

Narrative Report

February 2021 | Version 1.0





Overview: Heavy duty and off-highway consider total cost of ownership for alternative propulsion solutions as environmental pressures increase

Workhorses on a tight rein

Ranging from urban delivery vehicles to long haul trucks and very heavy-duty mining equipment, these vehicles have one important feature in common: they are purchased to do a job. Their operators require performance, reliability and overall cost-effectiveness. Nonetheless, operators face other important 'licence-to-operate' challenges; including, low- and zero-emission zones, running limits, urban circulation restrictions and driver working time directive rules. Harder still is the need to reduce global carbon emissions to net zero by 2050. Heavy duty vehicles, including buses, account for about 25% of all EU road transport CO₂ emissions.

Complexity can be costly

Medium- and heavy-duty road vehicles are typically produced by integrated majors with access to in-house powertrains. Vehicle platforms and parent company powertrains provide economies of scale for larger OEMs, although, Tier 1 powertrain supply is quite common. The picture is more mixed for off-highway equipment where hundreds of variants are produced, reliant on a Tier 1 powertrain supply, each with a specific purpose. Modularity is key to reducing complexity and increasing flexibility to get volumes up and costs down.

A race of three technologies

Uncertainly remains on different propulsion solutions. New thermal propulsion technologies, batteries and fuel cells each help address road transport's air quality and CO₂ ambitions. However, their suitability, maturity and cost vary by application. The industry and its supply chains benefit from commonality and scale, so narrowing options will allow resources to be focussed. Taking a careful view of each application allows the benefits of the options to be understood (though winners cannot be precisely forecasted). The roadmap, informed by a wide industry consultation, charts the journey of these three propulsion technologies and routes to mass market adoption.



Foreword and Acknowledgements



Graham HoareChair of the
Automotive Council

The APC would like to acknowledge the extensive support provided by industry and academia in development and publishing this roadmap.

We are grateful to the Automotive Council for entrusting us with the product and technology roadmaps refresh and their continued support.

This work has received significant support from BEIS (Department for Business, Energy and Industrial Strategy). The automotive sector began 2020 preparing for a uniquely disruptive decade. Stringent CO2 and air quality legislation regulation has underscored a shift in powertrain development with promising alternatives emerging. The coming decade is no different with key technologies such as autonomy, connectivity and electrification enabling an ambitious net zero transport systems by 2050. To realise this vision and maintain the automotive sectors sustained growth, our industry must continuously innovate so vehicles are both environmentally benign and cater for the world's changing mobility habits.

Since 2009, the Automotive Council has ensured the UK remains at the forefront of automotive technology development and production. Our product and technology roadmaps are an informative resource that are used globally as strategic documents. The updated 2020 product roadmaps are no different and mark a significant improvement from 2017. Developed through a robust industry consensus process, the updated product roadmaps offer a fresh way of charting the development of future vehicle innovations. By putting mobility at the heart of the update process, we were able to define powertrain development trajectories for light duty vehicles, better integrate heavy duty vehicles and off-highway vehicles as well as show a clear direction for the future of the bus and coach sector.

While organisations may take a different view on some topics, the roadmap's consensus driven approach and detailed analysis of trends make this document a must read for those working in low carbon mobility. The Automotive Council looks forward to continuing working with UK Government, academia and industry to ensure that the barriers to adopting new vehicle and powertrain architectures can be addressed and capitalised upon to provide sustainable benefits to us all.



Neville Jackson
Chair of the Automotive Council
R&D Workstream

Since they were first published in 2009, the Automotive Council's roadmaps have been instrumental in signposting the most likely evolving technology paths to deliver a de-fossilised and more sustainable future vehicle parc.

With almost 30% of all greenhouse gases in the EU coming from the transport sector, the industry is mobilising an ambitious plan to rapidly accelerate the development of zero-tailpipe and net-zero carbon propulsion technologies. This plan also requires the development of sustainable, renewable and clean energy sources and the infrastructure to deliver this in accessible form to consumers and operators, including that required for off-road and construction vehicles.

Battery electric technology has developed at a promising pace, with signs of significant early market share uptakes in most geographies. The technology selection for heavy duty and off-highway vehicles remains challenging with long distance transport, high-power demands and viable business cases to consider. The bus and coach sector is well on its way to expanding its fleets of battery electric and fuel cell vehicles to meet mass mobility needs although more needs to be done to make these vehicles affordable.

By using powertrain power ratings and energy sources to map the demand of each vehicle type, the 2020 roadmaps communicate competing technologies that can deliver the sector's long-term zero tailpipe and net-zero carbon ambitions.

The UK has an important and long-standing role to play in the automotive supply chain as it competes in an increasingly challenging international market. Our aim with these roadmaps is to show that the Auto Industry has a largely common, logical and well planned vision in developing propulsion technology towards a greener future.

