummins Power Generation product line revenues are an exception, as they are broken out in more detail[90]. Market segmentation must instead be inferred from company catalogues. Combined with studies completed by DESNEZ and the NAEI, this report has attempted a top-down market segmentation assessment of UK gen sets sales.

Despite the lack of data noted above, PRODCOM[91] (Eurostat/ONS) product codes and the CEASER NRMM Register[92] do help to give some indicative breakdown. These two data sets segment the market for generator sets by 'apparent power class' (kilovolts-amperes, or KVA)[93]. This data can be used to segment the generator market in KVA bands (≤ 75, 75–375, 375–750, > 750 kVA)[94].

[88] https://tcp-eco.co.uk/product/ecolite-th200/
[89] https://www.geopura.com/how-hydrogen-generators-work/
[90] [Caterpillar | 2024 Segment Highlights]
[91] https://www.ons.gov.uk/businessindustryandtrade/manufacturingandproductionindustry/datasets/ukmanufacturerssalesbyproductprodcom

[92] https://www.cesarscheme.org/

[93] The ONS PODCOM data tracks generator set sales under the codes 27.11.31. (diesel gensets by kVA band) and 27.11.32. (spark-ignition and "other" sets).

[94] The exact power output (and therefore likely energy demand) from these units will vary slightly. However, a typical method is to convert the kVA value into kW directly and then reduce the figure by ~ 10% so a 75 kVA generator is likely to provide peak power in the order of ~70 kW.

The above data for likely power outputs for generator sets was used to assist in determining the likely energy consumption of UK generator sets. This was then cross-referenced to other reports and statistics on UK energy use (typically reported in thousands of barrels of oil equivalent per year, or MWh per year for the entire sector). This was combined with the estimate of UK-manufactured Gensets (as reported by CEA experts in Table 16) and probable equipment lifetimes and operating hours[Error! Bookmark not defined.,95,96].

This information was further triangulated with UK import/export data (which can overstate the total numbers of generator sets, as not all sets are sold and used in the UK). Taken together (PRODCOM data, KVA estimates of power, UK national estimates of total fuel use by sector, published stakeholder estimates of duty cycles and operational lifetimes, and expert testimony on the likely size and distribution of the UK generator set market), these sources were used to create an estimate of energy demand by generator sets, and their likely replacement cycles. This, in turn, was used to estimate battery and hydrogen uptake scenarios for this sector out to 2050.

In summary:

- **Duty cycles & load factors** use UK inventory defaults (NAEI/DESNZ). Real projects vary; standby sets are hour-limited and last longer (20–30 years) than mobile site units (~8 years typical in inventory).
- **Fuel rates** use EMEP/EEA specific-fuel-consumption ranges by power band; actual fuel use depends on load, maintenance, and ambient conditions.
- **London centric NRMM Stage V compliance** (Stage V for 37–560 kW generators) is assumed to tilt sales toward Stage V models in Greater London; outside London, site policies vary.

## 7.5 Scenario modelling

### *Legislated uptake modelling*

As detailed in the roadmaps in section 2, there are key legislative targets that are planned between now and 2050 that will drive technology change. This forecast follows a legislative pathway, aligned with the UK's legally binding target of Net Zero by 2050. The following assumptions were used:

- **Phasing out fossil fuels**. The 2022 withdrawal of the red diesel rebate for construction and manufacturing is treated as a starting point, raising the total cost of ownership for conventional diesel gensets and improving the relative attractiveness of alternatives such as HVO. The model assumes escalating legislative pressure on fossil fuels.
- **Stricter emissions standards.** The forecast assumes emissions rules for NRMM tighten beyond current Stage V. In addition, the expansion of local Ultra Low Emission Zones (ULEZ) and Clean Air Zones (CAZ) increasingly restricts combustion engines in urban and sensitive locations, pushing a shift to zero-emission technologies (battery electric and fuel cell).
- **Infrastructure and support.** The forecast assumes delivery of UK Government strategies on hydrogen, carbon capture and energy security. This includes scaling up green hydrogen production and post-2030 build-out of associated distribution, making hydrogen a practical and accessible fuel.
- **Technology maturity.** The forecast assumes continuing reductions in the cost of batteries and hydrogen fuel cells, alongside improvements in performance and energy density. H2-ICE is treated as a viable, lower-capital-cost transitional option versus fuel cells, particularly for retrofits or where the higher efficiency of a fuel cell is not essential.

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[95] https://www.gov.uk/government/publications/non-road-mobile-machinery-decarbonisation-options-feasibility-study
[96] Non-agricultural NRMM (2025): https://naei.energysecurity.gov.uk/sites/default/files/2025-03/2_NAEI_Improvement_Report_Non-Agricultural_NRMM_0.pdf

- **Fuel sustainability.** HVO and other biofuels are considered important bridging fuels, but their long-term growth is assumed to be constrained by feedstock availability and sustainability concerns, preventing them from serving as the ultimate solution. The uptake of such fuels is projected to be lower and less sustained than in the NRMM market, especially in smaller gensets. This is because, unlike NRMM, genset operations don't involve the severe logistical challenges of electrifying mobile, heavy machinery.
    - If Battery electrification and fuel cell deployment in road transport prove successful, there will be increasing pressure to ban the use of carbon-based fuel combustion; This will generate a significant increase in the uptake of hydrogen, and possibly ammonia, as zero-emission tailpipe fuels. However, **this has not been modelled in the legislative or accelerated uptake scenarios**.

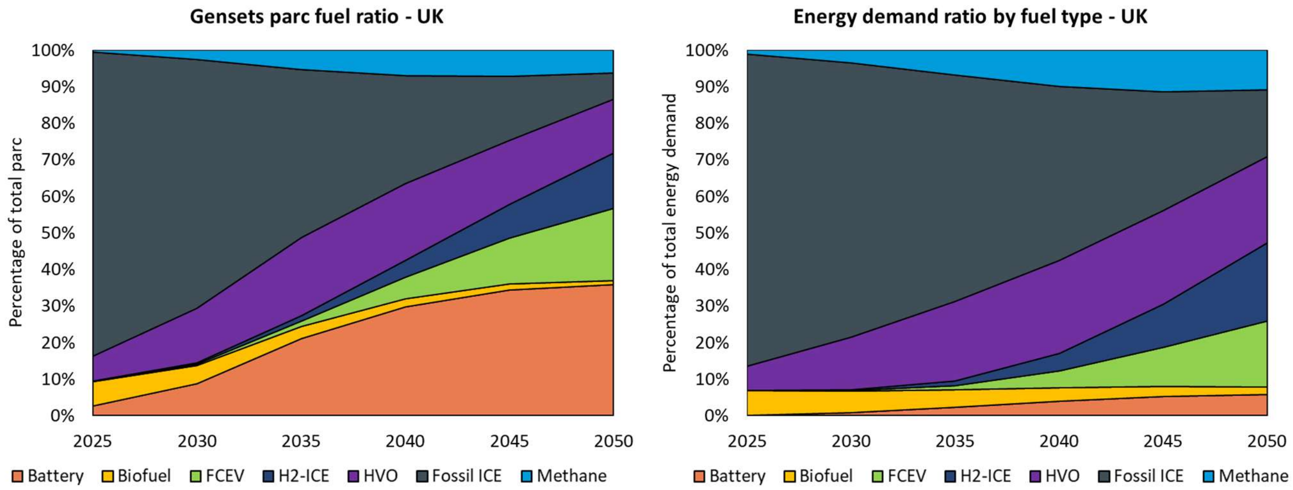


*Figure 35: Gensets parc and energy demand for the UK's Heave Genset fleet by fuel type 2025-2050 – Legislated Scenario*

## *Accelerated uptake modelling*

The accelerated uptake scenario is built on the same core assumptions of the legislated scenario with the following additional assumptions:

- A future ban on new sales of ICE small gensets (7.5 to 75 kVA) by 2040.
- Stricter usage criteria with more stringent, emissions-based standards governing the operation of existing gensets are being introduced.
- Lower and less sustained uptake of HVO and biofuels as bridging fuels due to availability issues for sustainable biofuels

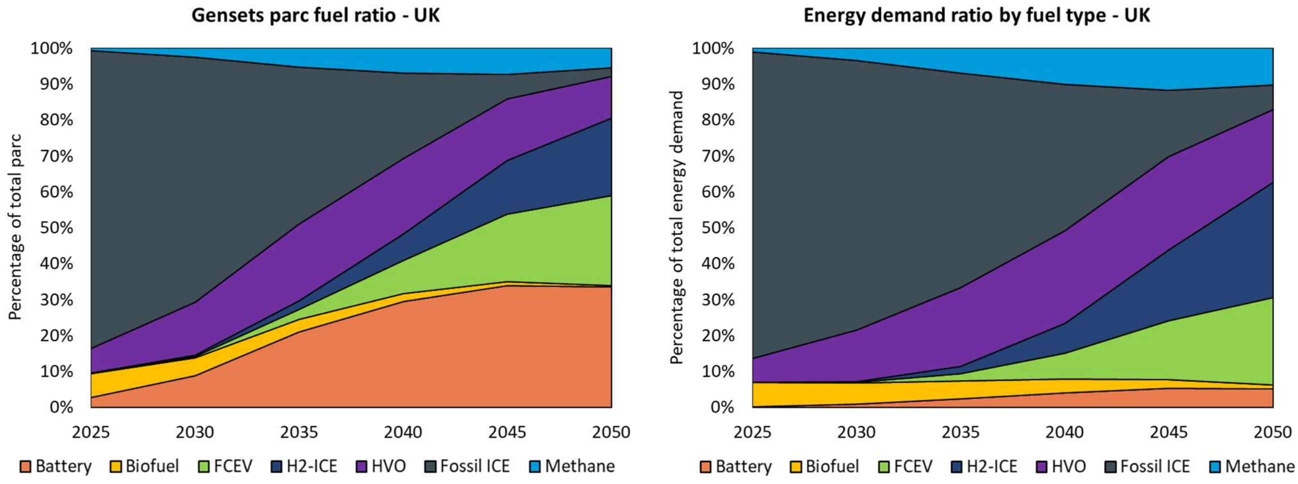


*Figure 36: Gensets parc and energy demand for the UK's Heavy Genset fleet by fuel type 2025-2050 - Accelerated Scenario*

- Total number of gensets in the UK is assumed to remain at around **108,870 machines.**
- Table 19 shows total energy demand estimates for LCVs in both scenarios (to three significant figures)

*Table 19: Total energy demand in GWh for the UK genset fleet under the legislated and accelerated scenarios*

| Year | Legislated scenario (GWh) | Accelerated Scenario (GWh) |
|---|---|---|
| 2025 | 39,500 | 39,500 |
| 2030 | 39,000 | 39,000 |
| 2035 | 38,100 | 37,900 |
| 2040 | 36,600 | 36,100 |
| 2045 | 35,000 | 34,100 |
| 2050 | 33,600 | 32,900 |

## 7.6 Location-specific demand estimates

### 7.6.1 Legislated Scenario

Under the legislated scenario, the 2040 hydrogen demand from gensets generally follows the same geographic distribution as that of NRMM. The demand is concentrated in key industrial and urban areas, with significant clusters located in the Greater London area, East Suffolk, and the South West. Other notable clusters, with a projected demand of 5 to 10 tonnes per day, also appear in the West Midlands and North West near Manchester (Figure 37)

By 2050, the demand for hydrogen from gensets is forecast to ramp up significantly. While London remains a high-demand cluster, the East Suffolk cluster expands. New major demand clusters, requiring over 10 tonnes of hydrogen per day, are projected to appear in the North East, the North West around Manchester, and in Scotland, specifically around Glasgow and Perth. The distribution of smaller clusters (under 10 tonnes per day) also becomes much wider, with increased presence across the Southern Coast, the East of England, and the Midlands (Figure 38).

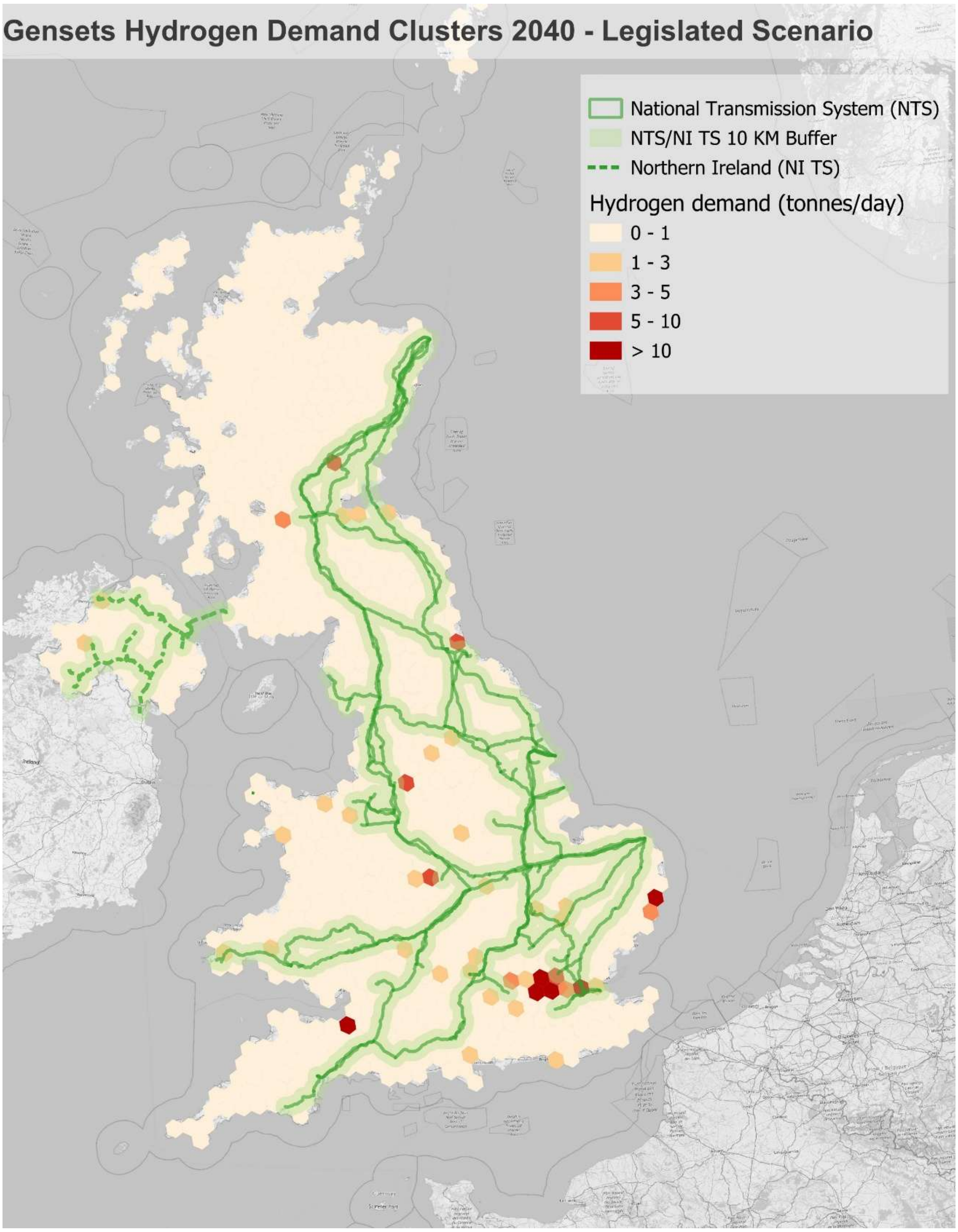


*Figure 37: Gensets hydrogen demand clusters in 2040 under the legislated scenario*

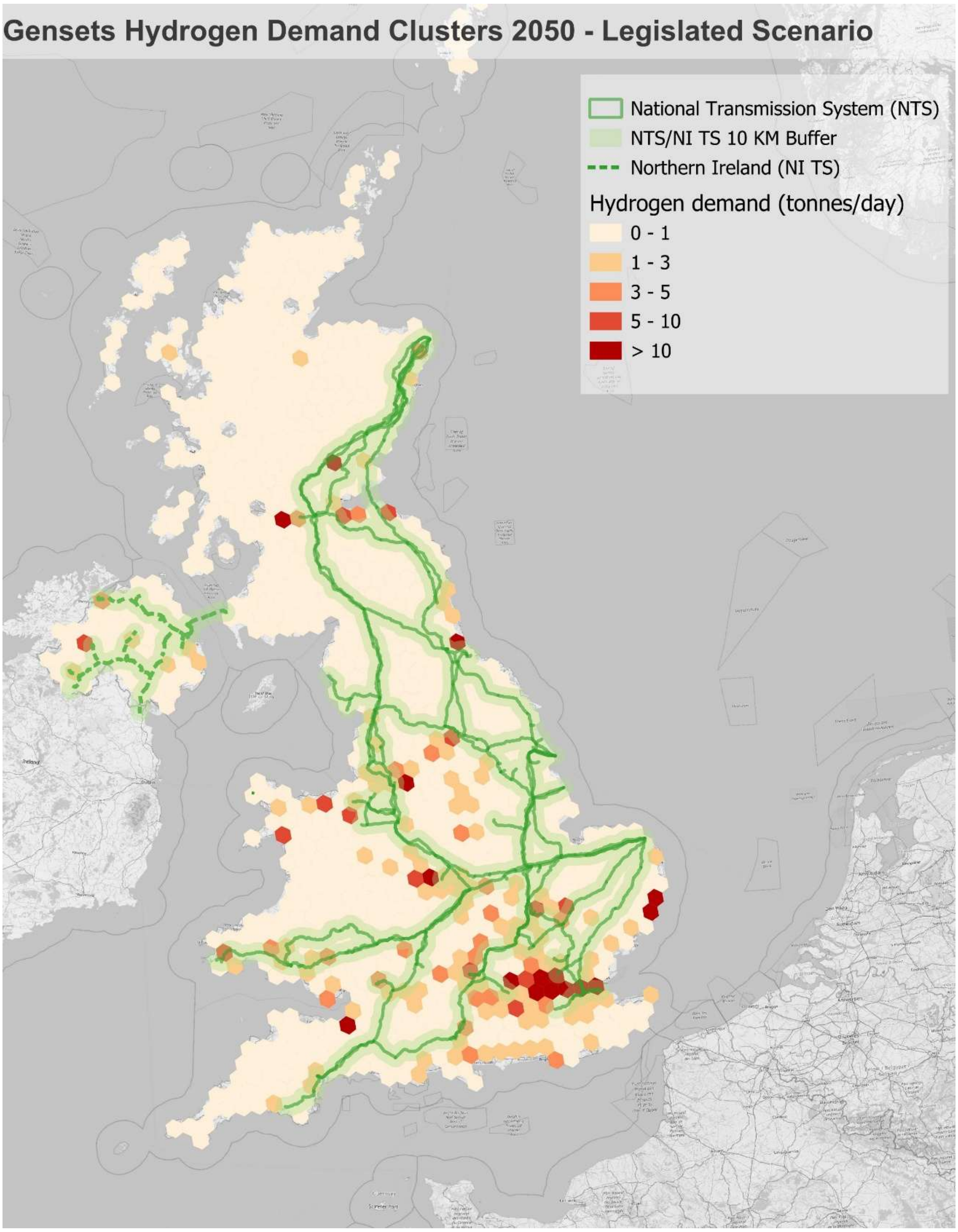


*Figure 38: Gensets hydrogen demand clusters in 2050 under the legislated scenario*

### 7.6.2 Accelerated Scenario

Under the accelerated scenario, the 2040 hydrogen demand from gensets is already substantial and geographically widespread. Major demand clusters requiring more than 10 tonnes of hydrogen per day are established in the Greater London area, East Suffolk, the West Midlands, the South West near Bristol, and the Northeast near Newcastle. In addition to these high-demand zones, significant clusters of 5 to 10 tonnes per day are present in Glasgow and the Northwest near Manchester. Smaller clusters, with demand between 1 and 5 tonnes per day, are scattered across other regions, notably in Surrey and Yorkshire (Figure 39).

By 2050, the demand for hydrogen from gensets is projected to intensify and become more distributed across the country. In London, demand clusters generally exceed 10 tonnes per day, while the existing hubs in East Suffolk and the West Midlands also expand. New major demand centres requiring over 10 tonnes per day emerge in North Wales in Gwynedd, Glasgow and Perth, and the Southwest near Bristol. The footprint of medium-sized clusters (5 to 10 tonnes per day) also broadens significantly, with notable expansion in Surrey, along the South Coast, in Yorkshire, and across the Northwest. Furthermore, demand in the central belt of Scotland between Glasgow and Edinburgh increases, with most clusters in this corridor exceeding 5 tonnes per day (Figure 40).

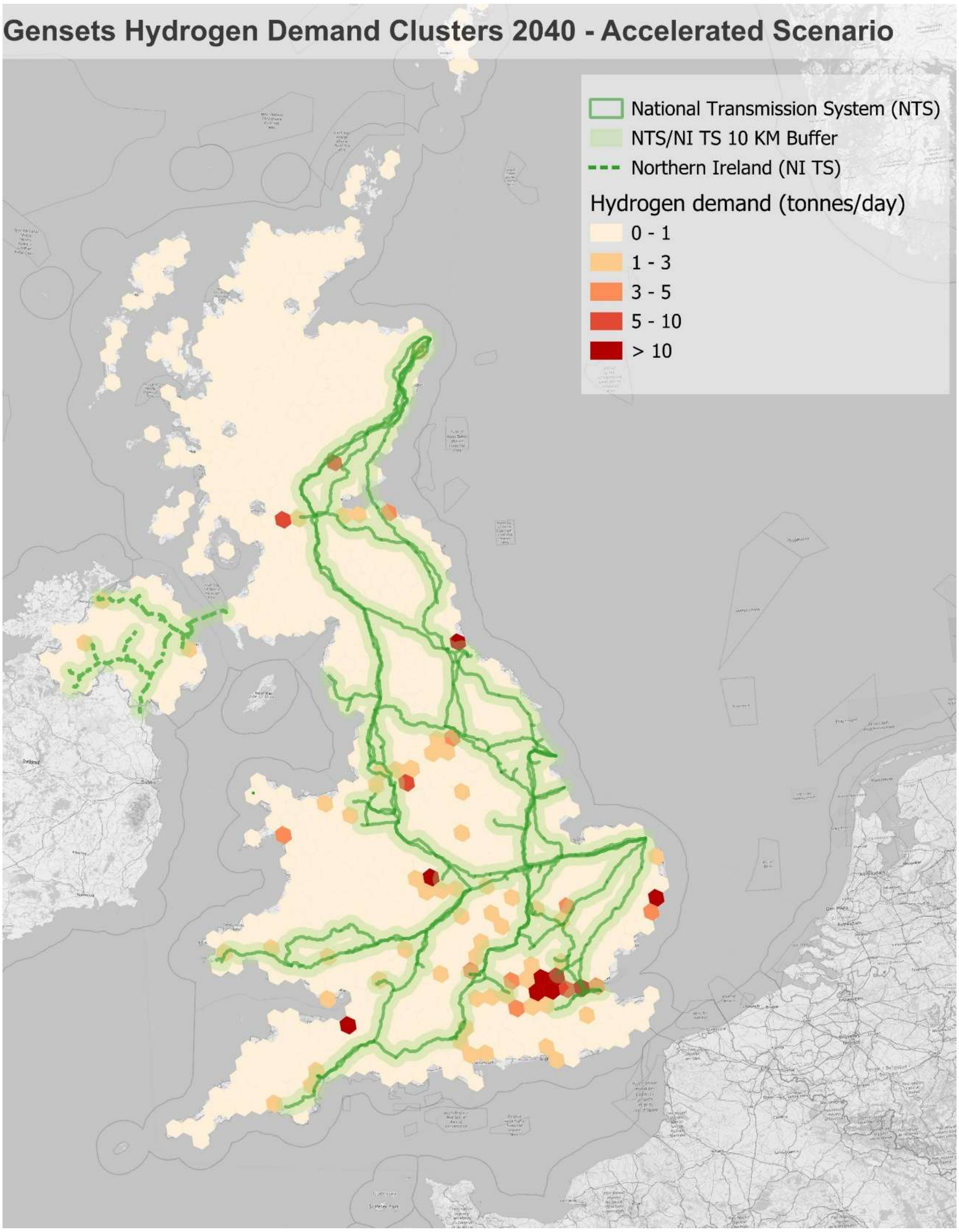


*Figure 39: Gensets hydrogen demand clusters in 2040 under the accelerated scenario*

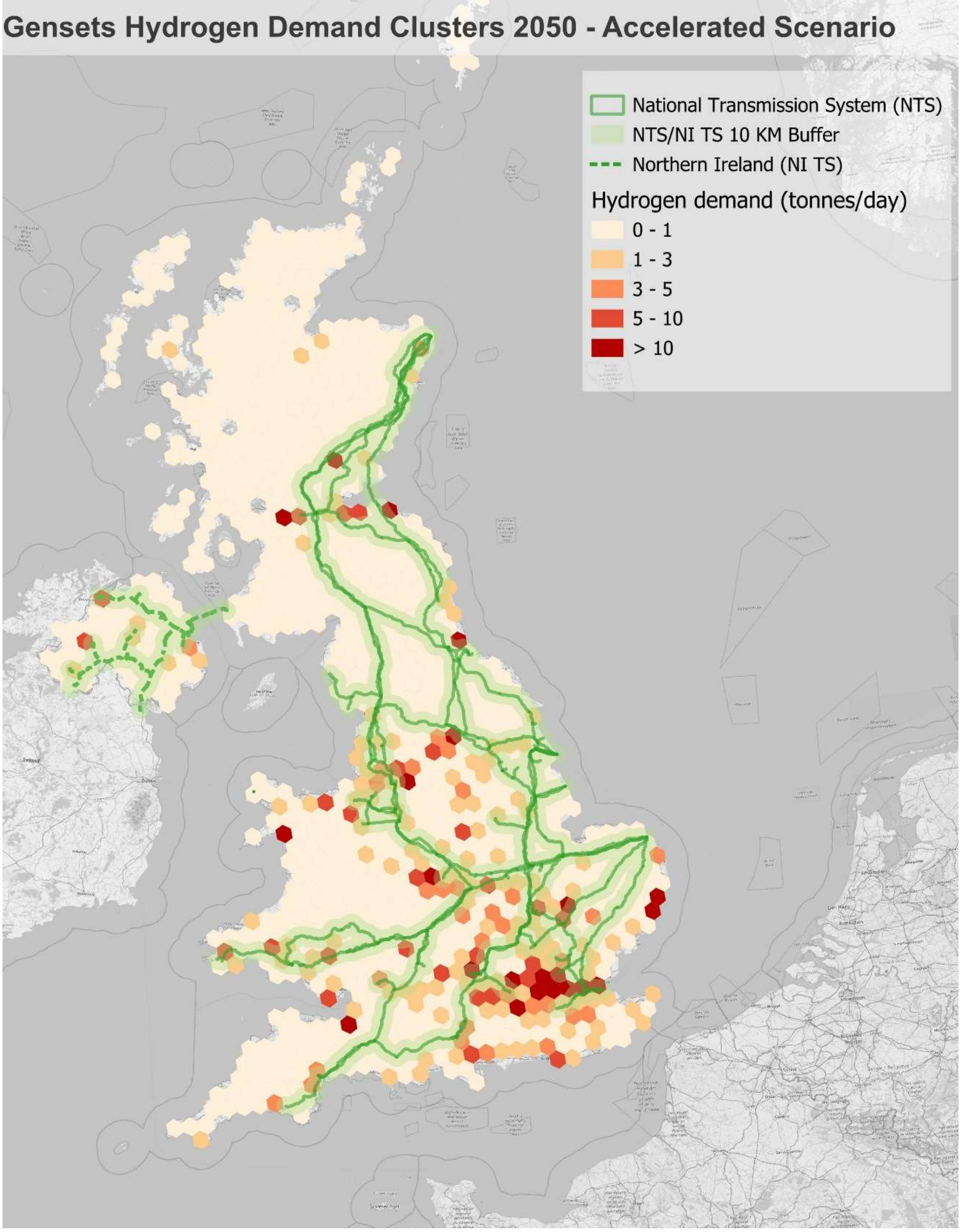


*Figure 40: Gensets hydrogen demand clusters in 2050 under the accelerated scenario*

# 8 Hydrogen demand potential: Maritime

The role of hydrogen in the maritime sector is a highly debated topic and there are high levels of uncertainty about technology pathways. As with the NRMM sector, 'maritime' is an all-encompassing term of significant legislative and regulatory importance, applying to a vast array of equipment, vessels, and operational patterns. It covers vessels ranging from small leisure vessels under 23 meters that never stray more than a few kilometres from shore, to 'mega ships' that transport raw materials and finished goods around the globe.

A wide range of factors will affect the energy demand profile of a particular vessel, or family of vessels. These factors include the vessel's size, the distance and speed of its travel, the weather and tide conditions it encounters, and its gross weight. For the larger, longer-distance vessels carrying heavy loads, several novel power trains are competing in the market, including methanol and ammonia. Additionally, the market share of Liquid Natural Gas (LNG) is increasing, with bioLNG (liquid biomethane) becoming a more significant option, and an identified pathway for LNG ships to reduce their GHG emissions.

For the smallest vessels, particularly many small leisure craft, battery electrification can likely provide much, if not all, of their power demands. Large ships such as ferries with well-defined, repetitive routes can also be well-suited for battery electric.

Maritime demand for energy is further complicated by port-side equipment. Exact estimates of energy use in these environments can get extremely complicated, as the links between maritime, warehousing, industrial NRMM, portside construction NRMM, logistics, road transport, and even mining (some ports and vessels are dedicated to mining and dredging activities exclusively) become complex.

If there is maritime demand for hydrogen in the future, maritime powertrains (both at sea and for port side activities), it's likely to occupy a very specific 'niche'. 'Short sea' shipping is the transport of goods and passengers over relatively short distances, typically coastal routes, or across smaller seas (such as the North Sea in a UK context). The UK short sea sector is a large niche, with 68% of all UK tonnage being defined as short sea operations[97]. Based on 2021 estimate of UK maritime shipping demand[98], that equates to approximately 4.7 million tonnes of fuel for short sea shipping (roughly 55 MWh of fuel consumed).

However, the future total energy demand for UK shipping is anticipated to reduce rapidly, through improved efficiency practices.

**CCC assumptions in efficiency measures:**

The CCC 7th budget[99] states that for all maritime craft (not just the short sea sector) "*the shipping sector can almost completely decarbonise through improved ship efficiencies and a switch to low-carbon fuels and electricity*". This may be somewhat optimistic, but it does suggest that a range of measures, including enhanced propeller design, slower steaming speeds, and other enhancements, can collectively make a substantial contribution to reducing energy consumption in shipping.

Efficiency improvements for maritime shipping are predicted to provide a 48% reduction in emissions and therefore fuel use by 2040[100]. If even a portion of the anticipated efficiency measures are realised, this will significantly reduce the total fuel requirements for the global maritime sector.

