Bus and Coach Roadmap 2020

Narrative Report

February 2021 | Version 1.0

automotive council UK

ADVANCED PROPULSION CENTRE UK

Overview: Bus and coach propulsion must evolve to meet demands of citizens, whilst remaining viable for their operators

Carbon regulations tightening, urban restrictions tighter still

Many buses are technically ‘medium-duty vehicles’, but their urban duties expose them to the toughest demands from regulators and citizens. Coaches face similar challenges, with routes that often start and end in cities. Long subject to tailpipe pollution limits, the bus and coach sector now faces CO_2 EU regulations, with targets defined for 2025 and 2030 – a function of the need to reduce global carbon emissions to net-zero by 2050. Transport is responsible for nearly 30% of the EU’s total CO_2 emissions; 25% of this is from heavy duty vehicles, including buses and coaches. Increasing concerns around urban pollution and congestion means stricter tailpipe regulations, urban circulation restrictions, life cycle manufacturing demands and more, making clean buses and coaches essential for public transport.

Viable OEM and Tier 1 solutions needed

Coaches are typically produced by integrated HDV majors with access to in-house powertrains. Their low emission options depend on the choices offered by the parent company who benefit from economies of scale. Coach buyers are largely TCO-focused commercial operators. Conversely, buses are typically assembled by specialists who purchase powertrains from preferred suppliers. Bus designs and propulsion may be tailored to specific applications, enabling novel solutions to be adopted - evident in the already wide variety of low emission city bus types. Buses are largely purchased and operated commercially under conditions set by local policymakers.

A race of three technologies

Uncertainly remains on different propulsion solutions. New thermal propulsion technologies, batteries and fuel cells each help address bus and coach air quality and CO_2 ambitions. However, their suitability, maturity and cost vary by application. Operator models will need to adapt to exploit the characteristics of each technology to ensure economic viability. The bus and coach industries and their 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.

A full glossary is provided at the end of this report

Foreword and Acknowledgements

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).

Graham Hoare
Chair of the
Automotive Council

The automotive sector began 2020 preparing for a uniquely disruptive decade. Stringent CO_2 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 Passenger Mobility

ICEs give way to mission-suited batteries with fuel cells competing in the long-term.

For buses whose routes include zero emission zones, range extender ICE vehicles provide battery range extension to operate in geofenced areas for the near-term. Battery buses are well-suited to urban operation offering zero tailpipe emissions. Large battery packs offer versatility across different routes but may reduce passenger capacity due to packaging constraints. Smaller packs can be used on buses for well-defined routes, especially if combined with fast opportunity charging. Supercapacitors are potentially suitable for vehicles that require very fast charging but are less common. Both large- and small-battery EV buses are expected to evolve from variants of conventional bus designs towards tailored platforms. Offering longer range, faster fuelling and less impact on passenger capacity than batteries, fuel cells can work well for urban buses especially if higher range is required. For larger adoption, fuel cell costs need to reduce, and stack lifespan extended before they can be competitive on a TCO basis.

New demand-service urban transit solutions are likely to appear in the medium-term, providing tailored routes for changing passenger needs. Integrated BEV and CAV technology could develop in the long-term, offering intelligent route and energy management vehicles.

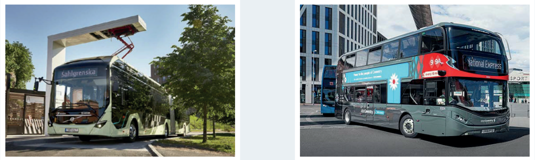
Urban Mobility

Zero tailpipe emissions led

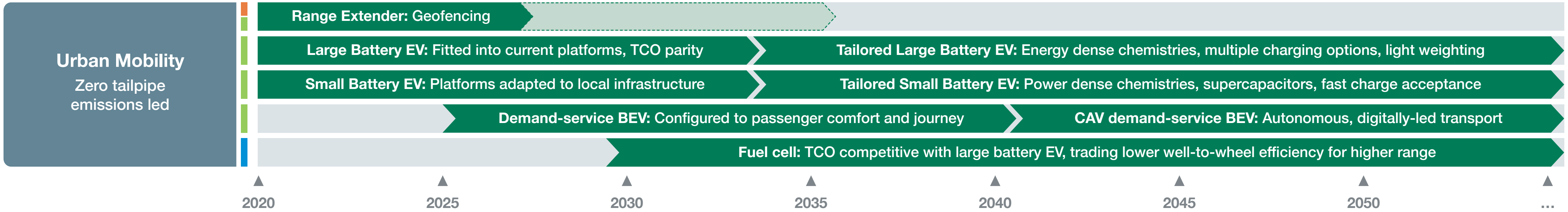
Typically Low / Medium Power

New mobility vehicles for bus-rapid-transit

Community based transport



Buses with fixed city and urban routes



Urban Mobility

Zero tailpipe emissions led

Range Extender: Geofencing

Large Battery EV: Fitted into current platforms, TCO parity

Tailored Large Battery EV: Energy dense chemistries, multiple charging options, light weighting