Executive Summary

Urban Service and Off-highway Vehicles

ICE hybrids, batteries and fuel cells each suit specific settings.

Goods vehicles and off-highway equipment in restricted zones have strict tailpipe pollutant requirements, because of city, port or airport-zoning, or indoor operation. Such vehicles typically have low to medium peak power requirements and, where some emissions are possible, potentially will hybridise in conjunction with low carbon fuels. Where zero tailpipe emissions are required, battery power can suit these needs

combined with dedicated charging to match operational patterns. If high levels of onboard energy are required, then fuel cells are well-suited for this application but need further development. In the long-term, costs of FCEVs will come down as adoption increases and could become competitive with BEVs. They will need further lifespan improvements to compete on a TCO basis.

Urban Services and Off-highway Zero tailpipe emissions led

Typically Low / Medium Power



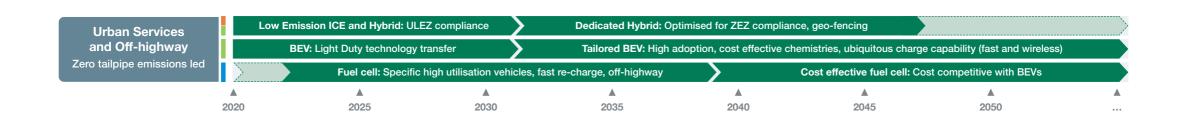






Goods and Service Vehicles

Off-highway Vehicles



Long Range and Off-highway Vehicles

ICEs will evolve and hybridize, batteries may play in niches, fuel cells will grow.

Goods vehicles and off-highway equipment for long range often need high flexibility (hours or miles-per-day without refuelling), demand high peak loads and operate unpredictable patterns. Achieving these requires high onboard energy or frequent recharging. ICEs and liquid fuels are attractive for OEMs in these scenarios, with high-efficiency ICE architectures expected in the medium-term. Fuels with low or zero carbon content, including hydrogen, will be required for emissions control. ICE hybrids are suitable where zero-emission zone access is needed, for example in

city centres. There is an emergence of BEV platforms for medium-duty trucks, but the trade-off between battery weight, vehicle payload and recharging infrastructure makes this a challenging widespread solution. Fuel cell systems can store higher onboard energy than batteries, for a given weight, making them attractive in high utilisation settings. However, they still need cost and lifespan improvements to become TCO competitive. An extensive hydrogen re-fuelling network, based on renewable generation, is also needed to support fuel cell fleets.

Long Range and Off-Highway Net-zero* emissions led

Typically Medium / High Power



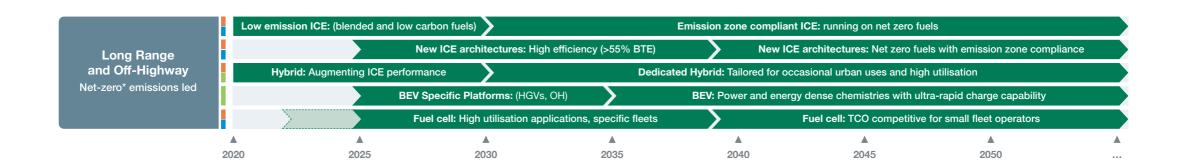
Regional Delivery and Services



Long Range Delivery and Services



Off-highway Vehicles



External Energy Source Vehicles

Remote and underground locations with on-site electricity provision, already benefit from these vehicle. Catenary solutions are increasing in interest but need infrastructure.

Vehicles and equipment with a connected (semi- or fully-) energy source avoid the need for much onboard energy storage. This is a unique category on the roadmap that accommodates certain niche applications. For underground mines and some construction sites, umbilically-connected electric equipment may be effective, allowing zero-emission operation in an enclosed area. Overhead catenary electrification of goods vehicles is technically feasible, but widespread infrastructure requires significant

government support together with a solution to transition from 'the grid' onto smaller trunk roads. A possible exception is for defined 'A to B' shuttle routes. Off-highway vehicles with access to renewable electricity, hydrogen, or biomass for biogas, benefit from closed-loop fueling systems. Examples include quarry sites and farms producing their own sustainable fuel or energy locally. These opportunities are very setting-specific and not universally applicable.





