Mobility of Goods

Narrative Report

2024

automotive council UK

ADVANCED PROPULSION CENTRE UK

Produced by the Advanced Propulsion Centre UK on behalf of the Automotive Council UK

Information correct at time of publication

Contents

1 Introduction

1.1 Foreword to the 2024 roadmaps

Neville Jackson
Chair, Automotive Council Strategy Group

Arun Srinivasan
Chair, Automotive Council Future Technology Group
Deputy Chair, Automotive Council UK

The UK Automotive Council is well known for producing robust and detailed technology roadmaps that define potential routes for Automotive including Commercial Vehicles and Off-Road machinery and related products to achieve our UK environmental and societal goals. Roadmaps are a function of current knowledge and as new ideas and technologies emerge, must be regularly renewed. This exercise, led by the Advanced Propulsion Centre UK, has generated the fourth generation of these roadmaps.

Whilst many organisations develop roadmaps as part of their product planning process, the Automotive Council roadmaps are unique in providing a consented view from the Automotive sector including Commercial Vehicle and Off-Road Machinery, in the UK. This enables us to define common future challenges and where to focus collaborative R&D and capital resources in developing successful, sustainable, net-zero solutions.

These solutions must also meet future consumer needs and not introduce challenges in experience or limitations in operation. Often, more than one technical approach appears viable to meet future needs. It is important that all of these approaches are explored and introduced to market as the carbon reduction goal becomes more urgent. Ultimately, it is possible that one approach may dominate but we cannot afford to wait for this to emerge.

1.2 The purpose of the 2024 roadmaps

The Automotive Council UK roadmaps outline key themes, trends and drivers in the global automotive industry. This narrative report explains and provides insights to support the roadmap's themes. It helps clarify the reasons behind the roadmap's content and how it should be used.

The report aims to guide research and development (R&D), innovation, cross-sector collaboration, and system-level interactions. A list of recommendations for how industry, academia, and government can use this information is shown opposite:

Industry

- Compare in-house R&D priorities with industry trends and drivers in the automotive sector.
- Evaluate supply chain risks and develop strategies for sustainable and circular business models in automotive products.
- Help start-ups by guiding their technology focus, investment choices, and collaboration plans.

Academia

- Address long-term research challenges that need to be solved.
- Align university research, education, and skills development with the automotive industry's needs.
- Strengthen partnerships between academia and industry to apply research to real-world solutions.

Government and policymakers

- Understand key themes and trends in automotive technologies.
- Direct policy and funding to support R&D priorities and innovation for reaching net zero.
- Promote cross-sector collaboration and trade policies that benefit the automotive industry and broader industrial sectors.

1.3 Building a consensus

This consensus roadmap has been developed through the facilitation of the Advanced Propulsion Centre UK (APC), with contributions from 436 individuals representing 230 organisations, which include government, industry and academia.

Collating the information required for the 2024 roadmaps has only been possible due to the breadth of contribution and valuable feedback from those who have fed into the process, which began in early 2023. The APC would like to thank everyone who gave their time and input across the various webinars, workshops, and surveys conducted.

As a result of this consultation across industry and academia the 2024 roadmaps build on previous versions and demonstrate the significant change that is happening across the automotive sector and its supporting industries.

Special thanks go to members of a working group that was formed to support the development of this roadmap. Organisations involved include: Zenzic, Zemo, WMG, SMMT, Connected Places Catapult, CCAV, Innovate UK UKRI, Innovate UK KTN, Mobilize, Nissan Technical, Horiba Mira, University of Leeds, Nissan Technical Centre Europe and Ford.

Figure 1: Representation by individual and organisation

436 Individuals

OEM	24%	(104)
Supply chain / SMEs	40%	(176)
RTO	15%	(67)
Academia	5%	(23)
Government	8%	(33)
Other	8%	(33)

230 Organisations

OEM	14%	(32)
Supply chain / SMEs	51%	(117)
RTO	11%	(25)
Academia	7%	(15)
Government	7%	(17)
Other	10%	(24)

Adrian Hallmark
Chair
Automotive Council UK

As we stand on the cusp of a new era in the automotive industry, the importance of strategic foresight has never been greater. The Automotive Council UK Roadmaps 2024 provide a strategic vision that places the automotive sector at the heart of the global transition towards net zero. Evolving the Automotive Council product roadmaps from 2020 into brand new system-level roadmaps 2024 underscores the critical role the automotive sector will play in the broader transport ecosystem.

The roadmaps outlined in this document are the result of extensive collaboration between industry leaders, policymakers, and academic experts. They are designed to navigate the complexities of a rapidly evolving market, where technological advancements, environmental imperatives, and shifting consumer expectations are driving unprecedented change.

Central to our vision is the transition towards a net zero and sustainable transport ecosystem. The roadmaps highlight key areas such as electrification, digitalisation, and advanced manufacturing, which will be crucial in maintaining the UK's leadership in the global automotive industry. They also highlight the critical challenges of supply chain resilience, and regulatory alignment across automotive and the broader transport sector as well as energy sector in an increasingly interconnected world.

All roadmaps are accompanied with a detailed narrative report to offer more details and description of the trends and drivers and support call to action for all stakeholders across the automotive industry. The journey ahead will require agility, collaboration, and a shared commitment to excellence. By embracing the insights and strategies contained within these pages, we can collectively ensure that our automotive sector remains at the forefront of global progress, delivering value not only to the economy but to society at large.

We invite you to explore these roadmaps, to reflect on the opportunities they present, and to join us in shaping a future that is as dynamic as it is sustainable.

Mike Hawes
CEO
SMMT

Transitions to new technologies are never smooth. Innovation is the starting point, but market shifts depend on many factors: functionality, usability, affordability. Competition can accelerate the pace and stimulate alternative strategies and, indeed, technologies.

The UK's transition to a net zero economy depends on decarbonising road transport. But in doing so we must ensure we maintain mobility for all people and all services. Plotting this transition, therefore, needs roadmaps that anticipate the trends and drivers of change, allowing policymakers, investors, businesses and consumers to make informed decisions.

The Automotive Council last delivered roadmaps in 2020. We were acutely conscious that we were entering a "disruptive decade"; climate change, air quality regulation, societal demand and the expectation of rapid market transformation were compelling heavy investment in electrified powertrains. What was not forecast was the global disruption of covid, constrained supply chains, geopolitical tensions and increasing protectionism, all of which combined with economic conditions, to slow the uptake of new technology vehicles.

Addressing these issues while sustaining societal mobility demands contributions from stakeholders outside the traditional automotive industry. It demands new system-level roadmaps; focussed not just on automotive products and technologies but their role in the broader transport ecosystem – the mobility of both people and goods. Different vehicle applications will require different solutions. There will be a range of complementary private and public transport solutions – some individual, some shared; some requiring high-power solutions, some much less. And this diversity of technologies will apply equally to the mobility of goods.

These two new roadmaps are intended to support the UK in its transition to cleaner, more sustainable and intelligent forms of mobility. At a time of such fierce global competition, the companies and governments that can anticipate the future, plan for it and invest in it, will succeed. We want the UK to succeed, and the benefits shared by all.

Professor Sarah Sharples
Chief Scientific Adviser
Department for Transport

The UK automotive industry is a key driver for growth within the UK economy. Automotive related manufacturing contributes to £22 billion in value to the economy, and invests around £4 billion each year in R&D. It employs in total around 800,000 people in the country.

The system level roadmap responds to a changing automotive environment and provides a resource for automotive industrial strategy community, to build synergies across its system interfaces with the wider transport ecosystem. The roadmap highlights the current and future mobility landscape and shows key mobility trends and regulatory drivers which have potential to shape automotive road transport technologies for the movement of people and goods. The The Automotive Council UK's system level roadmaps highlight the importance of interfaces for automotive industry with adjacent sectors like energy, infrastructure, rail, and mobility services for an accelerated transition to a net-zero future. A true successful zero emission technology transition requires collaboration with key stakeholders across governments, industry, academia, and start-up communities. The roadmaps provide a helpful basis for the holistic system thinking that is needed to pull this complex and transformative path for our future generations and society, by not placing the automotive industry as an isolated innovation island, but as a key actor within the wider transport ecosystem.

Ian Constance
CEO
Advanced Propulsion Centre UK

The automotive industry is uniquely positioned to lead the charge towards a net-zero transport ecosystem. As such we have evolved our 2020 product roadmaps into system-level roadmaps providing a more holistic view of the role of the automotive industry in the transition of the transport sector in the journey towards net zero.

The roadmaps outlined in this document are the result of extensive collaboration across the automotive and the broader transport sector, reflecting the diverse expertise and perspectives necessary to accelerate progress.

The strategic direction and associated partnerships detailed in these roadmaps are key to unlocking the potential of new technologies, from advanced propulsion systems to connected and autonomous vehicles. Equally important is the alignment of policy and funding with these technological advancements, ensuring that the right resources are in place to support innovation and implementation at scale. This coordinated approach will help us overcome the challenges of decarbonisation and make sustainable transport accessible to all.

By setting ambitious targets and fostering innovation, we can drive change not only within our industry but across the broader transport landscape. The Automotive Council roadmaps provide a clear pathway for this journey, highlighting the opportunities and challenges that lie ahead. We invite all stakeholders to explore these roadmaps and join us in driving the next phase of innovation and sustainability in the UK automotive industry.

1.4 Mobility of Goods – overview

This roadmap responds to a changing automotive environment and is an evolution of the 2020 Light Duty Vehicles, Heavy Goods and Off-Highway Vehicles.

The Mobility of Goods Roadmap provides a resource for automotive industrial strategy planning, helping to build synergies across its interfaces with the wider transport system. It highlights both the current and future mobility landscape, capturing key trends and drivers that shape automotive road transport for the movement of goods with an eye on sustainability and working towards net zero.

This 2024 version has the addition of a dedicated section to focus on off-highway vehicles, also known as non-road mobile machinery (NRMM) in response to understanding and recognising the specific needs and requirements for the decarbonisation of sectors such as construction and agriculture.

The Mobility of Goods Roadmap focuses on the UK and EU markets, while this supporting narrative report also includes international references for context.

Additionally, the roadmap acknowledges the importance of last-mile delivery logistics and the role this plays in decarbonising urban centres with dedicated analysis for ultra-light goods vehicles (ULGVs).

The roadmap features as part of a series of documents focusing on six automotive technologies as well as two system-level roadmaps; Mobility of Goods and Mobility of People.

The roadmap is split into three categories covering localised movements, long-haul movements and NRMM. Each category consists of the following sections:

Energy vectors and vehicle propulsion type

Energy sources used within the transport sector for different types of vehicle and powertrain.

Drivers and regulations

Policy, environmental, social and economic drivers that exert influence on vehicle designs and powertrains.

Technology enablers

Engineering and technology enablers that exert influence on vehicle designs and powertrains.

Infrastructure enablers

Infrastructure enablers that exert influence on vehicle designs and powertrains.

Certainty levels are applied to individual bars within the roadmaps and includes topics at pilot / trial or proof-of-concept, as well as topics where there is both a reduced or increased level of certainty. The corresponding legend is shown below. In the narrative report, the drivers and regulation, technology and infrastructure enablers for localised and long-haul movements are covered together for ease of reading. This is due to similar vehicles used for both product use-cases.

- High level of certainty
- Lower level of certainty
- Pilot / trials / PoCs

This narrative report is divided into the following sections based on the product use-case and customer needs:

- localised movements
- long-haul movements
- Non-road mobile machinery (NRMM)

1.5 Mobility of Goods – influencing trends

The transport and automotive sectors have changed dramatically in recent years and will continue to evolve. The drivers of these transformations are multi-faceted, encompassing demographic and social, economic, environmental, political and technological factors. While the adoption of a range of technologies, services and new business models have disrupted transport at a rapid pace, changing the way goods and services move.

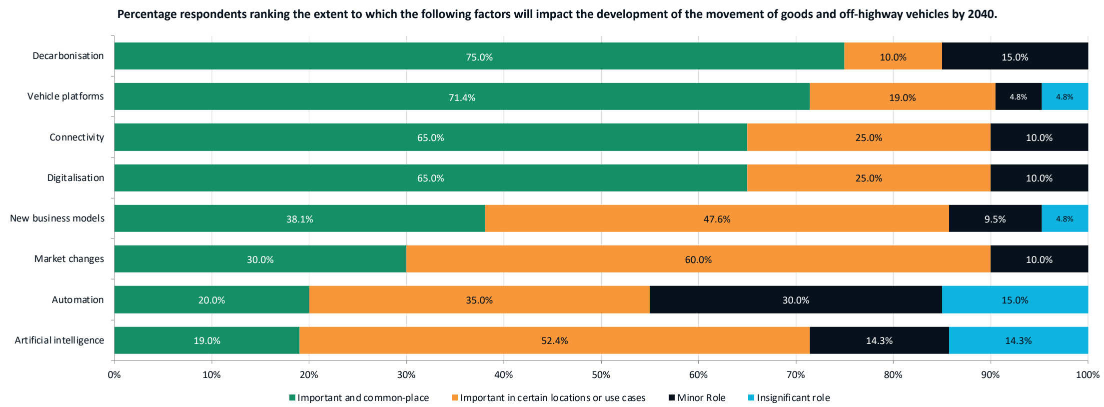
Understanding the pace of these changes is important to ensure that benefits of more efficient, safer and cost-effective transport services are maximised for the commercial sector, whilst potential risks such as increased congestion, collisions and worsening air quality are minimised.

Additionally, the impact of the COVID-19 pandemic has posed significant challenges to the planning and operation of transport systems, fundamentally disrupting or accelerating travel and logistic trends. Thinking holistically about the opportunities and risks the future could hold enables proactive and efficient design and delivery of future transport infrastructure and services.

Stakeholder survey

The Advanced Propulsion Centre UK (APC) asked industry stakeholders (including academia and policy / government organisations) to specify the top three trends influencing road transport and the mobility of goods by 2040. They identified decarbonisation, vehicle platforms and connectivity (see Figure 2).