Small Battery EV: Platforms adapted to local infrastructure

Tailored Small Battery EV: Power dense chemistries, supercapacitors, fast charge acceptance

Demand-service BEV: Configured to passenger comfort and journey

CAV demand-service BEV: Autonomous, digitally-led transport

Fuel cell: TCO competitive with large battery EV, trading lower well-to-wheel efficiency for higher range

Long Range Passenger Mobility

Cleaner ICEs can continue in some settings, fuel cells well-suited as lifetimes increase, batteries under specific conditions.

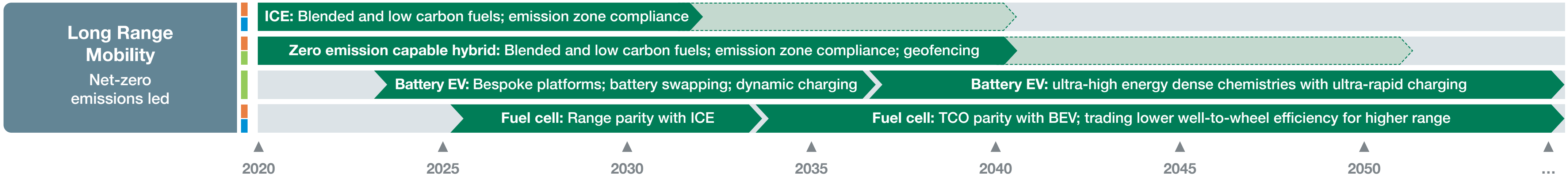
Long range buses and coaches are expected to feature an evolution of ICE in the near-term, providing high efficiency for highway and low (but not zero) emission in cities, by running on low carbon fuels. A more versatile near-term option is advanced hybrid ICE, also running on low carbon fuels, with some EV-only range for urban sections of inter-city journeys. Battery vehicles may suit longer range vehicles where dynamic route charging or depot solutions like battery swapping become available. As battery chemistries evolve to higher energy densities and charging capability, this will provide opportunities for vehicle design optimisation and increased use. Fuel cells are well-suited to long range travel and where refuelling points are far apart, but longer stack lifetimes and lower costs need to be developed and demonstrated to compete on a TCO basis. Fuel cell vehicles generally offer lower system efficiencies than battery vehicles, but more onboard energy storage for a given weight or vehicle capacity and hence longer range.

Long Range Mobility
Net-zero* emissions led

Typically Medium Power

Long distance coaches

Buses with flexible semi-urban and rural routes



Long Range Mobility
Net-zero emissions led

ICE: Blended and low carbon fuels; emission zone compliance

Zero emission capable hybrid: Blended and low carbon fuels; emission zone compliance; geofencing

Battery EV: Bespoke platforms; battery swapping; dynamic charging

Battery EV: ultra-high energy dense chemistries with ultra-rapid charging

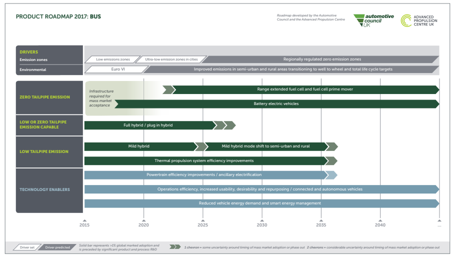
Fuel cell: Range parity with ICE

Fuel cell: TCO parity with BEV; trading lower well-to-wheel efficiency for higher range

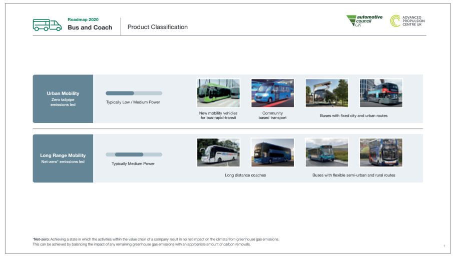
Roadmap Development

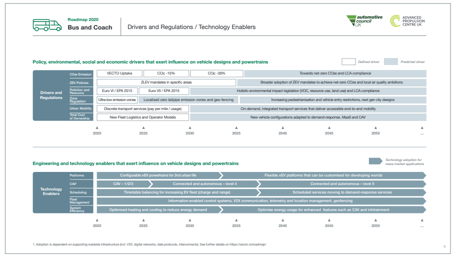
The 2020 roadmap responds to a changing automotive environment