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97 https://www.gov.uk/government/statistics/port-freight-annual-statistics-2024/port-freight-annual-statistics-2024-route-information

98 https://www.gov.uk/government/statistics/transport-and-environment-statistics-2023/transport-and-environment-statistics-2023

99 Climate Change Committee (2025) The Seventh Carbon Budget: achieving a UK net zero emissions target. [Online] (Online). https://www.theccc.org.uk/publication/the-seventh-carbon-budget/ [Accessed 14 August 2025].

100 Laffineur, L et al (2023). The implications of the IMO Revised GHG Strategy for shipping. Global Maritime Forum. (online) https://globalmaritimeforum.org/insight/the-implications-of-the-imo-revised-ghg-strategy-for-shipping/

There is a risk that the maritime energy estimates used in this report are overestimating energy demand across all sectors. This knock-on effect of shipping efficiency improvements on the hydrogen market segment is difficult to predict. Hypothetically, certain sectors of shipping would be removed from the market's potential for hydrogen fuel, making battery electrification more suitable for those vessels. Equally, there will be some shipping which, with the predicted efficiency improvements, may reduce their total energy requirements sufficiently to make hydrogen fuel viable. This model assumes the net impact on the number of vessels adopting hydrogen as a fuel will be zero.

The proposed efficiency measures comprise a range of technological and operational enhancements that improve a ship's energy efficiency, including wind assistance, propeller ducts, rudder bulbs, and speed optimisation. While some efficiency measures are cost-effective and being adopted globally today, no efficiency measures are assumed to have been adopted by 2024 in the CCCs “Balanced Pathway” scenario.

The CCC model is the backbone of our estimates of energy demands for shipping, and assumes uptake of new efficiency measures scales up quickly from 2025 onwards, with 99% of ships (by gross tonnage but excluding naval and inland waterways and leisure shipping) having adopted at least one efficiency measure by 2030. Naval shipping is assumed not to take up any efficiency measures in the pathway, due to restricted information about the naval fleet and its operational patterns. Inland waterways and leisure shipping are assumed not to take up any efficiency measures, due to limited evidence about the existing fleet.

The CCC report also allows the distribution of net demand to be assessed through its analysis of emissions for various other sectors in the UK. Approximately 21% of the UK's shipping emissions originate from domestic vessels, and 7% arise from the use of inland waterways. Around 50% of domestic shipping emissions and 92% of international shipping emissions in 2022 came from vessels over 5,000 gross tonnes. Around 35% of domestic shipping emissions and 77% of international shipping emissions in 2022 came from cargo ships. Around 22% of domestic shipping emissions and 19% of international shipping emissions in 2022 came from cruises and ferries.

Lastly, previous work by Cenex has indicated that vessels over 10,000 tonnes, or that travel more than 135 nautical miles between refuelling events, are unlikely to use gaseous hydrogen as a fuel.

Taken together, these sources allow an overall estimate of what proportion of the UK maritime sector, and inland waterway vessels, may or may not switch to hydrogen in the future.

## 8.1 Market segmentation

Segmentation of maritime energy demand by vessel type is extremely challenging. Very high-level assumptions can be made, but the ability to triangulate or validate these assumptions is extremely limited without access to pay-wall-protected databases of shipping details and movements between ports.

To overcome this, fuel-based market segmentation has been adopted. With the various types and grades of Marine Fuel Oil (MFO) aggregated under one heading, and other more niche fuels (such as Liquid Propane gas (LPG), or LNG being listed separately (see section 8.5 for examples.)

## 8.2 Sector-specific technology status and trends

MFO is the dominant energy carrier in the maritime sector. There has been significant growth in LNG and LPG shipping, and there is increasing interest in both ammonia and methanol as potential shipping fuels. Battery electrification of the smallest coastal and inland waterway vessels is likely. However, there may be a role for hydrogen power in near-shore activities for larger vessels, especially where OSP is not available, to provide a zero-emission power supply.

## 8.3 Sector-specific policy and regulatory context

By its very nature, shipping is an international activity, and subject to policy and regulation at a Global, Regional, and National scale. At the time of writing, the International Maritime Organisation (IMO) is committed to achieving its Strategy on Reduction of GHG Emissions from Ships, which sets a "*common ambition to reach net-zero GHG emissions from international shipping by or around (i.e., close to) 2050*". This plan includes emissions reduction checkpoints of at least −20% (striving −30%) by 2030 and at least −70% (striving −80%) by 2040 versus 2008 total annual emissions. The Strategy also targets the uptake of zero/near-zero-GHG energy to be at least 5% (striving 10%) of shipping energy use by 2030. These are sector-wide goals for international shipping under IMO; domestic voyages may be further regulated by national and regional legislation (above and beyond the IMO targets).

**Global policy (IMO EEXI/CII, SEEMP III):** There are legally binding commitments which impact ship power considerations today. Since 1 Jan 2023, ships under 400 Gross Tonnes (GT) must meet Energy Efficiency Existing Ship Index (EEXI) requirements. These EEXI limits legislate technical efficiency limits. must be surveyed and a certificate granted for the ship to be permitted to conduct business. Ships greater than 5,000 GT are now rated annually on CII (operational carbon-intensity) with corrective action plans in Part III of the Ship Energy Efficiency Management Plan (SEEMP Part III) for those vessels that failed emission certification, but have a plan to correct the filing. These rules are changing energy use in port-side operations today. Tighter Carbon Intensity Indicator (CII) reduction factors are pushing owners toward speed optimisation, hull/propeller upgrades, weather routing, and—where viable—wind-assist.

For ports and this modelling work, the impact is twofold:

(i) more ships arrive with energy-saving technology, and

(ii) operators look to cut at-berth fuel burn that worsens CII, increasing interest in On-shore Power Supplies (OPS) such as electrical grid connections to run essential 'hotel loads' while dockside. OPS is only the preferred option when the grid mix and tariffs are more cost-effective than burning Marine Fuel Oil (MFO)[101]

**EU Policy (ETS, FuelEU, AFIR):** From 2024, the European Union Emissions Trading System (EU-ETS) puts a price on ship $CO_2$ emissions, including at-berth. It introduces what are termed "surrender ramping" rates of increase in taxation on carbon dioxide emissions while berthed. After an agreed initial period, the vessel owners/operators will be required to pay additional environmental protection fees, which ramp up over time. This means that ships are incentivised to either leave port quickly or utilise zero-emission power for hotel loads while docked. Failure to do so leads to ever-increasing carbon costs.

The EU Maritime regulations add a GHG-intensity trajectory from 2025 and, crucially for ports, a zero-emissions-at-berth requirement from 2030. This applies to both container and passenger ships. In parallel, the Alternative Fuels Infrastructure Regulation (Regulation (EU) 2023/1804) (AFIR (EU 2023/1804)) obliges TEN-T ports to deploy shore-side electricity for these ship types by 2030.

The combined effect of these EU policies will be an increase in demand for multi-megawatt charging facilities for ships, and (likely) increased demand for hydrogen or hydrogen-based fuels portside for auxiliary engines, portside generators, and ship main propulsion.

There are tens to hundreds of MegaWatt-hours of energy demand per vessel for busy EU passenger/container hubs. Any third-country port (such as those in the UK) competing for those vessel calls will feel pressure to offer compatible OPS.

**UK Policy** (policy direction, UK-ETS, shore power). The UK is not bound by EU law post-Brexit, but EU-trading ships will carry OPS capability and expect grid hookups that do comply with EU

[101] UK flag guidance mirrors this and explicitly requires SEEMP III updates.

regulations and standards. Domestically, the UK has confirmed it will bring maritime into the UK-ETS from 2026 (domestic voyages and in-port emissions), adding a home-market carbon price that makes plugging in more attractive where the grid $CO_2$-intensity and tariff undercut auxiliary engines.

The UK government has run a shore-power call for evidence and opened a Net Zero Ports call (2025) on enabling infrastructure. Both measures signal policy movement, even as formal UK-wide OPS mandates are still under consideration. There will almost certainly be a rising electrical demand at berth, larger peak capacities (often 5–10 MW per connection for ferries/cruise/container), and a growing need for grid reinforcement, smart scheduling, and behind-the-meter flexibility (onsite storage/solar, demand management) to handle clustered calls.

Grid bolstering with hydrogen power generation may well be one solution to assist grid-constrained ports in achieving these additional power demands. The increasing use of hydrogen (or hydrogen-derived fuels) powered auxiliary systems for use whilst in the UK's air quality emission-controlled waters may also increase. The market penetration of these technologies will be highly dependent on the price point set by EU and UK regulators for CO2e emission whilst berthed, or awaiting a berth.

The requirements for reduced emissions while underway may also drive an in increase in hydrogen fuel for shipping, even if only for nearshore steaming, before entering international waters.

## 8.4 Evidence base and data gaps

Using the official DfT PORT0301/PORT0499 datasets, it is possible to map out the top 50 UK ports by tonnage (Figure 41).

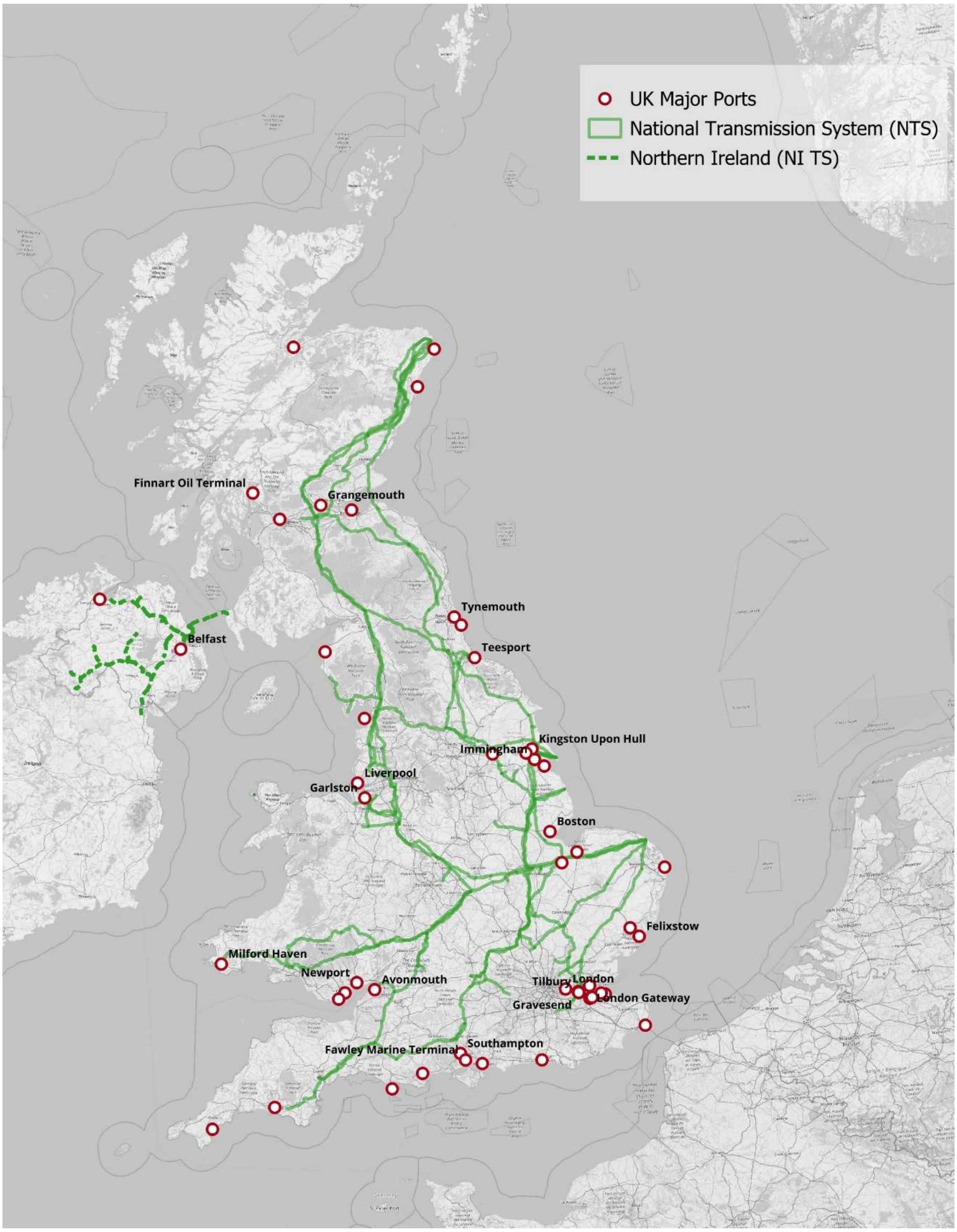



*Figure 41: UK major ports by tonnage (some labels are redacted for visual clarity)*

Bunkering (the refuelling of vessels both while docked and at sea) allocations were derived by apportioning the national bunkers total (~22.5 TWh/yr in 2024, from 1.9 Mt marine fuels in DUKES) according to port tonnage share. Onshore Power Supply (OPS) (also known as 'cold-ironing' and 'shore power'), electricity was identified only for Southampton (~6.3 GWh in 2022), based on $CO_2$ savings data from ABP/Safety4Sea.

To estimate shore-side energy demand, the DESNZ Subnational Electricity and Gas Consumption Statistics (2005–2023) were used. These datasets provide non-domestic electricity and gas GWh values per Local Authority. Each port was mapped to one or more LAs, and their 2023 totals aggregated. This yielded official commercial energy demand values for all ports in England, Wales, and Scotland. Belfast was marked as pending (separate NI dataset yet to be found). Some ports (Milford Haven, Holyhead, Cardiff) showed "0" electricity values due to DESNZ suppression for confidentiality reasons; these are not true zeros.

There is no directly available data on port-side fuel and energy use in the public domain. All values in this report have been inferred from publicly available data on marine fuel oils (MFOs), commercial gas consumption, and commercial electricity consumption.

It is worth noting that while most of UK goods either directly or indirectly pass through a port at some point (as raw materials if not as finished components); most warehousing activity happens elsewhere. Typically, warehousing (and its associated NRMM use) is located closer to inland distribution hubs rather than directly within port precincts. There is a growing interest in port-adjacent or bonded warehousing, but most market coverage, development, and value remain outside port zones. From this we infer that the additional energy demands for warehousing in ports will not significantly increase our energy estimates.

For inland waterways, the most comprehensive study (DEFRA's 2011 study) gives the only open national baseline: ~51 kt gas oil/yr for inland craft (≈0.60 TWh/yr propulsion energy). This was apportioned across clusters: Canal River Trust (CRT) network (~32,600 boats) ~390–450 GWh; Broads Authority (~12,500 boats, many hire craft) ~100–150 GWh; EA navigations ~30–60 GWh; Scottish Canals ~30–60 GWh. Together, these align with the DEFRA baseline**. Inland propulsion and energy demand is two orders of magnitude smaller than seagoing bunkers**.

For inland waterways in particular, All-UK vessel stock across all navigation authorities is not published as a single dataset. The Association of Inland waterway Authorities (AINA) last comprehensive boat-number report is from 2008. None of the inland water authorities report energy use. Instead, it must be inferred based on vessel size and typical usage patterns as reported by individual authorities and associations.

## 8.5 Scenario modelling

### *Legislated uptake modelling*

This scenario models a conservative, compliance-driven energy transition. The pace is dictated by the gradual implementation and strengthening of existing international regulations, rather than a radical market or policy shift. It assumes a slower, more protracted phase-out of fossil fuels.

- *Regulatory Framework & Pace*
    - Primary Driver: Compliance with the International Maritime Organization's (IMO) initial GHG Strategy ambitions, including adherence to the Energy Efficiency Existing Ship Index (EEXI) and the Carbon Intensity Indicator (CII)[102].
    - Regulatory Pace: Assumes a gradual, linear tightening of regulations post-2030. The framework encourages incremental efficiency gains and fuel blending rather than forcing wholesale fleet replacement.
    - Carbon Pricing: A global carbon price is assumed to be implemented, but at a level that is significant yet not prohibitive, making continued (though declining) use of fossil fuels economically viable through the 2030s and into the 2040s.
- *Technology & Fuel Uptake*

[102] International Maritime Organization. (n.d.). EEXI and CII - ship carbon intensity and rating system. Retrieved September 19, 2025, from https://www.imo.org/en/MediaCentre/HotTopics/Pages/EEXI-CII-FAQ.aspx

- Dominant Strategy: The primary compliance mechanism for the existing fleet is the use of low-GHG "drop-in" biofuels blended with conventional fuel oils.
- Fossil LNG: Fossil LNG continues to be a significant transition fuel, valued for its immediate reduction in criteria pollutants and lower carbon emissions compared to fuel oil. Its phase-out is protracted, extending beyond 2045.
- New Fuel Adoption: The uptake of vessels capable of running on methanol and ammonia is demand-responsive and gradual, limited by higher capital expenditure (CAPEX) and the slower development of supply infrastructure. These fuels do not achieve significant market share until the late 2030s.
- Hydrogen: The direct use of hydrogen as a fuel is confined to niche applications and pilot projects such as short-sea, ferries that are not suited to battery electrification. This does not represent a significant portion of the fuel mix within the forecast period.

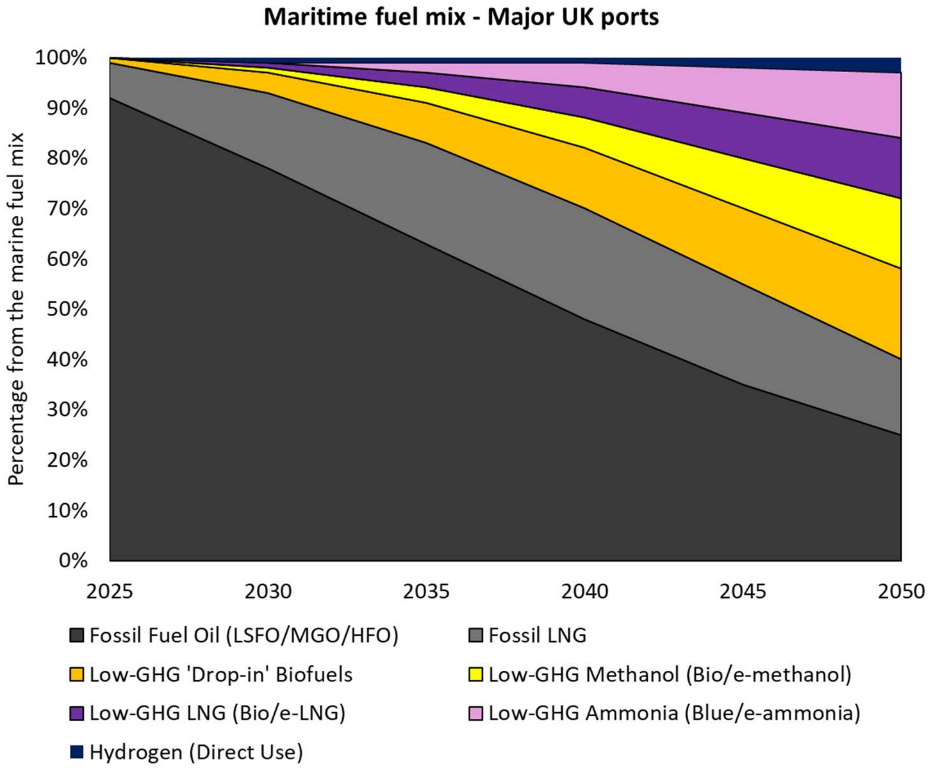



*Figure 42: Maritime fuel mix at UK major ports 2025-2050 - Legislated Scenario*

### *Legislated uptake modelling*

This scenario models a rapid, economically driven transition spurred by the impending implementation of the IMO's Net-Zero Framework (NZF). It presupposes a faster technological shift and a near-complete phase-out of fossil fuels by 2050.

- Regulatory Framework & Pace
  - Primary Driver: The enforcement of the IMO's NZF, projected to commence in 2028. The core mechanisms are stringent with well-to-wake GHG Fuel Intensity (GFI) reduction targets set at least 20% in 2030 and 70% in 2040 (compared to 2008 levels)[103]
  - Economic Imperative: The high cost of non-compliance under the NZF (e.g., Tier 2 Remedial Units at an initial price of 380 USD/t$CO_2$eq) creates an economic imperative

[103] International Maritime Organization, "2023 IMO Strategy on Reduction of GHG Emissions from Ships," Resolution MEPC.377(80), adopted July 7, 2023.

to shift to low- and zero-GHG fuels, making the higher CAPEX for new technologies economically rational.

- Decarbonisation Goal: The overarching goal driving investment and operational decisions is the achievement of net-zero emissions by or around 2050, necessitating an aggressive phase-out of all fossil fuels.

- Technology & Fuel Uptake
  - Dominant Strategy: A rapid increase in the order and delivery of dual-fuel vessels, particularly for LNG and methanol in the near-to-medium term, as observed in the 2025 vessel order book.
  - LNG Pathway: LNG-capable vessels are built with the strategy of using fossil LNG initially and then transitioning to low-GHG bio-LNG and e-LNG to meet tightening GFI targets.
  - New Fuel Adoption: The strong business case for avoiding NZF penalties accelerates investment in methanol and subsequently ammonia-capable vessels. These fuels achieve significant market penetration more than a decade earlier than in the Legislative Scenario.
  - Hydrogen: While still a minor fuel in the overall mix, the urgent need for all available zero-emission solutions leads to a slightly larger and earlier adoption of direct hydrogen in specific, suitable vessel segments. This will likely be contracted in near-shore movements, and Short Sea cargo trips for vessels under 10,000 gross tonnes (with vessels in the order of 5,000 gross tonne the most likely adopter of hydrogen technology.)

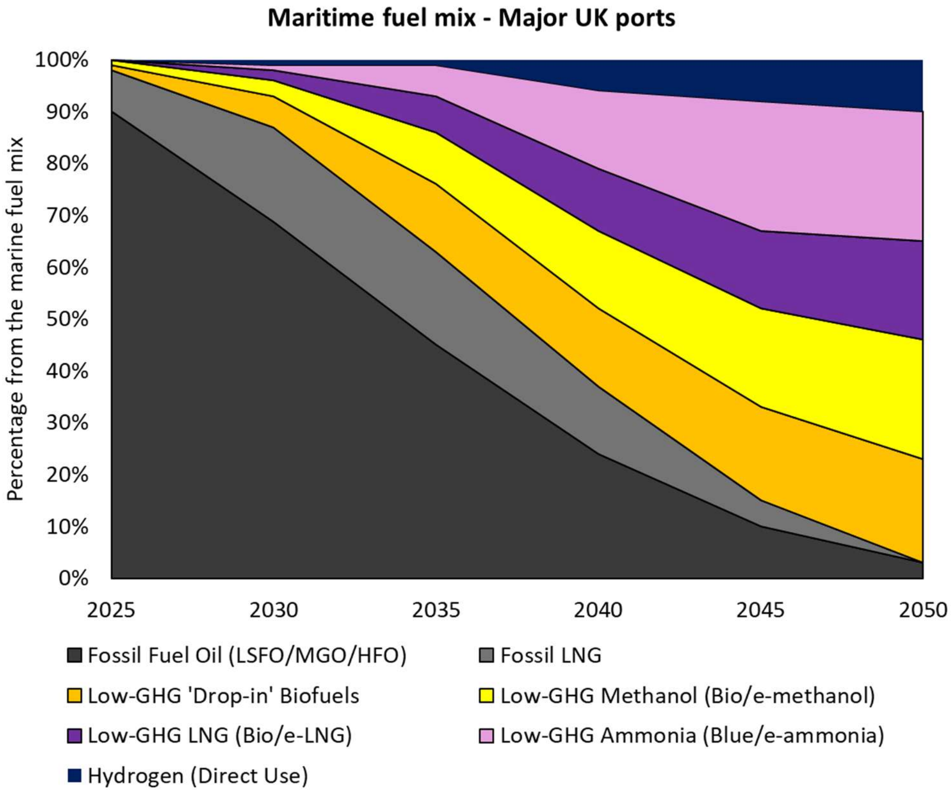



*Figure 43: Maritime fuel mix at UK major ports 2025-2050 - Accelerated Scenario*

- Modelling maritime energy demand relied on a top-down approach on port level. Therefore, total energy demand in GWh is the same in both scenarios which only differ in fuel mix.
- Table 20 shows total energy demand estimates by vessels in major UK ports from 2025 to 2050 (to three significant figures).

*Table 20: Total energy demand in GWh for the UK genset fleet under the legislated and accelerated scenarios*

| Year | Both scenarios (GWh) |
|---|---|
| 2025 | 37,100 |
| 2030 | 37,500 |
| 2035 | 38,500 |
| 2040 | 39,300 |
| 2045 | 40,000 |

## 8.6 Location-specific demand estimates

### *8.6.1 Legislated scenario*

Under the legislated scenario, the adoption of hydrogen in the maritime sector is projected to be gradual. The model estimates initial demand emerging between 2030 and 2040 to be low and highly localised around key ports. **The most significant demand cluster is at the Port of Southampton, requiring between 5 and 10 tonnes per day.** Other major ports show more moderate demand, with Liverpool, Felixstowe in the East of England, and Thamesport in the Southeast each projected to require between 3 and 5 tonnes per day. The Humberside ports and Milford Haven in Wales represent a third tier of early adoption, with demand in these locations estimated at 1 to 3 tonnes per day (Figure 44 and Figure 45).

By 2050, the legislated scenario forecasts a significant and more widespread increase in hydrogen demand across the UK's key ports. **The highest demand is concentrated at the ports of Southampton, Felixstowe, Liverpool, and Thamesport, with each projected to require more than 10 tonnes per day.** A secondary tier of significant demand, between 5 and 10 tonnes per day, is expected at the ports in Hull in Yorkshire and the Humber and Milford Haven in Wales. Demand at Avonmouth in the Southwest is projected to be in the 3 to 5 tonnes per day range. The geographic footprint of hydrogen adoption expands further with a number of ports showing demand of 1 to 3 tonnes per day, including the London and Tilbury Ports in the Greater London Area, Garston Port in the Northwest, the Tynemouth and Teesport ports in the Northeast, Belfast in Northern Ireland, and Grangemouth Port in Scotland (Figure 46).

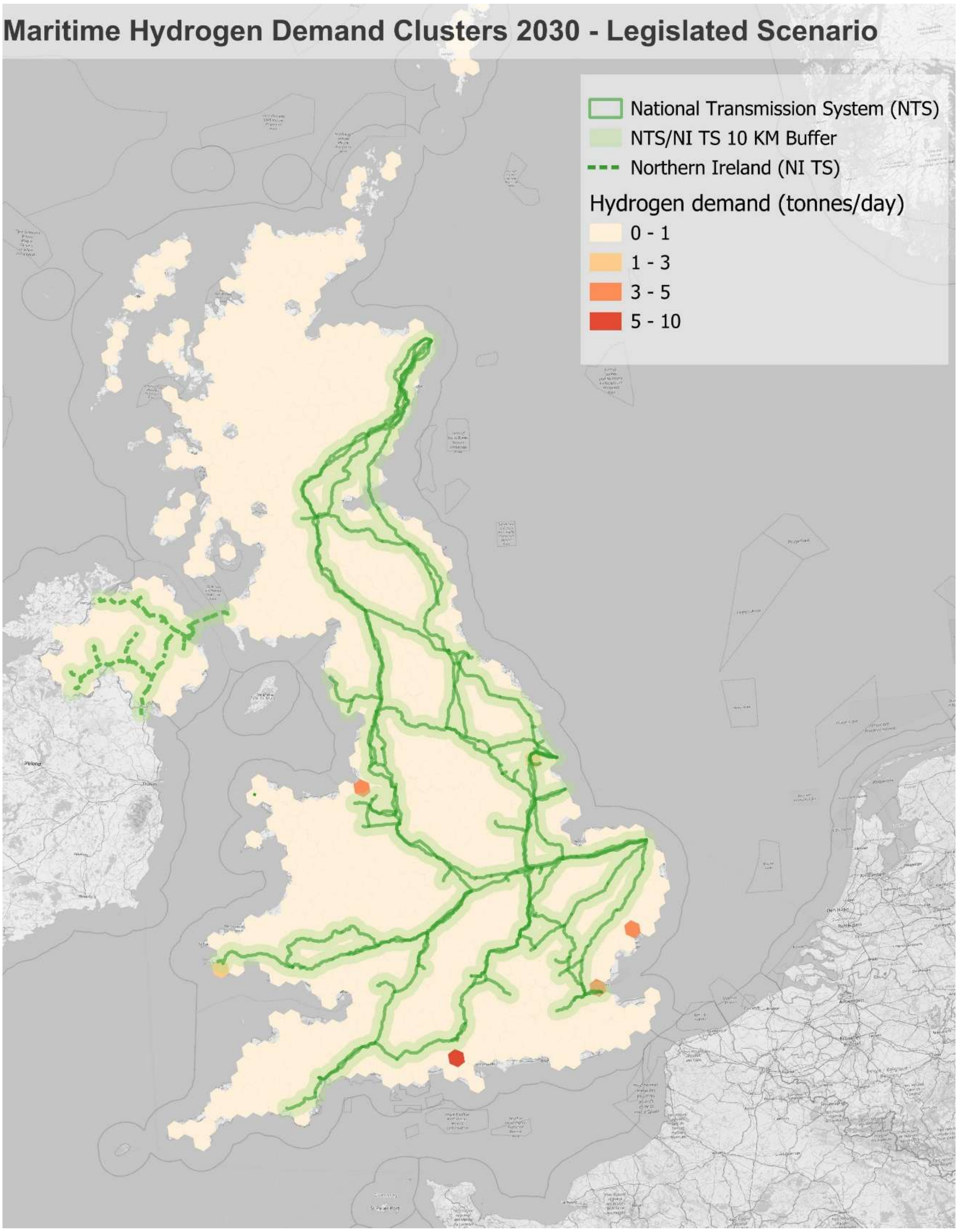



*Figure 44: Maritime hydrogen demand clusters in 2030 under the legislated scenario*