Roadmap Development

The 2020 roadmap responds to a changing automotive environment

2017 Commercial and Off-Highway Vehicle Roadmap



2020 Heavy Goods >3.5t and Off-highway Vehicle Roadmap







Changes to industry drivers

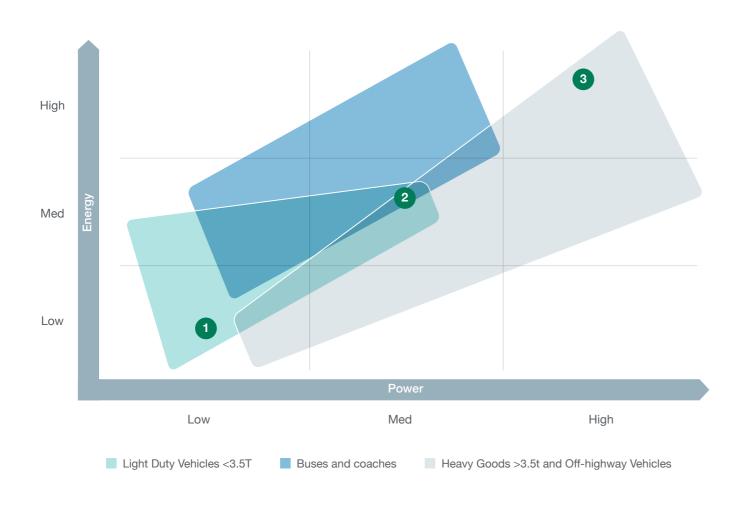
- Net-zero ambitions to decarbonise transport by 2050
- The first-ever EU-wide CO₂ emissions standard for heavy-duty vehicles, introduced in 2019, with targets to 2030
- For many heavy goods and off-highway vehicles, battery technology on its own cannot provide a practical solution due to high utilisation and energy demands. Fuel cells is emerging as a promising propulsion technology.
- Zero-emission zone regulations are growing in number

Changes to roadmap structure

- A three-page format explaining vehicle types, the roadmap, and drivers and enablers
- Clearer information on off-highway vehicles and applications
- Product and application types, based on power and energy:
 - Goods vehicles and off-highway equipment in restricted zones (low/medium power, low/medium energy)
 - Goods vehicles and off-highway equipment in long range settings (medium/high power, medium/high energy)
 - Vehicles and equipment in settings with a connected energy source (various power and energy levels). Links added to energy carriers related to each propulsion technology
- Energy carriers are linked to each propulsion technology

Presenting products in a new way

A new classification using product type combined with typical usage patterns; expressed in POWER and ENERGY.



The new Automotive Council roadmaps for 2020 appreciate that different vehicle applications will require different powertrain solutions based on their energy and power demands.

Off-highway vehicles have special circumstances that the roadmap takes into account

Use Case Considerations

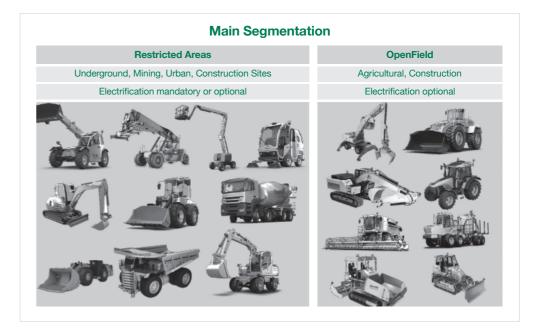
- · May include intermittent use
- Load / power are key factors, required to deliver 'work'
- Power infrastructure / tethering is a key decider –
 On-board or off-board
- Site management & local resources govern energy vector
- Special use case vehicles, designed for function / operation
- Economics / TCO different due to production volumes and utilisation variance
- Restricted environment versus open field is critical for health and safety operations

Industry Sectors

- Agriculture
- Construction
- Mining
- Defence
- Industrial

Specific Drivers

- Environmental / Air Quality
- TCO / Economic / Utilisation
- Specialist use cases



Roadmap Narrative



Product Classification





Urban Services and Off-highway Zero tailpipe emissions led

Typically Low / Medium Power









Goods and Service Vehicles

Off-highway Vehicles

Long Range and Off-Highway Net-zero* emissions led

Typically Medium / High Power



Regional Delivery and Services



Long Range Delivery and Services



Off-highway Vehicles

External
Energy Source
Net-zero* emissions led

All Power Levels



Closed loop Fueled Vehicles



Future Catenary Vehicles



Tethered Off-highway Vehicles



High Utilisation, Remote-site Vehicles

Product Classification





Urban Services and Off-highway Zero tailpipe emissions led

Goods and service vehicles and off-highway equipment in restricted zones

Typically, low to medium peak power due to modest duty cycles. Low to medium onboard energy is required as range is constrained by the setting in which they operate, for example an urban area or port.

Product types vary from medium duty vans and urban service vehicles to light (in the context of their sector) construction and materials handling equipment. These include off-highway vehicles for indoor use.

The main environmental influence is towards zero tailpipe emissions to improve urban air quality or enable indoor operation. For urban construction equipment noise curfews may also limit operating hours.

Zero tailpipe

No pollutant or GhG emissions at tailpipe.