Figure 2: Top trends influencing road transport and mobility of goods by 2040



Source: The APC Mobility of Goods Survey, 2023

The key themes impacting on mobility of goods by 2040 are expanded upon in the following narrative

Decarbonisation

The rise of international trade has increased carbon emissions, making supply chain logistics a significant contributor to greenhouse gas (GHG) emissions. Today's changing energy landscape is driving logistics organisations to re-examine how they consume and manage energy demand. With low-carbon energy generation playing an increasing role in the power mix, advancements are being made in electricity production, introducing new opportunities for stakeholders to embrace low- or zero-carbon energy systems to help transport goods and services from origin point to end-consumers.

Vehicle platforms

The vehicle platform can be described as the collaboration of certain components of a vehicle that shares a set of common design, engineering and production efforts. A single platform can be shared between a brand's or automotive group's various vehicles for economies of scale. These technological developments will influence how commercial vehicles are designed and will be play an important role in accelerating the adoption of zero-emission vehicles (ZEV).

Connectivity

This refers to an interdependent set of communication devices and internet of things (IoT) technologies that change the key logistical processes to become more customer-centric by sharing data, information and facts with supply chain partners. This will support stakeholders in the mobility of goods ecosystem through to 2040 by providing real-time data and insights to strengthen their supply chain.

Key changes effecting the sustainability and shared economy up to 2025 include:

Focus on sustainability / environmental consciousness

A survey of consumers (McKinsey) revealed that 46% of respondents have already switched to more sustainable brands or products with a further 16% planning to make considerable changes to promote sustainability[1]. This will have implications on the type of suppliers procured by organisations to provide goods and services. For example, selecting those that demonstrate low / zero carbon modes of transport to deliver items.

Shared economy

The rise of the shared economy comes as attitudes towards ownership of assets are changing. Increasingly people are becoming more open to usership over ownership. Whilst this is more common for private travel, the commercial sector, particularly smaller businesses, has begun to adopt similar practices, for example, using shared e-cargo bikes and shared electric vans.

Behaviours are changing and the economic value society placed on vehicle ownership is shifting. Technology has facilitated the emergence of new ways in which companies can access, use and finance transport for their logistics operations, reducing the economic value gained from owning a vehicle dedicated to a single organisation.

1 Future of public transport (kpmg.com)

2 | Product classification used in the report

2.1 | Product classifications

Below is a short overview of the different types of mobility of goods assessed in the roadmap:

Localised goods movement

Typically represents trips within the commercial sector under 150 miles, with journeys using connector and distributor roads.

Long-haul mobility of goods

Typically represents trips over 150 miles, including those primarily on the national road network, connecting producers and consumers both within countries and across international borders.

Off-highway (including NRMM)

Off-highway mobility of goods includes the use of non-public roadways for commercial purposes, e.g. construction or agricultural activity. Vehicles used include non-road mobile machinery (NRMM).

3 | Narrative to roadmap

3.1 | Energy vectors used in this report

The energy vectors that support the propulsion technologies

ICE-led

In addition to petrol and diesel, this includes lower carbon internal combustion engine (ICE) fuels and hydrogen ICE that uses hydrogen as fuel. Plug-in hybrids, featuring net-zero fuelled ICE and renewably-sourced electricity, are considered possible in the long-term, using the following sources: advanced biofuels, natural gas fuels, synthetic fuels and e-fuels.

Battery-led

Battery electric vehicles (BEVs) use an electric motor and battery storage packs and are heavily reliant on electric vehicle (EV) charging points for storing battery energy. A dedicated charging infrastructure for the commercial sector is anticipated to be rolled out to 2030 and beyond for the use of light-goods vehicles (LGVs) and heavy-goods vehicles (HGVs) at both depots / warehouses and kerbside public spaces.

Localised renewable sources for off-highway vehicles (NRMMs) are being explored further to provide a viable alternative to producing electricity. This would be enabled if planning permission can be secured and grid connections are available (via the district network operator (DNO)), which are both currently limiting factors. This includes pop-up solar power farms and wind turbines at larger industrial sites, often seen in the agriculture and construction sectors. This offers alternative energy vector sources for the agricultural sector rather than relying on the development of hydrogen pipelines or hydrogen production technologies.

Fuel cell-led

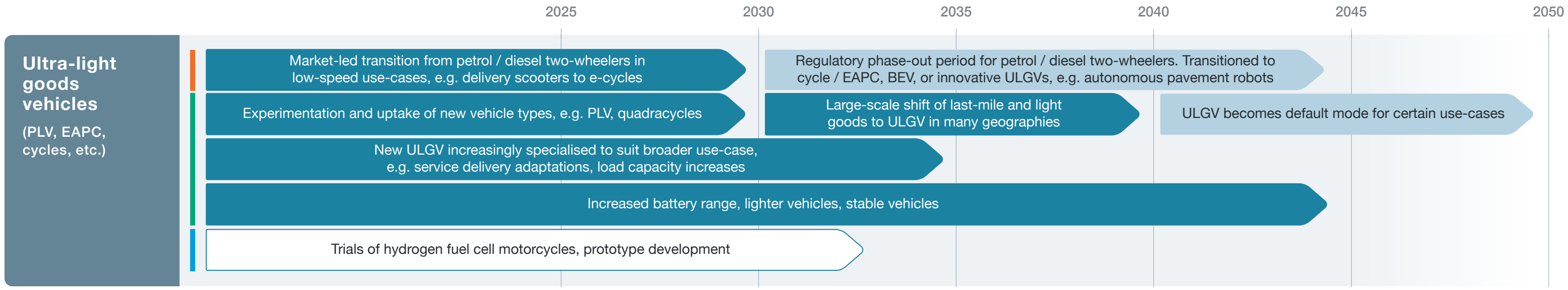
This includes fuel cell electric vehicles (FCEVs) powered by hydrogen fuel cells (HFCs) where vehicles make use of a fuel cell to generate electricity to power their onboard electric motor. Hydrogen can be produced through steam methane reformation (SMR), which requires carbon capture and storage in order to be considered emissions-free, or electrolysis from low-carbon electricity.

— ICE-led
— Battery-led
— Fuel cell-led

3.2 Energy vectors and propulsion type for localised mobility of goods and long-haul mobility goods

Key takeaways for localised goods movement

- Electric micromobility modes (primarily e-bikes, e-cargo bikes, and e-scooters) are gradually seeing an increase in uptake after the COVID-19 pandemic for the movement of goods / products / services with e-cargo bikes becoming popular in urban areas, particularly in Western Europe (accounting for two-thirds of demand), and their uptake is expected to increase over time.
- The nature of LGV usage and associated requirements makes BEV a very credible pathway for full decarbonisation and suitable vehicles are already available with increasing adoption. BEVs are likely to make up the majority of LGV zero-emission fleets. Further action over and above switching last-mile delivery vans to BEVs is likely to be necessary to achieve net-zero targets for 2050, for example financial incentives, road-user charging, improved charging infrastructure and behavioural changes.
- Transitioning to zero emissions will be more challenging for HGVs than other segment of the automotive sector. HGVs operate on a continual use-cycle so need fast refuel capabilities. The decarbonisation in HGVs will have different solutions for different use-cases. It is likely a combination of propulsion technologies will be applied to decarbonise HGV fleets, for example hydrogen fuel cell technologies. For localised depot based use-cases, batteries will play a greater role.



Ultra-light goods vehicles (ULGVs) for localised goods

In the period to 2030, there will be a market-led transition from ICE to electric for micromobility and mopeds.

The following ULGV types prove best-suited for use in high-density areas like city centres:

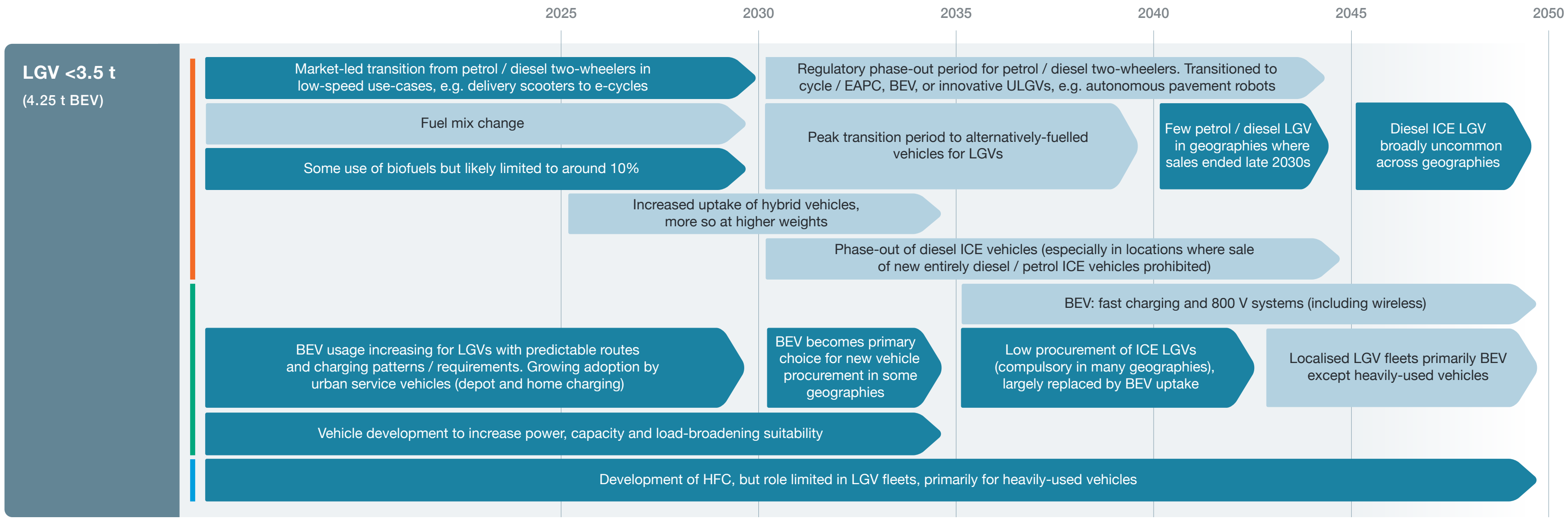
- Electric micromobility (primarily e-bikes and e-scooters) are gradually seeing an increase in uptake after the pandemic for both the movement of goods, services and people.
- E-cargo bikes are becoming popular in urban areas, particularly in Western Europe for small deliveries. The uptake of e-cargo bikes is expected to increase. They are best-suited to delivering low volumes of light goods in small catchment areas, in particular goods that may be perishable and have a limited delivery window.

The last-mile delivery in dense cities and urban centres are trialing and adopting quadracycles and e-cargo bikes to improve air quality. For example, Amazon's e-cargo bikes and on-foot deliveries are now operational from hubs in more than 20 cities across the UK and Europe[2]. Limited trials of HFC motorcycles are expected in the short-term, although the mainstream adoption of this technology is currently uncertain.

High level of certainty
Lower level of certainty
Pilot / trials / PoCs

ICE-led
Battery-led
Fuel cell-led

2 https://www.aboutamazon.eu/news/sustainability/bringing-electric-cargo-bike-deliveries-to-croydon-england



LGV for localised goods movement

ICE-led

By 2030, the majority of LGVs and cars used for deliveries will still be expected to have ICE or hybrid engines. At this point, the dominant fuel mode for commercial LGVs will still be liquid fuels; including hydrogen, biofuels and fossil fuels. It is anticipated that ICE-vehicle sales will peak but begin to decrease through to the 2030s.

The greatest transition for alternative fuel modes is expected to gain traction from 2030 to 2050 with Europe, US and China anticipated to lead the transition.

Battery-led

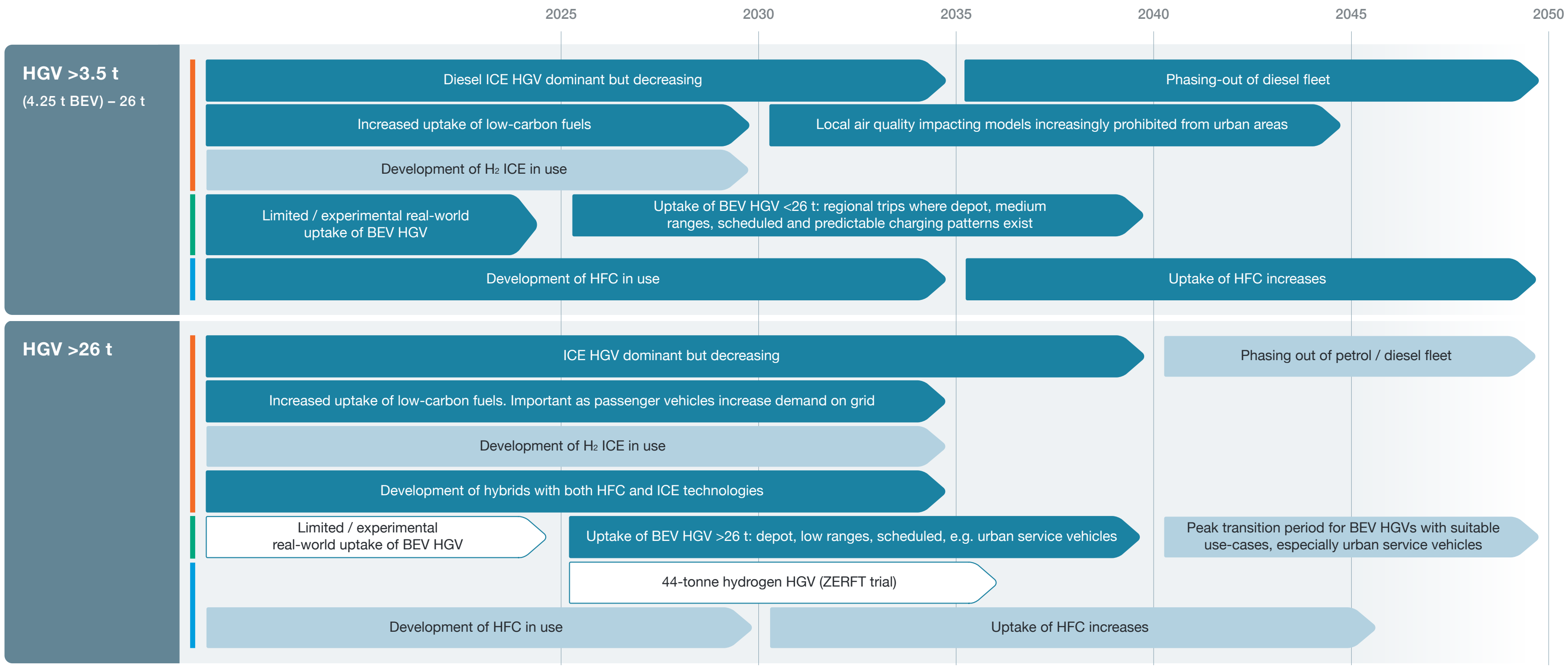
The uptake of electric commercial vehicles has been dominated by the increased adoption of ultra-low emission vans. The nature of LGV usage and associated requirements makes BEV a very credible pathway for full decarbonisation and suitable vehicles are available with increasing adoption. BEVs are likely to make up the majority of LGV zero-emission fleets where battery power is well-suited in combination with dedicated charging stations to match operational patterns.