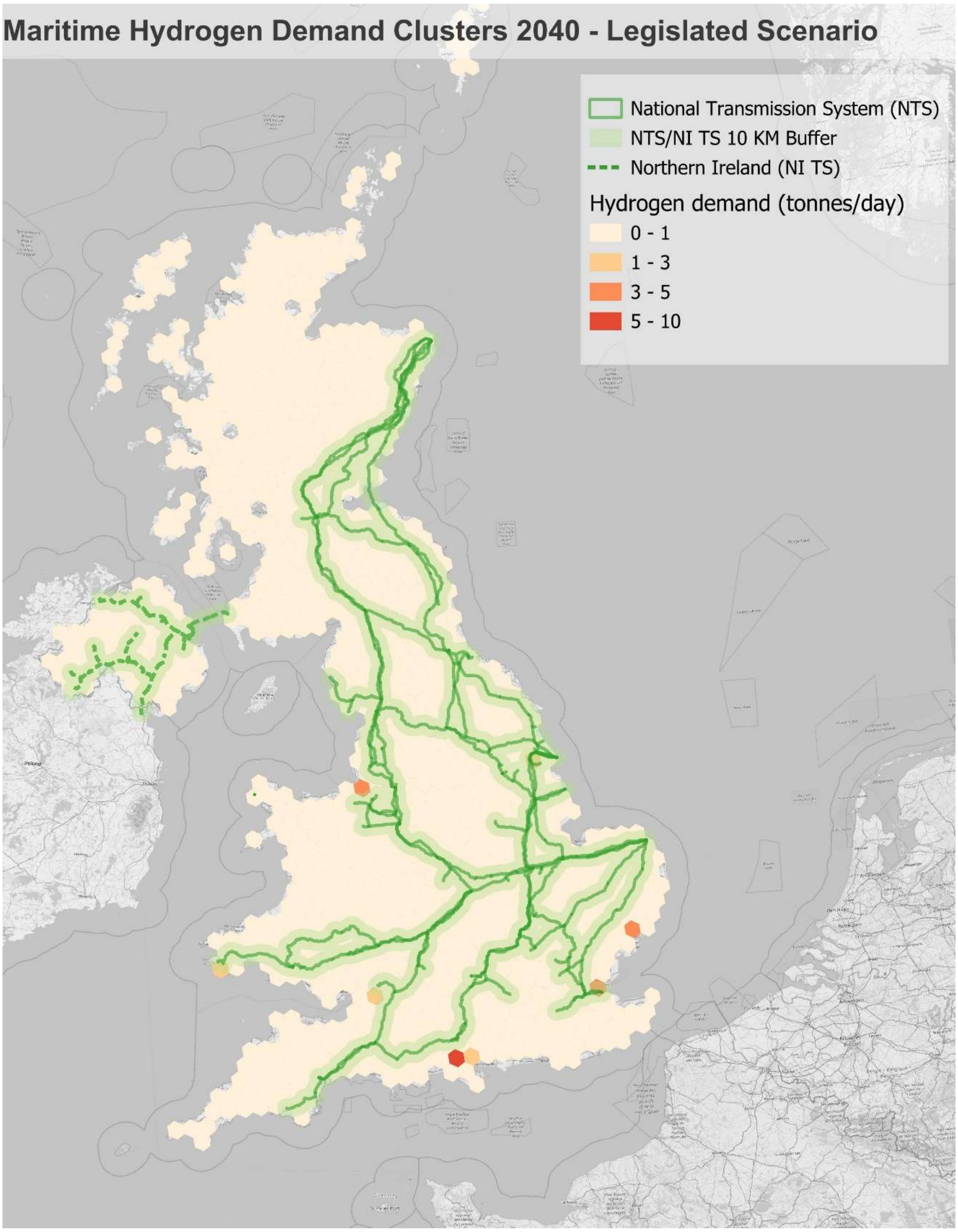



*Figure 45: Maritime hydrogen demand clusters in 2040 under the legislated scenario*

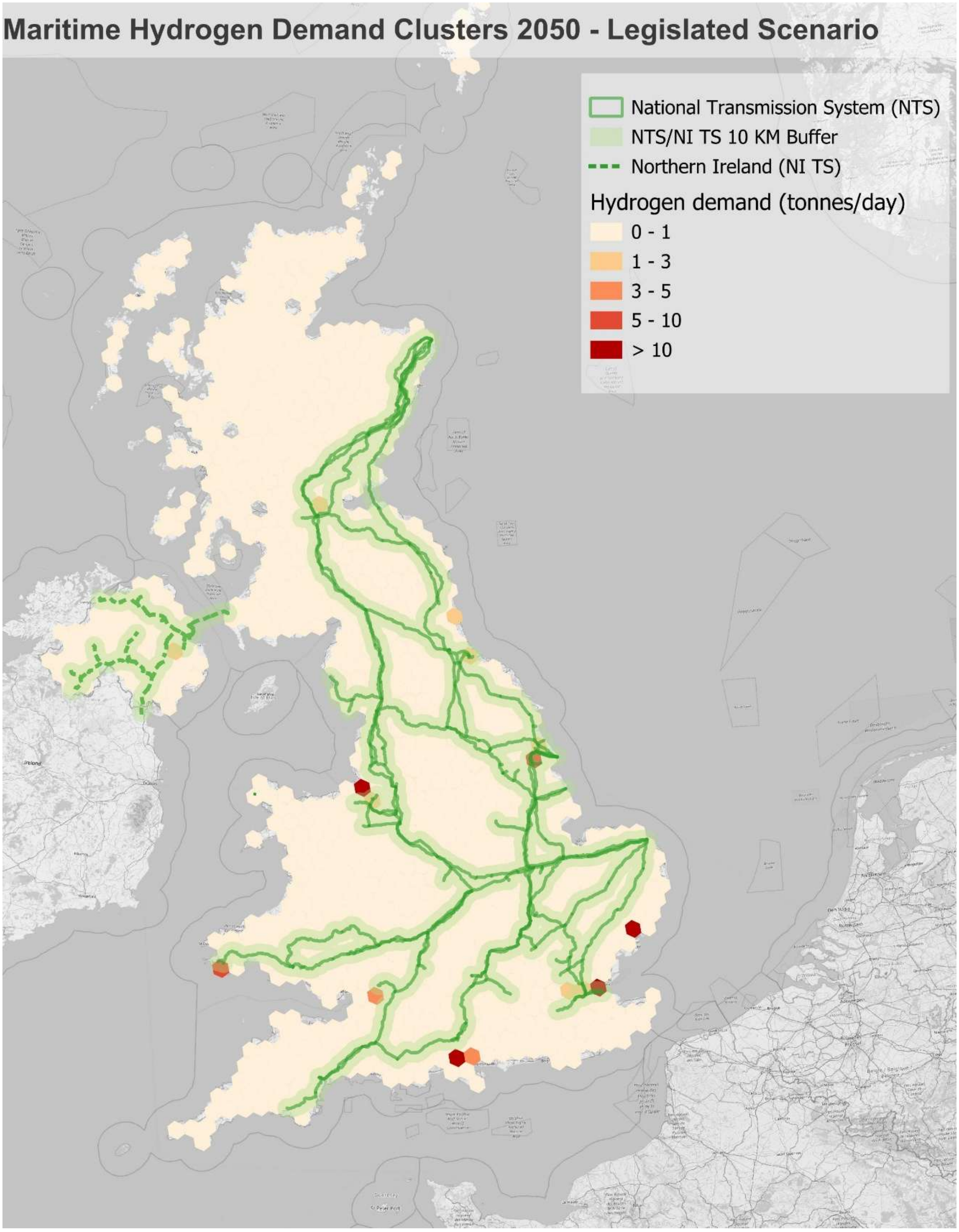



*Figure 46: Maritime hydrogen demand clusters in 2050 under the legislated scenario*

### *8.6.2 Accelerated scenario*

Under the legislated scenario, the adoption of hydrogen in the maritime sector is projected to follow the same gradual and nascent patterns of the legislated scenario in 2030. **Southampton Port remains the major demand hotspot with more than 10 tonnes per day.** Felixstowe Port, Thamesport, and Liverpool Port play a secondary role with demand levels of above 5 tonnes per day (Figure 47).

In 2040, however, the demand grows significantly both in magnitude and distribution when compared to the legislative scenario. **Thamesport, Milford Haven, Liverpool and Felixstowe join Southampton Port in the list of ports requiring more than 10 tonnes per day.** Secondary demand clusters appear in the Humberside ports and Avonmouth Port, requiring between 5 and 10 tonnes per day. Belfast Port shows a moderate demand between 3 and 5 tonnes per day. Other ports across the UK show lower levels of demand (1 to 3 tonnes per day) including Tynemouth and Teesport in the Northeast, Dover and Medway in the Southeast, and Grangemouth Port in Scotland (Figure 48).

By 2050, the accelerated scenario forecasts significant intensification of demand across the 2040 major hotspots, especially in the **Humberside ports cluster and Avonmouth Port which exceed 10 tonnes per day.** Demand also increases significantly in Grangemouth, Tynemouth, Teesport and Belfast with each exceeding 5 tonnes per day. Furthermore, new emerging demand clusters appear in Aberdeen in Scotland and Londonderry in Northern Ireland (Figure 49).

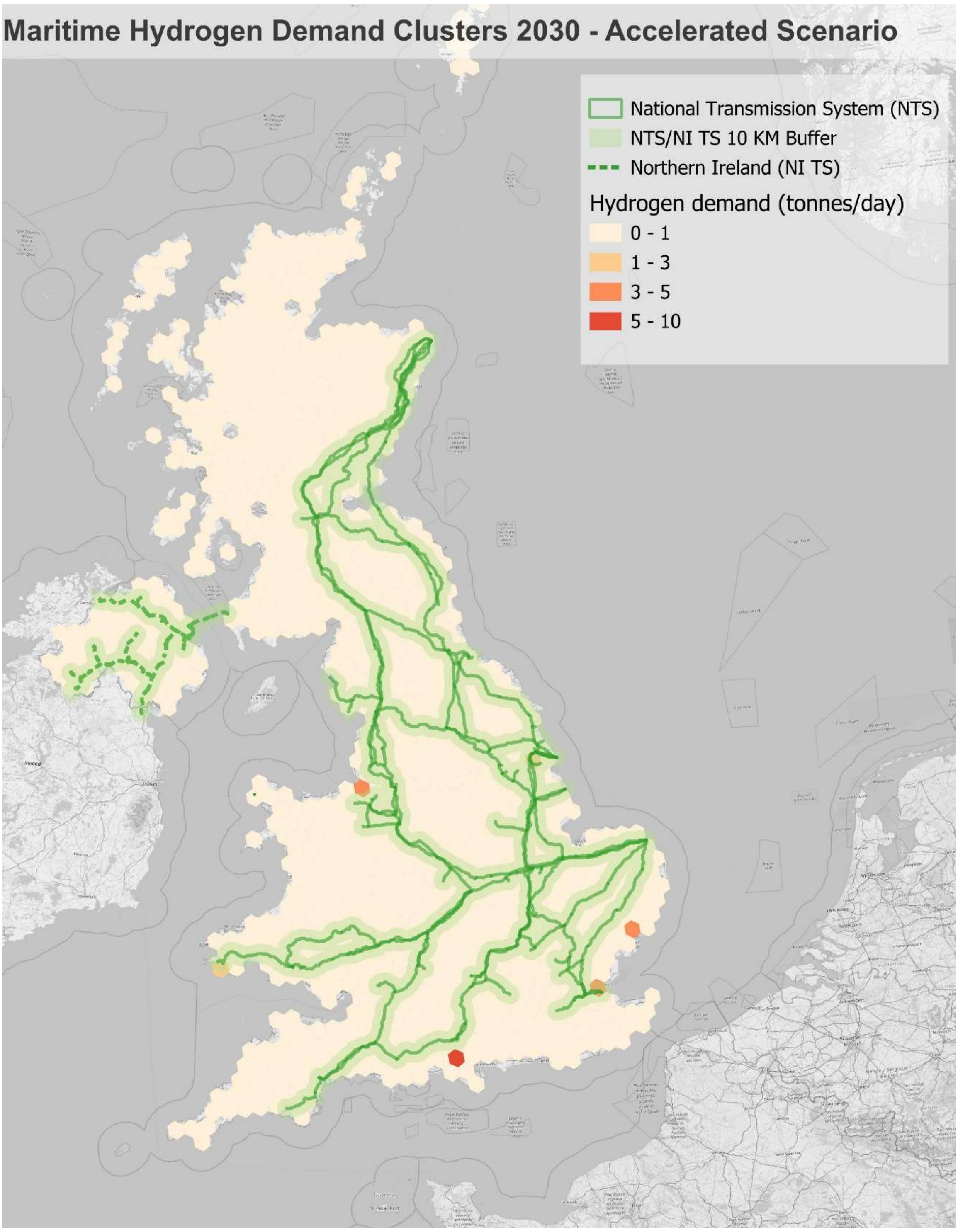



*Figure 47: Maritime hydrogen demand clusters in 2030 under the accelerated scenario*

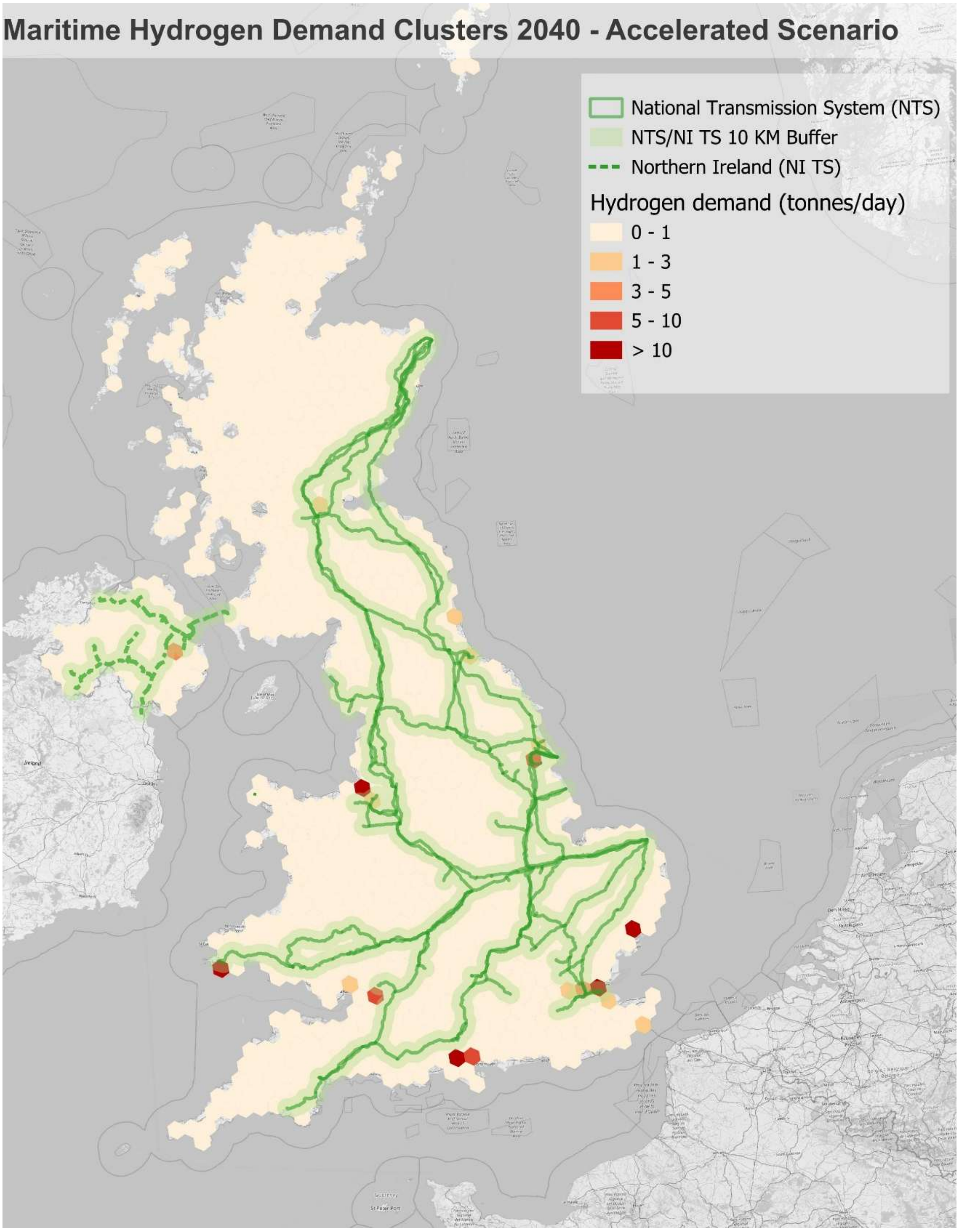



*Figure 48: Maritime hydrogen demand clusters in 2040 under the accelerated scenario*

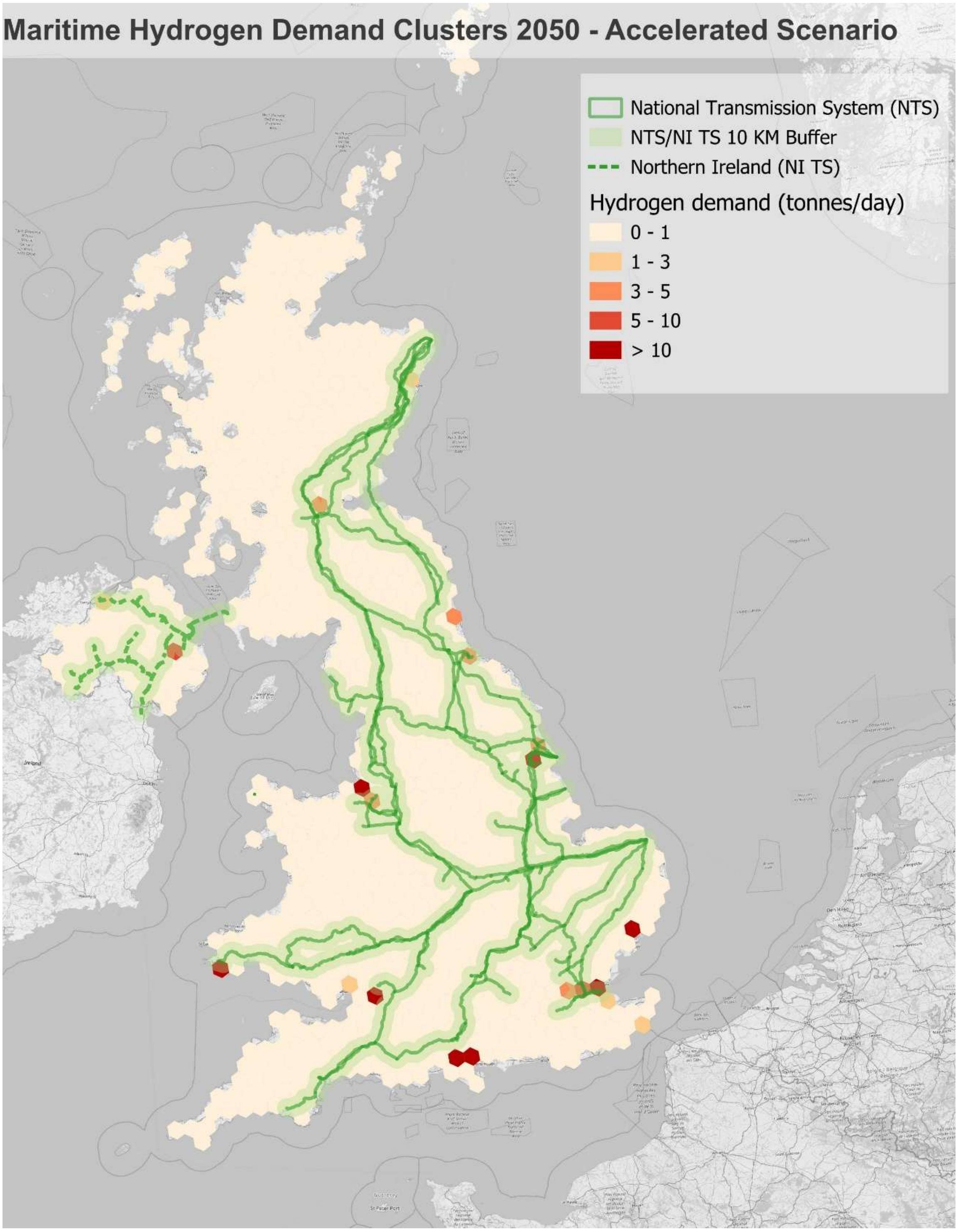



*Figure 49: Maritime hydrogen demand clusters in 2050 under the accelerated scenario*

# 9 Synthesis and aggregate UK hydrogen demand

This section of the report summarises all energy consumption across all sectors and presents the likely total hydrogen demand from the transport and NRMM sectors in scope.

## 9.1 Consolidated demand 2025-2050

Figure 50 through Figure 53 show the total estimated hydrogen demand over time within each of the market sectors in scope, for both the legislated and accelerated scenarios. Note that the maritime energy estimate data is excluded from Figure 52 and Figure 53 as the methodology for estimating maritime energy use is fundamentally different from the approach taken in other sectors. A table of hydrogen demand values is also given in tables 21 and 22.

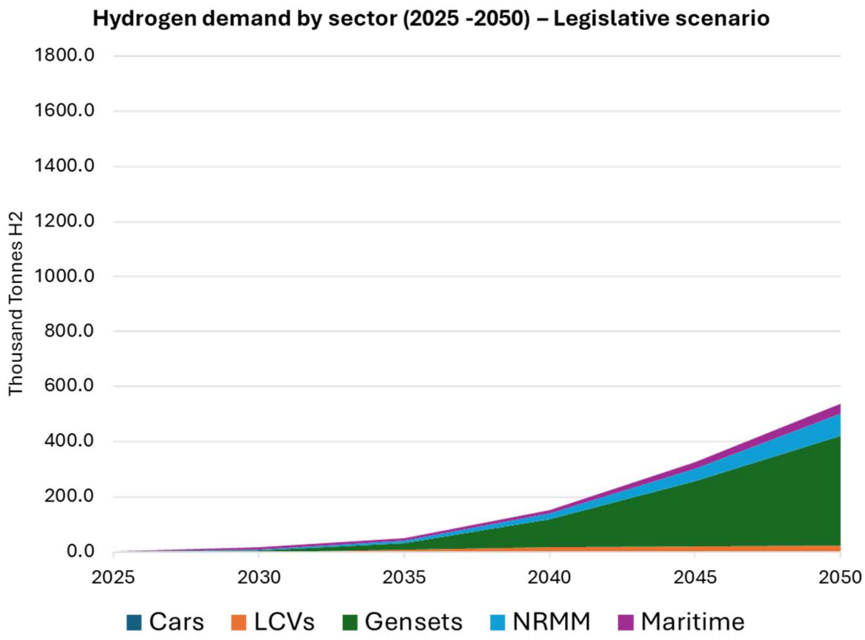



*Figure 50: Estimated size of hydrogen demand by sector – Legislated Scenario.*

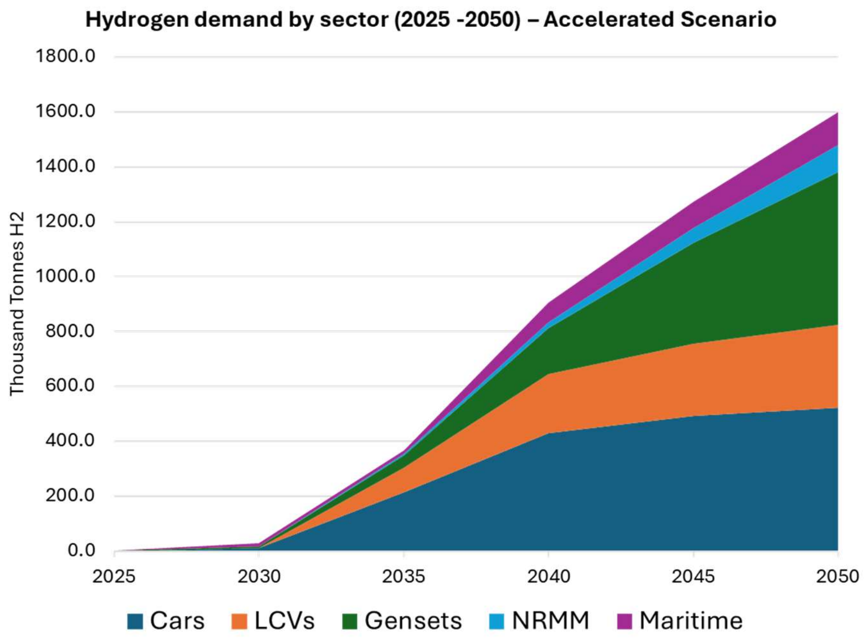



*Figure 51: Estimated size of hydrogen demand by sector – Accelerated Scenario*

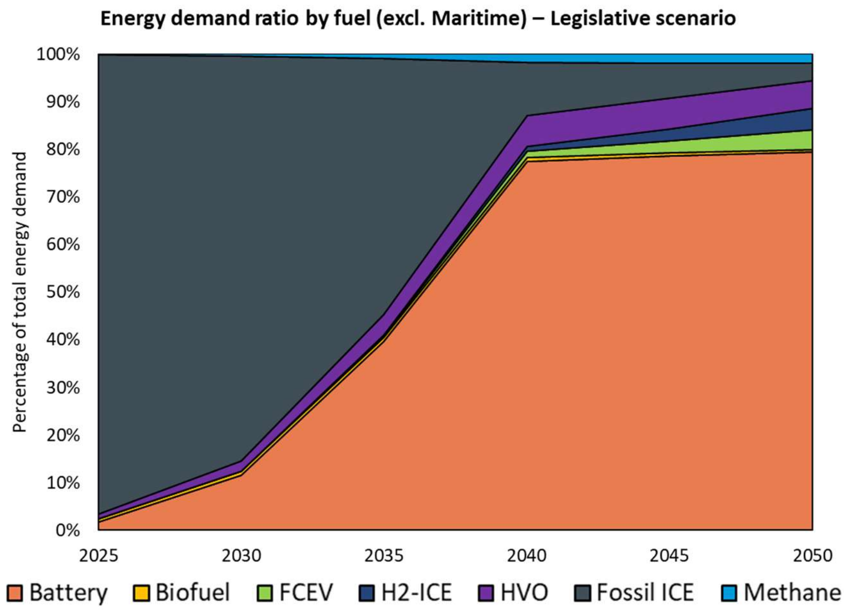



*Figure 52: Percentage of energy demand from different fuels per modes excluding maritime – Legislated Scenario*

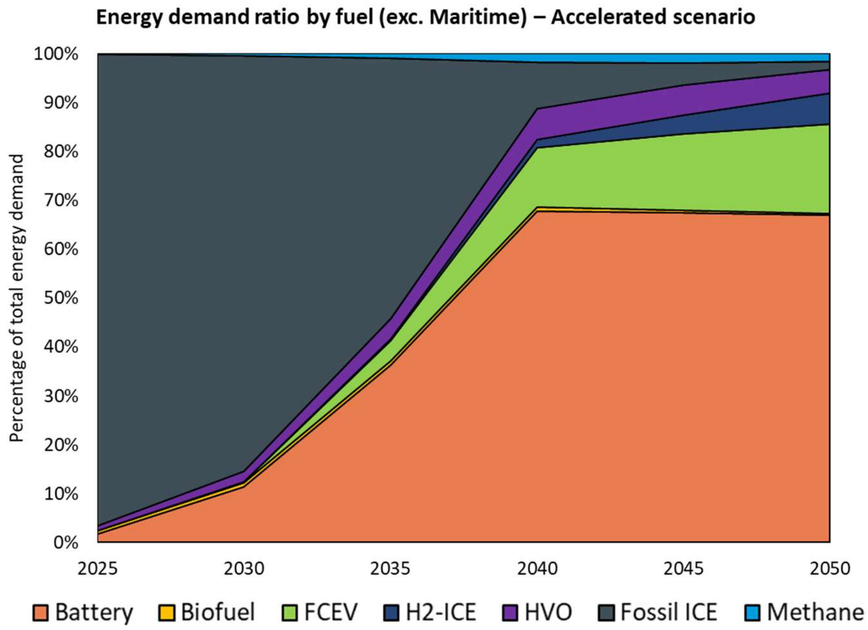



*Figure 53: Percentage of energy demand from different fuels per modes excluding maritime – Accelerated Scenario*

## 9.2 Sectoral comparison

This section provides a numeric reference of the results for future updates by National Gas, as technologies take market share over the coming decades.

*Table 21: Estimated demand of hydrogen by sector (thousand tonnes) – Legislated scenario*

| Sector | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
|---|---|---|---|---|---|---|
| Cars | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| LCVs | 0.0 | 0.0 | 7.9 | 18.7 | 23.3 | 26.6 |
| Gensets | 0.2 | 5.1 | 26.2 | 103.6 | 235.7 | 398.5 |
| NRMM | 0.0 | 1.1 | 6.4 | 19.9 | 44.9 | 79.7 |
| Maritime | 0.0 | 11.4 | 11.6 | 11.8 | 24.0 | 36.6 |
| **Total** | **0.2** | **17.5** | **52.1** | **154.0** | **327.8** | **541.3** |

*Table 22: Estimated demand of hydrogen by sector (thousand tonnes) – Accelerated scenario*

| Sector | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
|---|---|---|---|---|---|---|
| Cars | 0.0 | 10.2 | 189.1 | 381.9 | 435.6 | 464.1 |
| LCVs | 0.0 | 0.0 | 105.7 | 251.6 | 310.1 | 351.9 |
| Gensets | 0.2 | 5.1 | 45.7 | 167.6 | 369.5 | 558.9 |
| NRMM | 0.0 | 1.1 | 6.4 | 21.8 | 52.4 | 96.4 |
| Maritime | 0.0 | 11.4 | 11.6 | 70.7 | 95.9 | 122.0 |
| **Total** | **0.2** | **27.7** | **358.4** | **893.5** | **1263.5** | **1593.4** |

## 9.3 Geographic clusters of hydrogen demand

### *9.3.1 Legislated scenario*

The aggregated hydrogen demand under the legislated scenario shows a progressive evolution driven by specific industrial, maritime, and power generation applications. In 2030, the overall demand is nascent and highly localised (Figure 53). The few emerging clusters, with demand between 3 and 10 tonnes per day, are situated in coastal areas around the Port of Southampton, Suffolk (i.e. Sizewell Power Generation Complex) and the North West near the Liverpool Port.

By 2040, the landscape of hydrogen demand expands considerably in both geographical spread and intensity (Figure 54). The most significant growth is seen in Greater London, which becomes a major demand centre with multiple clusters requiring 10-25 tonnes per day, and some exceeding 25 tonnes. This intensification is driven primarily by the considerable growth in the use of gensets. Beyond London, new demand clusters emerge across the country's industrial and logistical heartlands. These are largely fuelled by the uptake of hydrogen for NRMM and gensets in industrial zones and at key ports like Felixstowe. The contribution from road transport sectors like LCVs remains minimal.

The projection for 2050, shown in Figure 55, reveals a mature network of hydrogen demand focused on industrial and maritime hubs. The cluster in London becomes the epicentre of UK demand, with areas requiring over 100 tonnes per day, a result of the comprehensive adoption of hydrogen for gensets. The map also shows the emergence of other major high-demand clusters. A significant zone requiring 50-100 tonnes per day develops in the Northwest, centred around Liverpool and Manchester, driven by a combination of maritime demand at the Port of Liverpool and extensive NRMM usage. A similar high-demand cluster appears in Scotland's Central Belt, indicating significant industrial uptake.