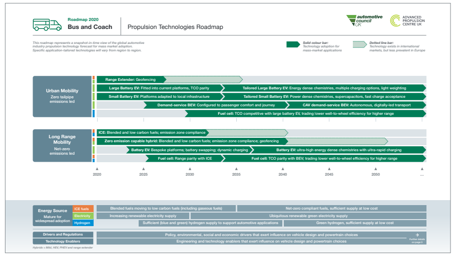
2017 Bus roadmap



2020 Bus and Coach roadmap







Changes to industry drivers

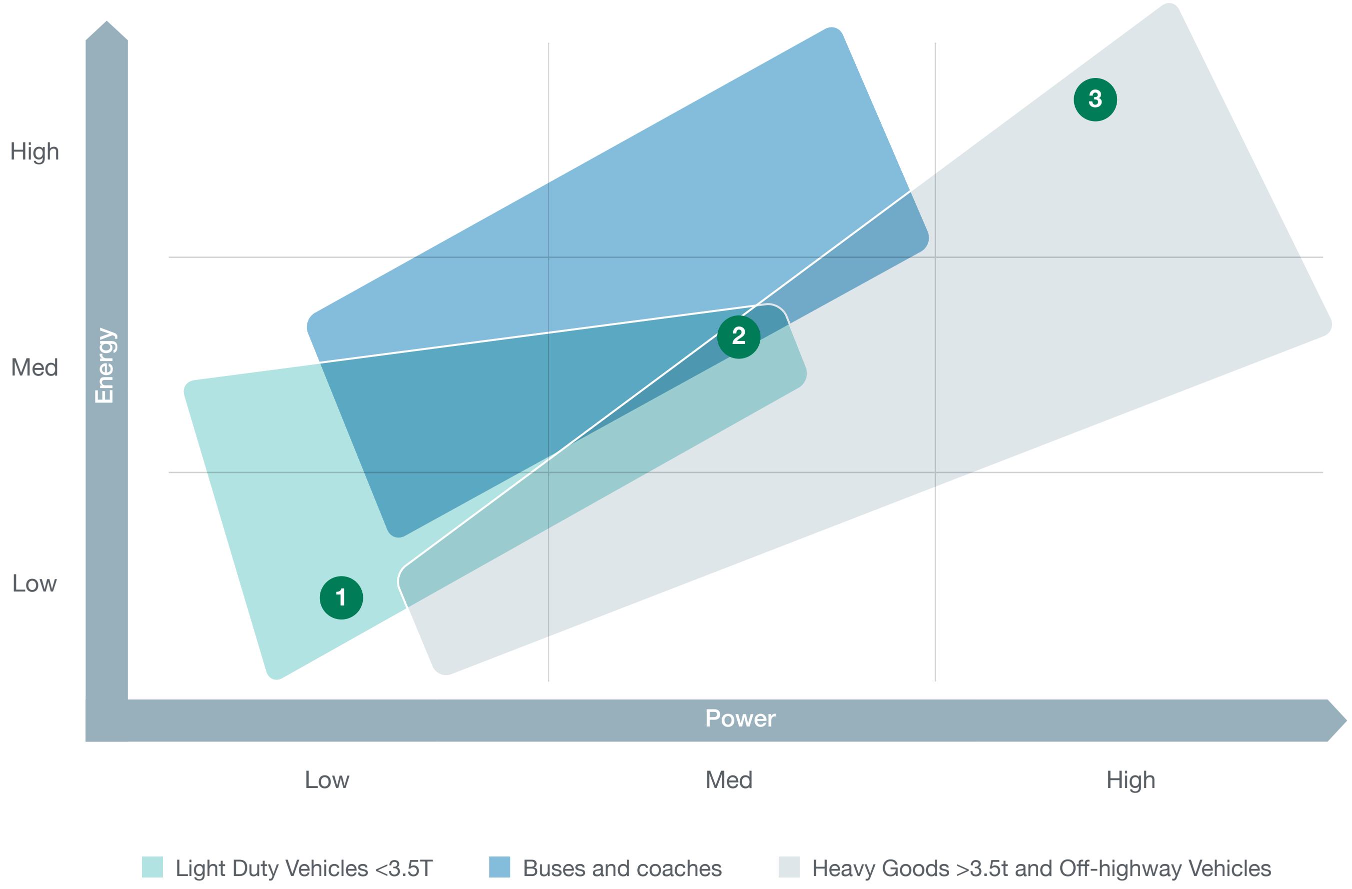
- Net-zero ambitions to decarbonise transport by 2050
- The first-ever EU-wide CO_2 emissions standard for heavy-duty vehicles, introduced in 2019, with targets to 2030
- Zero-emission zone regulation in a growing number of cities
- Passenger demand and mobility preferences are changing