Fuel cell-led

There are major challenges to overcome for mass adoption of hydrogen fuel cells, including the lack of fuelling stations and the difficulty of supplying green hydrogen to power them, hence the wide adoption of fuel cell vehicles in this sector remains uncertain.

High level of certainty
Lower level of certainty
Pilot / trials / PoCs

ICE-led
Battery-led
Fuel cell-led



HGV for localised goods movement (4.5 t – 44 t)

ICE-led

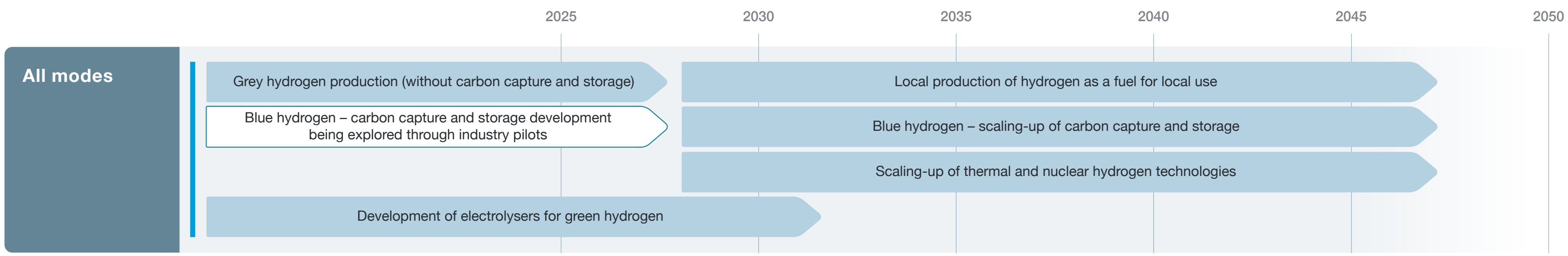
Up to 2030, diesel is expected to be the dominant fuel for HGVs. There are potential low-carbon fuel alternatives to diesel-powered vehicles, however, there are concerns about the pathway to large-scale production for the non-fossil fuels.

Battery-led

For localised back-to-base use-cases under 26 tonnes, battery will likely play a significant role. Battery-electric HGVs are starting to be used in many geographies for localised 'back-to-base' journeys with predictable schedules that make planning for charging easier, such as urban service-vehicles. Fully electric refuse vehicles are in operation in many geographies and are capable of completing a full 10-hour shift[3].

3 Clean air: City Corporation to become first UK authority to run fully electric refuse truck fleet (cityoflondon.gov.uk)

High level of certainty
Lower level of certainty
Pilot / trials / PoCs
ICE-led
Battery-led
Fuel cell-led



Fuel cell-led

FCEVs might offer a decarbonisation solution in regions where road freight covers long distances (such as North America), rather than Europe. Innovate UK predicts that 17% of the truck fleet in the UK could become hydrogen by 2050[4].

The UK Hydrogen Strategy Roadmap aims for industrial applications in transport to be operational in the mid-2020s (2025-2027)[5], including extensive HGV, rail and marine shipping trials.

4 https://iuk.ktn-uk.org/wp-content/uploads/2024/02/11312_UK-Transport-Vision-2050-2nd-edition-SP-Final.pdf
5 https://assets.publishing.service.gov.uk/media/64c7e8bad8b1a70011b05e38/UK-Hydrogen-Strategy_web.pdf

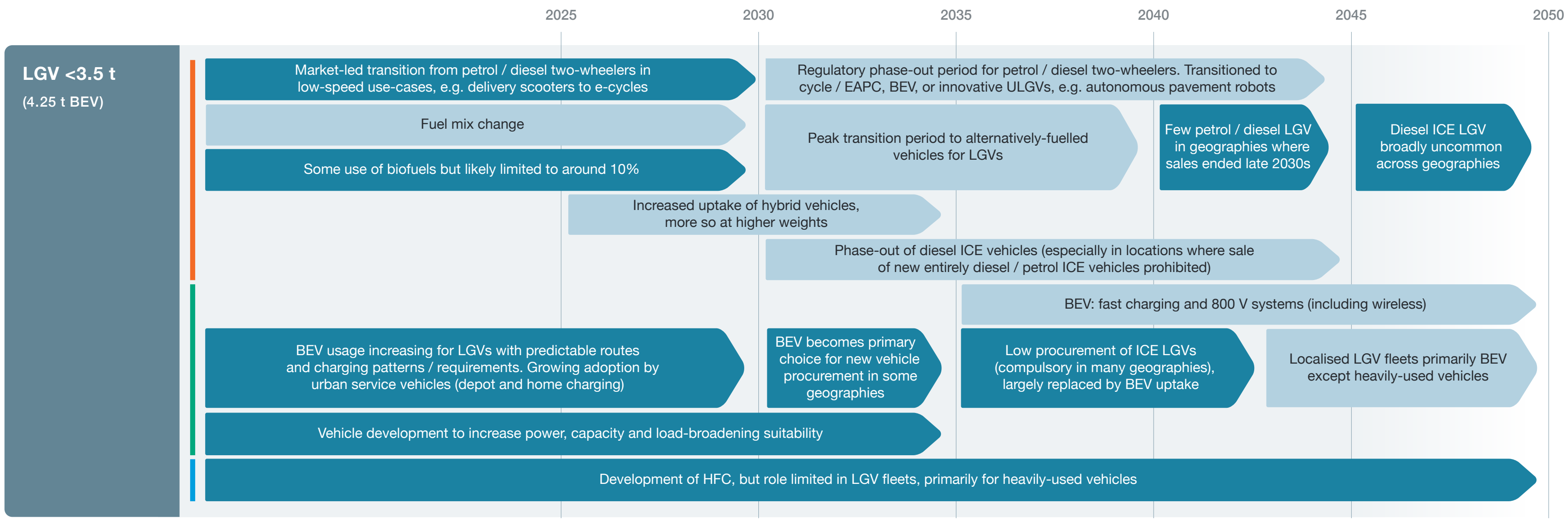
High level of certainty
Lower level of certainty
Pilot / trials / PoCs
ICE-led
Battery-led
Fuel cell-led

Key takeaways for long-haul goods movements

For the LGV sector travelling longer distances, fleets will primarily be battery electric by 2040s in most continents. However, ULGV usage for the long-haul sector will be limited in use-cases.

Advancements in battery packs and the evolution of higher voltage systems architecture provide a credible pathway for the electrification of HGVs under 26 tonnes for long-haul goods movement. There are limited trials on electric road systems (ERS) around the world as an alternative propulsive system for long-haul goods movement, however there are high levels of uncertainty regarding its future growth.

FCEVs might play a niche role in the future fleet of HGVs over 26 tonnes, though there are doubts over sufficient scaling of large-scale hydrogen refuelling infrastructure. FCEVs may offer a decarbonisation solution in regions where road freight covers long-distance corridors, e.g. North America.



LGVs – under 3.5 tonnes for long-haul

ICE-led

As illustrated for localised goods movement, in 2030, the dominant fuel mode for private LGVs will still be liquid fuels, including fossil fuels, e-fuels and hydrogen.

Battery-led

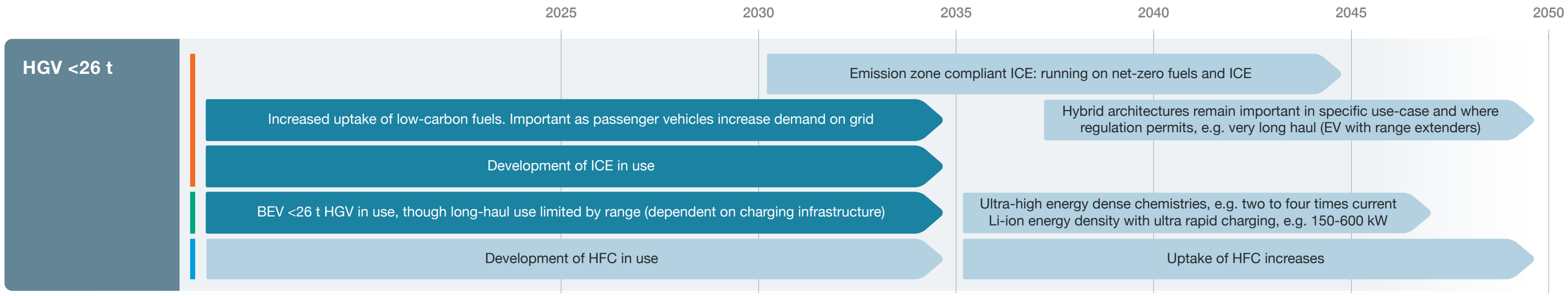
The nature of LGV usage and associated requirements make BEV a very credible pathway for full decarbonisation and suitable vehicles are incoming to the market. BEVs are likely to form the majority of zero-emission LGV fleets. BEVs in the UK experienced a marginal market share increase in 2022-23 (YTD figures), from 5.3% to 5.5% specifically for commercial vehicles up to 6 tonnes[6]. Electric-LGV sales worldwide increased by over 70% in 2021, with the dominant markets being China, Europe and Korea[7]. The uptake of electric commercial vehicles has been dominated by the increased adoption of ultra-low emission vans, as opposed to HGVs.

Fuel cell-led

Advances in BEVs, coupled with a lack of hydrogen refuelling stations, means it is unlikely FCEVs will make-up a significant proportion of LGV fleets.

6 SMMT (2023), Light Commercial Vehicle Registrations – UK vans and trucks
7 IEA (2022), Global EV Outlook 2022, Trends in electric light-duty vehicles

High level of certainty
Lower level of certainty
Pilot / trials / PoCs
ICE-led
Battery-led
Fuel cell-led



HGVs – under 26 tonnes for long haul

ICE-led

Many of the same factors impacting HGVs under 26 tonnes in localised-goods movement apply to long-haul HGVs.

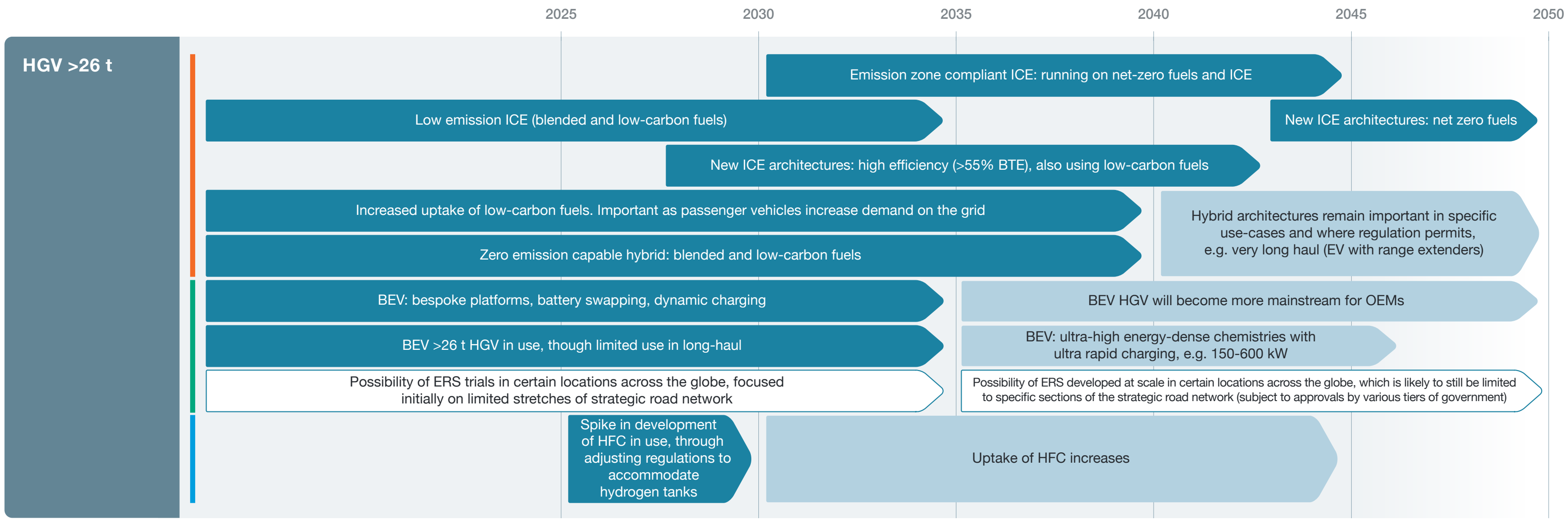
Battery-led

HGVs under 26 tonnes face similar challenges to electrification as heavier vehicles, however it is likely that these will be overcome faster as technologies develop, e.g. as battery-energy densities improve. A strong reduction in running costs turns long-haul into a more compelling business case for BEVs. Fast-charging infrastructure enables this use-case without meaningful payload or charging time losses while retaining the energy-cost advantage. There are technological advancements in the form of 800 V architecture and high-density batteries that will improve the overall charging time and the vehicle range respectively.

Fuel cell-led

It is likely that developments will begin at the lighter end of this weight category, as 7.5 tonne HFC vehicles capable of travelling over 500 km are already in production.