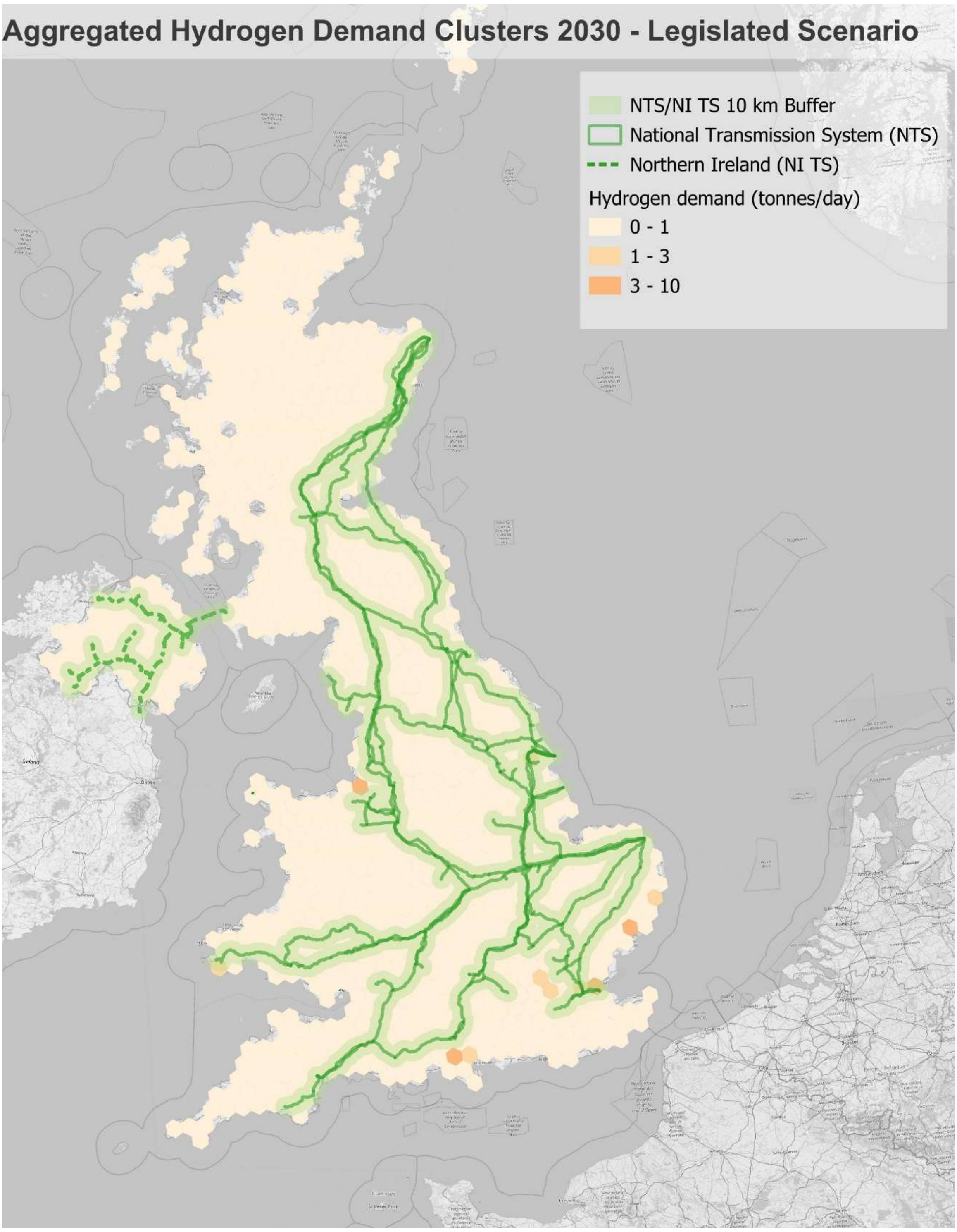



*Figure 54: Hydrogen demand clusters in 2030 under the legislated scenario*

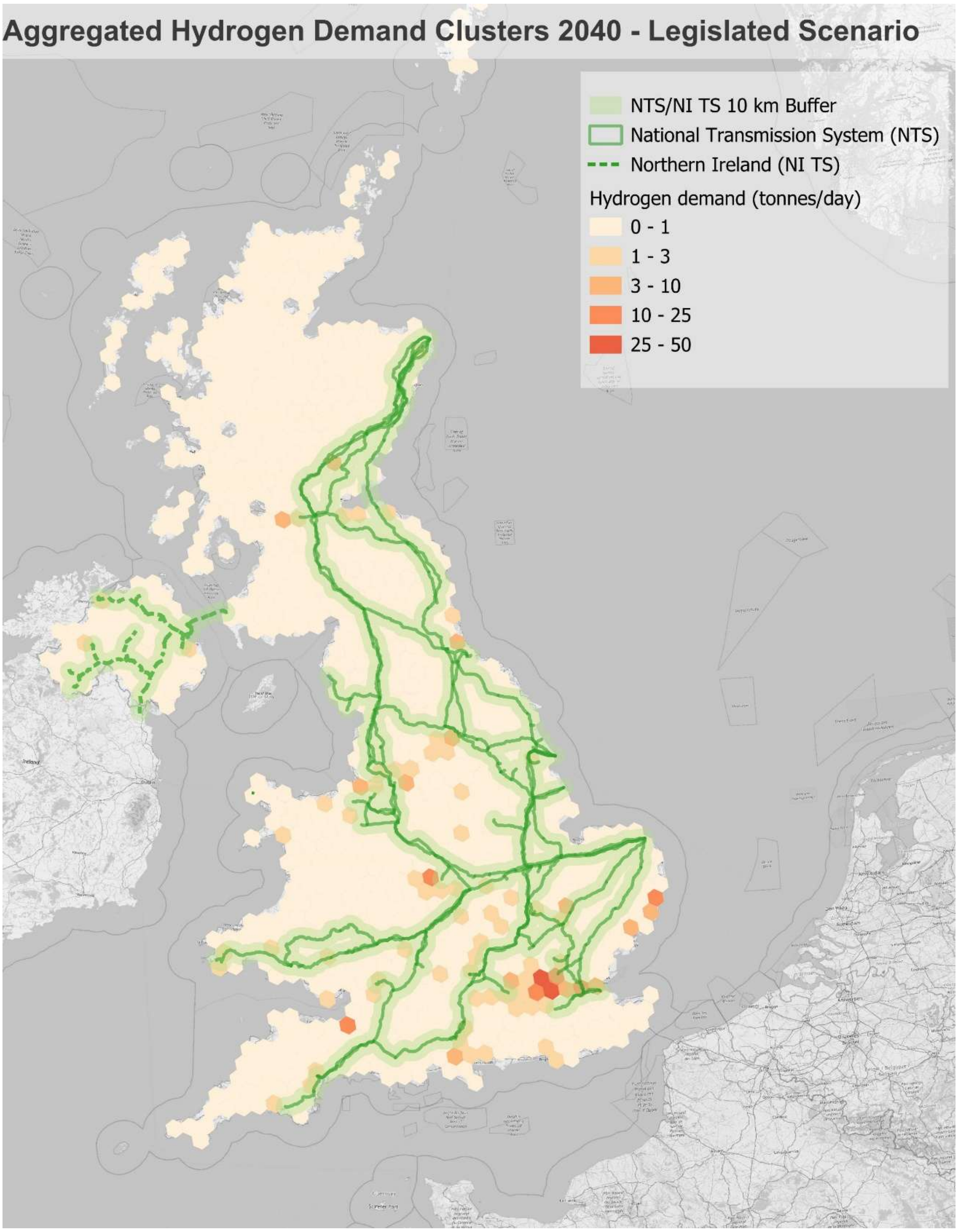



*Figure 55: Hydrogen demand clusters in 2040 under the legislated scenario*

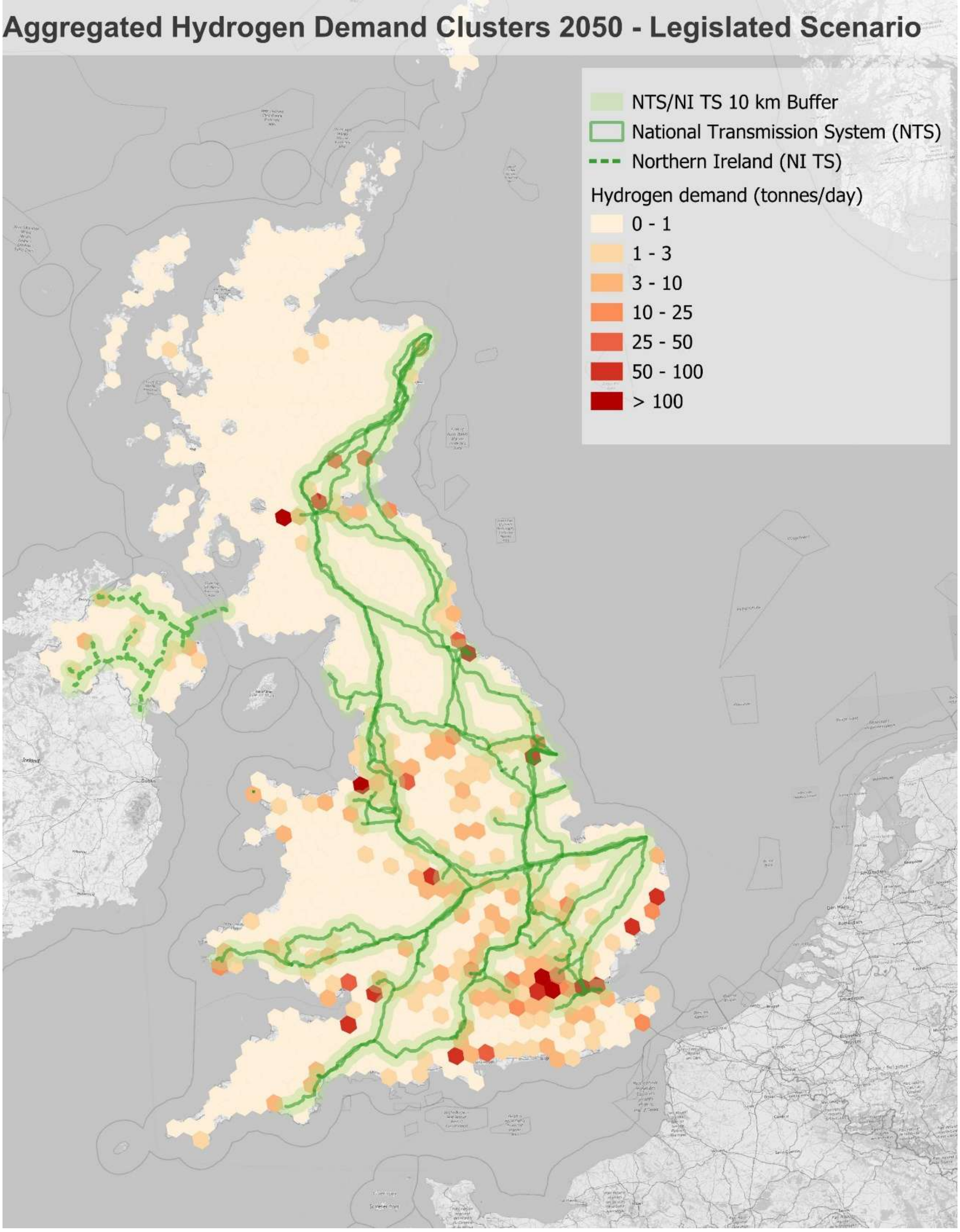



*Figure 56: Hydrogen demand clusters in 2050 under the legislated scenario*

When aggregating demand into potential hubs with a 50-mile service radius, several key locations emerge under the legislated scenario. Major hubs are identifiable around London, Southampton, Felixstowe, Liverpool, and Milford Haven, driven by the concentration of industrial and maritime activity. In 2030 and 2040, the demand in these hubs is primarily dominated by the needs of Non-Road Mobile Machinery (NRMM) and gensets.

This analysis also clarifies the role of Light Commercial Vehicles (LCVs). While their demand does not form distinct clusters at the granular hexagon level (approximately 10 km radius), LCVs contribute significantly to the overall demand when aggregated at the broader hub level, capturing usage from a much larger operational area. As with the hexagon-level analysis, passenger cars make no considerable contribution, in line with the scenario's focus on electrification for personal transport.

By 2050, a notable shift occurs in the sectoral contribution to these hubs. The share of hydrogen demand from the maritime sector increases significantly, particularly in port locations like Southampton and Felixstowe. This rise is attributed to the comprehensive decarbonisation of all portside energy usage as part of the strategy to achieve Net Zero, making maritime activities the primary driver of demand in these key coastal hubs.

The figures below show aggregated demand and sectoral contribution of all sectors. Giving the large contribution of the portside energy use to the overall hydrogen demand in 2050, the authors created additional maps with the maritime sector excluded. These maps can be found in **Appendix F: Total hydrogen demand for all sectors excluding maritime.**

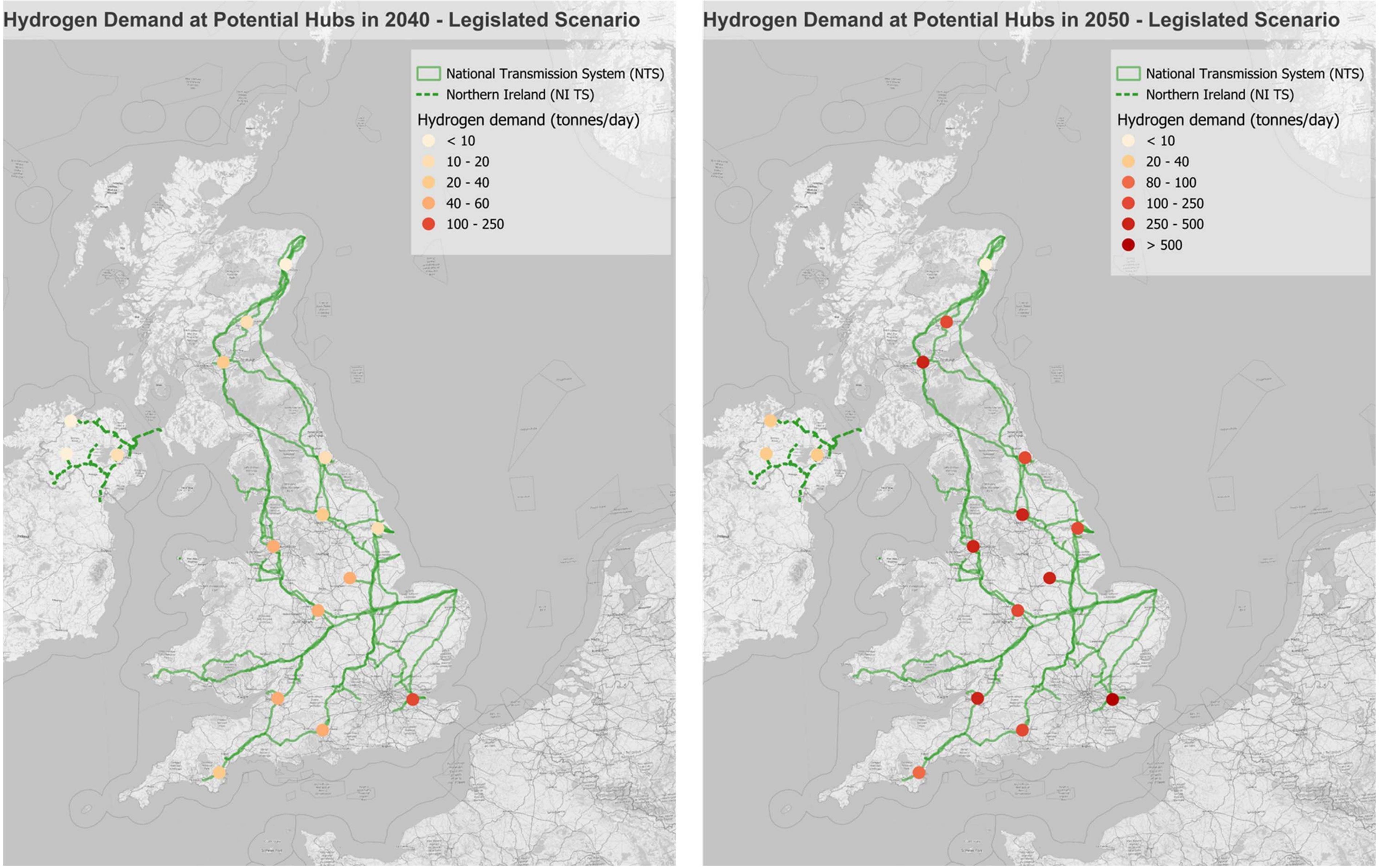
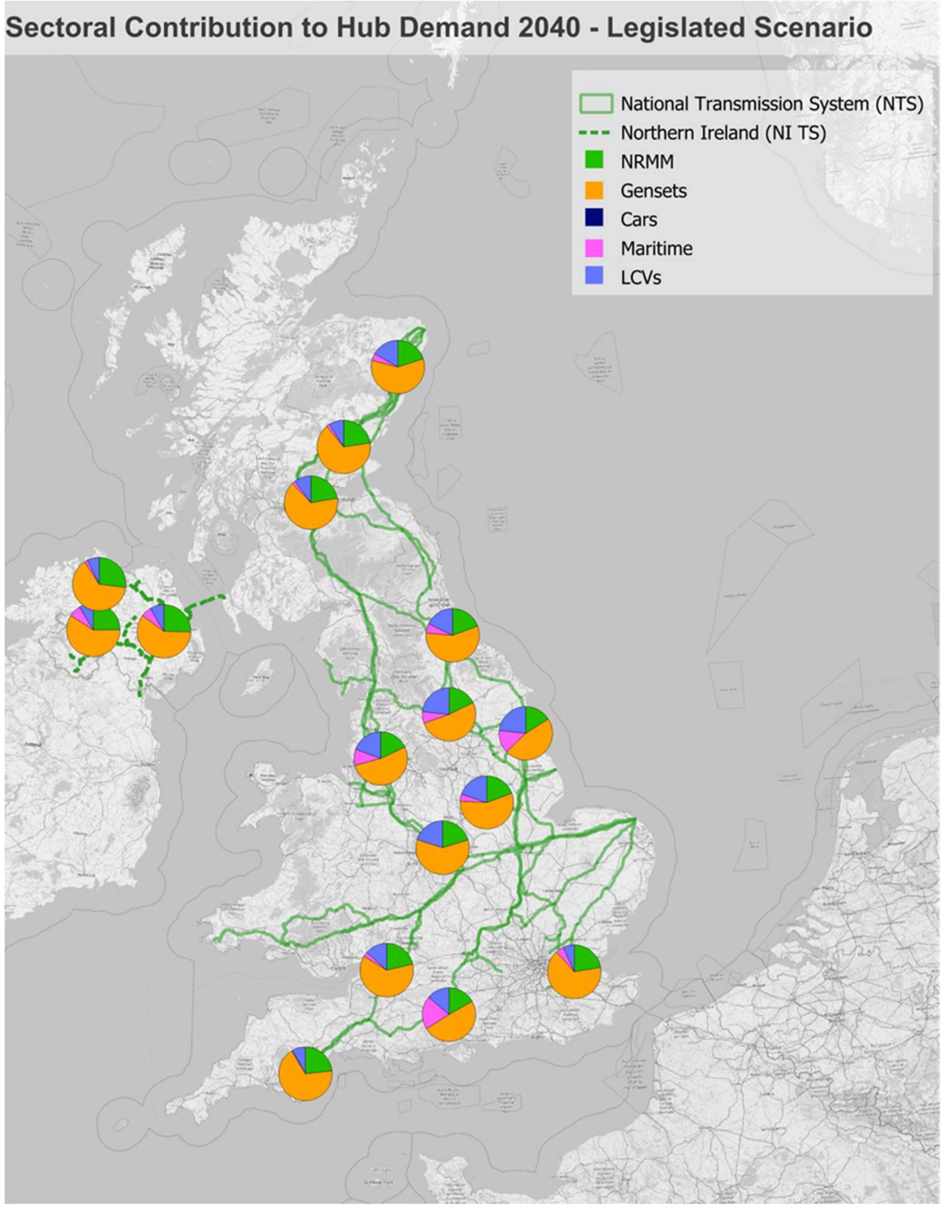



*Figure 57: Hydrogen demand at potential hub locations in 2040 and 2050 under the legislated scenario*



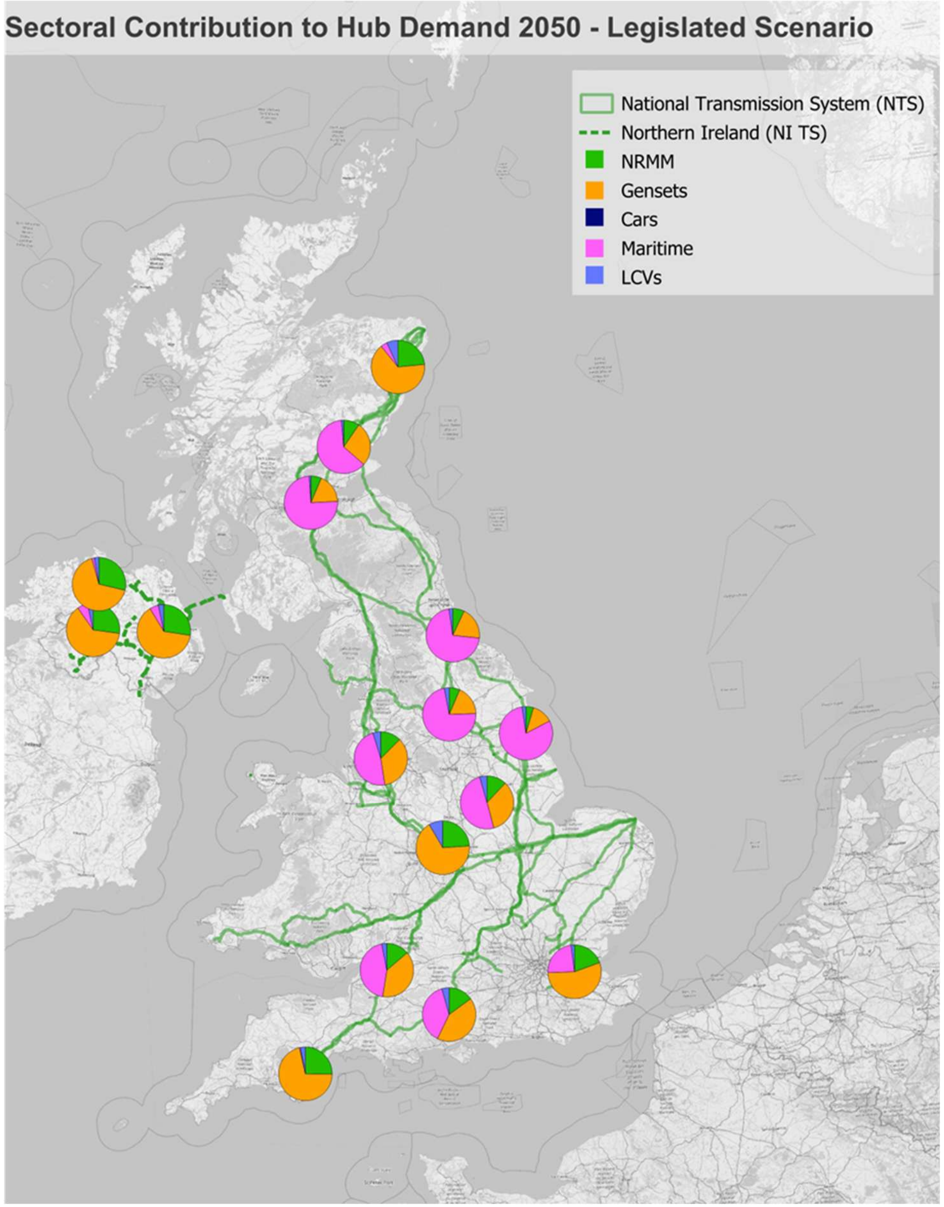




*Figure 58:Relative contribution to hydrogen demand by sector at potential hub locations in 2040 and 2050 under the legislated scenario*

### *9.3.2 Accelerated scenario*

Under the accelerated scenario, the aggregated hydrogen demand shows a much more rapid and widespread evolution. In 2030, as shown in Figure 59, demand is already more substantial and geographically dispersed than in the legislated scenario, with clusters of 10-25 tonnes per day evident in major urban centres like London, the Midlands, and the Northwest. This early demand is primarily driven by initial uptake in the maritime sector at key ports like Southampton and Liverpool, and by industrial applications. While the transition for road transport begins in this period, the contribution from passenger cars and LCVs is not yet considerable, representing only the nascent stages of adoption.

By 2040, the hydrogen economy matures significantly, with demand intensifying across the country (Figure 60). The clusters in London, the Northwest, and the Midlands expand dramatically, with several areas exceeding 100 tonnes per day. This substantial growth is a result of the combined demand from a large-scale transition of passenger cars and LCVs to hydrogen, layered on top of growing demand from NRMM and gensets in urban areas. Major ports, particularly Southampton, Liverpool, and Felixstowe, also become significant demand hubs as the maritime sector's transition accelerates.

The projection for 2050 (Figure 61) illustrates a deeply integrated, high-volume hydrogen network. Demand hotspots in London and the Northwest now exceed 500 tonnes per day, forming extensive metropolitan demand zones. This reflects a comprehensive decarbonisation across all sectors, where dense urban and industrial demand from gensets and NRMM is overlaid with the increased demand from a fully transitioned road transport fleet. Significant clusters also mature in Scotland's Central Belt and along the south coast, driven by a combination of road transport, maritime, and industrial use.

Unlike the legislated scenario, which is dominated by industrial and maritime applications, the accelerated scenario's demand profile is characterised by the powerful synergy between transport and industrial sectors. The extensive network of demand along motorways, driven by cars and LCVs, merges with the concentrated industrial, power generation, and maritime clusters.