Long Range and Off-Highway

Net-zero* emissions led

Goods vehicles for long range and off-highway equipment for heavy work

Typically, medium to high power as duty cycles can require heavy goods movement or high torque. Medium to high energy required as operators require long distance capability for vehicles and flexibility between refueling or high-intensity longer operating cycles for off-highway equipment.

Product types vary between medium- and heavy-duty trucks operating regionally and internationally in some cases. Off-highway equipment is very diverse in this category, covering construction, mining, materials handling, agriculture and other sectors.

The focus of these vehicles is on achieving net-zero emissions compliance for a wider and varied range of duty cycles.

*Net-zero:

The activities within the value chain of vehicle manufacturing result in no net impact on the climate from GhGs. This can be achieved by balancing the impact of any remaining GhG emissions with an appropriate amount of GhG removal.

External Energy Source

Net-zero* emissions led

Vehicles and equipment in settings with a connected energy source

Such vehicles cover many levels of energy and power with varied duty cycles, aided by a partial or complete connection to an energy source or within close proximity of re-fuelling.

Product types are diverse and very context-specific, for example heavy duty goods vehicles with overhead catenary connections on the highway (pantograph), tethered underground mining vehicles with an umbilical cable connection, farm vehicles that can refuel with biogas on-site and remote mine sites able to generate sufficient renewable electricity to service local fleets.

The main environmental influence is towards net-zero GhG emissions compliance.

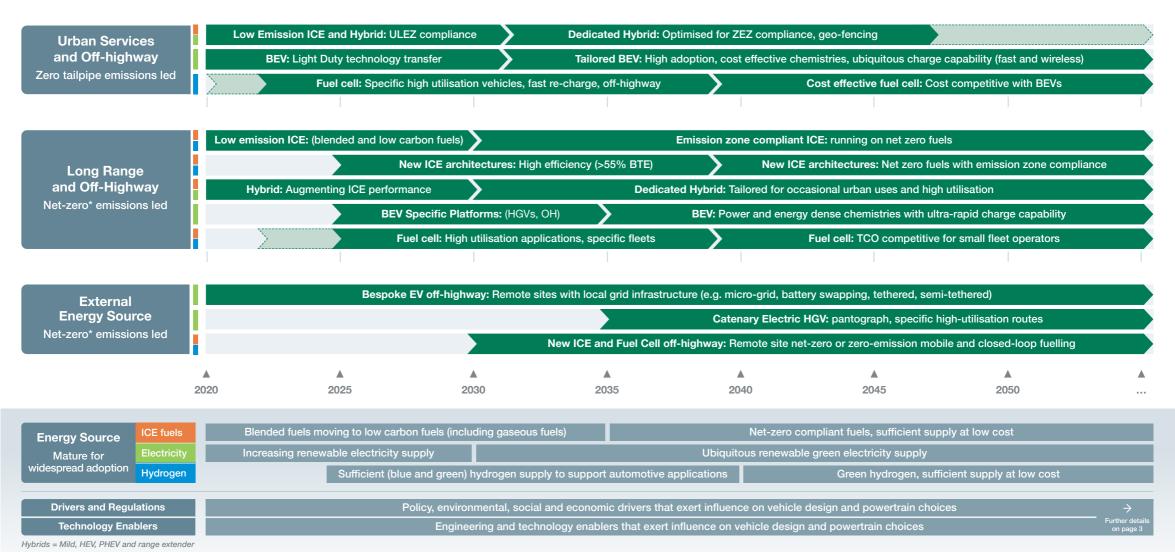






This roadmap represents a snapshot-in-time view of the global automotive industry propulsion technology forecast for mass market adoption. Specific application-tailored technologies will vary from region to region.

Solid colour bar: Technology adoption for mass-market applications Dotted line bar:
Technology exists in international
markets, but less prevalent in Europe



Propulsion Technologies Roadmap

Energy Source and Applicability

Roadmap 2020



Heavy Goods >3.5t and Off-highway Vehicle

Propulsion Technologies Roadmap

Urban Services and Off-highway Zero tailpipe emissions led

Example 1: Urban ICE and Hybrid energy sources

ICE fuels and electricity both required for these vehicles. Near term focus on blended liquid fuels featuring low carbon components. Higher blends give way to liquid and gaseous low carbon fuels produced by methods that are potentially net-zero GhG compliant. Dedicated plug-in hybrids also fed directly by low carbon electricity.

Long Range and Off-Highway

Example 2: New ICE architecture energy sources

In addition to blended and low-carbon fuels, significant gain with zero-carbon fuels like, hydrogen are promising for long range vehicles. Hydrogen combustion engines with, suitable aftertreatment for NOx management, can provide a cost-effective net-zero emissions solution for many heavy duty and off-highway vehicles in this category.