High level of certainty
Lower level of certainty
Pilot / trials / PoCs
ICE-led
Battery-led
Fuel cell-led



HGVs – over 26 tonnes for long haul

ICE-led

The high expense of alternatively-fuelled vehicles and a higher cost-per-mile of lower emission combustion fuels, mean diesel-fuelled larger HGVs (over 26 tonnes) are most common and will remain so for the next decade in long-haul goods movement. However, it is expected that lower carbon ICE fuels could achieve lower emissions up to 2035 and could potentially increase with sufficient governmental support. There are hybrid and plug-in hybrid trucks available in the market that act as a range extender with the combined output of electric powertrain and traditional ICE. The traditional ICE engines could run with low-carbon fuels, such as hydrotreated vegetable oil (HVO) or biodiesel. This will provide the capability for the vehicles to run fully electric in urban and low-speed environments.

Battery-led

Long-haul HGVs over 26 tonnes are considered the most challenging fleet to decarbonise. Batteries do not suit the high power and long distances required with the additional mass from larger batteries impacting load capacity and efficiency. This may be rectified through increased development of battery energy densities. A possible solution would be the development of battery swapping networks (in which expended batteries are swapped for fully-charged replacements, essentially immediately refuelling the vehicle). China is currently leading in the battery-swapping truck technologies, with 49.5% of electric trucks sold in 2022 with swap-capabilities[8]. Battery-swapping trucks require dedicated swapping stations and there are challenges around standardisation for full-scale commercialisation.

Fuel cell-led

FCEVs may play a niche role in the future fleet of HGVs over 26 tonnes. FCEVs might offer a decarbonisation solution in other regions like North America, according to the APC's UK HDV Supply Chain Opportunities to 2035 insight report. Analysis conducted highlights a potential market in the UK for up to 25% of the overall future sales of HGV trucks in fuel cell technologies by 2035. There are currently long-haul 44 tonne trucks in China from Hybot illustrating the capability of 1,000 km range[9].

8 https://theicct.org/china-is-propelling-its-electric-truck-market-aug23/
9 https://www.hydrogeninsight.com/transport/chinese-start-up-unveils-worlds-first-gaseous-hydrogen-truck-with-1-000km-range/2-1-1570968

High level of certainty
Lower level of certainty
Pilot / trials / PoCs
ICE-led
Battery-led
Fuel cell-led

3.3 Drivers and regulations for localised and long-haul goods

Primary themes

Below is a summary of key issues for localised and long-haul goods movement.

Emission standards and life cycle impact

Tailpipe emissions and vehicle end-of-life processes are already governed by regulations in many countries. These are being strengthened and are likely to feature greater life cycle considerations, reflecting a move to a more circular economy.

CO_2 reduction and zero impact vehicle (ZIV) policies

CO_2 emission targets and zero emission vehicle mandates for heavy vehicles around the globe has impacted original equipment manufacturer (OEM) development of battery electric models.

Emissions targets set by governments for both vehicle sales and localised emission zones will be a significant driver in the development and uptake of ZIVs. In the long-term, these can be expected to grow in number and across more markets to meet net-zero targets. For example, the European Commission is committed to tackling climate and environmental related challenges through an objective for net emissions by 2050.

Regional policies

There is a strong focus on the introduction of urban planning (Ultra Low Emission Zone, '15-minute cities'). This influences how different goods vehicles can enter urban cores, including greater restrictions on timings and the types of vehicle used. In addition, the introduction of more stringent noise restrictions will influence timings of deliveries (particularly overnight).

Adoption incentives

The EU 'Fit for 55'[10] regulation proposes to gradually reduce the cap of emission credits that manufacturers can receive for eco-innovations that verifiably reduce CO_2 emissions on the road.

Total cost of ownership (TCO)

Improvements in range and reductions in purchase price will make EVs more cost-effective when comparing the TCO to that of ICE vehicles.

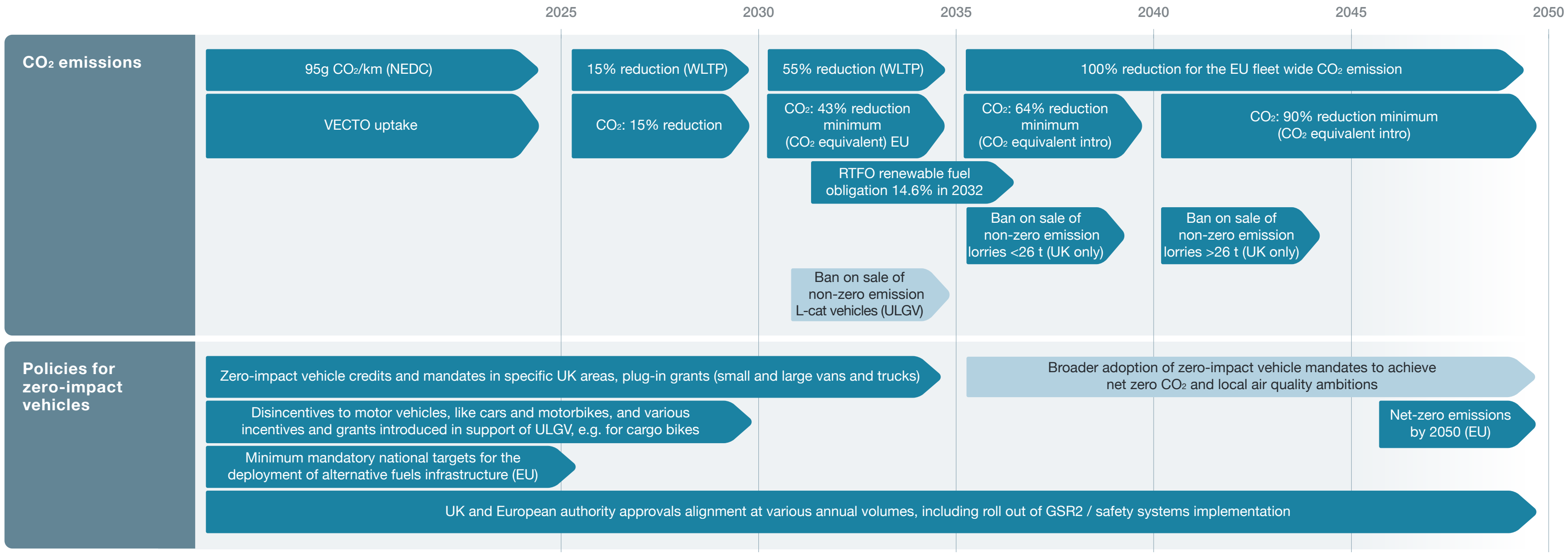
Market demand / change

Consumer behaviour continues to influence market demand and changes, particularly so since the COVID-19 pandemic. Consumer preference, coupled with corporate social responsibility (CSR) targets could determine choices made for fleet powertrains.

Emission standards and life cycle impact

The European Commission has adopted a single type approval of motor vehicles, engines and components with the introduction of Euro 7 emission rules, replacing Euro 6 for cars and vans and Euro 6 for lorries and buses[11]. Additionally, Euro 7 addresses emissions from brakes and microplastic emissions from tyres. It is expected that from July 2025, all new motor vehicles will have to meet these standards, regardless of fuel type, with the exception of small manufacturers who have until 2030.

10 https://www.consilium.europa.eu/en/policies/green-deal/fit-for-55/#:~:text=Fit%20for%2055%20refers%20to,line%20with%20the%202030%20goal
11 Commission proposes new Euro 7 standards (europa.eu)



CO_2 emissions

Over the past decade, OEMs have been responding to tailpipe CO_2 regulations and challenging sales-weighted zero-emission fleet targets set for 2030. Additionally, there is the 2035 ban on the sale of new ICE cars and vans in the UK. For HGVs, this ban comes into place in 2040. Regulatory emission targets will facilitate the development of ZEVs driving competition in the market.

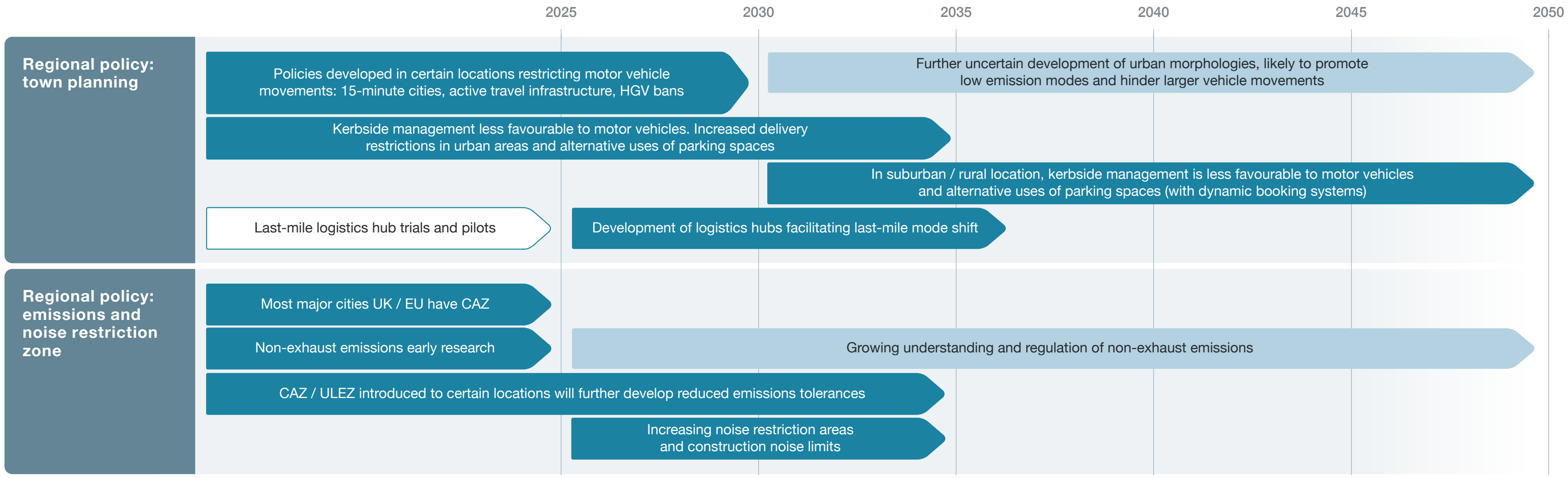
The European Commission has adopted stricter ‘Fit for 55’ regulation for new cars, vans and HDVs with:

- 55% CO_2 emission reductions from 2030 to 2034 compared to 2021 levels
- 100% CO_2 emission reductions from 2035[12]
- 65% CO_2 emission reduction for new HDVs from 2035
- 90% CO_2 emission reductions for new HDVs from 2040

Policies for zero-impact vehicles

More than 150 cities have implemented measures supporting mode shift from vehicle-dominant travel to sustainable transport including shared mobility initiatives for the commercial sector, e.g. e-cargo bike and electric van-sharing schemes, and financial incentives[13]. For example, California regulators approved new rules requiring HDVs sold in the state in 2036 to be zero emission.

12 ‘Fit for 55’: Council adopts regulation on CO2 emissions for new cars and vans - Consilium (europa.eu)
13 The future of mobility in 2035 | McKinsey



Regional policy

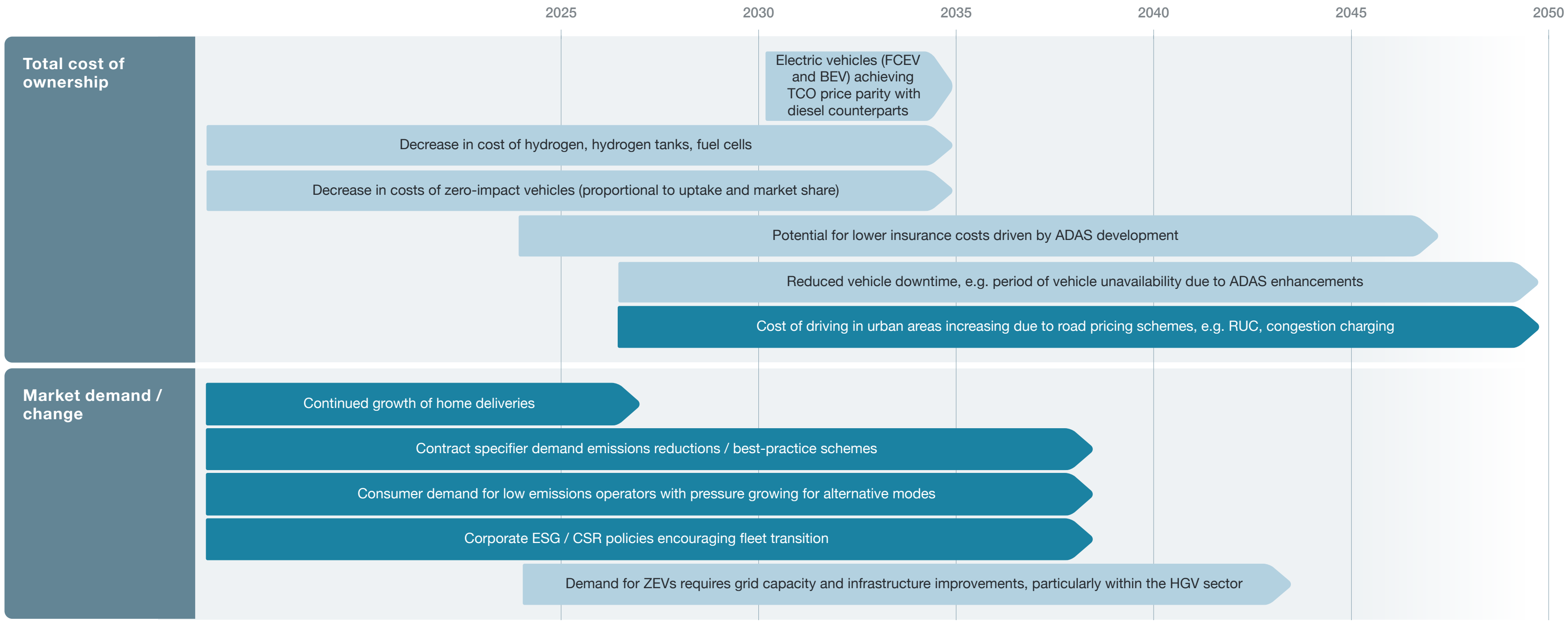
Town planning policies can force changes or set standards within the urban freight sector, such as the introduction of clean air zones (CAZs) and kerbside regulations in cities, which have the potential to significantly shape freight operations for localised movements. Low emission zones (LEZs) and ultra low emission zones (ULEZs) are encouraging faster investment in newer, cleaner vehicles which exhibit greater efficiency levels.