Changes to roadmap structure

- A three-page format explaining vehicle types, the roadmap, and drivers and enablers
- Coaches have been added to the bus roadmap
- Product and application types, based on power and energy:
  - Urban passenger mobility (low/medium power, medium energy)
  - Long range passenger mobility (medium power, medium/high energy)
- 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.

Roadmap Narrative

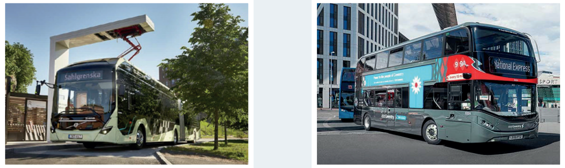
Product Classification

Urban Mobility
Zero tailpipe emissions led

Typically Low / Medium Power

New mobility vehicles for bus-rapid-transit

Community based transport



Buses with fixed city and urban routes

Long Range Mobility
Net-zero* emissions led

Typically Medium Power

Long distance coaches

Buses with flexible semi-urban and rural routes

***Net-zero:** The activities within the value chain of a company result in no net impact on the climate from greenhouse gas emissions. This can be achieved by balancing the impact of any remaining greenhouse gas emissions with an appropriate amount of carbon removals.

Product Classification

Urban Mobility
Zero tailpipe emissions led

Urban Mobility

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 in urban areas or shuttle services.

Product types range from bus-rapid-transit (BRT) vehicles with dedicated lanes and routes, medium-duty community vehicles to urban single decker and double decker buses.

The primary environmental focus is towards zero tailpipe emissions to meet urban air quality requirements. These vehicles continue to face increasing pressures to accelerate decarbonisation and reduce pollution.

Zero tailpipe

No pollutant or GhG emissions at tailpipe.

Long Range Mobility
Net-zero* emissions led

Long Range Mobility

Typically, medium power as vehicle mass and torque needs are higher. Medium to high energy required for long range travel and national routes.

Product types include regional and intercity coaches, and buses in semi-urban and rural settings.

These are driven towards net-zero GhG emissions, since urban access for such vehicles is either limited, or net-zero transport vehicles are permissible under certain settings.