Net-zero* emissions led

Example 3: Fuel cell energy sources

Hydrogen fuel cells require low carbon sources i.e., blue hydrogen (from natural gas with CCS) or green (from renewable electricity). Solid oxide fuel cells can operate on existing commercial fuels, e.g., blended bio-fuels, and at high fuel efficiencies.

External Energy Source

Net-zero* emissions led

Example 4: New ICE and fuel cells energy sources

With an increasing number of biogas and e-fuels that support net-zero GhG commitments, like bio-methane produced using an anaerobic digester for ICE or fuel cells running on hydrogen, both energy carriers provide a low- or zero-carbon solution.

Energy Source

Mature for widespread adoption Hvdrogen

ICE fuels

Drivers and Regulations

Technology Enablers

Hybrids = Mild, HEV, PHEV and range extender

Energy Source

The roadmap provides a list of relevant low-carbon energy carriers that support the vehicle propulsion technologies. The colours codes (orange, green and blue) are shown against each vehicle application, some of which can be supported by more than one energy source. An increasing supply of carbon-neutral energy, based on renewable sustainable sources are of interest for transport decarbonisation. These are current forecasts aimed at mature mass-market adoption.

Drivers and Enablers are provided on a separate page

The link on the RHS of this bar takes you to the relevant drivers and enablers

Urban Services and Off-highway

Roadmap 2020



Heavy Goods >3.5t and Off-highway Vehicle

Propulsion Technologies Roadmap

Urban Services and Off-highway Low Emission ICE and Hybrid: ULEZ compliance

Dedicated Hybrid: Optimised for ZEZ compliance, geo-fencing

BEV: Light Duty technology transfer

Tailored BEV: High adoption, cost effective chemistries, ubiquitous charge capability (fast and wireless)

Zero tailpipe emissions led

Fuel cell: Specific high utilisation vehicles, fast re-charge, off-highway

Cost effective fuel cell: Cost competitive with BEVs

Urban ICE and Hybrids

Plug-in hybrid ICE vehicles allow use in zero-emission zones for the near term with additional range outside of the zones provided by ICE but need to utilise low and net-zero carbon fuels to manage stricter CO2 regulations going forward.

Longer term, zero emission running will be necessary in larger defined zones, suitable for optimised plug-in hybrids whilst expecting stronger jurisdiction mandates to follow that may result in hybrid bans in certain markets.

Urban BEV

Where zero tailpipe emissions are required, battery power is well-suited in combination with dedicated charging to match operational patterns - for example fast and/or opportunity charging, potentially wireless.

As these vehicles are sensitive to operating costs for viable economics, the maturing LDV battery electric technology can make a useful contribution to aid adoption into the goods transport and machinery sector. Large heavy batteries compromise the amount of useful fee-earning payload a vehicle can carry or affect overall efficiency due to weight increases. Improved battery chemistry and route charging are expected in the near- to medium-term.

Urban Fuel Cell

If high levels of onboard energy, vehicle utilisation or fast fueling are needed for the application then fuel cells will soon be compatible and, with further cost reductions in the medium term, be competitive with

More than 25,000 fuel cell-powered forklifts are already in commercial use in the US. The figure for Europe is much lower but this is likely to change as the economics and versatility compared to battery vehicles is showing to be an advantage.

ICE fuels Hydrogen Blended fuels moving to low carbon fuels (including gaseous fuels)

Net-zero compliant fuels, sufficient supply at low cost

Increasing renewable electricity supply

Ubiquitous renewable green electricity supply

Sufficient (blue and green) hydrogen supply to support automotive applications

Green hydrogen, sufficient supply at low cost

Drivers and Regulations

Energy Source

Mature for widespread adoption

Technology Enablers

Policy, environmental, social and economic drivers that exert influence on vehicle design and powertrain choices

Engineering and technology enablers that exert influence on vehicle design and powertrain choices