Consolidation and micro-logistics centres will continue to be piloted in major global cities that have the potential to spur significant levels of modal shift to electric LGVs and e-cargo bikes for last-mile deliveries. The increase in shorter journeys to undertake deliveries and servicing through these modes may heighten demand for these facilities.

Regulation around emission and noise restriction zones is likely to be introduced within the next decade. This will see restrictions on noise from both vehicles and the associated loading and unloading activity, outside of peak hours. This is likely to have a significant impact on the types of vehicles used for off-peak deliveries, particularly within urban centres cited near residential areas.

National / internal policy

It is anticipated more policies and guidance will be introduced specific to the strategic road network that supports countries' decarbonisation plans and help achieve net-zero goals. These could include measures like dedicated refuelling and recharging capabilities at freight hubs in convenient locations to the strategic road network. There will be a need to increase HGV dimensions and weight limits, allowing new types of ZIVs to be brought to market. Policies will need to be considered in the short-term to allow longer heavier vehicles (LHVs) or higher weight limit vehicles / gigaliners to be trialled and brought to market.



Total cost of ownership (TCO)

Improvements in range and reductions in purchase price will make EVs more cost-effective when compared to the TCO of ICE vehicles (expected from 2030 onwards). EVs require less servicing, maintenance and repairs as they have fewer moving parts.

The cost of driving ICE vehicles in cities is likely to increase (due to stricter emission standards, parking, congestion charge zones, etc.), which will encourage companies to transition their fleets to zero-impact modes. TCO assumptions must include further availability of funding and consider the number of actual sales within these specific vehicle markets.

Over time, more advanced driver assistance systems (ADAS) could result in lower insurance costs. TCO analysis for HGVs on alternative-fuel technologies compared to ICE engines needs more work and study as the technology matures in battery-electric-powered trucks.

Market demand / change

Consumer behaviour and the desire for faster and more convenient freight, e.g. the rise of home deliveries, will influence how deliveries and servicing activity takes place in the post COVID-19 future. There are likely to be further changes around consumer preferences and CSR factors that can drive a supplier’s choice of fleet. For localised movements, this may encourage suppliers that use ZIVs or can increase the use of ultra-light vehicles for last-mile deliveries, such as e-cargo bikes. Major global retailers are recognising the importance of low-environmental impact vehicles and have included plans for low-carbon application and electrification of fleets in their sustainable strategy plans.

3.4 | Technology and infrastructure enablers for localised and long-haul movements

Most of the new additions to the 2024 roadmaps are related to efficiencies in the long-haul supply chain, whether that is systems, powertrains, platforms, communications or digitalisation.

Charging infrastructure and grid development

The transition to ZIVs will be supported by an extensive charging network offering various types of charging for different needs. Government investment into a charging infrastructure will increase industry confidence to transition to EVs. A focus should be placed on accelerating planning and approvals, expansion of power grids and the designation of suitable sites for charging at deports / warehouses as well as public hubs / kerbside locations.

Smaller vehicle optimisation / infrastructure development

Many urban areas are directly encouraging the use of ULGVs by trialling or supporting logistics hubs or trans-shipment locations to improve the efficiency of transferring goods to smaller, lighter, ZEVs for the last-mile of the journey.

Hydrogen production and refuelling

Green hydrogen production will start to rapidly scale-up from 2030 onwards due to renewable electricity generation and will impact propulsion types for longer trips made by vehicles to transport goods.

System efficiency, powertrain efficiency and platform

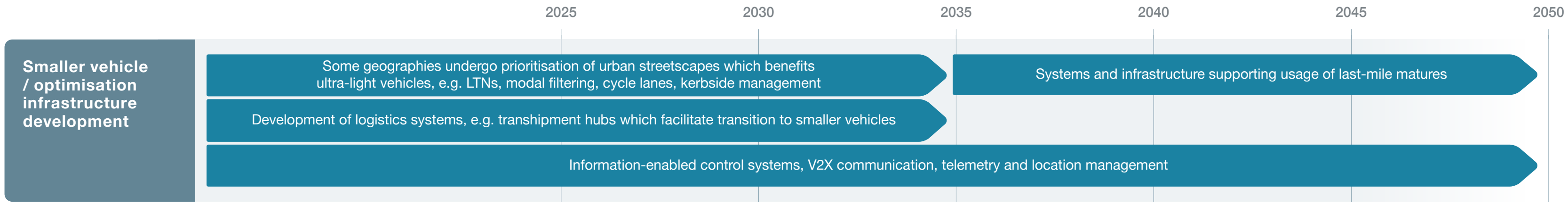
Longer, heavier vehicles may become more efficient than conventional vehicles and enhanced efficiency through innovation in aerodynamics will progressively be achieved within the < 26 and 4.25 t segment for long-haul applications.

Automation

In the UK, automation terminology is moving away from using the Society of Automotive Engineers (SAE) levels 0-5 towards the application of the categories 'user in charge' and 'no user in charge'. There are likely to be changes to vehicular design for the handling and management of goods where a driver is not required.

Digitalisation and fleet management

Further emphasis has been placed on digitalisation and projections for data-sharing between different players within the goods movement sector to support seamless supply-chain management. There is more focus on digital applications, which will support the long-haul sector further if data-sharing between key players is fostered.

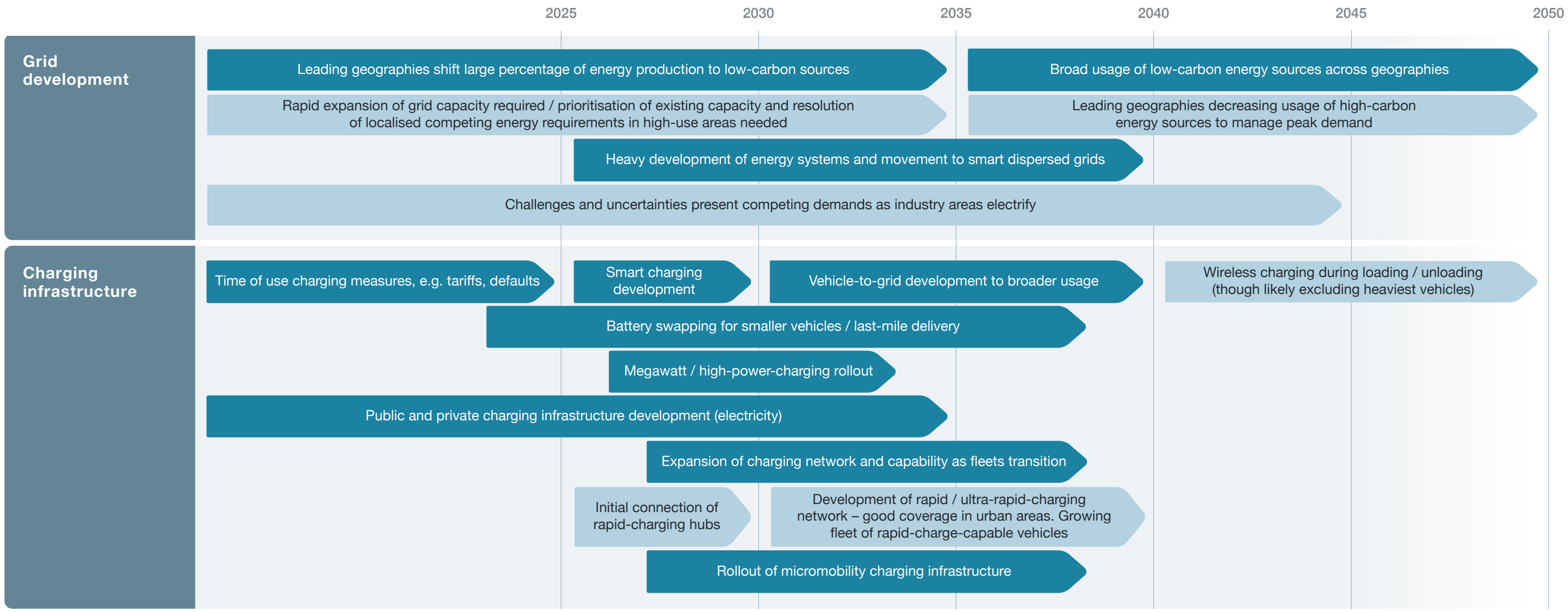


Smaller vehicle optimisation / infrastructure development for localised movements

The development of logistics systems, such as the last-mile logistics hub also know as microhubs, will help to scale and roll out electrified local cargo bikes and other similar ULGVs.

As local councils and administrations tighten the emission and CAZ mandates, electrified last-mile deliveries become very important.

High level of certainty
Lower level of certainty
Pilot / trials / PoCs



Grid development and charging infrastructure

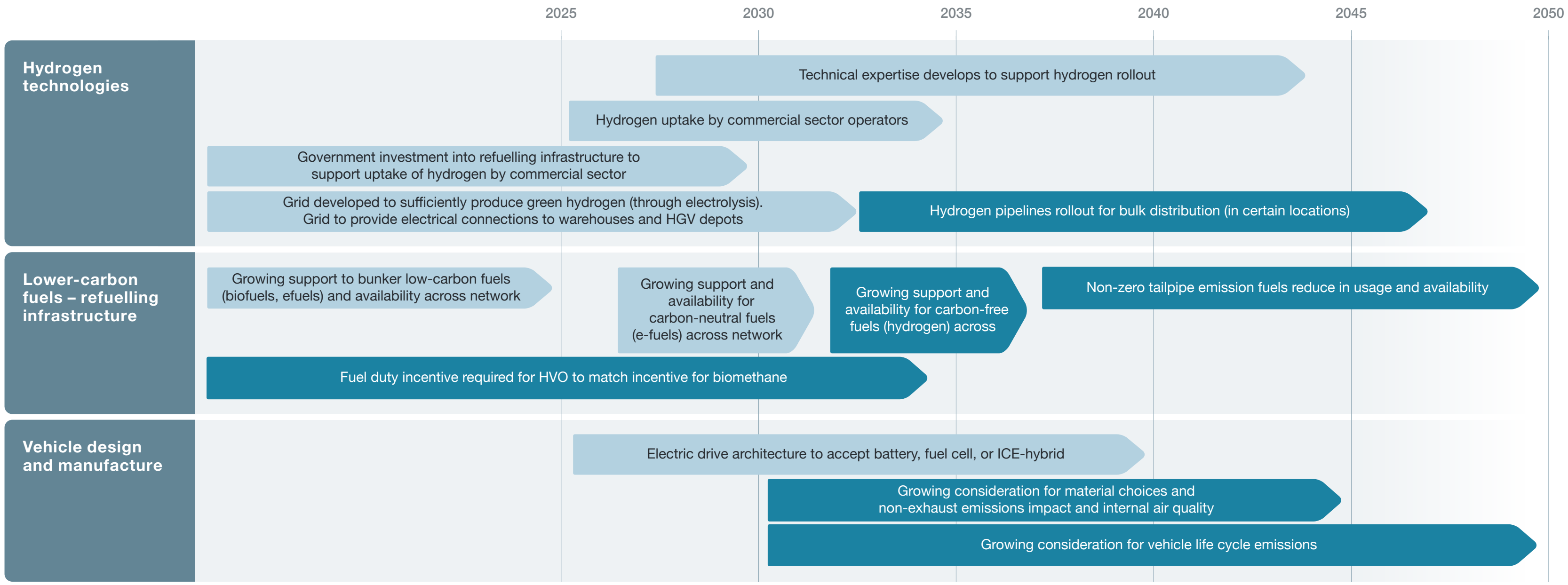
Public charging for commercial sector vehicles, such as rapid-charging hubs and on-street charging, will provide charging opportunities for delivery drivers without access to private parking. Scaling-up opportunities for non-rapid-charging will be particularly important in urban areas. For example, BP has acquired one of the largest truck stops in Europe and plans to transform the site by installing mega-watt chargers for electric HGVs[14].

As countries scale-up the production of low-carbon electricity from renewable energy sources, there is a growing challenge to modernise the grid to enable it to handle the decentralisation of energy storage systems.

ZIV adoption will be further aided by technologies, such as vehicle-to-grid (V2G). V2G technology will enable effective management in peak demand on local grids. EV owners can sell energy back to the grid, which is stored in their plugged-in vehicle, if they use commercial EVs for delivery of goods and undertaking servicing trips. It is likely that this will become a widespread practice.

Battery as a Service (BaaS) has become commonplace for smaller vehicles such as mopeds in Asian markets and could become more widespread. It would enable customers to exchange a depleted battery in their car or van for one which is fully charged, removing the need to wait whilst the vehicle charges. Another advantage is that customers do not have to worry about battery degradation in their vehicle, as they do not own the battery.

14 https://www.fleetnews.co.uk/news/bp-pulse-acquisition-to-support-electric-hgvs-with-mega-watt-chargers



Hydrogen technologies

Currently, hydrogen is expensive to produce, transport and store. Regulatory frameworks will be introduced to guide and support the development of the technology. Technology and the costs of hydrogen distribution are expected to be reduced by economies of scale.

The hydrogen refuelling network in the EU is in the early stages of development with central Europe leading the way while northeastern Europe is lagging with very limited development of infrastructure. Hydrogen refuelling stations are due to be implemented in Europe in coming years. Initially, these will cater to HGVs and will be more widely used as more hydrogen-powered vehicles are introduced. It is expected that from 2025 to 2030, the number of these stations will more than triple in the leading European countries, for example Germany is projected to have 300 stations by this time with 150 in the UK[15].