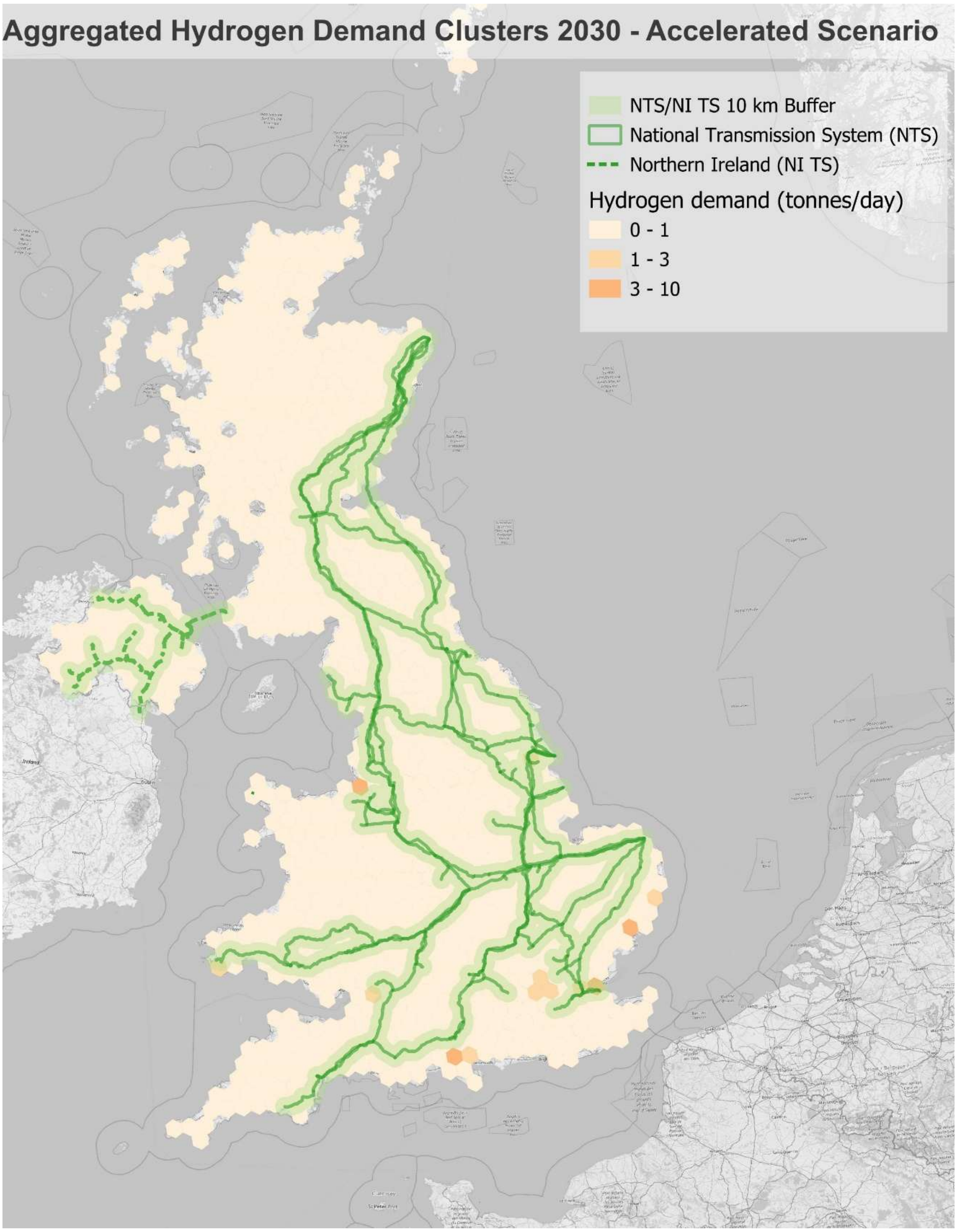



*Figure 59:Hydrogen demand clusters in 2030 under the accelerated scenario*

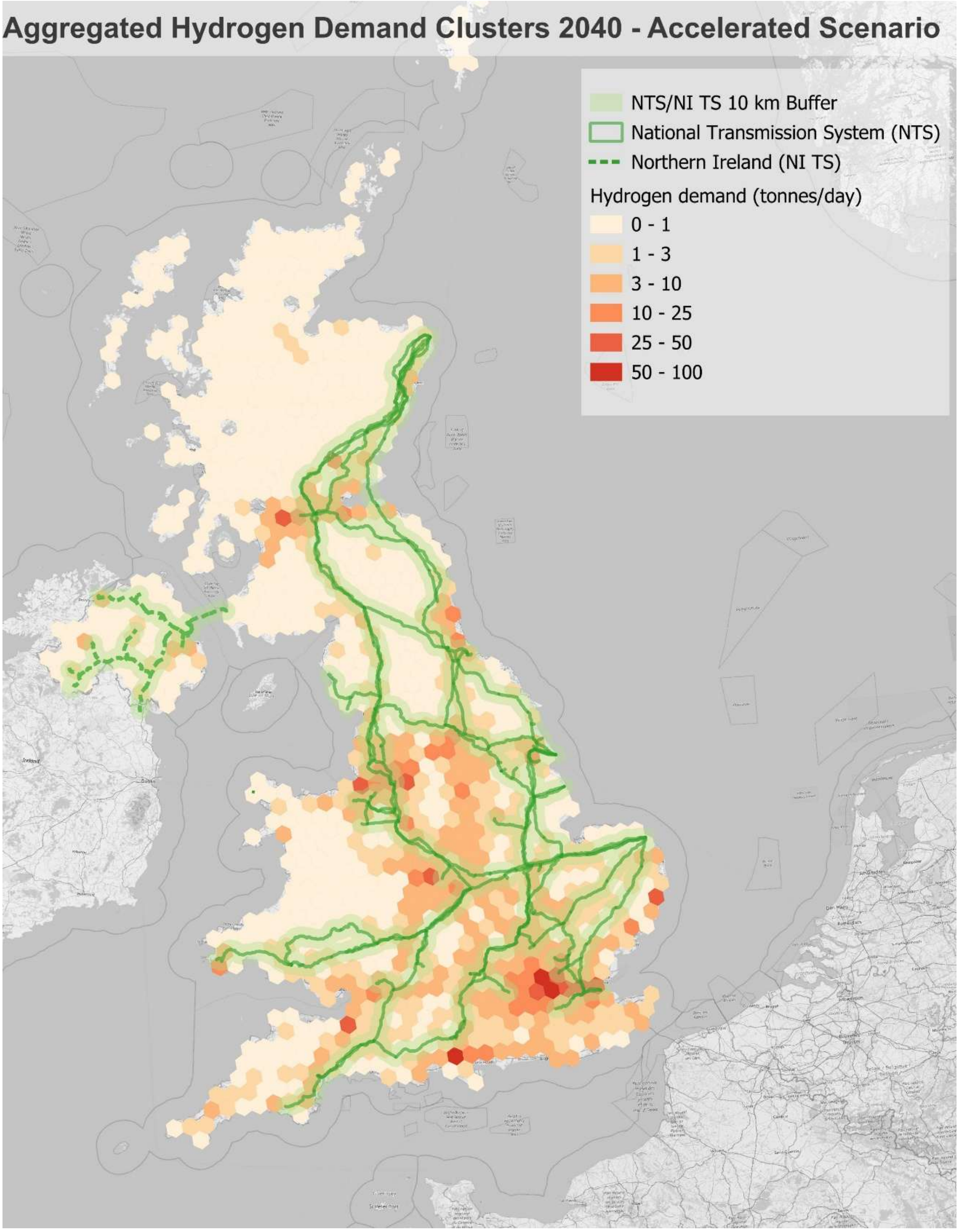



*Figure 60: Hydrogen demand clusters in 2040 under the accelerated scenario*

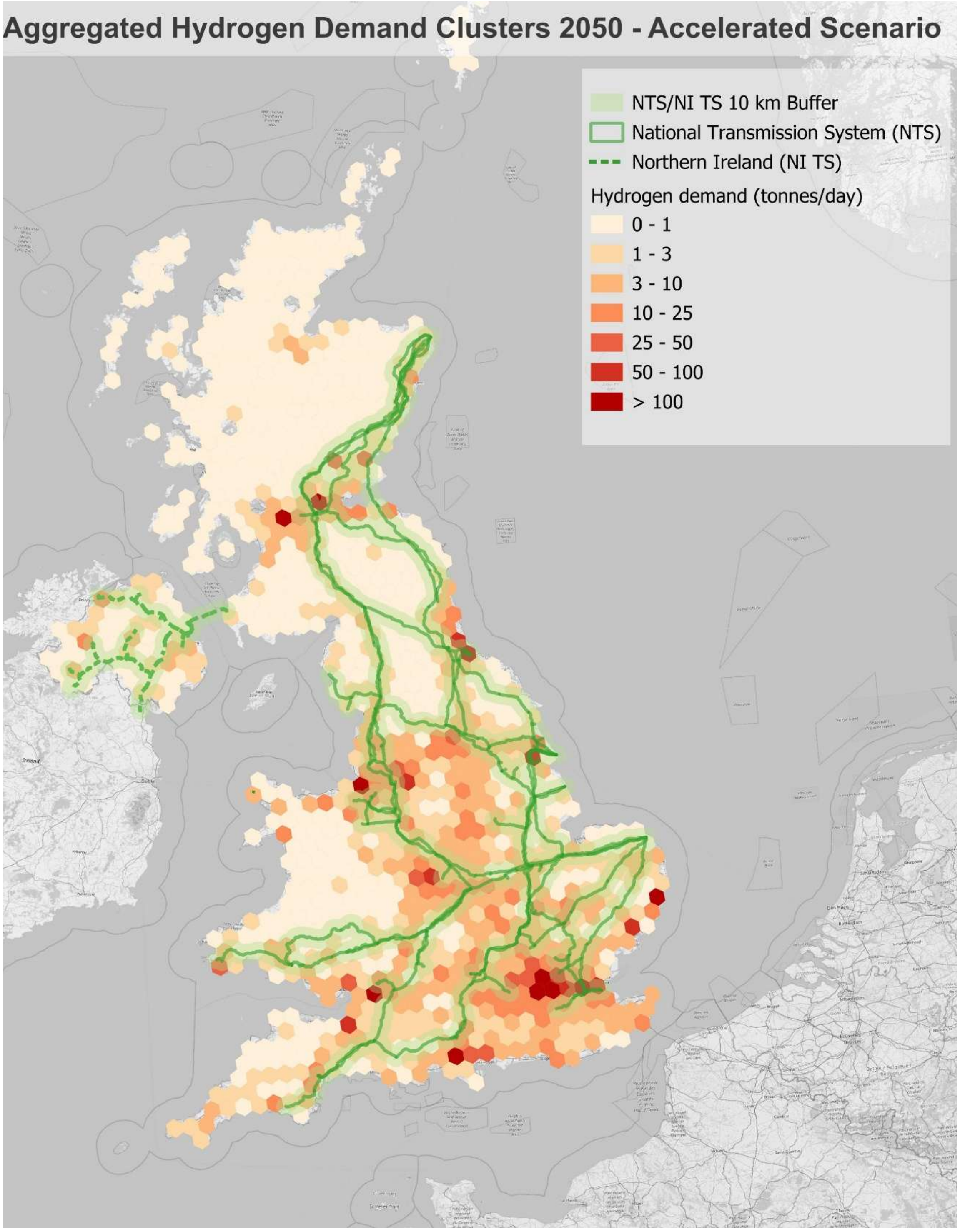



*Figure 61: Hydrogen demand clusters in 2050 under the accelerated scenario*

Under the accelerated scenario, aggregating demand at a hub level with a 50-mile radius reveals a rapid and diverse evolution of the hydrogen economy. By 2040, major hubs emerge in key industrial, port, and inland metropolitan locations. The sectoral contribution analysis for this period shows a considerable shift towards transport, with road vehicles (cars and LCVs) becoming the dominant driver of demand in most hubs, particularly inland centres like the Midlands. In London, while transport also constitutes the largest share, a significant secondary demand from NRMM and gensets is present. Port hubs such as Southampton and Liverpool exhibit a more mixed profile, with considerable maritime demand supplementing the high consumption from road transport.

By 2050, demand intensifies across all hubs, and the sectoral mix evolves distinctly in different locations. In key port hubs like Southampton, North West and North East, the drive for full decarbonisation of portside activities results in the maritime sector's share of hydrogen consumption growing dramatically to become the largest single source of demand. This rebalances the local energy mix; while absolute demand from road transport continues to grow, its proportional share within these coastal hubs decreases significantly compared to 2040. The London hub undergoes a unique transition: the demand from NRMM and gensets expands to become the primary usage, overtaking the previously dominant road transport sector.

The accelerated scenario therefore presents a fundamentally different demand profile at the hub level compared to the legislated scenario. Instead of being primarily anchored by industrial and maritime activity, the demand is characterised by a diverse mix of sectors, supercharged by the widespread adoption of hydrogen as a decarbonisation option for hard to electrify road transport in most regions. This creates larger, more numerous, and more geographically dispersed high-demand hubs, with a dynamic interplay between transport, industrial, and maritime needs shaping the final profile of each location.

The figures below show aggregated demand and sectoral contribution of all sectors. Giving the large contribution of the portside energy use to the overall hydrogen demand in 2050, the authors created additional maps with the maritime sector excluded. These maps can be found in **Appendix F: Total hydrogen demand for all sectors excluding maritime**

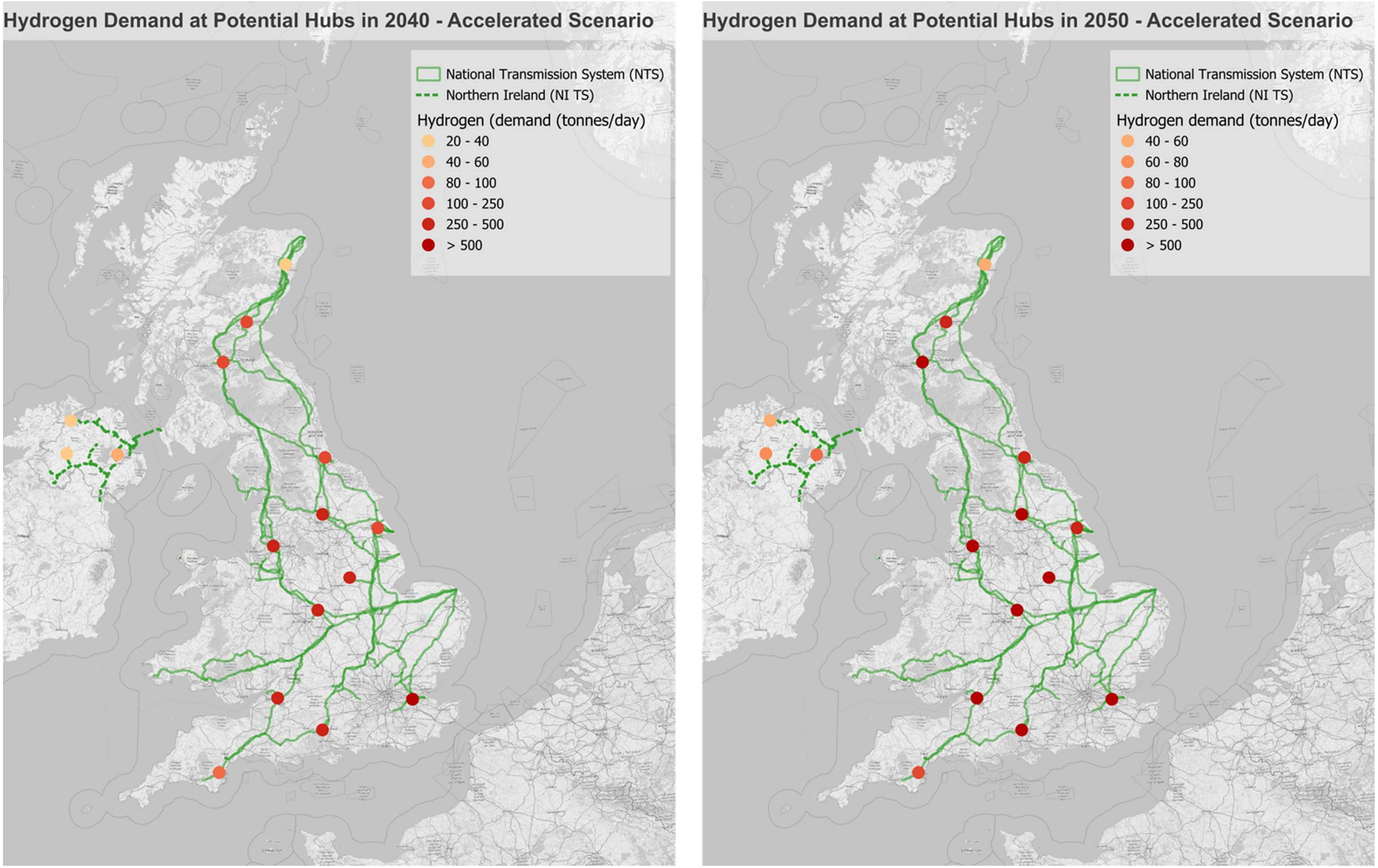



*Figure 62: Hydrogen demand at potential hub locations in 2040 and 2050 under the accelerated scenario*

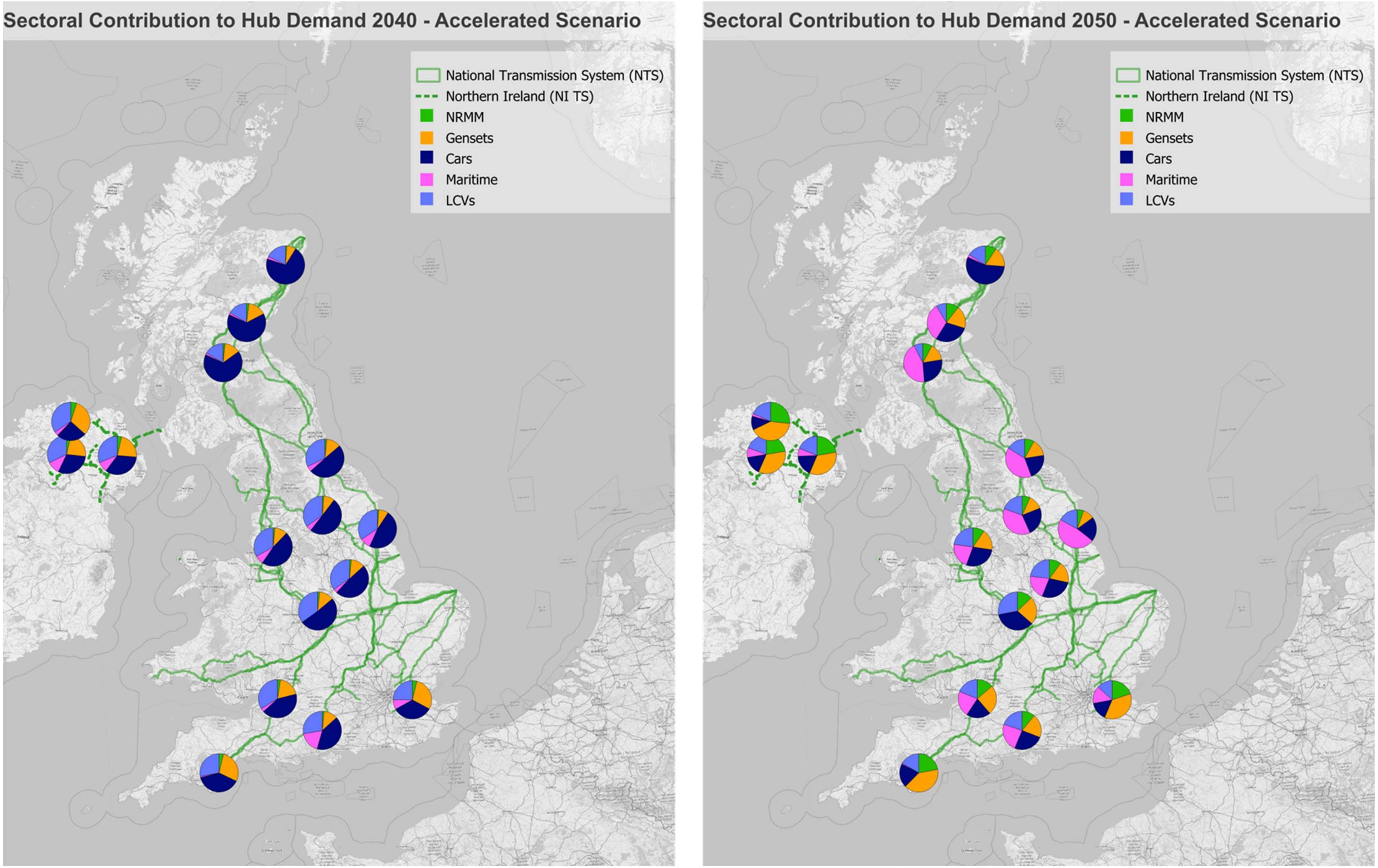



*Figure 63:Relative contribution to hydrogen demand by sector at potential hub locations in 2040 and 2050 under the accelerated scenario*

## Appendix A: AI Usage Declaration

Generative AI has been used in this project in the following forms:

| AI Usage Type | Description | Used in this report? (Yes/No) |
|---|---|---|
| **Information summarisation** | Summarising background information, literature, or datasets. | Yes |
| **Draft text generation** | Assisting with drafting sections of narrative text. | Yes |
| **Editing and refinement** | Rewording, improving clarity, or restructuring draft text. | Yes |
| **Data analysis assistance** | Supporting analysis of datasets (e.g., pattern identification, basic statistical interpretation). | No |
| **Visualisation assistance** | Helping generate charts, diagrams, or conceptual visuals. | No |
| **Formatting and style suggestions** | Suggesting document formatting, structure, or layout improvements. | No |
| **Idea generation / brainstorming** | Supporting creative idea development, concepts, or framing of content. | Yes |
| **Translation support** | Assisting with translation of content between languages. | No |
| **Coding / scripting assistance** | Assisting with scripts or code relevant to the report (e.g., data processing). | Yes |

# Appendix B: Technical Information on Powertrain technologies

Additional detail, by technology

### *Internal Combustion Engines*

The basic principles of internal combustion engines are fuel and oxygen intake, compression, combustion, and combustion product exhaust.

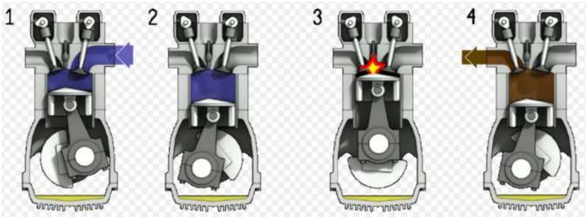



*Figure 64: Four-stroke internal combustion*[104]

Figure 64 illustrates the four phases of a four-stroke piston engine :

1. **Intake** (suck): The intake valve opens, and the fuel and the oxygen are sucked into the cylinder by its downward movement.
2. **Compression** (squeeze): Both the intake and exhaust valves are closed, and the upward movement of the cylinder compresses the fuel and air mixture.
3. **Combustion** (bang): After the cylinder has compressed the fuel and air mixture to the maximum pressure it can, the fuel is ignited. In a patrol car this is achieved with a spark plug. The air and fuel mixture explodes, and the force of the explosion drives the piston downwards. This explosive force provides the power to move the vehicle.
4. **Exhaust** (blow): The exhaust valve opens, and the piston's upward travel pushes all the exhaust gasses out of the cylinder. In the ethanol and oxygen example we used before (**Error! Reference source not found.**) the exhaust gases would be $CO_2$ and $H_2O$. If we had used air instead of oxygen, we would expect $N_2$ (and a few other trace chemicals) to be part of the exhaust gases as well. Those other chemicals are important, and we will talk about them more later.

As each piston completes its four-stroke cycle, it rotates the crankshaft and powers the wheels via the transmission (the clutch, gearbox and all the other components required to transfer energy to the wheels).

**Dual fuel systems** An ICE can work on a variety of fuels. One way of reducing emissions is to use a low or zero-carbon fuel in the engine. Conventional fossil fuel-powered ICEs can operate as a 'dual fuel' or ‘blended fuel’ system by adding a lower carbon fuel such as FAME, ethanol, HVO, methane, or hydrogen to the combustion mix. However, as the percentage presence of alternate fuels increases, the engine may need significant modification for different fuels. These modifications add complexity and cost (for example, the cost of the hydrogen tanks) to the vehicle, and the emissions benefit is lower than if a true zero-emission fuel is used to power the vehicle.

A further drawback of the ICE dual fuel system is that alongside the $O_2$ drawn into the combustion chamber, other gases in the air, particularly nitrogen ($N_2$) are also present. These compete with fuel for oxygen in the combustion process, producing nitrogen oxides (often written as 'NOx'). Poorly controlled fuel combustion also results in carbon monoxide (CO), carbon (soot, or particulate matter (PM)) and unburnt fuel (often called volatile organic compounds, or VOCs): NOx and VOCs are the visible portion of air quality pollution (often reported as ‘smog). PM is also an important AQ pollutant, but not visible to the naked eye.

*Figure 65: Smog comparison*[105]

[104] CC BY-SA 3.0: User Zaphyris: Wikimedia foundation

[105] CC BY-SA 4.0 user Tomskyhaha Wikimedia foundation

The immediate and long-term health impacts to all segments of society that result from AQ pollution are well documented and a significant driver of emission reduction legislation. [106]

**Fossil fuels** such as diesel and petrol (gasoline) make up the vast majority of ICE fuel use worldwide. All regions of interest mandate the inclusion of renewable fuels blended in with conventional fossil fuels.

**Biofuel blends below 30%.** Biofuels are renewable from biological raw materials (energy crops or organic waste). The CO2 emissions generated by combusting biofuels are accepted as zero emissions in most legislation for GHG calculation purposes, but not for AQ emission legislation. Biofuels from biogenic waste can have a lower carbon intensity than those from energy crops. The manufacture of biofuels can result in negative GHG emissions (by avoiding methane released to the atmosphere by certain types of organic wastes); however, the supply of negative-emission biofuels is extremely limited.

Agricultural NRMM users may be one market where negative emission biofuels can have a role to play in the future. Global biofuels make up approximately 6% of all energy inputs[107] in 2022. The newest engines and fuel supply chains can take up to 20% of blended fuel systems, and research is ongoing to achieve up to 30% blends of fossil-based fuels with biological content. However, the uptake of biofuels may struggle to achieve this figure for a variety of reasons, not least of which is the availability of agricultural land for the growing of energy crops (the "food Vs fuel" issue)[108], and the required development of new technologies to meet the anticipated global demand for more food safe biofuels.

Long haul duty cycles account for the largest portion of HGV GHG emissions**Error! Bookmark not defined.**, and biofuels are a viable interim fuel to reduce emissions ahead of the 2050 target.

**B100/FAME is 100%** biodiesel (usually fatty acid methyl ester (FAME)), and it requires some changes to storage and management procedures due to increased sensitivity to water contamination, leading to reduced life span (due to microbial growth). FAME feedstocks are typically corn, wheat, sugar beet, or similar crops, and there are approximately 500 FAME biodiesel plants globally. It is possible to manufacture from non-food crops, and even some biological waste streams, but the refining technology is not well developed, with only a dozen or fewer systems available globally.

**Bioethanol** typically uses stalks, corn stover and sugarcane bagasse or other solid plant waste in its manufacture and is mainly a biological fermentation process involving yeast or bacteria. Bioethanol can also be blended in with conventional petroleum fuels and can be found in blends as high as 85% with conventional engines. Even higher blends of ethanol are possible, and fuel-flexible vehicles (FFVs) can operate on 100% ethanol (and are common in Brazil)

**HVO** Hydrotreated vegetable oil (HVO) and is a paraffinic fuel chemically like fossil fuel diesel. It is a 'drop-in' fuel that can be substituted in no impact on operations or infrastructure. HVO can be produced from virgin vegetable oil, typically crude palm oil, and waste feedstock such as UCO and waste vegetable oils. Efforts are being made to increase the volume of HVO produced from waste-based raw materials (with certification of fuel origins becoming increasingly important for some sectors[109]). HVO is produced by hydrotreating vegetable oils and fats. In this process, hydrogen is used to remove oxygen from the vegetable oil molecules and to split the molecules into separate hydrocarbon chains equivalent to those found in conventional fossil fuel diesel. HVO must conform with European Standard EN15940. HVO is typically supplied in pure form, comprising of 100% renewable fuel.

**Biomethanol** is typically produced through the catalytic conversion of biomethane (which puts bioethanol production in direct competition with biomethane fuel production supply chains)

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[106] Royal Society (2021): Effects of net-zero policies and climate change on air quality: The Royal Society (Online). https://royalsociety.org/-/media/policy/projects/air-quality/air-quality-and-climate-change-summary.pdf?la=en-GB&hash=E8650539DD5F180B2A4094A9279F4EC7

[107] IEA (2024): Bioenergy: International energy agency (Online). https://www.iea.org/energy-system/renewables/bioenergy

[108] IRENA (2019): Advanced Biofuels: IRENA.org (Online). https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Nov/IRENA_Advanced-biofuels_2019.pdf

[109] CI (2023): Environment Agency softens HVO stance and sponsors study: The Construction Index.co.uk (Online). https://www.theconstructionindex.co.uk/news/view/environment-agency-softens-hvo-stance-and-sponsors-study

**Biomethane:** Biomethane is the renewable equivalent of natural gas (methane). It can be used as a fuel drop for CNG and LNG natural gas vehicles. Typically, biomethane is made from a variety of organic waste materials via the process of anaerobic digestion. Existing natural gas distribution grids can facilitate the adoption of biomethane uptake. However, gas-powered vehicles are a small niche of the market. (approximately 23,000,000 vehicles worldwide [110], or 1.6% of the global vehicle market), and the infrastructure required for their further adoption is not well-developed.

**Dedicated hydrogen ICEs** There is much research and development to create ICEs that can run on 100% hydrogen. No carbon molecule is involved in hydrogen combustion, which will eliminate the production of CO2, CO, VOCs, and PM originating from fuel combustion. But NOx is likely to remain a problem (though there are unsubstantiated claims of significantly reduced Nox emission through the use of 'lean' fuel:air ratios. JCB claims their H2-ICE engines produce remarkably little NOx, but this has yet to be independently verified[111]. Hydrogen gas supply chains are poorly developed. Ongoing research is underway to assess the extent to which hydrogen can be integrated into existing natural gas supply infrastructure.

However, it is essential to note that natural gas vehicles make a niche contribution to the transportation sector, and relying solely **on existing natural gas infrastructure to foster the growth of the hydrogen transport system may be insufficient to achieve significant market uptake**. It is important to note that all four regions of interest have publicly stated plans to include hydrogen gas in the transport system by 2050 (though with limited concrete plans on how to do so).

### *Electric drive trains*

All current ZEVs do not have an internal combustion engine and instead are driven by an electric motor, which is powered by electricity generated by a battery and/ or a hydrogen fuel cell, which converts stored chemical energy into electrical energy.

Electric vehicles (EVs) are powered by electricity, usually via an electrically charged battery pack that powers the motor to turn the wheels. Plug-in electric vehicles (PiVs) are recharged using a dedicated charging unit, where the car's charge port is connected to a source of electricity, and the vehicle receives power stored in the battery.

Fully electric vehicles do not produce tailpipe emissions, making them more environmentally friendly than ICE-powered vehicles. Electric vehicles are also significantly quieter than ICE-powered vehicles. Due to wind or tyre resistance, they only produce significant sound when travelling at moderate to high speeds. Some EV models also produce artificial sounds when travelling at very low speeds (when they are the quietest) for the safety of pedestrians.

Like ICE vehicles, electric cars have a thermal cooling system. Their batteries, containing lithium ions, are prone to heating when used and therefore need to be kept at an optimal operating temperature. The same goes for the power electronics and other key components. EVs also contain a battery management system that makes sure the energy levels produced and consumed by the car are consistent; this protects the battery from burning out.

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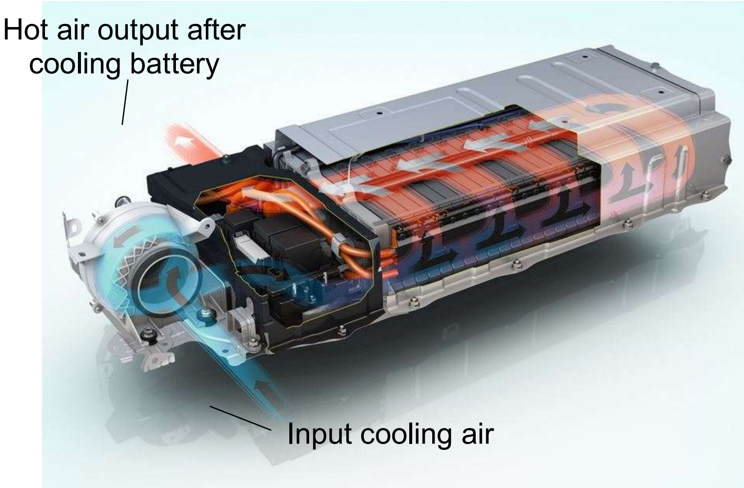
[110] US DoE (2024): Alternative fuels data centre; Natural Gas Vehicles: US department of energy (Online). https://afdc.energy.gov/vehicles/natural-gas

[111] PIN (2023): JCB Launch New Hydrogen Combustion Engine: PIN online: International Labmate Ltd. (Online). https://www.petro-online.com/news/hydrogen-fuel/181/international-environmental-technology/jcb-launch-new-hydrogen-combustion-engine

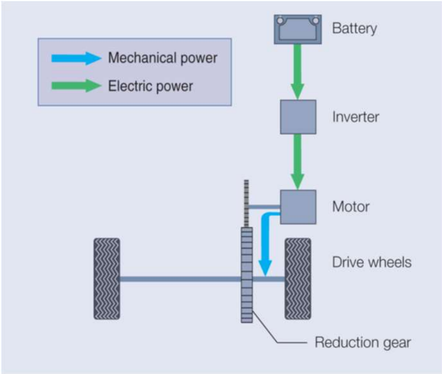



However, there is a host of different terminology that can be used to describe electric vehicles based on the power source and drivetrain used to drive the vehicle. For example, the terms ‘plug-in vehicle’ (PiV) and ‘electric vehicle’ can be used as blanket terms for any vehicle with a plug socket, including battery electric, plug-in hybrid, and range-extended electric vehicles.

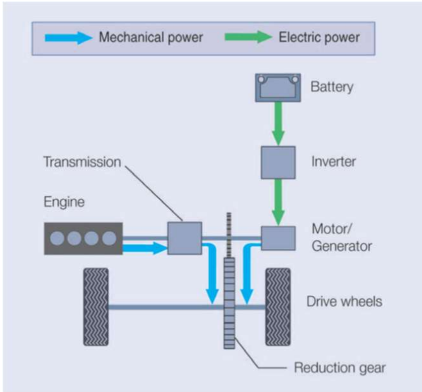
The main EV types are:

1. Battery Electric Vehicle (BEV): A vehicle that runs purely on electric power, stored in an on-board battery that is charged from mains electricity (typically at a dedicated chargepoint).
2. Plug-in hybrid electric vehicle (PHEV): A vehicle with a traditional internal combustion engine and a small rechargeable battery, allowing for either pure electric-powered driving or a combination of the petrol/diesel engine and electric motor.
3. Range-extended EV (REEV): A vehicle with an electric drivetrain, with a small petrol generator to charge the battery when range is depleted for longer trips. Often considered a type of PHEV.
4. Fuel Cell Electric Vehicle (FCEV): A vehicle which uses a hydrogen fuel cell to power its electric motor. The fuel cells create the electricity to power the car.