Hybrids = Mild, HEV, PHEV and range extender

Long Range and Off-Highway

Roadmap 2020 Heavy Goods >3.5t and Off-highway Vehicle Propulsion Technologies Roadmap **Long Range Conventional ICE** Long Range New ICE Long Range Hybrids Lower emission ICE are evolving, using blended ICEs and liquid fuels are attractive for OEMs in these Suited to vehicles with frequent stop/start allowing energy recovery. Systems are expected to evolve and lower carbon fuel. Fuels with low or zero applications, and more advanced high-efficiency carbon content, including hydrogen, are already ICE architectures are expected in the medium term. towards dedicated hybrid designs similar to LDVs, allowing some zero-emission running for restricted being considered. ICE hybrids are suitable where Radical improvement in engines, e.g., recuperating a zero-emission mode is needed (for example city split cycle, at very high BTEs are likely to supersede zone use. some applications. centre operation). Low emission ICE: (blended and low carbon fuels) Emission zone compliant ICE: running on net zero fuels **New ICE architectures:** High efficiency (>55% BTE) New ICE architectures: Net zero fuels with emission zone compliance Long Range and Off-Highway Hybrid: Augmenting ICE performance Dedicated Hybrid: Tailored for occasional urban uses and high utilisation Net-zero* emissions led BEV Specific Platforms: (HGVs, OH) BEV: Power and energy dense chemistries with ultra-rapid charge capability Fuel cell: High utilisation applications, specific fleets Fuel cell: TCO competitive for small fleet operators Long Range BEV Long Range Fuel Cell In some settings batteries will apply, but the tradeoff between battery weight, Fuel cell vehicles and equipment can achieve a higher onboard energy than batteries vehicle fee-earning payload and recharging infrastructure needs makes this less for a given weight, so for high utilisation applications where very low emissions are likely as a widespread solution. This challenge results in greater uncertainly and required, they can compete with BEV. However, hydrogen fuelling will be required to suit multiple propulsion choices for long distance goods trying to deliver net-zero operating patterns. Fuel cell systems for HGVs and OH need to achieve higher durability GhG emissions. lifespan targets than for passenger cars and further cost reductions are needed. Blended fuels moving to low carbon fuels (including gaseous fuels) Net-zero compliant fuels, sufficient supply at low cost ICE fuels **Energy Source** Increasing renewable electricity supply Ubiquitous renewable green electricity supply Mature for widespread adoption Hydrogen Sufficient (blue and green) hydrogen supply to support automotive applications Green hydrogen, sufficient supply at low cost **Drivers and Regulations** Policy, environmental, social and economic drivers that exert influence on vehicle design and powertrain choices **Technology Enablers** Engineering and technology enablers that exert influence on vehicle design and powertrain choices Hybrids = Mild, HEV, PHEV and range extender

External Energy Source

Roadmap 2020



Heavy Goods >3.5t and Off-highway Vehicle

Propulsion Technologies Roadmap

Urban Services and Off-highway

Zero tailpipe emissions led

Long Range and Off-Highway External Energy Bespoke off-highway EV

Remote off-highway or enclosed settings with access to on-site electricity for battery charging or tethering (connected-to-grid). Examples include quarry sites, underground mines and farms. Opportunities are very specific to the setting so unlikely to be universally applicable. These require a local infrastructure provision that is managed by the local site. Semi-tethered refers to vehicles that can return to on-site charging stations for charging in between operation.

External Energy Catenary Electric HGV

Overhead catenary electrification of heavy goods vehicles is technically feasible, with a potential focus on inter-city major highways. There is a significant amount of interest growing in national transport strategies to the pantograph infrastructure required to deliver this along with customised vehicles. This can be well-suited for long range goods transport.

However, many do not see the establishment of widespread infrastructure as feasible in the short-medium term, by which time other options may have taken hold. A notable exception to this is for defined 'A to B' shuttle routes.

External Energy New ICE and Fuel Cell off-highway

Remote locations where net-zero ICE fuels, like biomass for biogas, or locally stored hydrogen gas supplies present interesting possibilities for closed-loop systems. Mining and agriculture are candidate settings, but energy availability is very context-specific.

Currently, agricultural vehicles running on site-manufactured bio-methane, produced in an anaerobic digestor, offer a sustainable and environmentally route to decarbonisation.

External Energy Source 1

Bespoke EV off-highway: Remote sites with local grid infrastructure (e.g. micro-grid, battery swapping, tethered, semi-tethered)

2

Catenary Electric HGV: pantograph, specific high-utilisation routes

Net-zero* emissions led

3

New ICE and Fuel Cell off-highway: Remote site net-zero or zero-emission mobile and closed-loop fuelling

Energy Source

ICE fuels

Blended fuels moving to low carbon fuels (including gaseous fuels)

Net-zero compliant fuels, sufficient supply at low cost

Mature for widespread adoption

Electricity

Hydrogen

Increasing renewable electricity supply

Ubiquitous renewable green electricity supply

Sufficient (blue and green) hydrogen supply to support automotive applications

Green hydrogen, sufficient supply at low cost

Drivers and Regulations

Policy, environmental, social and economic drivers that exert influence on vehicle design and powertrain choices

rther details

Technology Enablers

Engineering and technology enablers that exert influence on vehicle design and powertrain choices