Lower carbon fuels – refuelling infrastructure

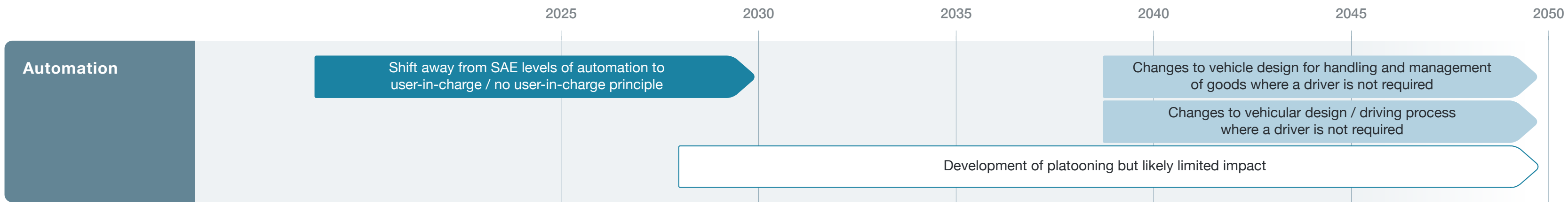
Low carbon fuel options will expand and proliferate with usage of green hydrogen and direct air capture CO_2. There are planned capacities and refineries to develop low-carbon fuels through power to liquid processes. There will be niche developments of HGVs that are tailored to run on non-fossil fuels.

Vehicle design and manufacture

Non-exhaust emissions are attracting attention in research as their proportionate emissions impact will grow with tailpipe emissions as a result of increased BEV and FCEV adoption. Increased vehicle weight owing to batteries is expected to increase non-exhaust emissions due to additional impact on road surfaces and braking. There is growing public awareness and regulatory support for reducing the health impacts of poor air quality and this is expected to impact vehicle design with efforts focussed on reducing health impacting emissions from construction materials.

15 Europe: hydrogen refuelling stations forecast by country 2030 | Statista

High level of certainty
Lower level of certainty
Pilot / trials / PoCs



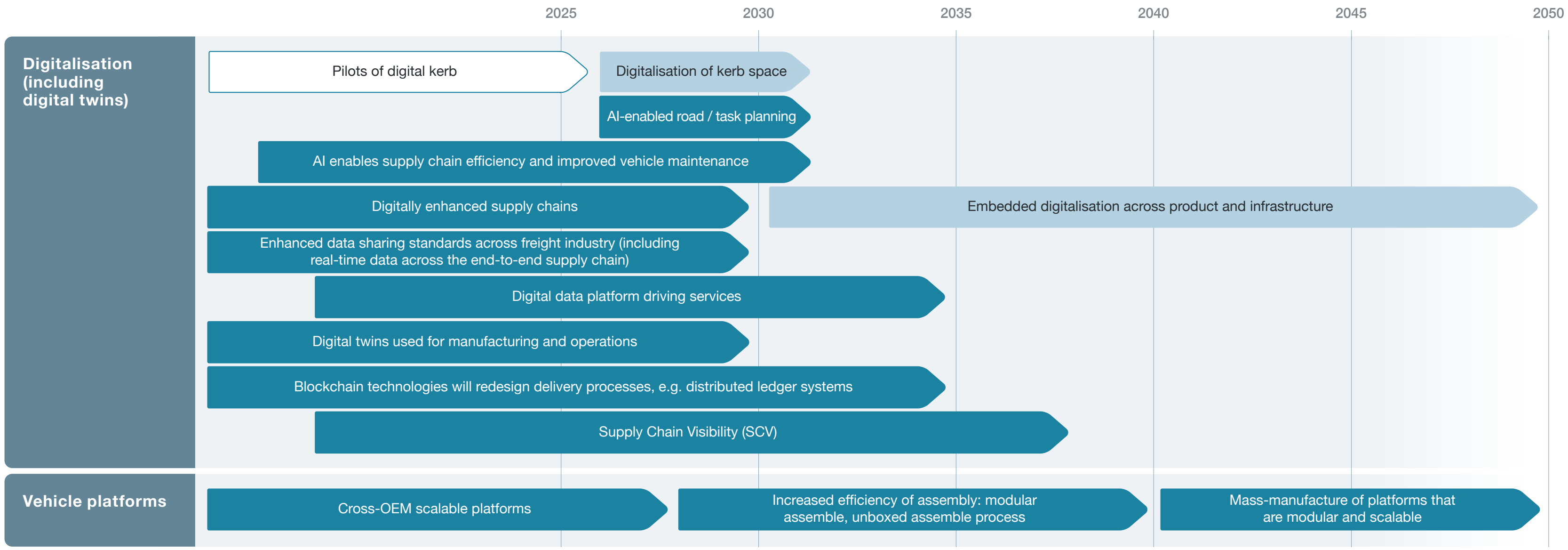
Automation

Connected and autonomous vehicles (CAVs) are continuing their progression towards higher levels of automation. These are well-suited for EV integration and offer potential for a growth in demand for particular use-cases, such as on-demand deliveries due to potentially lower costs.

The automotive vehicle industry is expected to transition from the SAE levels of automation to the user in charge / no user in charge principal. It is expected that by 2035 up to 40% of new vehicles will have self-driving capabilities, but these would fall within the user-in-charge category[16]. If these systems are adopted by the public for commercial use, driver assistance could reduce accidents by up to 15% by 2030[17]. Development in automation could lead to platooning and other efficiency-driven highway measures.

16 cam-2025-realising-benefits-self-driving-vehicles.pdf (publishing.service.gov.uk)
17 The future of autonomous vehicles (AV) | McKinsey

High level of certainty
Lower level of certainty
Pilot / trials / PoCs



Digitalisation

Artificial intelligence (AI) enabled supply chain interaction on a common digital platform for engineering, manufacturing and procurement can allow concurrent vehicle development across multiple suppliers. Advanced digital tools, processes and systems for vehicle design and development is growing at pace. Data collected from various sources provides a repository that relevant parties can access simultaneously, such as customers, shippers and logistics operators for collaborative decision-making[18]. Data collected and analysed from vehicles throughout their life cycle will also aid in their optimisation. Digital twins of vehicles will enable enhanced productivity with accelerated development of vehicle design for technologies such as batteries and powertrains. During a vehicle's operation, the technology could help extend vehicle lifespan with maintenance issues and ways to optimise operation flagged.

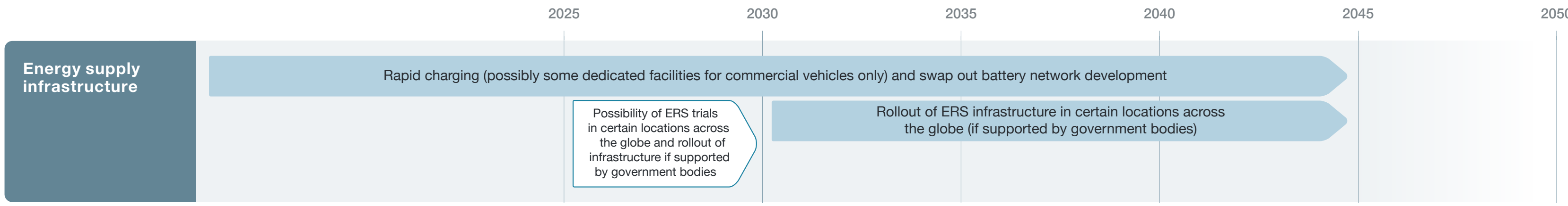
Digitalisation of the kerb is an area increasingly attracting attention-enabling kerb space to be used by multiple vehicle types and uses, e.g. taxi-loading and offloading, goods delivery, micromobility parking and private car parking. As CAV services become mainstream, they should connect with digital kerb solutions for efficient operations.

Vehicle platforms

OEMs are expected to continue to centralise vehicle designs upon a small number of underpinning platforms, providing a cost-effective production footprint. Scalable and modular BEV platforms lend themselves to mass-manufacture across the commercial sector with platforms shared across several OEMs to apply their own body designs and specific powertrain features.

18 Digital technology in freight, UK Parliament Post, Postnote Number 692 (February 2023)

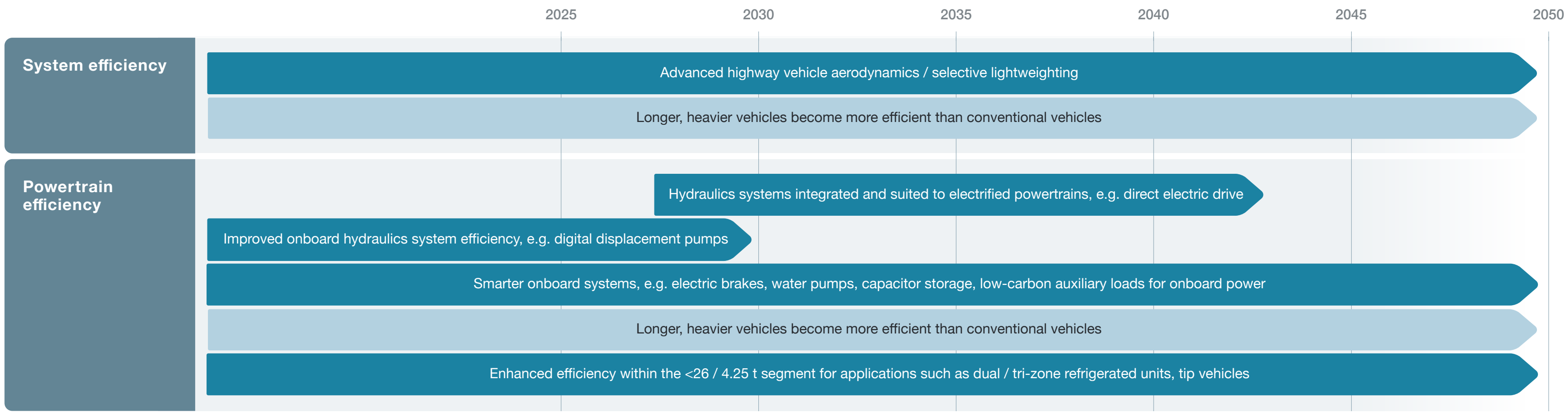
High level of certainty
Lower level of certainty
Pilot / trials / PoCs



Energy supply infrastructure

ERS has conductive or overhead charging infrastructure, for example via electric power cables that HGVs can attach to (catenary). These charge HGVs as they drive, enabling longer range in one charge, negating the need to have smaller batteries on board. ERSs have been trialed in Germany and Sweden using Scania hybrid-electric trucks. However, there are uncertainties for its future with no meaningful development commitments to date.

High level of certainty
Lower level of certainty
Pilot / trials / PoCs



System efficiency

System efficiency for HGVs can be achieved through advancements in technologies, such as advanced aerodynamics and the application of lightweight structures. UK Government has announced legislation aimed at making HGVs more efficient via aerodynamic features and elongated cabs[19].

Efficiencies can be achieved through the consolidation of goods into larger vehicles. LHVs or higher weight-limit vehicles / 'gigaliners', e.g. very large multi-trailer vehicles, are increasingly being considered and trialled across several geographies. These changes are subject to feasibility considerations on the impact and adaptability to the existing infrastructure. The key area of development in progressing further with LHVs is the consideration regarding the impact on the physical structures of the road network, as well as mixing with traffic[20].

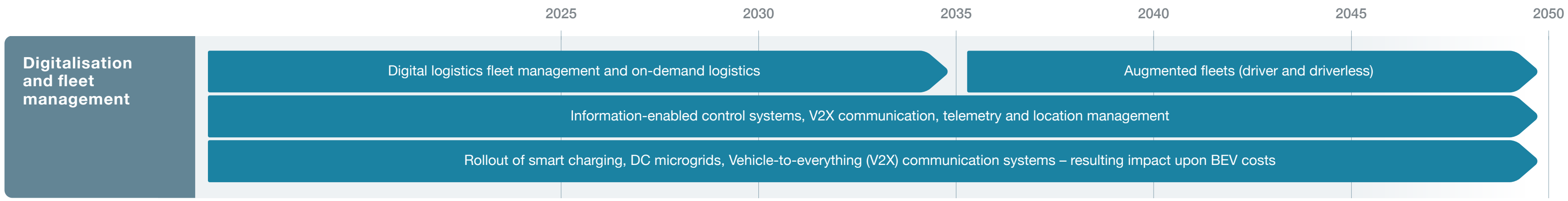
Powertrain efficiency

As previously identified in the 2020 Automotive Council roadmaps, increasing the efficiency of onboard equipment drive systems is vital for long-haul vehicles. Hydraulic systems take a major load on the engine, so efficiency gains and reduced losses make transitioning to electrified powertrains more feasible.

Digital displacement pumps can reduce energy demands by up to 30% on conventional hydraulic systems, reducing demand for the onboard energy storage and increasing equipment productivity. Increased onboard smarter integration of electric drive, power electronics and battery traction units can result in an efficient powertrain system for HGVs.

19 https://www.bvrla.co.uk/resource/legislation-changes-to-allow-more-aerodynamic-features-for-hgvs.html
20 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1098909/lhv-trial-feasibility-study.pdf

High level of certainty
Lower level of certainty
Pilot / trials / PoCs



Digitalisation and fleet management

Digital logistics fleet management help streamline day-to-day fleet operations through digital solutions. They support better insights into how a fleet operates, like optimising fuel consumption and identifying ideal driver behaviour for operational savings, therefore extending vehicle lifetime. Fleets enabled with vehicle-to-everything (V2X) capability provide safety, efficiency and environmental benefits. The advent of decentralised power generation can result in the need for a DC microgrid that distributes direct power within a small geographic area. These could be utilised to power the electrified heavy goods fleets in remote areas.

High level of certainty
Lower level of certainty
Pilot / trials / PoCs

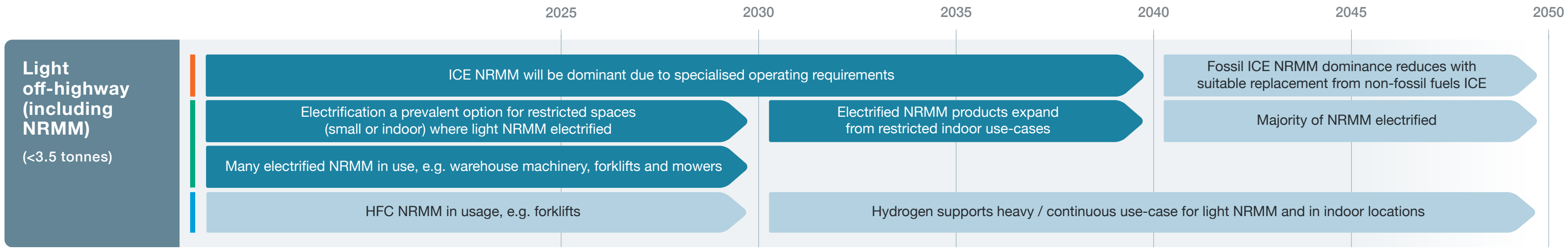
3.5 Energy vectors and vehicle propulsion type for off-highway (including NRMM)

Key takeaways for off-highway (including NRMM)

ICE technologies will be dominant in the off-highway and NRMM segment due to the tough and specialised operating requirements. Bio-gas and low-carbon fuels will play a key role in decarbonisation of agricultural vehicles.