***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.

Roadmap 2020

Bus and Coach

Propulsion Technologies Roadmap

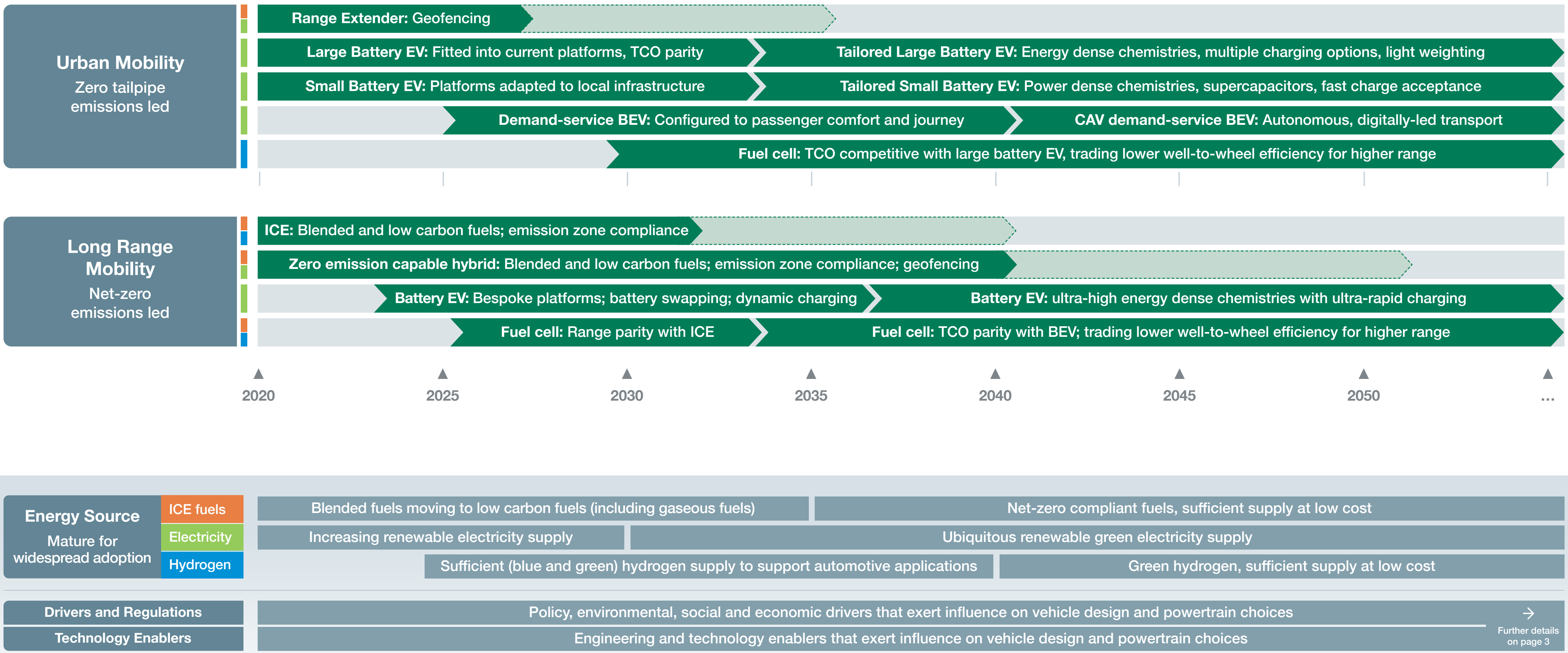
automotive council UK

ADVANCED PROPULSION CENTRE UK

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*



Urban Mobility
Zero tailpipe emissions led

Range Extender: Geofencing

Large Battery EV: Fitted into current platforms, TCO parity

Tailored Large Battery EV: Energy dense chemistries, multiple charging options, light weighting

Small Battery EV: Platforms adapted to local infrastructure

Tailored Small Battery EV: Power dense chemistries, supercapacitors, fast charge acceptance

Demand-service BEV: Configured to passenger comfort and journey

CAV demand-service BEV: Autonomous, digitally-led transport

Fuel cell: TCO competitive with large battery EV, trading lower well-to-wheel efficiency for higher range

Long Range Mobility
Net-zero emissions led

ICE: Blended and low carbon fuels; emission zone compliance

Zero emission capable hybrid: Blended and low carbon fuels; emission zone compliance; geofencing

Battery EV: Bespoke platforms; battery swapping; dynamic charging

Battery EV: ultra-high energy dense chemistries with ultra-rapid charging

Fuel cell: Range parity with ICE

Fuel cell: TCO parity with BEV; trading lower well-to-wheel efficiency for higher range

Energy Source
Mature for widespread adoption

ICE fuels: Blended fuels moving to low carbon fuels (including gaseous fuels) | Net-zero compliant fuels, sufficient supply at low cost

Electricity: Increasing renewable electricity supply | Ubiquitous renewable green electricity supply

Hydrogen: Sufficient (blue and green) hydrogen supply to support automotive applications | Green hydrogen, sufficient supply at low cost