Hybrids = Mild, HEV, PHEV and range extender





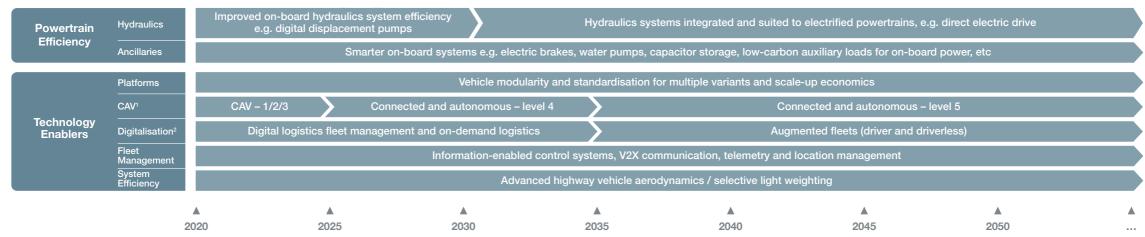


Drivers and Regulations / Technology Enablers

Policy, environmental, social and economic drivers that exert influence on vehicle designs and powertrains Defined driver Predicted driver **VECTO Uptake** CO₂: -15% CO2: -30% (CO2e intro) Towards net-zero CO2e and LCA compliance CO2e Emission **ZEV Policies** ZLEV super credits and mandates in specific areas Broader adoption of ZEV mandates to achieve net-zero CO2e and local air quality ambitions Euro VII+ / EPA 2015 MY27 Euro VI / EPA 2015 Euro VII / EPA 2015 Pollution and **Drivers and** Holistic environmental impact legislation (VOC, resource use, land use) and LCA compliance Resource / NRE Stage V / NRE Stage V+ / NRE Stage V++ Regulations Zone Regulation Ultra-low emission zones Localised zero tailpipe emission zones and geo-fencing Increasing pedestrianisation and vehicle entry restrictions, next gen city designs New Freight Logistics and Business Models, **Total Cost** High utilisation fleets (digitally-enabled), Pay-per-mile Business Models of Ownership Productivity Improvements, Sustainability Strategy \blacksquare \blacksquare \mathbf{A} 2020 2025 2030 2035 2040 2045 2050

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





^{1.} Adoption is dependent on supporting roadside infrastructure (incl. V2X, digital networks, data protocols, interconnects). See further details on https://zenzic.io/roadmap/

^{2.} More details on digitalisation will be available on the IDE roadmap from March 2021

Drivers and Regulations

Roadmap 2020



Heavy Goods >3.5t and Off-highway Vehicle

Drivers and Regulations / Technology Enable

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

		_								
Drivers and Regulations	1 CO2e Emission	VECTO Uptake	CO2: -15%	CO2: -30% (CO2e intro)	2e intro) Toward		ds net-zero CO2e and LCA compliance		
	2 ZEV Policies	ZLEV s	ZLEV super credits and mandates in specific areas			Broader adoption of ZEV mandates to achieve net-zero CO2e and local air quality ambitions				
	Pollution and Resource	Euro VI / EPA 2015 / NRE Stage V	Euro VII / EPA 2015 / NRE Stage V+	Euro VII+ / EPA 2015 MY27 / NRE Stage V++	Holistic environmental impact legislation (VOC, resource use, land use) and LCA compliance					
	Zone Regulation	Ultra-low emission zones	Localised zero tailpipe emiss	d zero tailpipe emission zones and geo-fencing		Increasing pedestrianisation and vehicle entry restrictions, next gen city designs				
	Total Cost of Ownership	New Freight Logistics and Business Models, Productivity Improvements, Sustainability Strategy			High utilisation fleets (digitally-enabled), Pay-per-mile Business Models					
		A	A	A	A	A	A	A		
		2020	2025 20)30 2	035	2040	2045	2050		

CO_{2e} Emissions

Heavy duty vehicle OEMs faced EU tailpipe CO₂ regulation from 2019 (for the first time), defining stricter targets in 2025 and 2030. These include a super-credits system for early action ZEVs to offset high CO₂ emitting vehicles. VECTO is the new simulation tool for HDVs developed by the European Commission to calculate CO₂ emissions and fuel consumption.

2

ZEV Policies

Already prevalent in LDV markets, such incentives are limited for HDVs. However, the evolution of regulations in the LDV sector and net-zero GhG commitments by 2050 suggest these instruments may be applied to HDVs in the longer term. Current EU ZLEV targets include super credits moving to mandates incentivising zero-emission HDVs.

3

Pollution and Resource

Pollutant emissions (NOx, HC, CO) from both goods vehicles and off-highway machinery are regulated by Euro VI (and above) and tiered US EPA standards, for example.

Defined driver

Predicted driver

The emission regulatory framework for off-highway vehicles fall under the NRMM and related NRE standards that is currently defined for Stage V.

4

Zone Regulation

The desire for improved air quality in a growing number of cities worldwide is resulting in city-level low emission zones, covering both goods vehicles and construction equipment. In some cities the hours of operation are also curtailed by noise regulations which preclude the use of diesel engines.