Electrification in the off-highway segment will be restricted to specialised use-cases such as mining trucks for fixed site operations. This is due to the development and rollout of bespoke microgrids.

Hydrogen technologies will be restricted to development of H_2 ICE engines with potential longer lead-time for market maturity.



Light off-highway (including NRMM)

ICE fuels

ICE-enabled technologies will be dominant at least until 2040 in NRMM due to the need for specialised operating requirements.

Electricity

The complex requirements and relative technology immaturity will initially push light NRMM electrification to indoor spaces before 2030, seeking to expand use-cases as the battery technology evolves.

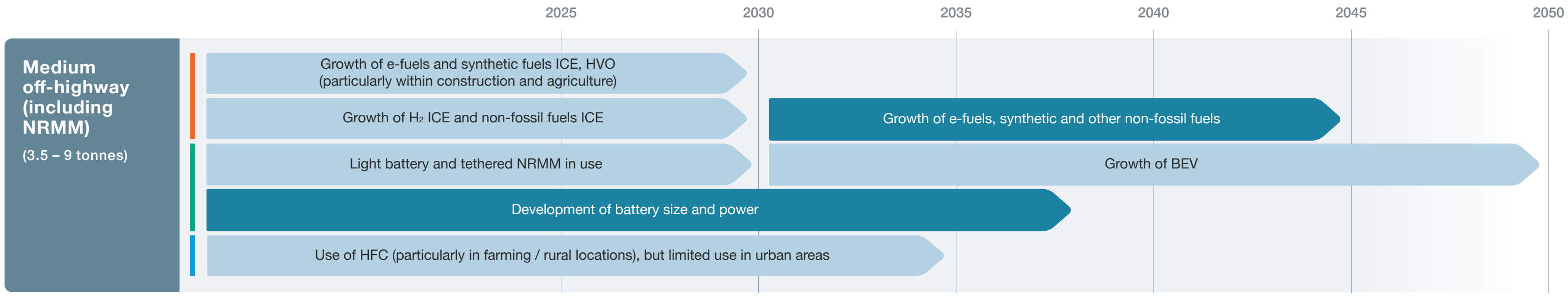
Hydrogen

HFC technologies may also develop for light NRMM, particularly in remote locations. Amazon has installed a hydrogen production system capable of powering 400 HFC-powered forklifts at one of its fulfilment centres in North America[21]. 90% of Toyota's forklift range is HFC electric, including lithium-ion battery-powered and hydrogen-powered trucks.

21 https://www.ivtinternational.com/news/hydrogen/amazon-installs-hydrogen-production-system-for-forklifts.html

High level of certainty
Lower level of certainty
Pilot / trials / PoCs

ICE-led
Battery-led
Fuel cell-led



Medium off-highway (including NRMM)

ICE fuels

One of the key challenges facing decarbonisation in the farming sector is the need to find an alternative to diesel as the main fuel for ICE to power cultivation and other farm tasks. Biomethane-fuelled vehicles will continue to be provided as a diesel replacement and, increasingly, ICE hydrogen is being trialled for this sector.

Battery-led

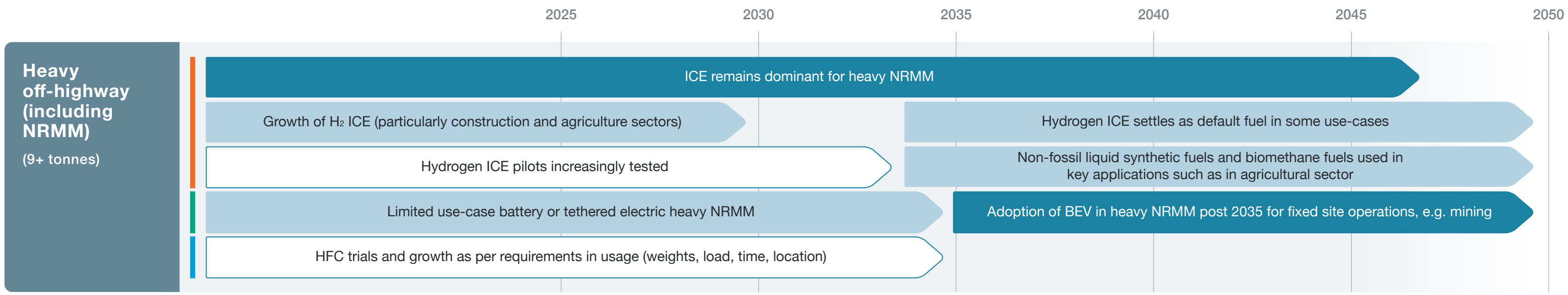
Localised renewable sources are being explored further to provide a viable alternative to producing electricity if planning permission can be secured and grid connections are available (via the DNO), both are currently limiting factors. This includes pop-up solar power farms and wind turbines at larger industrial sites (agriculture and construction sectors). This offers alternative energy vector sources for the agricultural sector through decentralised power generation. DC microgrids could play a key role in providing green electricity for the off-road remote locations.

Hydrogen led

Currently NRRM usage of hydrogen for medium to heavy tonnage vehicles is restricted to pilots and trials.

High level of certainty
Lower level of certainty
Pilot / trials / PoCs

ICE-led
Battery-led
Fuel cell-led



Heavy off-highway (including NRMM)

ICE fuels

Within heavy NRMM, ICE is expected to dominate in the longer-term. For heavy machinery, such as some farm vehicles, biogas upgraded to fuel grade bioCNG is currently the only affordable diesel replacement in advance of alternative high-torque powertrains being developed. Bennamann and New Holland partnership announced the world's first liquid methane fuelled tractor in December 2022[22]. The non-venting cryogenic tanks keep the methane as a liquid at -162°C producing a new source of clean power for the tractor[23].

Electricity

The demand for zero-emission electrified construction sites intensifies the strategic importance of developing fossil-free heavy-duty construction machines. Multiple solutions can be applied to power the electrified vehicle, including cables, batteries, or fuel cells, depending on the machine and its user-case.

BEV

BEVs within the heavy-duty sector are currently impractical for equipment with high-power demand as the batteries would be too heavy and expensive.

Hydrogen

HFC trials are currently deployed but there are very limited applications due to the lack of technology maturity for high-temperature fuel cells needed for off-road applications.

22 https://bennamann.com/new-holland-agriculture-debuts-worlds-first-liquid-methane-fuelled-tractor/
23 https://media.cnh.com/EMEA/cnh/LATEST-NEWS/new-holland-agriculture-debuts-world-s-first-lng-tractor/s/68636ec4-451c-4e7b-8826-4e08d794dc68

High level of certainty
Lower level of certainty
Pilot / trials / PoCs
ICE-led
Battery-led
Fuel cell-led

3.6 | Drivers and regulations for off-highway (including NRMM)

Drivers and regulations summary

Emissions standards

European Non-Road Engine (NRE) emission standards must be adhered to for this sector, which have been previously synchronised with US EPA emissions standards. The advance of Stage V emissions into V+ and V++ has been retained from the previous Automotive Council roadmaps. EU proposals (introduced 2020) for vehicles have been added in this roadmap, which applies to the off-highway sector and includes targets to reduce CO_2 emission by 90% by 2040 (compared to 2019 levels).

ZIV policies

The pathways of incentives for zero-impact off-highway vehicles are still to be established, however it is anticipated some types of vehicle credit and / or mandate might be developed as new models come to market. UK and European authority approvals are starting to occur, mainly focused on General Safety Regulation 2 standards / safety system implementation.

Regional policy

This affects emissions and noise restriction zones and it is anticipated that more stringent restrictions will be placed on off-highway activity in urban areas for construction activities, e.g. restricting timings, noise limits.

Adoption incentives

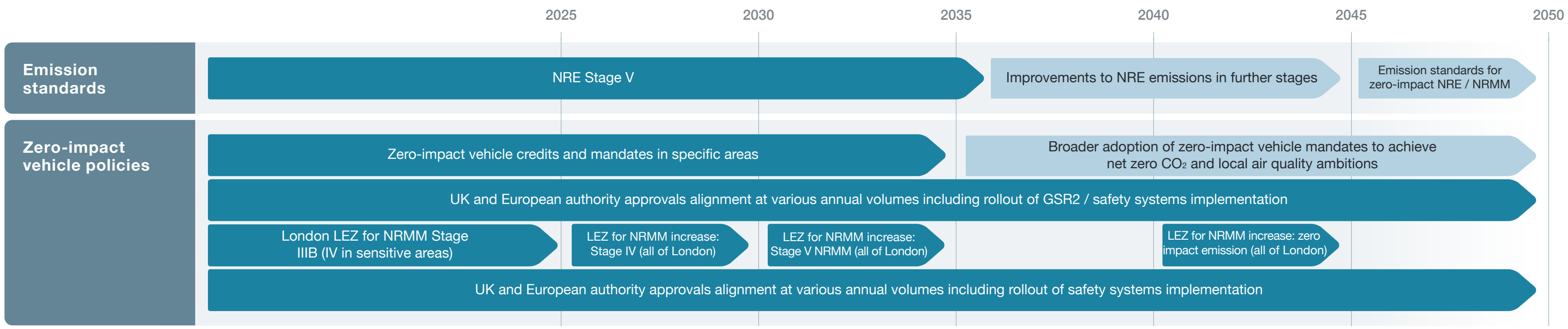
From 2027, the EU carbon pricing scheme Emissions Trading System 2 (ETS2) will apply to construction activity emissions, which require fuel manufacturers to purchase carbon credits. It is not yet determined whether the UK Emissions Trading Scheme (ETS) will align with the EU ETS2 scheme.

Total cost of ownership (TCO)

Developments in lower emission off-highway vehicle production, e.g. hydrogen production, ZIVs should reduce purchase costs over time, allowing for a reduction in TCO for EVs. However, there may be less reductions for the off-highway sector with the continued use of ICE owing to difficulties using EV technologies for non-road activities because of charging issues and high-power requirements.

Market demand / change

Construction and agriculture companies are likely to see change based around consumer preferences and CSR obligations. This will drive decisions on fleets and will be evaluated as part of procurement decisions. For off-highway activity this may encourage the selection of suppliers that can demonstrate ZIVs within their fleet, or a concentrated effort to procure these types of vehicle going forward.



Emissions standards

NRE stage V standards in EU for NRMM will continue to dictate and govern the emission standards.

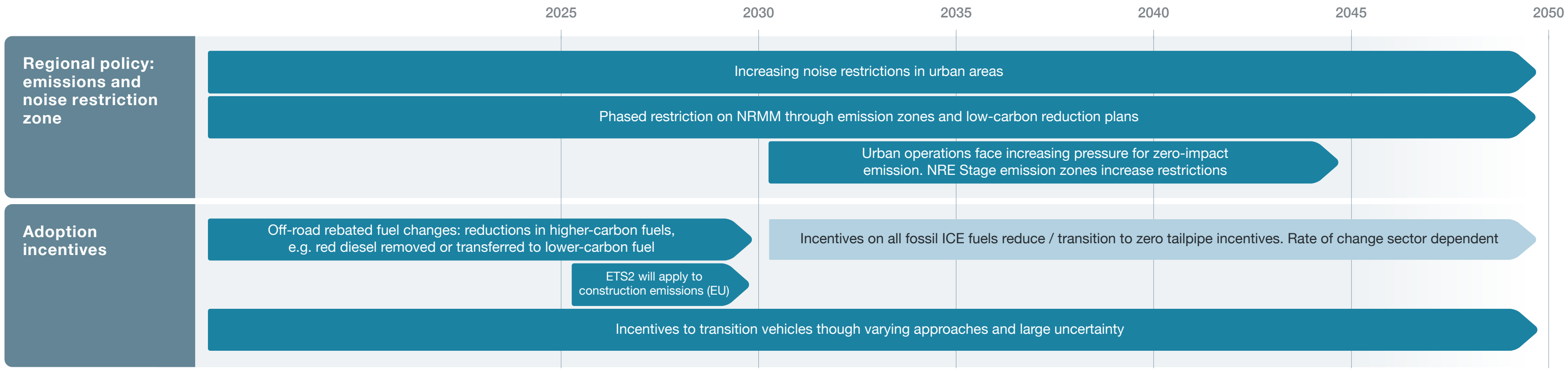
ZIV policies

The pathways of incentives for zero-impact off-highway vehicles are still to be established. It is anticipated that vehicle credits and / or mandates will be developed as new models come to market.

The standards for the NRMM low-emission zones will get tighter over time in major cities. Emissions from NRMMs in the construction sector in particular, is a significant contributor to urban air pollution globally. In London we have seen the Mayor and London Borough's planning powers enforce control over NRMM emissions on construction sites[24].