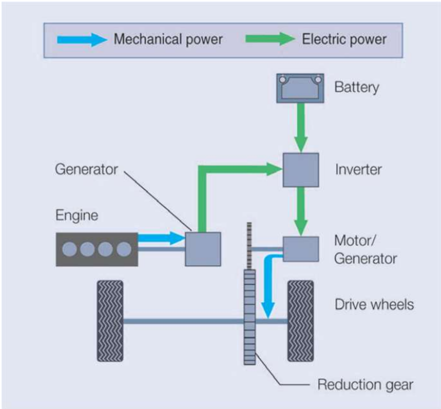
A typical PHEV can drive for about 30 miles using electric-only power, after which the combustion engine will take over. Therefore, short trips can be 100% electric in a PHEV. However, for longer trips, the initial 30 miles would be undertaken as electric, with the remaining distance driven mainly on the internal combustion engine.



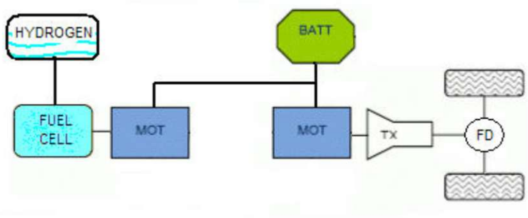

*1. BEV*




*2. PHEV*




*3. REEV*




*4. FCEV*

## *Technology A – Notes on battery electrification*

**Lithium-ion battery plug-in vehicles (Li-ion PiVs.)** are the dominant battery chemistry and are likely to remain so. This includes 'hybrid' vehicles that may combine onboard battery energy storage with another power train to increase range and fuel flexibility.

One of the key drivers of the uptake of battery electrification in the road transport market, and the reason it is strongly argued for in a variety of other markets, has been the significant fall in the cost of battery systems. Battery packs are made up of dozens, or even hundreds of individual battery cells, packaged together. A study by BloombergNEF [112] demonstrates this fall in the price per kWh for battery packs (see Figure 66).

It is unclear how much further this trend can continue (for existing Li-ion battery chemistries) with ever-increasing demand and ever reducing raw materials and processing capability. DLL staff are advised to monitor battery prices as a point of reference when considering Accelerated uptake in the future

[112] (2023) Lithium-Ion Battery Pack Prices Hit Record Low of $139/kWh: BloombergNEF (Online). https://about.bnef.com/blog/lithium-ion-battery-pack-prices-hit-record-low-of-139-kwh/

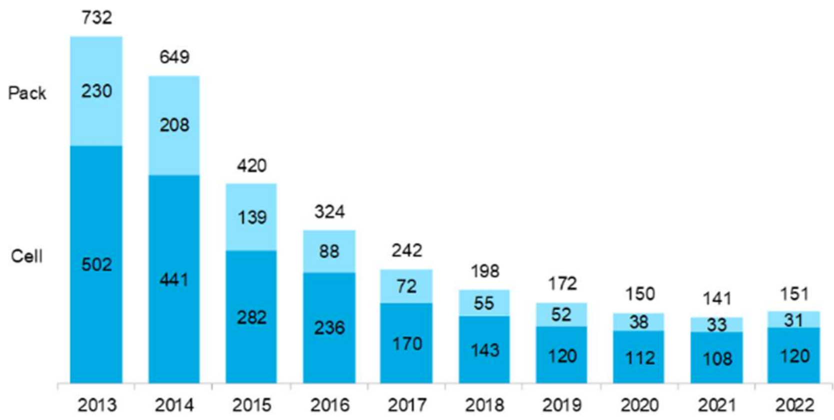



*Figure 66: Cell and pack historic prices (USD per kWh)*

### *Hydrogen Fuel Cells*

**Hydrogen fuel cells** (H2FCs), a direct electrical power train like a battery system, that utilise chemical reactions with hydrogen and oxygen to generate electricity onboard the vehicle. Fuel cells are inherently more efficient than ICE because they do not burn the fuel. Instead, a sequence of electrochemical reactions is catalysed to separate the oxygen (O2) molecules in the air, and the hydrogen (H2) molecules form the fuel tank and combine them into water ($H_2O$) whilst generating electricity and heat. A fuel cell vehicle includes a fuel cell stack (multiple fuel cells combined to generate sufficient power to propel the vehicle), air compressors, hydrogen tanks, batteries, power electronics, and electric motors.

When most of the power comes from the fuel cell stack, we refer to that as a fuel cell electric vehicle (FCEV). If the battery provides more power and is plugged into a socket to recharge, we call that vehicle a range-extended fuel cell electric vehicle (RE-FCEV, sometimes written as Rex-FCV).

The workings of a fuel cell electric vehicle are summarised below and shown in Figure 67:

- Hydrogen gas from the tank is supplied to the fuel cell stack.
- Air is also supplied to the fuel cell stack.
- The oxygen and hydrogen combine in the fuel cell stack to generate electricity and water (for those who would like more information on how this works, the operation of a **proton exchange membrane fuel cell (PEMFC)**
- Generated electricity is supplied to the electric motor and/or battery. The battery acts as an energy store, providing additional energy to the vehicle for acceleration events, and can also capture **regenerative energy** from braking to improve vehicle efficiency.
- The motor provides power to the wheels.
- Water is emitted from the vehicle

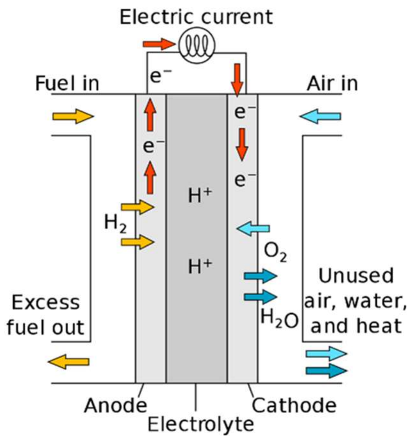



*Figure 67: schematic of H2FC*

Hydrogen for transport applications is a nascent technology (hydrogen only recently achieved legislative status as a 'fuel' instead of an industrial chemical. However, low and zero-emission hydrogen use is essential for the global transition to net zero. All three regions of interest have plans to foster and develop a global trade in hydrogen and develop their own hydrogen production facilities. Heavy vehicles are a key market for the early adoption of hydrogen powertrain technologies. Despite being identified as a key pillar of the Net Zero by 2050 objective, **there is still uncertainty as to how much of a contribution low and zero-emission hydrogen can make towards achieving net zero emissions for road-going and NRMM equipment.**

The IEA tracks the status of global hydrogen projects[113], and summarised results for each region are reported here. In the EU27+ there are 202 existing hydrogen production projects, with 101 production centres under construction or that have received a successful financial investment decision (303 projects in total); with an anticipated production volume of 804,000 tonnes of low-emission hydrogen production per year by 2030. An additional 307 feasibility studies are underway for additional hydrogen production facilities. The EU has also mandated the construction of hydrogen refuelling infrastructure along the major trade routes of the 'Ten-T' corridor[115].

In the America region, there are currently 71 operational hydrogen production centres. A further 18 production centres are under construction or have received a successful financial investment decision (32 projects in total). These projects would generate some 63,000 tonnes of low-emission hydrogen per year per year by 2030. 47 feasibility studies are underway to identify suitable sites for still more low and zero-emission (green) hydrogen production per year by 2030.

In Australia, there are currently 14 operational hydrogen production centres. A further 33 production centres are under construction or have received a successful financial investment decision (102 projects in total). These projects would generate some 1,306,000 tonnes of low-emission hydrogen per year by 2030. Forty-one feasibility studies are underway to identify suitable sites for producing more low- and zero-emission (green) hydrogen per year by 2030. However, recent news has reported some dramatic slowdowns in implementing hydrogen projects, despite final investment decisions being signed.

**Despite all the above, there is still uncertainty as to how much of a contribution low and zero emission hydrogen can make towards achieving net zero emissions for road-going and NRMM equipment.**

The ICCP also states [114] that a multifuel approach with smaller categories of vehicles dominated by PiV powertrain adoption is likely, hydrogen fuel cell adoption is likely if it can achieve the $40 (2017 USD value) per kW target price for delivered fuel cell systems, perhaps with ammonia or methanol-based fuel distribution systems. However, no significant hydrogen (or ammonia) uptake is likely before 2030. Bioethanol and fossil fuels have already been added to the existing forecourt dispenser system. Except for Germany, Sweden, South Korea, and Japan, the global adoption of public hydrogen refuelling infrastructure has yet to succeed.

This should change across the EU over the next five years, if existing legislation remains in force (and is enforced) by EU member states, such as the 2023 update to the European Union Alternative Fuel Infrastructure Regulation (AFIR)[115]. However, to achieve those goals, significant planning and implementation are required for both PiV charging infrastructure and hydrogen refuelling infrastructure across the economically crucial 'Ten-T' transport network is required over the next five years.

A key barrier to adopting hydrogen and alternative fuels such as ammonia is the lack of refuelling infrastructure and supply chains to create the required infrastructure. Most, if not all, hydrogen refuelling

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[113] IEA (2024b): Hydrogen production projects interactive map (Online). https://www.iea.org/data-and-statistics/data-tools/hydrogen-production-projects-interactive-map

[114] Jaramilo, P.S. (2022): Transport. In IPCC, 2022: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change: Cambridge University Press (Online). https://www.ipcc.ch/report/ar6/wg3/chapter/chapter-10/

[115] ICCT (2023): European Union Alternative Fuel Infrastructure Regulation: International Council on Clean Transport (Online). https://theicct.org/wp-content/uploads/2023/04/AFIR-EU-Policy-Update-A4-Final.pdf

stations created in the regions of interest to date can be broadly thought of as prototype or demonstration projects. These are research and development projects and typically have had a very low throughput capacity, could only serve a small variety of make and model of vehicle, and had a price tag ranging "*… between USD0.6 million and USD2 million for hydrogen at a pressure of 700 bar and a delivery capacity of 1300 kg per day. The investment cost of hydrogen refuelling stations with lower refuelling capacities (~50 kg H2 per day) delivered at lower pressure (350 bar) range between USD0.15–1.6 million."*[114] With a limited number of vehicles available to utilise this infrastructure, the dispensed hydrogen cost can end up costing an unsustainable "*USD15–25 per kg H2*"[114].

It is worth noting that even if hydrogen vehicle populations increased to a point where there was sufficient demand to spread the core infrastructure costs, for electrolytically produced hydrogen, very low-cost electricity will still be required to achieve price parity with fossil fuels. There are assumptions that capital and operational costs will fall as programmes such as the proposed hydrogen refuelling infrastructure roll-out along the Ten-T corridors[115] alter the market landscape. However, this has yet to be demonstrated.

### *Fuel cell stack costings*

The values show in Figure 68 are specific to HDV 275 kW PEM at 50,000 units produced per year; cars and LCVs would have slightly shifted values compared to those shown. This DOE cost model[116] & [117] assumes durability oversizing (safety factors) and higher than normal Platinum loading. Alternative designs (lower Pt, different cooling/air systems) would change the costings, and are likely to be more suitable for cars and LCVs. The current DOE model assumes $150 per kW for the system ($41,250). Equivalent diesel system cost in the order of $14,000 to $18,000[118].

Adding in hydrogen fuel tanks, and sufficient hydrogen for a day's shift would increase the system cost by $46,000 to $51,000, for a total **eight-hour operational system cost in the order of $90,000.** The diesel price for fuel tnaks and eight hours o fopertaion would increase by up to $1,000, at most ($15,000 to $19,000). This pricing excludes all refuelling infrastructure.

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[116] DOE Hydrogen and Fuel Cell Technologies Office (2024). Program Record 24004: Heavy-Duty Fuel Cell System Cost—2023. U.S. DOE, 28 Aug. (online).https://www.hydrogen.energy.gov/docs/hydrogenprogramlibraries/pdfs/review24/24004-hd-fuel-cell-system-cost-2023.pdf. Hydrogen Program

[117] DOE Hydrogen and Fuel Cell Technologies Office / AMR (2024) Fuel Cell Cost and Performance Analysis (James et al.). (online). https://www.hydrogen.energy.gov/docs/hydrogenprogramlibraries/pdfs/review24/fc353_james_2024_o.pdf Hydrogen Program

[118] ICCT (2021) Estimated cost of diesel emissions control technology to meet future Euro VII standards. (online). https://theicct.org/wp-content/uploads/2021/06/tech-cost-euro-vii-210428.pdf

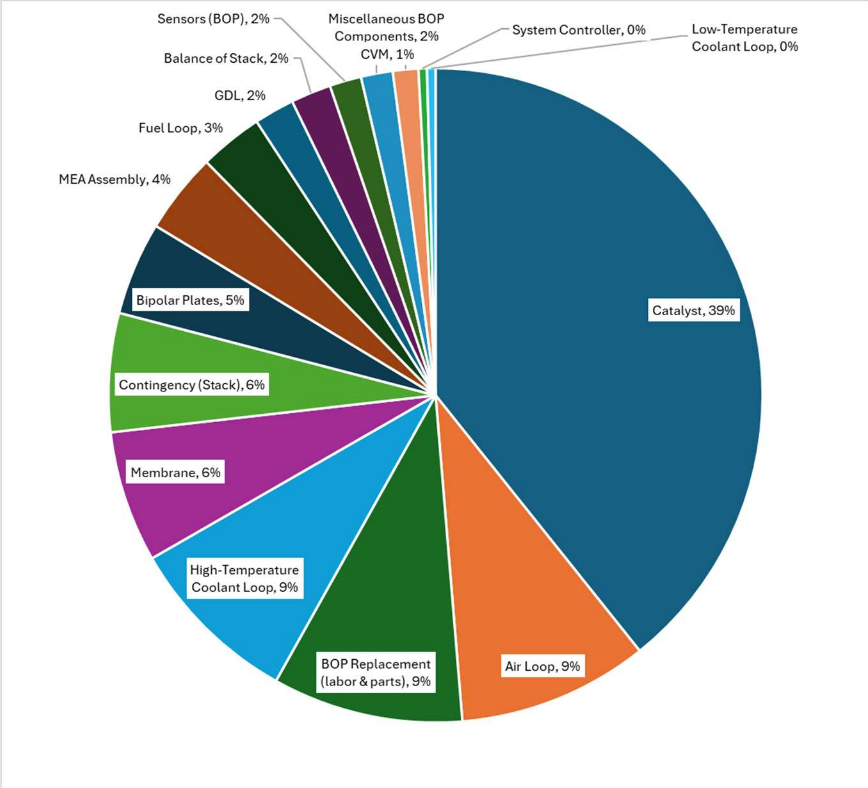


*Figure 68: 250 kW fuel cell system costs*

### *Battery Chemistries*

Online technology news sources will often comment on the uptake of a wide array of new battery chemistries. Lithium, nickel, cobalt, manganese and graphite are critical battery materials. Rare earths are required for permanent magnets that are vital EV motors*. "Electricity networks need a huge amount of copper and aluminium, with copper being a cornerstone for all electricity-related technologies.*" [119] It is likely that Lithium-ion chemistries will dominate for the foreseeable future. However, some commentators have highlighted that existing and planned (under construction) mining operations are only estimated to meet only half of projected lithium and cobalt demand and 80% of copper needs by 2030.

"*Energy transitions are already the major driving force for total demand growth for some minerals. Since 2015, EVs and battery storage have surpassed consumer electronics to become the largest consumers of lithium, together accounting for 30% of total current demand*." [120]

[119] IEA (2022): The Role of critical minerals in clean energy transitions: International energy agency (Online). https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions/mineral-requirements-for-clean-energy-transitions

[120] Fraunhofer ISI (2023): Alternative Battery Technologies Roadmap 2030+: Fraunhoffer Institute for Systems and Innovation Research (Online). https://www.isi.fraunhofer.de/content/dam/isi/dokumente/cct/2023/abt-roadmap.pdf

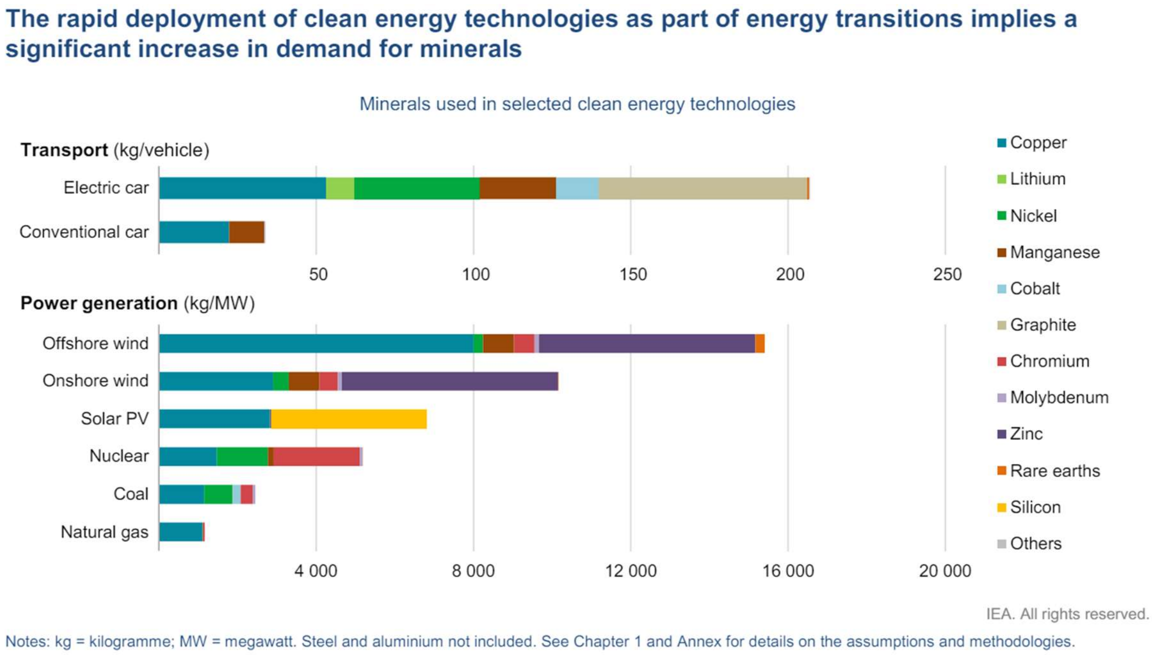


*Figure 69: Clean energy technology minerals demand [119]*

Overall, it has been estimated that to electrify all sectors that have stated ambitions to electrify as part of the **2050 net zero target would require a sixfold increase in global mineral mining activities by 2040.** [119]

Several other battery technologies are being studied and developed intensively to reduce constraints on Li-ion mineral supply chains. Alternative battery technologies that use cost-effective resources (lower cost compared to the incumbent Li-Ion technology) and abundant (increased security of supply for those nations with access to more abundant resources) are the most attractive for increased uptake. These cost-effective and abundant resources are inherently attractive to policymakers and manufacturers.

However, unless these alternative battery chemistry technologies make exceptional technical and manufacturing advances in the next decade, it is difficult to envisage a world where Li-ion battery systems are significantly displaced, especially as the proposed Li-ION recycling systems come online (assuming Li-Ion battery recycling plans proceed as planned over the next decade, which is far from certain).

Smaller, specialised, and luxury markets are the most likely route for novel battery chemistry to develop. For example, where longevity is more important than energy density, non-Li-ion chemistry may well find a significant niche, with Na-ION chemistries the current front runner to displace Li-Ion technology from the battery energy storage sector in the medium to long term. This in turn frees up existing and planned Li-ion supply chains to provide ever more transport solutions.

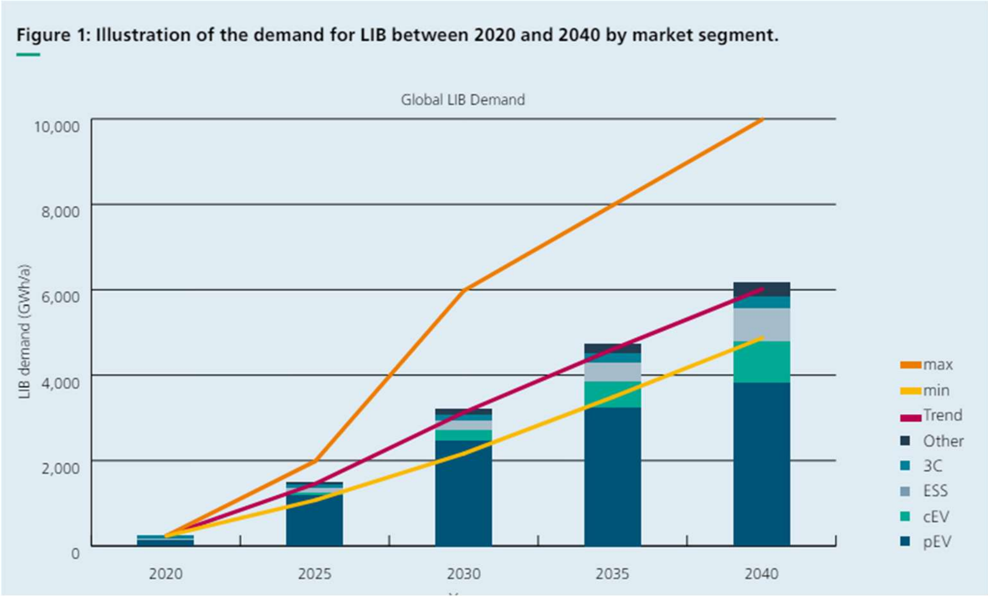


*Figure 70: Li-Ion battery technology demand forecast* **Error! Bookmark not defined.**

One more optimistic take on the issue of the lack of supply for critical net zero 2050 materials is that "*In the event of an oil supply crisis. By contrast, a shortage or spike in the price of a mineral affects only the supply of new EVs or solar plants. Consumers driving existing EVs or using solar-powered electricity are not affected. In addition, the combustion of oil means that new supply is essential to the continuous operation of oil-using assets. However, minerals are a component of infrastructure, with the potential to be recovered and recycled." [119]* It may be that supply constraint models based on combustion technologies overestimate the issue, though this may be small comfort, requiring only a fivefold increase in global mining activities to achieve net zero, and not six-fold!

## *Li-ion chemistries*

The anodes of most lithium-ion batteries are typically made from graphite, with the cathode made of a different mineral composition. Li-Ion composition of the cathode is what usually changes, making the difference between battery chemistries. Note that Lithium Titanate is one of the few battery chemistries applied to the graphite anode's surface.

The cathode material typically contains lithium along with other minerals including nickel, manganese, cobalt, or iron. Mix of these elements, and others, determines the battery's performance and cost.

There are six primary Li-Ion chemistries in common use

- Lithium Nickel Manganese Cobalt Oxide (NMC)
- Lithium Nickel Cobalt Aluminium Oxide (NCA)
- Lithium Iron Phosphate (LFP)
- Lithium Cobalt Oxide (LCO)
- Lithium Manganese Oxide (LMO)
- Lithium Titanate (LTO)

The seven most used Li-ion chemistries[121] are surmised in Figure 71.

[121] Marie, J.J. & Gifford, S. (2023): Developments in Lithium-Ion Battery Cathodes: Faraday Insights (18): Faraday Institute (Online). https://www.faraday.ac.uk/wp-content/uploads/2023/09/Faraday_Insights_18_FINAL.pdf

| Material formula | Abbreviation | Cost | Energy density | Thermal stability | Cycle life |
|---|---|---|---|---|---|
| $LiCoO_2$ | LCO | High | Moderate | Poor | Good |
| $LiFePO_4$ | LFP | Low | Low | Good | Good |
| $LiMn_2O_4$ | LMO | Low | Moderate | Good | Poor |
| $LiNi_{0.6}Mn_{0.2}Co_{0.2}O_2$ | NMC622 | High | High | Moderate | Good |
| $LiNi_{0.8}Mn_{0.1}Co_{0.1}O_2$ | NMC811 | High | High | Poor | Moderate |
| $LiNi_{0.8}Co_{0.15}Al_{0.05}O_2$ | NCA | High | High | Poor | Moderate |
| $Li_{1.2}Mn_{0.48}Ni_{0.16}Co_{0.16}O_2$ | LMR-NMC | Moderate | High | Moderate | Poor |

*Figure 71: seven most used Li-ion battery chemistries* [121]

There is a balancing act to be played with battery chemistries. Typically nickel increases the battery's energy density (longer ranges in EVs) but can make the battery unstable. Manganese and cobalt improve thermal stability and safety. NMC chemistries are reported based on the percentage presence of the constituents (NMC811 = 80% nickel, 10% manganese, and 10% cobalt, and NMC622 = 60% nickel, 20% manganese, and 20% cobalt.)

Aluminium also increase stability, but is less safe than other chemistries, costly, and therefore typically only used in in high-performance EVs.

Iron and phosphate are less costly than nickel and cobalt but have lesser specific energy result in shorter-range EVs (for batteries of the same size). LFP is considered one of the safest chemistries and has a long lifespan, enabling its use in energy storage systems with high cycle rates. At the time of writing, online automotive news sites reported that LFP battery chemistries were taking an ever-increasing market share for transport applications. [122 & 123]

Cobalt Oxide offers high energy-density improvements but results in a shorter battery lifespan, lower thermal stability, and limited specific power: this chemistry is well suited to low-power, small battery systems where cooling is easier (smartphones and laptops).

Manganese oxides batteries are more stable and suited to fast charging/discharging. LMO may be blended in with NMC battery packs to provide a more rounded performance (LMO for acceleration, NMO for long range driving, for example)

Lithium and titanium oxides applied in the anode, for improved safety and extreme temperature performance, but the battery capacity to store energy is highly compromised[124].

### Battery pack costings

Material costs for battery packs make up 58% of today's battery packs (anode, cathode, electrolyte, and separator films), or more if cell casing and current collectors are included (see Figure 72).

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[122] Pollard, J. (2023): LFP Becoming the Battery of Choice for Electric Vehicles: Asia Financial (Online). https://www.asiafinancial.com/lfp-becoming-the-battery-of-choice-for-electric-vehicles

[123] Clemmens, K. (2023): Tesla Kicks Off Future of LFP Batteries in EVs: EEPower.com (Online). https://eepower.com/tech-insights/tesla-kicks-off-future-of-lfp-batteries-in-evs/#

[124] Bhutada, G. (2023): The Six Major Types of Lithium-ion Batteries: A Visual Comparison: ElementsVisualCapitalist.com (Online). https://elements.visualcapitalist.com/the-six-major-types-of-lithium-ion-batteries/

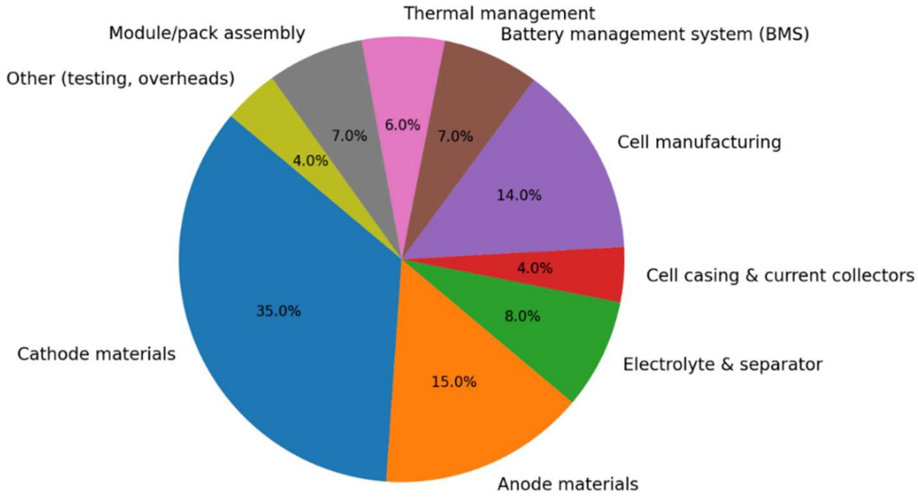


*Figure 72: Li-ion battery pack cost breakdown ($139/kWh – 2023/2024 percentages)* [125,126,127,]

### Worked 250 kW system battery equivalent scenario

The price equivalence for battery systems to a conventional 250 kW diesel engine is highly dependent on the hours of operation required between charging events[128] & [129]. Table 23 shows three scenarios of operations for a 275 peak power output system, operating at no more than 80% of maximum power output for 1, 4, and 8 hours.

*Table 23: 275 kW peak demand comparison scenarios for PiV powertrains*

| Duty (Hours) | Nameplate pack energy E_pack (kWh) | Indicative pack cost @ $115/kWh (US$) | Pack mass (LFP 135 Wh/kg → NMC 165 Wh/kg) | Approx. pack volume @ 450 Wh/L |
|---|---|---|---|---|
| 1 | 250/0.72 = 347 kWh | $40,000 | 2.59–2.12 t | 0.77 m³ |
| 4 | 1000/0.72 = 1,389 kWh | $160,000 | 10.30–8.42 t | 3.09 m³ |
| **8** | 2000/0.72 = 2,778 kWh | $319,000 | 20.60–16.84 t | 6.17 m³ |

This pricing excludes all charging infrastructure.

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[125] BloombergNEF, 2024 Lithium-Ion Battery Pack Prices See Largest Drop Since 2017, Falling to $115/kWh [Online] (Online). https://about.bnef.com/insights/commodities/lithium-ion-battery-pack-prices-see-largest-drop-since-2017-falling-to-115-per-kilowatt-hour-bloombergnef/ [Accessed 11 August 2025].

[126] Electrive.com, 2024 EV batteries now cost 115 USD per kWh on average [Online] (Online). https://www.electrive.com/2024/12/11/ev-batteries-now-cost-115-usd-per-kwh-on-average/ [Accessed 11 August 2025].

[127] pv-magazine-usa.com, 2024 BNEF: Lithium-ion battery pack prices drop to record low of $115/kWh [Online] (Online). https://pv-magazine-usa.com/2024/12/11/bnef-lithium-ion-battery-pack-prices-drop-to-record-low-of-115-kwh/ [Accessed 11 August 2025].

[128] U.S. DOE VTO (2022) FOTW #1234 — pack volumetric energy density trend (to ~450 Wh/L by 2020). (Online). https://www.energy.gov/eere/vehicles/articles/fotw-1234-april-18-2022-volumetric-energy-density-lithium-ion-batteries

[129] Argonne National Laboratory (2024) Estimated Cost of EV Batteries 2018–2023 (BatPaC-based) — $118/kWh rated. (online). https://www.anl.gov/sites/www/files/2024-06/EV%20Costs%202023%20for%20GPRA%20reporting%20%282023-09-17%29.pdf

### *Irreducible Film / Laminate Thicknesses in Li-ion Cells*

In battery pack design, it is not possible to reduce all inactive material indefinitely. There are practical lower bounds on current collectors, separator films/coatings, and cell-pack laminate structures (pouch, tabs, adhesives). These "irreducible" thicknesses, although small individually, accumulate across many layers. This generates a physical limit to the theoretical maximum specific energy and volumetric energy density of cells and packs (packs are made up of multiple cells, with additional control and cooling systems). The following table summarises typical baseline values and uncertainty bands for such components.