5

Total Cost of Ownership

Logistics is increasingly outsourced as a service and its procurement can be tied to sustainability objectives.

Decisions on fleet purchases (typically for emissions mitigation), new infrastructure costs for depot charging or fuelling equipment, a competitive commercial environment all demand a fresh look at viable logistics and business models for the sector. Seeking out productivity improvements, reducing on-board energy losses, increasing equipment utilisation are some of the ways in which TCO can be improved.

Powertrain Efficiency

Roadmap 2020



Heavy Goods >3.5t and Off-highway Vehicle

Drivers and Regulations / Technology Enable

1

Hydraulics

Increasing the efficiency of on-board equipment drive systems is vital for goods and off-highway vehicles, since their very high utilisation means small improvements yield big rewards. Hydraulic systems, especially for off-highway equipment, are a major engine load so efficiency gains and reduced losses complement a better suited electrified powertrain system.

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

2

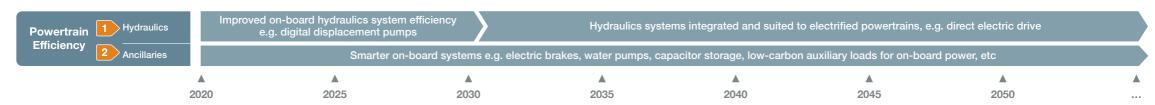
Ancillaries

Ancillary systems are mostly mechanical, driven by the primary ICE. Higher voltage electric systems enable some of these to be electrified e.g., pumps, brake servos, refrigeration compressors, cabin heaters. Electrification enables more precise control and avoids parasitic engine loads, increasing overall system efficiency.

As optimisation of on-board energy become a critical focus for new low-carbon systems, a systematic review and implementation of efficiency improvement measures, together with potential on-board solar capture, provide opportunities for TCO benefits.

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





Technology Enablers

Roadmap 2020



Heavy Goods >3.5t and Off-highway Vehicle

Drivers and Regulations / Technology Enable

1

Platforms

Modularity is very important for OEMs making relatively low numbers of a wide range of products. This applies especially to complex technologies whose cost is more influenced by production volume than physical mass, such as powertrains.

Scalable, modular BEV platforms lend themselves to mass manufacture and can leverage economies of scale.

2

CAV

Digital technologies are already influencing the off-highway sector, with some mine sites adopting driverless vehicles for safety and cost reasons. Similar changes are expected in other off-highway applications such as agriculture and materials handling. CAV technologies are also being considered for goods vehicles, meaning that very high utilisation could be achieved. More information on this is available on the Zenzic roadmaps.

3

Digitalisation

Goods vehicles are influenced by a wider trend towards digital logistics, whereby monitoring and utilisation can be improved and operating costs reduced. As TCO drives decisions in this sector, efficiencies through digital design tools, scheduling optimisation, digital fleet management, live track-and-reroute are all opportunities for economic improvements. More information on this is available on the IDE digitalisation roadmaps.

4

Fleet Management

Communication technologies are already enabling closer monitoring of vehicles. As on- and off-board technologies advance the control of vehicle energy functions becomes possible, for example through geofencing, switching to low emission mode and dynamic speed control. Telemetry and live data communications allows timely and flexible fleet decisions that can address changing market needs.

5

System Efficiency

Aerodynamic efficiency is particularly relevant for goods vehicles operating at highway speeds. Weight reduction is key for all goods vehicles where payload has high value, especially if battery electric propulsion is increasing vehicle mass.

Further efficiencies are covered under 'powertrain efficiency' in the previous section.



Glossary

Glossary

Abbreviation	Explanation					
BEV	Battery Electric Vehicle					
CAV	Connected and autonomous vehicle					
CCS	Carbon capture scheme					
FCEV	Fuel cell electric vehicle					
GhG	Greenhouse gas					
HDV	Heavy-duty vehicle					
HGV	Heavy goods vehicle					
ICE	Internal combustion engine					
LCA	Lifecycle assessment					
LDV	Light-duty vehicle					
MaaS	Mobility as a Service					
NRE	Nonroad engines					
NRMM	Non-road mobile machinery					
ОН	Off-highway					
TCO	Total cost of ownership					
ZEV	Zero-emission vehicle					
ZLEV	Zero- and low-emission vehicles					

This is an industry consensus roadmap facilitated by the APC

Summary of engagements during the 2020 roadmap refresh

Spread of companies that participated in the refresh

109 industry organisations participated in Workshops and Interviews38 additional industry organisations participated via the Online SurveyTotal engagements 147 Industry Organisations



A global view with international participation

Austria Singapore
Belgium Sweden
England Switzerland
Germany United States

Netherlands Wales Scotland Japan