24 https://www.london.gov.uk/programmes-and-strategies/environment-and-climate-change/pollution-and-air-quality/nrmm

High level of certainty
Lower level of certainty
Pilot / trials / PoCs



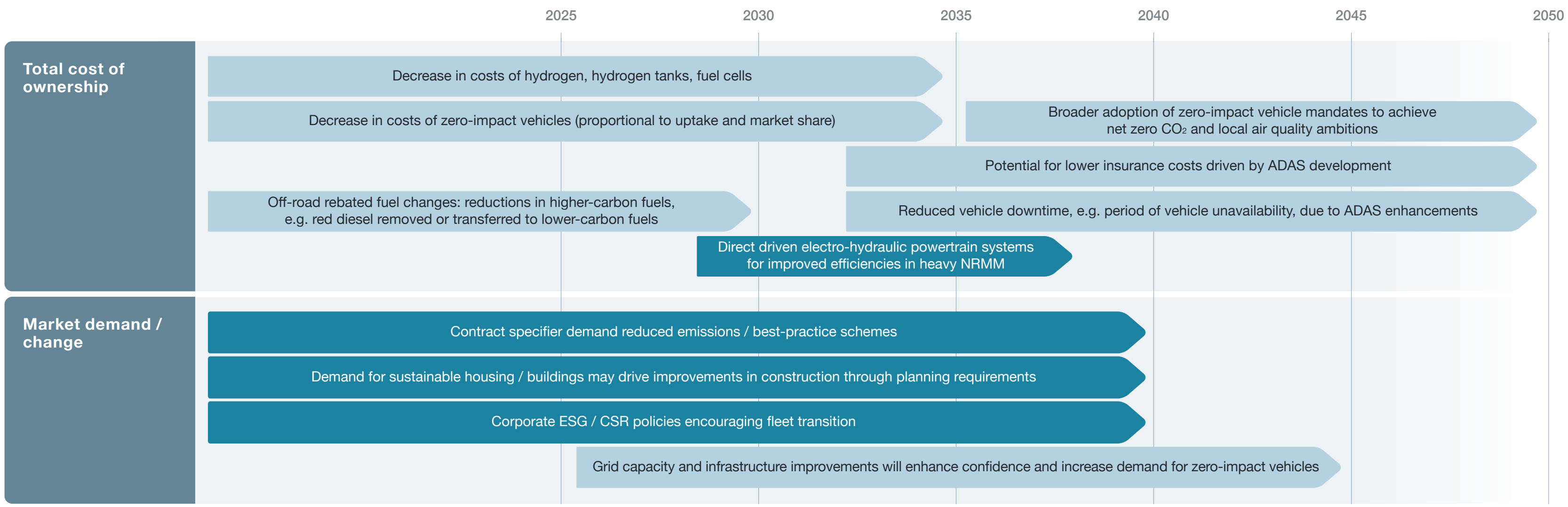
Regional policy: emissions and noise restriction zones

Increasing noise restrictions through local community actions and policy-making has an impact on off-highway activities in urban areas. We may expect a continued focus on phased emission restrictions for NRMM.

Adoption incentives

Many geographies are committed to the phasing-out of subsidies and tax incentives with negative environmental impacts. In the UK, this has seen the restriction of rebated fuels being limited in use primarily to off-highway agricultural vehicles and machinery. It is expected that many geographies will transition rebates and incentives toward lower emission propulsions. The Renewable Transport Fuel Obligation (RTFO) helps to encourage the supply of renewable fuels like HVO for use in off-highway applications. From 2027, the EU carbon pricing scheme ETS2 will apply to construction emissions, which requires fuel manufacturers to purchase carbon credits.

High level of certainty
Lower level of certainty
Pilot / trials / PoCs



Total cost of ownership (TCO)

Technology developments such as hydrogen fuel cells and storage tanks can have a positive impact on the overall TCO of zero-emission off-highway vehicles. Though their market and technology maturity is uncertain. Energy costs for production and transport are going to be a dominant factor and currently represent the largest unknowns with huge variability in electricity and hydrogen prices.

Integration of electro-hydraulic systems in NRMM and off-highway vehicles can drive high-power density and control, thus providing high efficiencies.

Market demand / change

Construction and agriculture companies are likely to see change based around consumer preferences and CSR obligations. This will drive decisions on fleets and will be evaluated as part of procurement decisions. For off-highway activity, this could encourage the selection of suppliers demonstrating ZIVs within their fleet, or a concentrated future effort to procure these types of vehicle.

High level of certainty
Lower level of certainty
Pilot / trials / PoCs

3.7 Infrastructure and technology enablers for off-highway (including NRMM)

Technology and infrastructure enablers

Energy and supply infrastructure

Energy supply and infrastructure are areas where NRMMs differ most from on-road vehicles, as infrastructure on-site is predominantly temporary. For all propulsion types, solutions for refuelling or charging need to be developed on-site rather than making use of public infrastructure. If energy costs significantly reduce, e-fuels may become a mainstream option for bulk usage.

Hydrogen production

Availability of hydrogen will be key for decarbonising localised activities in the off-highway sector. Wider trends in fleet are likely to impact costs for off-highway, e.g. competing with the HGV market for hydrogen could increase costs.

System efficiency

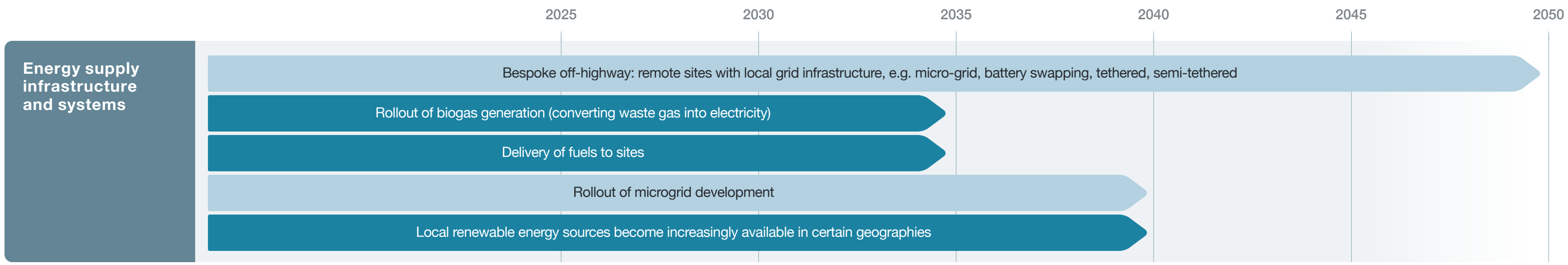
Increasing the efficiency of onboard equipment drive systems is vital for off-highway vehicles due to their power and drive-cycle requirements. Hydraulic systems are part of the operational power load, so efficiency gains and reduced losses complement a better-suited electrified powertrain system.

Lower carbon fuels network

HVO is currently being explored by operators looking to make emission reductions. However, supply and refuelling infrastructure remains a key issue.

Digitalisation and fleet management

Advanced digital tools, processes and systems for vehicle design and development is growing at pace. For NRMMs, this may focus on more site-specific systems that can be rolled out on private land, for example DC microgrids, internal V2X communication systems and driverless fleets for specific activities.



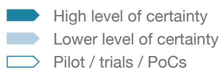
Energy and supply infrastructure

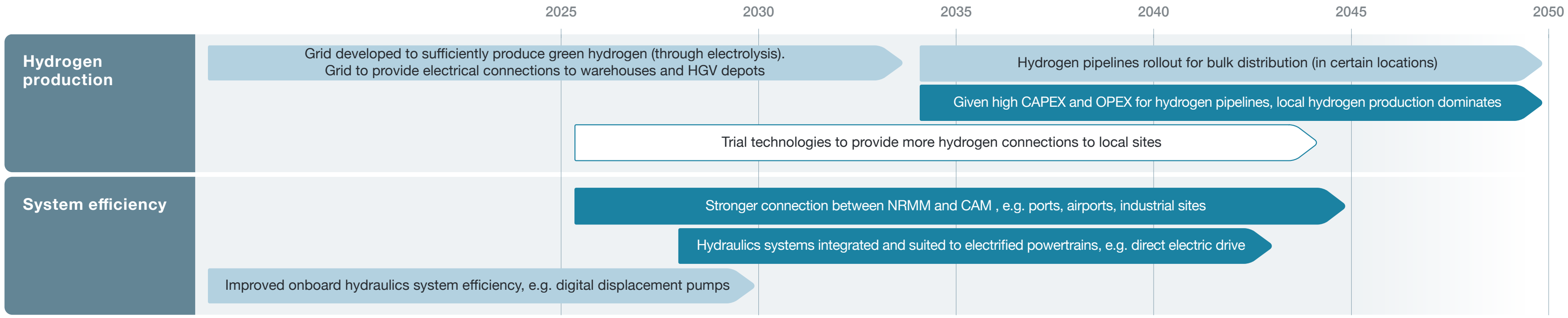
Operators need to have bespoke local-grid infrastructure or localised low-carbon fuel generation closer to the operation site.

It is likely that, with the high level of specialisation and operating context, various types of energy-supply infrastructures will be developed, e.g. micro-grid, battery swapping, tethered and semi-tethered EV charging, etc.

Energy costs for both the production and transport of alternative green energy are going to be the dominant factor and currently represent the largest unknowns, with assumptions about electricity and hydrogen pricing hugely variable.

If energy costs significantly reduce, e-fuels will become a mainstream option for bulk usage. The rollout of biogas generation supports the agricultural sector. Agricultural biogas plants utilise organic materials found on farms to generate biogas, a renewable fuel source and in turn renewable power through cogeneration / combined heat and power.





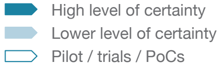
Hydrogen production

Circular economy principals may be applied to hydrogen production in off-highway activities and this is already happening in the agricultural sector in the form of waste-conversion activities. In an agricultural setting, ammonia from slurry and methane from anaerobic digestion can be used as fuels and are sources of hydrogen.

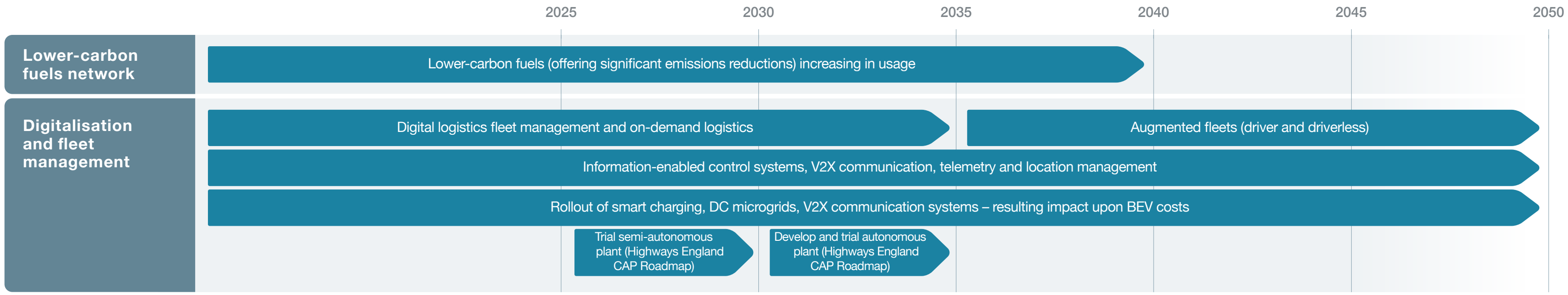
System efficiency

There are certain connected and automated mobility (CAM) elements that can be applied to private estates, e.g. ports, airports, and industrial sites, that are not on public highways. These private sites that are confined to smaller areas are often used for trials. For example, a new automated electric vehicle has been designed to move heavy cargo loads to and from aircraft at the UPS hub at East Midlands Airport (the UK's second-largest air cargo terminal). Additionally, Bristol Airport recently trialled a hydrogen-powered baggage tractor, said to be the first trial of its kind[25].

Digital displacement pumps can reduce energy demands by up to 30% on conventional hydraulic systems, reducing demand for the onboard energy storage and increasing equipment productivity.



25 UK hydrogen tractor



Lower-carbon fuels network

It is likely through market maturation and policy support, the costs and ease of access for lower-carbon fuels will improve in comparison to higher-carbon fuels. Cummins has approved the use of HVO biofuel for the full off-highway performance series line-up (3.8 to 15 litres)[26].

Digitalisation and fleet management

Similar to localised and long-haul sectors, digitalisation and fleet management will continue to support the off-highway sector. Advanced digital tools, processes and systems for vehicle design and development is growing at pace and for NRMMs this may focus on more site-specific systems that can be rolled-out on private land. DC microgrids might play a key role in ensuring there is uninterrupted power supply at off-site locations.

High level of certainty
Lower level of certainty
Pilot / trials / PoCs

26 https://thecea.org.uk/cummins-approves-the-use-of-hvo-biofuel-for-the-full-off-highway-performance/

Glossary

ADAS	Advanced driver assistance system
AI	Artificial intelligence
AIL	Abnormal indivisible load
BaaS	Battery as a service
BEV	Battery electric vehicle
CAM	Computer-aided manufacturing
CAV	Connected autonomous vehicle
CAZ	Clean air zone
CSR	Corporate social responsibility
DNO	District network operator
EPA	Environmental Protection Agency (US)
ERS	Electric road system
ETS	Emission trading system
ETS2	Emissions trading system 2
EU	European Union
EV	Electric vehicle
FCEV	Fuel cell electric vehicle
GHG	Greenhouse gases
HDV	Heavy-duty vehicle
HGV	Heavy goods vehicle
HVO	Hydrotreated vegetable oil
ICE	Internal combustion engine
IoT	Internet of things
LCA	Life cycle assessment
LEZ	Low emission zone
LDV	Light-duty vehicle
LGV	Light goods vehicle
LHV	Longer heavier vehicle
NRE	Non-road engine
NRMM	Non-road mobile machinery
OEM	Original equipment manufacturer
R&D	Research and Development
RTFO	Renewable Transport Fuels Obligation
SAE	Society of Automotive Engineers
SMR	Steam methane reforming
TCO	Total cost of ownership
UK	United Kingdom
ULEZ	Ultra low emission zone
ULGV	Ultra-light goods vehicle
V2X	Vehicle to everything (communication)
V2G	Vehicle to grid
VMT	Vehicle miles travelled
ZIV	Zero impact vehicle

System-Level Roadmaps

Mobility of People

Mobility of Goods

Technology Roadmaps

Electric Machines

Power Electronics

Electrical Energy Storage

Lightweight Vehicle and Powertrain Structures

Internal Combustion Engines

Hydrogen Fuel Cell System and Storage

Find all the roadmaps at

www.apcuk.co.uk/technology-roadmaps

automotive council UK

ADVANCED PROPULSION CENTRE UK

Established in 2013, the Advanced Propulsion Centre UK (APC), with the backing of the UK Government's Department for Business and Trade (DBT), has facilitated funding for 304 low-carbon and zero-emission projects involving 538 partners. Working with companies of all sizes, this funding is estimated to have helped to create or safeguard over 59,000 jobs in the UK. The technologies and products that result from these projects are projected to save over 425 million tonnes of CO_2.

The APC would like to acknowledge the extensive support provided by industry and academia in developing and publishing the roadmaps.