*Table 24: Irreducible Battery Component Thickness Ranges*

| Component | Lower-End Value | Range | Notes |
|---|---|---|---|
| **Cu current collector (anode side foil)** | ~ 6 µm | 4.5 µm to ~ 10 µm | Some ultra-thin foils of 4.5 µm are produced (though with yield/handling challenges). [130] |
| **Al current collector (cathode side foil)** | ~ 10 µm | ~ 8 µm to ~ 15 µm | In many designs, 10 µm is close to the practical floor; below that, mechanical strength and conductivity issues worsen[131] |
| **Separator base film** | ~ 8 µm | ~ 8 µm to ~ 12 µm | Typical commercial separators are in the 8–12 µm range[132]. |
| **Separator coatings (e.g. ceramic)** | ~ 0.5 to 3 µm | maybe up to ~ 5 µm | Coatings (e.g. $Al_2O_3$ or ceramic) are used for safety, thermal stability or shutdown behaviour; they add thickness but must remain thin[133]. |
| **Pouch / laminate / polymer envelope / adhesives / tabs** | ~ 20 µm (single layer polymer) | 10 µm to 50 µm (or more, depending on design) | Pouch film, tab overlaps, adhesive layers, insulating films, and edge seals all contribute. The effective "thickness" is often design-dependent and may include structural margin. (Note: this is less well reported in open literature.) |

**Lower-End Value** is the cutting edge of processing technology. These values have been demonstrated in advanced research or the best commercial practices. These tolerances are not achievable with low-cost production methodologies and are challenging to achieve at high enough yield rates to justify mass production investment.

**Range** reflects the tolerances, variation in supplier technology, and trade-offs (strength, yield, handling) for each component. Adhesives, tab overlaps, insulation, and mechanical supports are not always reported, and effective thickness may vary widely by cell format and safety margin.

**Manufacturing yield and mechanical robustness:** Thinner foils or films are harder to handle, more prone to tearing, wrinkling or defects during roll-to-roll processing, slitting, coating, winding or stacking. The thinner the material, the steeper the yield losses unless advanced material controls are used.

**Electrical, thermal, and mechanical trade-offs:** Reducing thickness also increases resistance (ohmic drop) and reduces mechanical stiffness, which may degrade high-C performance, especially across large

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[130] QuantumScape (2023) Energy density inactive materials and packaging efficiency (online) https://www.quantumscape.com/energy-density-inactive-materials-and-packaging-efficiency

[131] Scherzl P et al 2023 Electroforming as a Novel One Step Manufacturing Method for Li ion Current Collectors Batteries 9(8):422 (online) https://www.sciencedirect.com/science/article/pii/S2405829725000741

[132] TOB Machines .com (2025). 8µm 12µm PE Polyethylene Separator for Lithium ion Battery Specification. (Online) https://www.tobmachine.com/8-m-12-m-pe-battery-separator_p949.html

[133] Yomecs (2025). Lib Separator 12 µm Polyethylene Base Film Ceramic Coated. (online) https://youmecs.com/lib-separator-12-%CE%BCm-pe-film-ceramic-coated

cells or wide electrode geometries. In some studies, once foil thickness falls too far, the voltage drop across the collector becomes non-negligible (especially at high currents)[134].

**Separator safety/scrubbing tolerance:** The separator must maintain integrity under stress, temperature, and potential mechanical deformation. Very thin separators increase risk of puncture, shorting, or shrinkage under abuse. Several studies in the field of thin separator research report improved performance but also increased hazard sensitivity. Most recently, the report by Chung et al [135].

**Pack-level overhead accrual**: Even if cell internal films are optimised, at the pack level, additional components (interconnects, insulation, thermal barriers, structural frames, cell spacing and so on) accumulate. In practical EV or grid supporting battery packs, pack overhead (mass or volume not used for active electrochemical energy) can be 20–40% or more of the total.

**Diminishing returns at the margin**: As we have reduced 'inactive' thicknesses (for example, copper foil from ~20 μm historically to ~6 μm[130]) further gains become increasingly difficult to achieve. Mechanical, electrical and yield constraints limit progress. Any theoretical "zero thickness" of inactive layers is unattainable in realistic manufacturing.

**On vehicle battery installation and range impacts:** Automakers have increased a vehicle's effective driving range over time by fitting batteries with higher energy density into the same physical packaging envelope, achieving more kWh in the same volume[136, 137]. When adjusting for price and like-for-like vehicle specifications, a 1% improvement in battery pack capacity will result in a 0.5% to 0.8% increase in vehicle driving range. The 0.8% upper end is the physics-derived net result. Real-world manufacturing and installation processes typically equate to the 0.5% end of the potential range improvement [58, 138]

Taking all the above points together, this equates to **a likely ~25% improvement in battery pack power density between 2025 and 2037, which in turn equates to a ~13% uplift in PiV maximum range**, for existing battery chemistries.

### *Alternate battery chemistries*

Significant global investment in battery manufacturing technology has been focused on Li-ion chemistries. This results in a designed-in bias that is likely to promote Li-ion chemistries for the foreseeable future further.[139]

However, in applications requiring high energy and power density, Sodium ion (Na-ion) is the closest to commercialisation and approaches LFP cells in terms of performance (LFP). Na-ion is well suited 2–3 wheeled vehicles and small cars[139], and may play a significant role in diminishing demand for Li-ion technology for battery storage technologies (freeing up the supply chain to provide Li-ion to transport and mobile machinery markets). Of particular interest is the processing for Na-ion batteries is very similar to Li-ion.

This opens the possibility of Li-ion factories switching some or all their manufacturing capacity to Na-ion with little more than a thorough clean between production runs. As Li-ion mineral supplies become more constrained, Na-ion chemistry will become increasingly attractive to battery manufacturers seeking to keep their factories operating 24 hours a day.

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[134] Reiher M et al (2021) Cell Supply Chain Management and Surveillance Test Program. NASA (Online) https://arxiv.org/abs/2501.08436

[135] Chung R (2024) New Li-ion Technology Trends and Validation Process. NASA. (online) https://pmc.ncbi.nlm.nih.gov/articles/PMC9649724/?utm_source=chatgpt.com

[136] BMWBlog (2016) Battery cells physically the same size hold 50 % more energy in i3 94 Ah version available at https://www.bmwblog.com/2016/07/14/bmw-i3-battery-replacement-94ah-package-7000-euros/

[137] Car and Driver (2025) 2025 Porsche Taycan achieves higher capacity in identical battery footprint via improved chemistry available at https://www.caranddriver.com/news/a65491280/2025-porsche-taycan-huge-range-efficiency-gains-tested/

[138] BloombergNEF 2024 Lithium-ion battery pack prices fell 20% to $115/kWh available at https://about.bnef.com/insights/commodities/lithium-ion-battery-pack-prices-see-largest-drop-since-2017-falling-to-115-per-kilowatt-hour-bloombergnef/

[139] Fraunhofer ISI (2024): Benchmarking International Battery Policies: Fraunhofer ISI (Online). file:///C:/Users/nick.mccarthy/Downloads/benchmarking-international-battery-policies_2024.pdf

### *Solid state*

Reviewing the details for any claimed solid-state batteries reported in the press is important. Historically, many of the headline claims of breakthroughs in "solid-state" battery manufacturing are little more than slight improvements in liquid electrolyte battery chemistries with increased electrolyte viscosity being touted as "solid-state" or "semi-solid state". True solid-state battery chemistries (with their anticipated improvement in performance) have been developed, and a few commercialisations seem feasible. However, the manufacturing processes for solid-state deposition typically involve extremely low-pressure vacuum, which is difficult to mass-produce. [140]

For example, Toyota's proposed mass production of solid-state batteries (to be for sale as a commercial product by the 2030 [141]) will be limited to a peak production plant producing 10,000 packs per year (approximately 0.1% of Toyota's annual passenger car engine production for its own Toyota-branded vehicles).

There are many possible combinations of anodes, solid electrolytes and cathode concepts. Li metal anodes show potential for having the highest energy densities, but the technology for processing them is not yet well-established for large-scale manufacturing. Na-based anodes, on the other hand, are considered the technology of choice for next-generation solid-state Li-ion batteries. However, the energy densities of Na-anode-based solid-state batteries are low (though research continues). Solid-state cells with the highest energy densities can be achieved using NMC/NCA layered oxides. LFP materials are interesting mainly because of their lower costs and greater stability. [142]

Modern battery chemistries use a liquid electrolyte. A solid-state battery seeks to use a solid electrolyte. The USA, China, and South Korea are all investing heavily [140, 143] in this technology, and if anyone is to reverse the trend of solid-state batteries being anything more than high-priced luxury goods, it will probably be the South Korean battery manufacturers. Careful attention to news from this region is recommended.

### *Other niche chemistries*

A raft of possible battery chemistries is being researched. The interested reader is directed to the recent report by the for details, see Fraunhofer Institute reports:

- Fraunhofer ISI (2024): Benchmarking International Battery Policies: Fraunhofer ISI (online): https://www.isi.fraunhofer.de/content/dam/isi/dokumente/cct/2024/benchmarking-international-battery-policies_2024.pdf
- Marie, J.J. & Gifford, S. (2023): Developments in Lithium-Ion Battery Cathodes: Faraday Insights (18): Faraday Institute (online): https://www.faraday.ac.uk/wp-content/uploads/2023/09/Faraday_Insights_18_FINAL.pdf

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140 Inclán, I.R. (2024): Solid-state batteries for electric vehicles: Still in R&D or on the verge of commercialization?. Fraunhofer ISI.de (Online). https://www.isi.fraunhofer.de/en/blog/themen/batterie-update/feststoffbatterien-elektro-autos-kommerzialisierung-stand-forschung-entwicklung.html

141 Shah, A. (2024): Toyota to roll out solid-state battery EVs globally in a couple of years: Reuters (Online). https://www.reuters.com/business/autos-transportation/toyota-roll-out-solid-state-battery-evs-couple-years-india-executive-says-2024-01-11/

142 Fraunhofer ISI (2022): Solid State battery roadmap 2035+: Fraunhofer ISI (Online). https://www.isi.fraunhofer.de/content/dam/isi/dokumente/cct/2022/SSB_Roadmap.pdf

143 Papadopoulos, L. (2023): South Korea aims to deliver the world's first solid state-batteries for EVs: Interesting engineering.com (Online). https://interestingengineering.com/innovation/south-korea-worlds-first-solid-state-batteries

### *Peak Battery Performance Impacts on modelling assumptions*

### *Cenex internal data review (2023 to 2025) of 19,500 vehicles*

Cenex have completed a high-level review of the 20 or so fleets analysed by us over the last two and a half years. The fleets approaching Cenex for assistance in decarbonising their vehicles are somewhat self-selecting and are likely to include those fleets that find it most difficult to convert their vehicles to PiV equivalents.

Of the 20 fleets analysed, 50% had assessed annual mileage data, combined with monthly fuel reports. The remaining 50% were analysed in the same manner; however, representative vehicles and routes were monitored in far greater detail, either through the analysis of existing telemetry and fuel card records, or through the use of our in-house telemetric systems and detailed refuelling records.

The summarised results are presented in Table 25.

*Table 25: Cenex 2023 to 2025 fleet review assessment*

| | | | |
|---|---|---|---|
| **Local authority fleets** | | | | |
| 10 LA fleet examined in 2024/25 | | 1,337 Car & LCVs (=<3.5t) | | |
| | mean | % that may be possible with top up charging | likely 2050 13% range improvements | 2050 with top ups |
| % Cars that can transition today* | 59% | 89% | 67% | 100% |
| % LCVs (<3.5t) that can transition today* | 47% | 71% | 53% | 80% |
| **Blue light fleet** | | | | |
| over 17,000 vehicles considered (mean of means) 2024 | mean | % that may be possible with top up charging, ignoring TCO | likely 2050 13% range improvements | 2050 with top ups |
| Cars & LCVs (=<3.5t) that can transition to BEV today** | 21% | 32% | 24% | 36% |
| HGVs that can transition today** | 54% | 81% | 61% | 92% |
| **Utilities providers** | | | | |
| over 600 vehicles considered (2021/22) (inc PTO) | mean | % that may be possible with top up charging, ignoring TCO | likely 2050 13% range improvements | 2050 with top ups |
| Cars & LCVs (=<3.5t) that can transition to BEV today** | 49% | 74% | 55% | 83% |
| **Facilities provider** | | | | |
| over 600 vehicles considered (2021/22) (inc PTO) | mean | % that may be possible with top up charging, ignoring TCO | likely 2050 13% range improvements | 2050 with top ups |
| Cars & LCVs (=<3.5t) that can transition to BEV today** | 54% | 81% | 61% | 91% |
| HGVs that can transition today** | 8% | 13% | 10% | 14% |

* Vehicle are either able to compete on TCO AND meet the '2x daily average milage BEV range' rule of thumb

** vehicles with an average daily milage of <50% max BEV range (no TCO assessment)

All reported 'mean' values are a 'mean of means' across multiple vehicles, teams, and organisations

## Duty Cycles and Breakpoints

### Overview

A **duty cycle** describes how a vehicle or machine operates in real-world conditions over time. It covers how long it runs, how hard it works (load), and how much time it spends idling, accelerating, braking or stopped. Engineers use duty cycles to size engines, fuel systems, batteries or hydrogen tanks, and to estimate emissions and energy use.

### Cars and Light Commercial Vehicles (LCVs)

The ARTEMIS programme (“Assessment and Reliability of Transport Emission Models and Inventory Systems”) was an EU research project under the 5th Framework. One of its main outputs is a set of standardised European driving cycles representing typical real-world driving:

- **Urban:** low speed, frequent stops, high idling.
- **Rural/Road:** medium speed, fewer stops, mixed accelerations.
- **Motorway:** sustained high speed, minimal stops.

Each ARTEMIS cycle is a speed-versus-time trace (seconds on the x-axis, speed in km/h on the y-axis) that implicitly encodes power demand, accelerations, decelerations and idle time.

Cenex have developed a modified ARTEMIS cycle with an additional “mixed” category that combines elements from all three cycles. This has proven effective for assessing road traffic in the UK. The battery-suitability assumptions in this report are based primarily on ARTEMIS duty-cycle modelling, combined with operational data for non-standard duty cycles.

In the LCV sector, a well-populated database of energy demands, battery sizes, and costs enables the modelling of best- and worst-case scenarios for new technologies. This report defines a **breakpoint for battery adoption in LCVs at a gross vehicle weight of over 2.5 tonnes, where longer, more energy-intensive duty cycles, power take-off requirements,** and off-road capability begin to limit battery-only solutions.

### Non-Road Mobile Machinery (NRMM) and Generator Sets

Duty cycles for NRMM are highly variable and complex. The assessments in this report draw heavily on stakeholder work by ERM and Cenex (ERM, 2023: *Industrial Non-Road Mobile Machinery Decarbonisation Options: Techno-Economic Feasibility Study*[75]), which mapped NRMM duty cycles across multiple sectors.

Energy-density calculations show that, with current battery chemistry, plug-in vehicles (PiV) are extremely unlikely to meet the energy demands of many larger pieces of NRMM. Efficiency improvements and duty cycles with significant regenerative energy opportunities may enable cost-effective adoption in some cases.

However, for most large NRMMs, which periodically operate at very high intensity (multiple shifts per day for weeks at a time), electrification outside urban environments remains challenging. This report, therefore, defines **breakpoints for battery adoption in NRMM at 3.5 tonnes and 8 tonnes, reflecting the rising energy demand and the reduced** feasibility of battery solutions in heavier equipment. Extensive government subsidies may encourage adoption of larger PiV NRMM in some locations, but are unlikely to alter the technical breakpoints in the near term.

### Maritime

Duty cycles for shipping are even more problematic than for NRMM. For this reason, the analysis in this report focuses on total fuel consumption and calculated total $CO_2e$ use as the primary assessment tools, with limited input from vessel size, type, country of origin, estimated range and sector of operation. Proposed efficiency improvements further complicate attempts to model uptake by blurring the technical levers available.

Any rigorous treatment of ship energy consumption today would need to be reassessed as efficiency improvements are introduced in each segment. The **breakpoints for maritime** are also obscured by the need to differentiate between all ship energy demands, partial energy demands through dual-fuel or fuel-switching practices, and variations in shore-side power requirements, commonly referred to as “hotel loads.”

For this report, we assume that, once a given total energy demand is assigned to hydrogen, the percentage share of shipping energy demands (both propulsion and hotel loads) remains constant even if the exact shipping segment served changes.

For example, based on recent work completed by Cenex, a 10,000 GT cargo vessel travelling no more than 132 nm between refuelling stops could obtain around **10 % of its total energy demand from hydrogen**, either through a dual-fuel system or fuel switching to achieve near-zero air-quality emissions while in port. As vessels get smaller, this percentage energy contribution can rise, but hydrogen storage volume makes fuelling vessels below about **500 GT** difficult.

As battery technology for maritime applications improves, the lower end of this hydrogen-suitable range (500–10,000 GT) will increasingly shift to batteries, while ship efficiency gains will extend the upper end of the range of ships able to supply some or all of their energy demands through gaseous hydrogen. This report assumes these two effects cancel each other out, leaving the total hydrogen demand effectively unchanged, but confidence in this assumption is low. Net-zero combustion technologies for the maritime sector remain at an early stage of development.

**Suggested Breakpoint Table**

These sectoral break points inform our initial iterations in model development, alongside the roads reported in section 2. These breakpoints can be considered the lower limit (or range in the case of maritime) for the applicability of hydrogen technologies. There may well be a small percentage niche where hydrogen technologies can be utilised beyond the limits of these break points, but the majority of hydrogen fuel sales in each sector are assumed to follow this logic.

*Table 26: modelling assumptions, first iteration 'break point' assumptions on uptake of hydrogen fuel*

| Sector | Breakpoint(s) | Key Limiting Factors |
|---|---|---|
| **LCVs** | >2.5 t GVW | Longer duty cycles, PTO, off-road capability |
| **NRMM** | 3.5 t and 8 t | Rising energy demand, high-intensity operation |
| **Maritime** | ~500 GT to 10 000 GT (hydrogen share viable) | Storage volume, efficiency gains, battery competition |

# Appendix D: Modelling results

Additional details of model runs, graphs, and other data that are not included in the main body.

# Appendix E: Modelling Assumptions

*Table 27: Energy per mile for vehicle sizes, fuel types (Cars and LCVs)*

| Type | Size | Fuel | kWh per Mile |
|---|---|---|---|
| Cars | Small | Battery | 0.26 |
| Cars | Small | Biofuel | 1.09 |
| Cars | Small | HVO | 1.06 |
| Cars | Small | FCEV | 0.51 |
| Cars | Small | H2-ICE | 0.95 |
| Cars | Small | Methane | 0.9 |
| Cars | Small | ICE | 1.06 |
| Cars | Medium | Battery | 0.30 |
| Cars | Medium | Biofuel | 1.36 |
| Cars | Medium | HVO | 1.32 |
| Cars | Medium | FCEV | 0.56 |
| Cars | Medium | H2-ICE | 1.10 |
| Cars | Medium | Methane | 1.15 |
| Cars | Medium | ICE | 1.32 |
| Cars | Large | Battery | 0.36 |
| Cars | Large | Biofuel | 2.01 |
| Cars | Large | HVO | 1.95 |
| Cars | Large | FCEV | 0.7 |
| Cars | Large | H2-ICE | 1.45 |
| Cars | Large | Methane | 1.6 |
| Cars | Large | ICE | 1.95 |
| LCVS | Small | Battery | 0.35 |
| LCVS | Small | Biofuel | 1.02 |
| LCVS | Small | HVO | 0.98 |
| LCVS | Small | FCEV | 0.65 |
| LCVS | Small | H2-ICE | 1.2 |
| LCVS | Small | Methane | 1.15 |
| LCVS | Small | ICE | 1.31 |
| LCVS | Medium | Battery | 0.48 |
| LCVS | Medium | Biofuel | 1.32 |
| LCVS | Medium | HVO | 1.28 |
| LCVS | Medium | FCEV | 0.8 |
| LCVS | Medium | H2-ICE | 1.5 |
| LCVS | Medium | Methane | 1.45 |
| LCVS | Medium | ICE | 1.43 |

| | | | |
|---|---|---|---|
| LCVS | Large | Battery | 0.65 |
| LCVS | Large | Biofuel | 1.88 |
| LCVS | Large | HVO | 1.83 |
| LCVS | Large | FCEV | 1.1 |
| LCVS | Large | H2-ICE | 2.1 |
| LCVS | Large | Methane | 2.05 |
| LCVS | Large | ICE | 2.24 |

*Table 28: Average annual mileage by vehicle size, fuel type and country in 2024 (Cars and LCVs)*

| Location | Type | Size | Fuel | Average Annual Mileage | notes on mileage |
|---|---|---|---|---|---|
| **England** | Cars | Small | Battery | 9628.7 | mot average |
| **England** | Cars | Small | Biofuel | 6730.6 | Assumed ICE MOT average - No mileage for vehicle of this class |
| **England** | Cars | Small | HVO | 6730.6 | Assumed ICE MOT average - No mileage for vehicle of this class |
| **England** | Cars | Small | FCEV | 7073.7 | mot average |
| **England** | Cars | Small | H2-ICE | 6730.6 | Assumed ICE MOT average - No mileage for vehicle of this class |
| **England** | Cars | Small | Methane | 6518.9 | mot average |
| **England** | Cars | Small | ICE | 6730.6 | mot average |
| **England** | Cars | Medium | Battery | 9628.7 | mot average |
| **England** | Cars | Medium | Biofuel | 6730.6 | Assumed ICE MOT average - No mileage for vehicle of this class |
| **England** | Cars | Medium | HVO | 6730.6 | Assumed ICE MOT average - No mileage for vehicle of this class |
| **England** | Cars | Medium | FCEV | 7073.7 | mot average |
| **England** | Cars | Medium | H2-ICE | 6730.6 | Assumed ICE MOT average - No mileage for vehicle of this class |
| **England** | Cars | Medium | Methane | 6518.9 | mot average |
| **England** | Cars | Medium | ICE | 6730.6 | mot average |

| Location | Type | Size | Fuel | Average Annual Mileage | notes on mileage |
|---|---|---|---|---|---|
| England | Cars | Large | Battery | 9628.7 | mot average |
| England | Cars | Large | Biofuel | 6730.6 | Assumed ICE MOT average - No mileage for vehicle of this class |
| England | Cars | Large | HVO | 6730.6 | Assumed ICE MOT average - No mileage for vehicle of this class |
| England | Cars | Large | FCEV | 7073.7 | mot average |
| England | Cars | Large | H2-ICE | 6730.6 | Assumed ICE MOT average - No mileage for vehicle of this class |
| England | Cars | Large | Methane | 6518.9 | mot average |
| England | Cars | Large | ICE | 6730.6 | mot average |
| England | LCVS | Small | Battery | 5237.75 | mot average |
| England | LCVS | Small | Biofuel | 8223.45 | Assumed ICE MOT average - No mileage for vehicle of this class |
| England | LCVS | Small | HVO | 8223.45 | Assumed ICE MOT average - No mileage for vehicle of this class |
| England | LCVS | Small | FCEV | 10439 | mot average - low number of vehicles [1] |
| England | LCVS | Small | H2-ICE | 8223.45 | Assumed ICE MOT average - No mileage for vehicle of this class |
| England | LCVS | Small | Methane | 4876.4 | mot average |
| England | LCVS | Small | ICE | 8223.45 | mot average |
| England | LCVS | Medium | Battery | 5237.75 | mot average |
| England | LCVS | Medium | Biofuel | 8223.45 | Assumed ICE MOT average - No mileage for vehicle of this class |
| England | LCVS | Medium | HVO | 8223.45 | Assumed ICE MOT average - No mileage for vehicle of this class |
| England | LCVS | Medium | FCEV | 10439 | mot average - low number of vehicles [1] |

| Location | Type | Size | Fuel | Average Annual Mileage | notes on mileage |
|---|---|---|---|---|---|
| **England** | LCVS | Medium | H2-ICE | 8223.45 | Assumed ICE MOT average - No mileage for vehicle of this class |
| **England** | LCVS | Medium | Methane | 4876.4 | mot average |
| **England** | LCVS | Medium | ICE | 8223.45 | mot average |
| **England** | LCVS | Large | Battery | 6803.6 | mote average |
| **England** | LCVS | Large | Biofuel | 11369.75 | Assumed ICE MOT average - No mileage for vehicle of this class |
| **England** | LCVS | Large | HVO | 11369.75 | Assumed ICE MOT average - No mileage for vehicle of this class |
| **England** | LCVS | Large | FCEV | 11369.75 | Assumed ICE MOT average - No mileage for vehicle of this class |
| **England** | LCVS | Large | H2-ICE | 11369.75 | Assumed ICE MOT average - No mileage for vehicle of this class |
| **England** | LCVS | Large | Methane | 4693.9 | mot average - low number of vehicles [2] |
| **England** | LCVS | Large | ICE | 11369.75 | mot average |
| **Scotland** | Cars | Small | Battery | 8435.15 | mot average |
| **Scotland** | Cars | Small | Biofuel | 7091.95 | Assumed ICE MOT average - No mileage for vehicle of this class |
| **Scotland** | Cars | Small | HVO | 7091.95 | Assumed ICE MOT average - No mileage for vehicle of this class |
| **Scotland** | Cars | Small | FCEV | 10336.8 | Assumed ICE MOT average - No mileage for vehicle of this class |
| **Scotland** | Cars | Small | H2-ICE | 7091.95 | Assumed ICE MOT average - No mileage for vehicle of this class |
| **Scotland** | Cars | Small | Methane | 3894.55 | mot average |
| **Scotland** | Cars | Small | ICE | 7091.95 | mot average |

| Location | Type | Size | Fuel | Average Annual Mileage | notes on mileage |
|---|---|---|---|---|---|
| **Scotland** | Cars | Medium | Battery | 8435.15 | mot average |
| **Scotland** | Cars | Medium | Biofuel | 7091.95 | Assumed ICE MOT average - No mileage for vehicle of this class |
| **Scotland** | Cars | Medium | HVO | 7091.95 | Assumed ICE MOT average - No mileage for vehicle of this class |
| **Scotland** | Cars | Medium | FCEV | 10336.8 | Assumed ICE MOT average - No mileage for vehicle of this class |
| **Scotland** | Cars | Medium | H2-ICE | 7091.95 | Assumed ICE MOT average - No mileage for vehicle of this class |
| **Scotland** | Cars | Medium | Methane | 3894.55 | mot average |
| **Scotland** | Cars | Medium | ICE | 7091.95 | mot average |
| **Scotland** | Cars | Large | Battery | 8435.15 | mot average |
| **Scotland** | Cars | Large | Biofuel | 7091.95 | Assumed ICE MOT average - No mileage for vehicle of this class |
| **Scotland** | Cars | Large | HVO | 7091.95 | Assumed ICE MOT average - No mileage for vehicle of this class |
| **Scotland** | Cars | Large | FCEV | 10336.8 | mot average |
| **Scotland** | Cars | Large | H2-ICE | 7091.95 | Assumed ICE MOT average - No mileage for vehicle of this class |
| **Scotland** | Cars | Large | Methane | 3894.55 | mot average |
| **Scotland** | Cars | Large | ICE | 7091.95 | mot average |
| **Scotland** | LCVS | Small | Battery | 4810.7 | mot average |
| **Scotland** | LCVS | Small | Biofuel | 8584.8 | Assumed ICE MOT average - No mileage for vehicle of this class |
| **Scotland** | LCVS | Small | HVO | 8584.8 | Assumed ICE MOT average - No mileage for vehicle of this class |

| Location | Type | Size | Fuel | Average Annual Mileage | notes on mileage |
|---|---|---|---|---|---|
| **Scotland** | LCVS | Small | FCEV | 8584.8 | Assumed ICE MOT average - No mileage for vehicle of this class |
| **Scotland** | LCVS | Small | H2-ICE | 8584.8 | Assumed ICE MOT average - No mileage for vehicle of this class |
| **Scotland** | LCVS | Small | Methane | 8584.8 | Assumed ICE MOT average - No mileage for vehicle of this class |
| **Scotland** | LCVS | Small | ICE | 8584.8 | mot average |
| **Scotland** | LCVS | Medium | Battery | 4810.7 | mot average |
| **Scotland** | LCVS | Medium | Biofuel | 8584.8 | Assumed ICE MOT average - No mileage for vehicle of this class |
| **Scotland** | LCVS | Medium | HVO | 8584.8 | Assumed ICE MOT average - No mileage for vehicle of this class |
| **Scotland** | LCVS | Medium | FCEV | 8584.8 | Assumed ICE MOT average - No mileage for vehicle of this class |
| **Scotland** | LCVS | Medium | H2-ICE | 8584.8 | Assumed ICE MOT average - No mileage for vehicle of this class |
| **Scotland** | LCVS | Medium | Methane | 8584.8 | Assumed ICE MOT average - No mileage for vehicle of this class |
| **Scotland** | LCVS | Medium | ICE | 8584.8 | mot average |
| **Scotland** | LCVS | Large | Battery | 7686.9 | mot average |
| **Scotland** | LCVS | Large | Biofuel | 11008.4 | Assumed ICE MOT average - No mileage for vehicle of this class |
| **Scotland** | LCVS | Large | HVO | 11008.4 | Assumed ICE MOT average - No mileage for vehicle of this class |

| Location | Type | Size | Fuel | Average Annual Mileage | notes on mileage |
|---|---|---|---|---|---|
| **Scotland** | LCVS | Large | FCEV | 11008.4 | Assumed ICE MOT average - No mileage for vehicle of this class |
| **Scotland** | LCVS | Large | H2-ICE | 11008.4 | Assumed ICE MOT average - No mileage for vehicle of this class |
| **Scotland** | LCVS | Large | Methane | 11008.4 | Assumed ICE MOT average - No mileage for vehicle of this class |
| **Scotland** | LCVS | Large | ICE | 11008.4 | mot average |
| **Wales** | Cars | Small | Battery | 8504.5 | mot_average |
| **Wales** | Cars | Small | Biofuel | 7066.4 | Assumed ICE MOT average - No mileage for vehicle of this class |
| **Wales** | Cars | Small | HVO | 7066.4 | Assumed ICE MOT average - No mileage for vehicle of this class |
| **Wales** | Cars | Small | FCEV | 3770.45 | mot_average |
| **Wales** | Cars | Small | H2-ICE | 7066.4 | Assumed ICE MOT average - No mileage for vehicle of this class |
| **Wales** | Cars | Small | Methane | 9464.45 | mot_average |
| **Wales** | Cars | Small | ICE | 7066.4 | mot_average |
| **Wales** | Cars | Medium | Battery | 8504.5 | mot_average |
| **Wales** | Cars | Medium | Biofuel | 7066.4 | Assumed ICE MOT average - No mileage for vehicle of this class |
| **Wales** | Cars | Medium | HVO | 7066.4 | Assumed ICE MOT average - No mileage for vehicle of this class |
| **Wales** | Cars | Medium | FCEV | 3770.45 | mot_average |
| **Wales** | Cars | Medium | H2-ICE | 7066.4 | Assumed ICE MOT average - No mileage for vehicle of this class |
| **Wales** | Cars | Medium | Methane | 9464.45 | mot_average |
| **Wales** | Cars | Medium | ICE | 7066.4 | mot_average |

| Location | Type | Size | Fuel | Average Annual Mileage | notes on mileage |
|---|---|---|---|---|---|
| **Wales** | Cars | Large | Battery | 8504.5 | mot_average |
| **Wales** | Cars | Large | Biofuel | 7066.4 | Assumed ICE MOT average - No mileage for vehicle of this class |
| **Wales** | Cars | Large | HVO | 7066.4 | Assumed ICE MOT average - No mileage for vehicle of this class |
| **Wales** | Cars | Large | FCEV | 3770.45 | mot_average |
| **Wales** | Cars | Large | H2-ICE | 7066.4 | Assumed ICE MOT average - No mileage for vehicle of this class |
| **Wales** | Cars | Large | Methane | 9464.45 | mot_average |
| **Wales** | Cars | Large | ICE | 7066.4 | mot_average |
| **Wales** | LCVS | Small | Battery | 5259.65 | mot_average |
| **Wales** | LCVS | Small | Biofuel | 7807.35 | Assumed ICE MOT average - No mileage for vehicle of this class |
| **Wales** | LCVS | Small | HVO | 7807.35 | Assumed ICE MOT average - No mileage for vehicle of this class |
| **Wales** | LCVS | Small | FCEV | 7807.35 | Assumed ICE MOT average - No mileage for vehicle of this class |
| **Wales** | LCVS | Small | H2-ICE | 7807.35 | Assumed ICE MOT average - No mileage for vehicle of this class |
| **Wales** | LCVS | Small | Methane | 14793.45 | mot_average - low number of vehicles [1] |
| **Wales** | LCVS | Small | ICE | 7807.35 | mot_average |
| **Wales** | LCVS | Medium | Battery | 5259.65 | MOT_average |
| **Wales** | LCVS | Medium | Biofuel | 7807.35 | Assumed ICE MOT average - No mileage for vehicle of this class |
| **Wales** | LCVS | Medium | HVO | 7807.35 | Assumed ICE MOT average - No mileage for vehicle of this class |

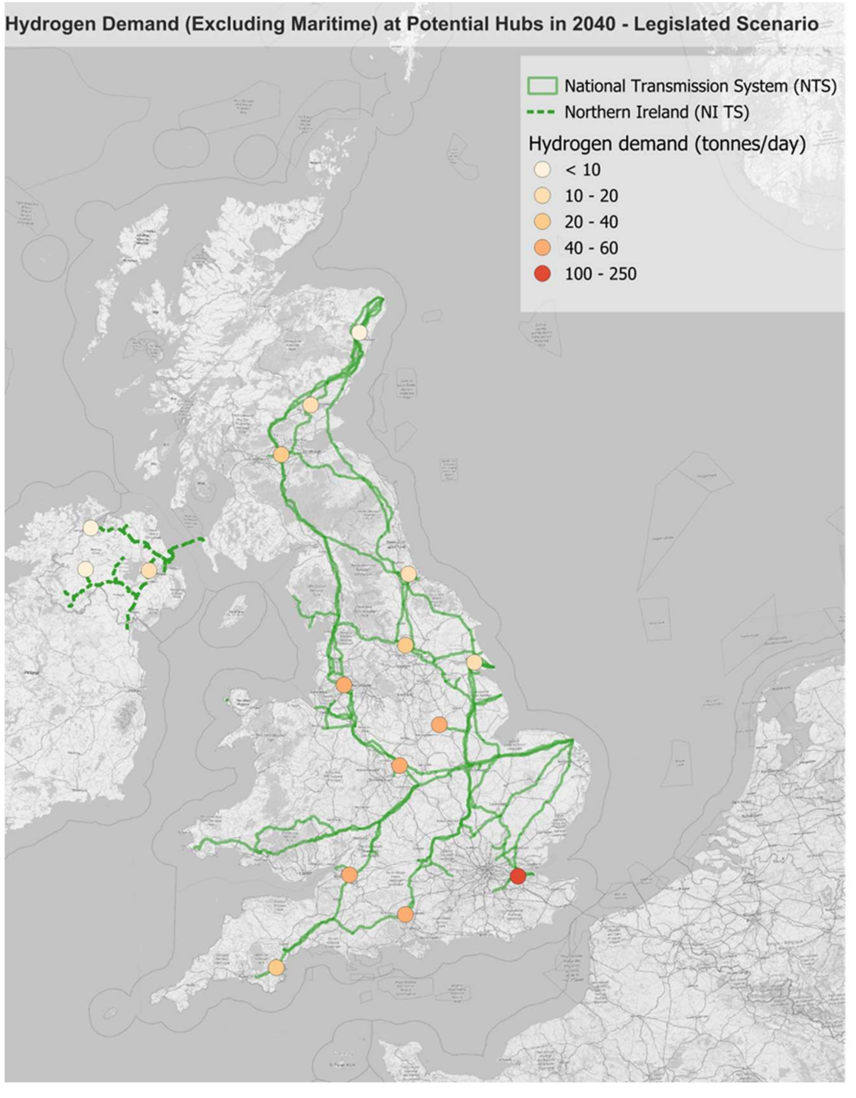
| Location | Type | Size | Fuel | Average Annual Mileage | notes on mileage |
|---|---|---|---|---|---|
| **Wales** | LCVS | Medium | FCEV | 7807.35 | Assumed ICE MOT average - No mileage for vehicle of this class |
| **Wales** | LCVS | Medium | H2-ICE | 7807.35 | Assumed ICE MOT average - No mileage for vehicle of this class |
| **Wales** | LCVS | Medium | Methane | 14793.45 | mot_average - low number of vehicles [1] |
| **Wales** | LCVS | Medium | ICE | 7807.35 | Wales MOT average |
| **Wales** | LCVS | Large | Battery | 7595.65 | Wales MOT average |
| **Wales** | LCVS | Large | Biofuel | 10201.75 | Assumed ICE MOT average - No mileage for vehicle of this class |
| **Wales** | LCVS | Large | HVO | 10201.75 | Assumed ICE MOT average - No mileage for vehicle of this class |
| **Wales** | LCVS | Large | FCEV | 10201.75 | Assumed ICE MOT average - No mileage for vehicle of this class |
| **Wales** | LCVS | Large | H2-ICE | 10201.75 | Assumed ICE MOT average - No mileage for vehicle of this class |
| **Wales** | LCVS | Large | Methane | 10201.75 | Assumed ICE MOT average - No mileage for vehicle of this class |
| **Wales** | LCVS | Large | ICE | 10201.75 | mot_average |
| **Ireland** | Cars | Small | Battery | 8504.5 | Wales MOT average |
| **N.Ireland** | Cars | Small | Biofuel | 7066.4 | Assumed ICE MOT average - No mileage for vehicle of this class |
| **N.Ireland** | Cars | Small | HVO | 7066.4 | Assumed ICE MOT average - No mileage for vehicle of this class |
| **N.Ireland** | Cars | Small | FCEV | 3770.45 | Wales MOT average |

| Location | Type | Size | Fuel | Average Annual Mileage | notes on mileage |
|---|---|---|---|---|---|
| **N.Ireland** | Cars | Small | H2-ICE | 7066.4 | Assumed ICE MOT average - No mileage for vehicle of this class |
| **N.Ireland** | Cars | Small | Methane | 9464.45 | Wales MOT average |
| **N.Ireland** | Cars | Small | ICE | 7066.4 | Wales MOT average |
| **N.Ireland** | Cars | Medium | Battery | 8504.5 | Wales MOT average |
| **N.Ireland** | Cars | Medium | Biofuel | 7066.4 | Assumed ICE MOT average - No mileage for vehicle of this class |
| **N.Ireland** | Cars | Medium | HVO | 7066.4 | Assumed ICE MOT average - No mileage for vehicle of this class |
| **N.Ireland** | Cars | Medium | FCEV | 3770.45 | Wales MOT average |
| **N.Ireland** | Cars | Medium | H2-ICE | 7066.4 | Assumed ICE MOT average - No mileage for vehicle of this class |
| **N.Ireland** | Cars | Medium | Methane | 9464.45 | Wales MOT average |
| **N.Ireland** | Cars | Medium | ICE | 7066.4 | Wales MOT average |
| **N.Ireland** | Cars | Large | Battery | 8504.5 | Wales MOT average |
| **N.Ireland** | Cars | Large | Biofuel | 7066.4 | Assumed ICE MOT average - No mileage for vehicle of this class |
| **Ireland** | Cars | Large | HVO | 7066.4 | Assumed ICE MOT average - No mileage for vehicle of this class |
| **Ireland** | Cars | Large | FCEV | 3770.45 | Wales mot_average |
| **Ireland** | Cars | Large | H2-ICE | 7066.4 | Assumed ICE MOT average - No mileage for vehicle of this class |
| **Ireland** | Cars | Large | Methane | 9464.45 | Wales MOT average |
| **Ireland** | Cars | Large | ICE | 7066.4 | Wales MOT average |
| **Ireland** | LCVS | Small | Battery | 5259.65 | Wales MOT average |
| **Ireland** | LCVS | Small | Biofuel | 7807.35 | Assumed ICE MOT average - No mileage for vehicle of this class |

| Location | Type | Size | Fuel | Average Annual Mileage | notes on mileage |
|---|---|---|---|---|---|
| **Ireland** | LCVS | Small | HVO | 7807.35 | Assumed ICE MOT average - No mileage for vehicle of this class |
| **Ireland** | LCVS | Small | FCEV | 7807.35 | Assumed ICE MOT average - No mileage for vehicle of this class |
| **Ireland** | LCVS | Small | H2-ICE | 7807.35 | Assumed ICE MOT average - No mileage for vehicle of this class |
| **Ireland** | LCVS | Small | Methane | 14793.45 | Wales MOT average - low number of vehicles [1] |
| **Ireland** | LCVS | Small | ICE | 7807.35 | Wales MOT average |
| **Ireland** | LCVS | Medium | Battery | 5259.65 | Wales MOT average |
| **Ireland** | LCVS | Medium | Biofuel | 7807.35 | Assumed ICE MOT average - No mileage for vehicle of this class |
| **Ireland** | LCVS | Medium | HVO | 7807.35 | Assumed ICE MOT average - No mileage for vehicle of this class |
| **Ireland** | LCVS | Medium | FCEV | 7807.35 | Assumed ICE MOT average - No mileage for vehicle of this class |
| **Ireland** | LCVS | Medium | H2-ICE | 7807.35 | Assumed ICE MOT average - No mileage for vehicle of this class |
| **Ireland** | LCVS | Medium | Methane | 14793.45 | Wales MOT average - low number of vehicles [1] |
| **Ireland** | LCVS | Medium | ICE | 7807.35 | Wales MOT average |
| **Ireland** | LCVS | Large | Battery | 7595.65 | Wales MOT average |
| **Ireland** | LCVS | Large | Biofuel | 10201.75 | Assumed ICE MOT average - No mileage for vehicle of this class |
| **Ireland** | LCVS | Large | HVO | 10201.75 | Assumed ICE MOT average - No mileage for vehicle of this class |

| Location | Type | Size | Fuel | Average Annual Mileage | notes on mileage |
|---|---|---|---|---|---|
| **Ireland** | LCVS | Large | FCEV | 10201.75 | Assumed ICE MOT average - No mileage for vehicle of this class |
| **Ireland** | LCVS | Large | H2-ICE | 10201.75 | Assumed ICE MOT average - No mileage for vehicle of this class |
| **Ireland** | LCVS | Large | Methane | 10201.75 | Assumed ICE MOT average - No mileage for vehicle of this class |
| **Ireland** | LCVS | Large | ICE | 10201.75 | Wales MOT average |

# Appendix F: Total hydrogen demand for all sectors excluding maritime



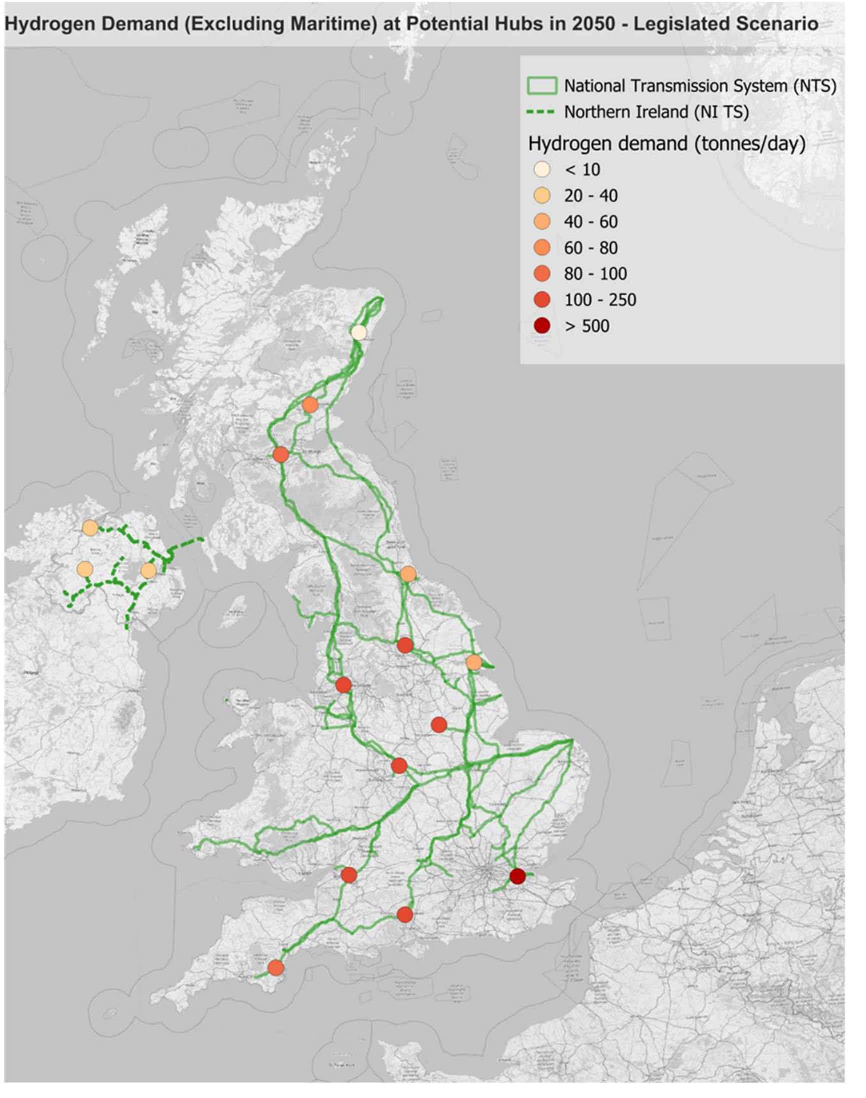




*Figure 73:Hydrogen demand (excluding maritime) at potential hub locations in 2040 and 2050 under the legislated scenario*

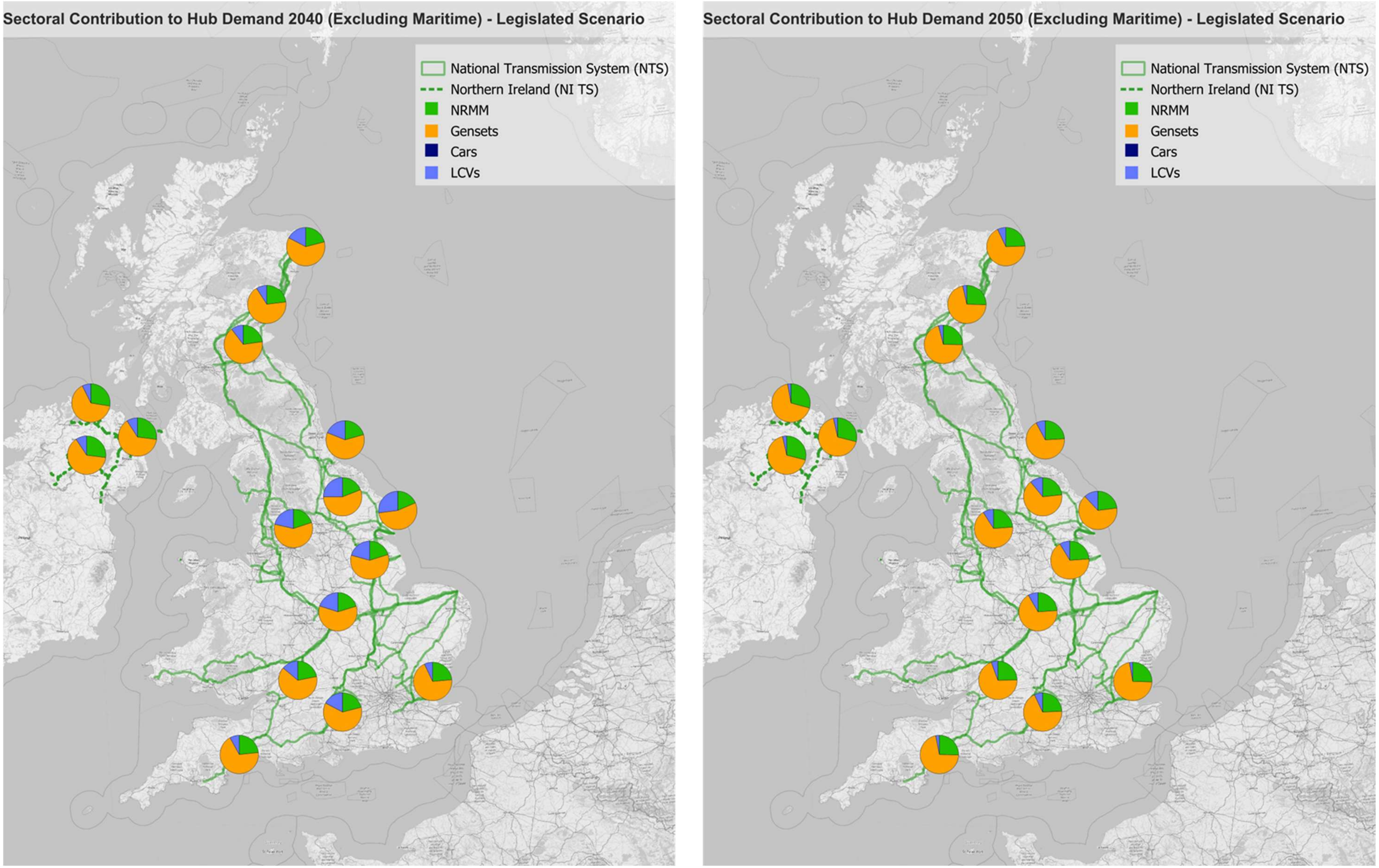



*Figure 74: Relative contribution to hydrogen demand by sector (excluding maritime) at potential hub locations in 2040 and 2050 under the legislated scenario*

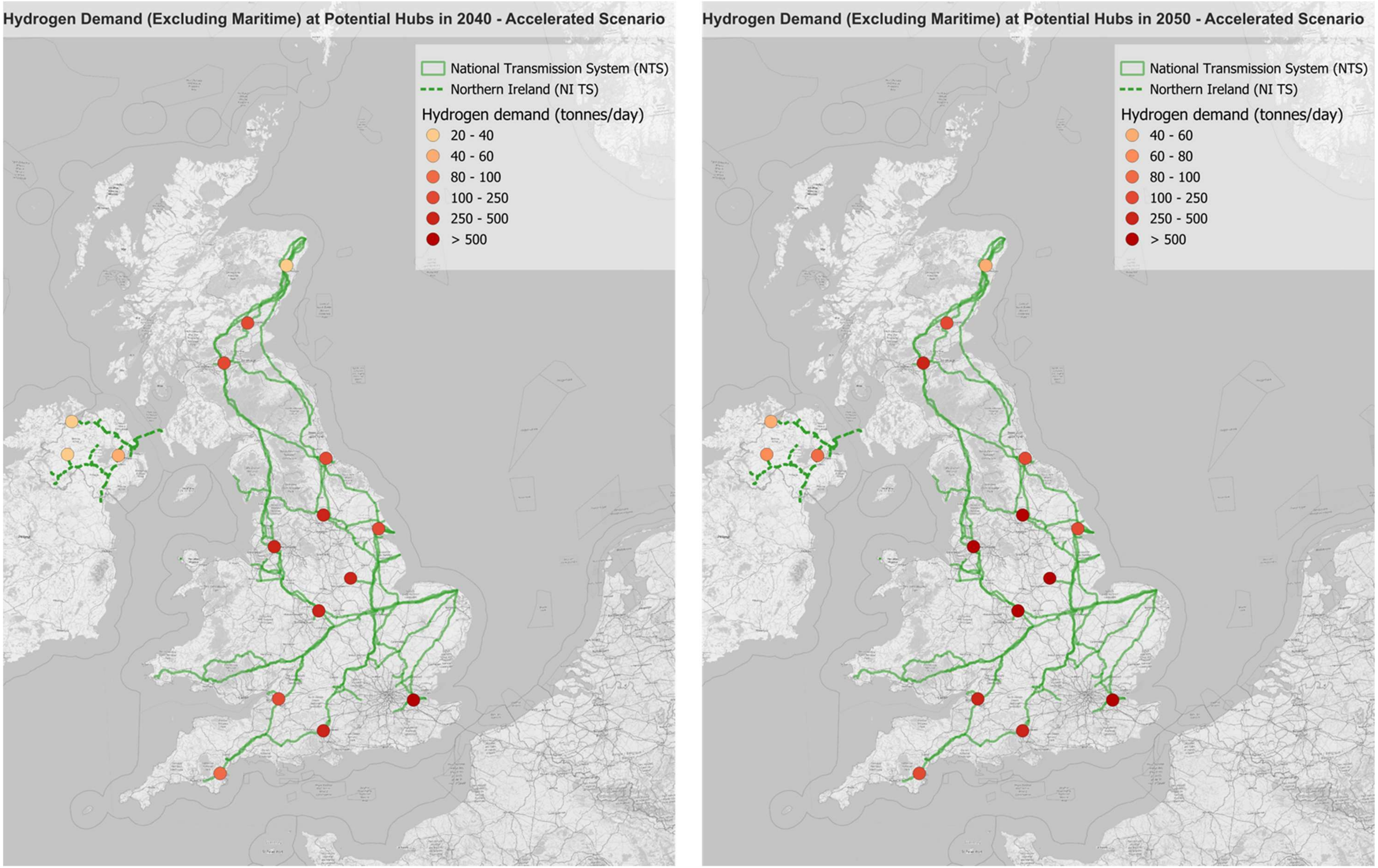



*Figure 75: Hydrogen demand (excluding maritime) at potential hub locations in 2040 and 2050 under the accelerated scenario*

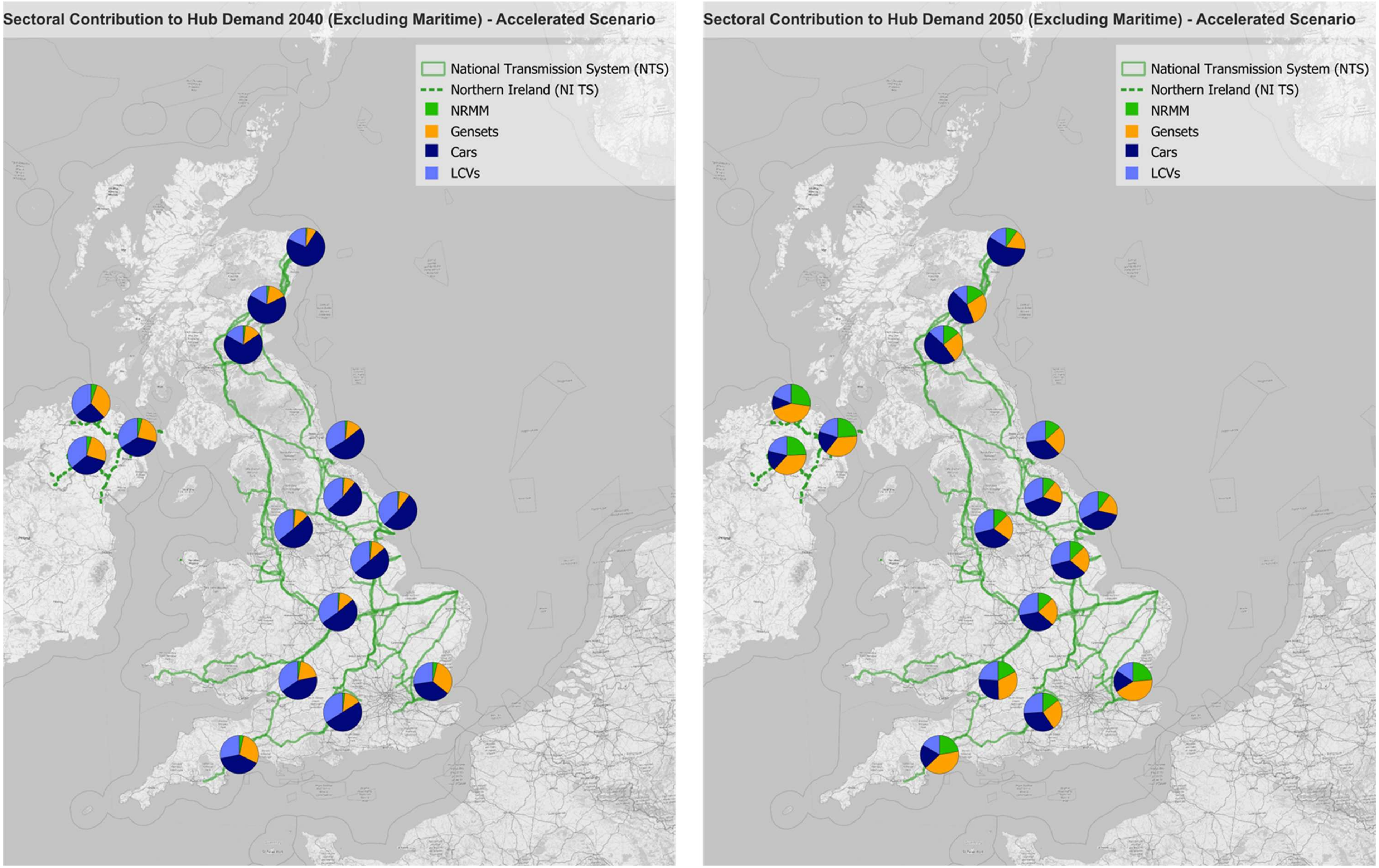



*Figure 76: Relative contribution to hydrogen demand by sector (excluding maritime) at potential hub locations in 2040 and 2050 under the accelerated scenario*

# Appendix G: References and Bibliography

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## Appendix H: Abbreviations

| Acronym | Meaning | Acronym | Meaning |
|---|---|---|---|
| AFIR | Alternative Fuels Infrastructure Regulation | ICE | Internal Combustion Engine |
| AINA | Association of Inland Navigation Authorities | IMO | International Maritime Organization |
| AMPS | Association of Manufacturers and Suppliers of Power Generating Systems | ISO | International Organization for Standardization |
| AQ | Air Quality | kVA | Kilovolt-ampere |
| B100 | 100% Biodiesel | kW | Kilowatt |
| B20 | Diesel with up to 20% biodiesel blend | kWh | Kilowatt-hour |
| B30 | Diesel with up to 30% biodiesel blend | LCV | Light Commercial Vehicle |
| B7 | Diesel with up to 7% biodiesel blend | LNG | Liquefied Natural Gas |
| BEV | Battery Electric Vehicle | LPG | Liquefied Petroleum Gas |
| CAPEX | Capital Expenditure | LSOA | Lower Layer Super Output Area |
| CAZ | Clean Air Zone | LWB | Long Wheel Base |
| CCC | Climate Change Committee | MFO | Marine Fuel Oil |
| CCGT | Combined Cycle Gas Turbine | MW | Megawatt |
| CEA | Construction Equipment Association | MWh | Megawatt-hour |
| CII | Carbon Intensity Indicator | NAEI | National Atmospheric Emissions Inventory |
| CO | Carbon Monoxide | NMC | Nickel Manganese Cobalt (battery chemistry) |
| CO2 | Carbon Dioxide | NESO | National Energy System Operator |
| DEFRA | Department for Environment, Food & Rural Affairs | NG | Natural Gas |
| DESNZ | Department for Energy Security and Net Zero | NGT | National Gas Transmission |
| DGW | Design Gross Weight | NI | Northern Ireland |
| DfT | Department for Transport | NOx | Oxides of Nitrogen |
| DVSA | Driver and Vehicle Standards Agency | NRMM | Non-Road Mobile Machinery |
| DUKES | Digest of UK Energy Statistics | NTS | National Transmission System |
| EA | Environment Agency | NZF | Net-Zero Framework |

| Acronym | Meaning | Acronym | Meaning |
|---|---|---|---|
| EEXI | Energy Efficiency Existing Ship Index | OEM | Original Equipment Manufacturer |
| EMEP/EEA | European Monitoring and Evaluation Programme / European Environment Agency | OPEX | Operational Expenditure |
| ERM | Environmental Resources Management | OPS | Onshore Power Supply (shore power) |
| EU | European Union | PHEV | Plug-in Hybrid Electric Vehicle |
| EU ETS | EU Emissions Trading System | Piva | Plug-in Vehicle |
| FAME | Fatty Acid Methyl Ester | PM | Particulate Matter |
| FCEV | Fuel Cell Electric Vehicle | PM10 | Particulate Matter ≤10 µm |
| GFI | Greenhouse gas fuel intensity | RAG | Red–Amber–Green (status rating) |
| GHG | Greenhouse Gas | REEV | Range-Extended Electric Vehicle |
| GT | Gross Tonnage | RTO | Research Technology Organisation |
| GW | Gigawatt | SEEMP | Ship Energy Efficiency Management Plan |
| GWh | Gigawatt-hour | SEPA | Scottish Environment Protection Agency |
| H2 | Hydrogen | SIC | Standard Industrial Classification |
| H2FC | Hydrogen Fuel Cell | SUV | Sports Utility Vehicle |
| HFCV | Hydrogen Fuel Cell Vehicle | TCO | Total Cost of Ownership |
| HGV | Heavy Goods Vehicle | TW | Terawatt |
| HRS | Hydrogen Refuelling Station | TWh | Terawatt-hour |
| HSE | Health and Safety Executive | ULEZ | Ultra Low Emission Zone |
| HVO | Hydrotreated Vegetable Oil | ZE | Zero Emission |
| HyNTS | Hydrogen in the National Transmission System | ZEV | Zero Emission Vehicle |
| ICCT | International Council on Clean Transportation | | |

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