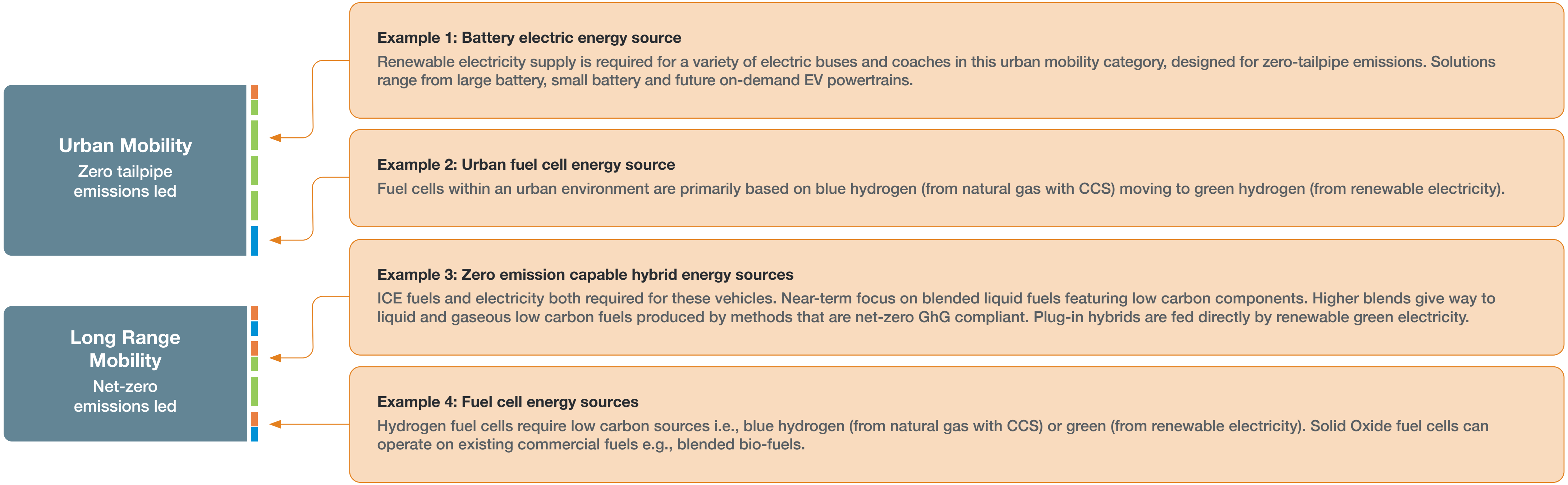
Drivers and Regulations: Policy, environmental, social and economic drivers that exert influence on vehicle design and powertrain choices

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

→ Further details on page 3

Hybrids = Mild, HEV, PHEV and range extender

Energy Source and Applicability



Urban Mobility
Zero tailpipe emissions led

Long Range Mobility
Net-zero emissions led

Example 1: Battery electric energy source
Renewable electricity supply is required for a variety of electric buses and coaches in this urban mobility category, designed for zero-tailpipe emissions. Solutions range from large battery, small battery and future on-demand EV powertrains.

Example 2: Urban fuel cell energy source
Fuel cells within an urban environment are primarily based on blue hydrogen (from natural gas with CCS) moving to green hydrogen (from renewable electricity).

Example 3: Zero emission capable 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 net-zero GhG compliant. Plug-in hybrids are fed directly by renewable green electricity.

Example 4: 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.

Energy Source
Mature for widespread adoption

- 🟧 ICE fuels
- 🟩 Electricity
- 🟦 Hydrogen

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.

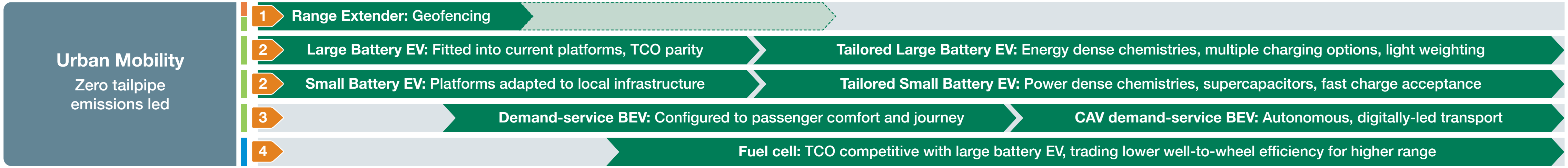
Drivers and Enablers are provided on a separate page
The link on the RHS of this bar takes you to the relevant drivers and enablers.

Urban Mobility

Roadmap 2020

Bus and Coach

Propulsion Technologies Roadmap



Urban Mobility

Zero tailpipe emissions led

1 **Range Extender:** Geofencing

2 **Large Battery EV:** Fitted into current platforms, TCO parity

Tailored Large Battery EV: Energy dense chemistries, multiple charging options, light weighting

2 **Small Battery EV:** Platforms adapted to local infrastructure

Tailored Small Battery EV: Power dense chemistries, supercapacitors, fast charge acceptance

3 **Demand-service BEV:** Configured to passenger comfort and journey

CAV demand-service BEV: Autonomous, digitally-led transport

4 **Fuel cell:** TCO competitive with large battery EV, trading lower well-to-wheel efficiency for higher range

Long Range Mobility

Net-zero emissions led

1

Urban Range Extender

Where routes include zero emission zones, ICE can act as range extender for battery hybrid buses. Geofencing prevents ICE operation within designated zones in certain urban settings.

2

Urban BEV (Large an Small Battery):

Batteries are well-suited for urban zero-emission operations. Large batteries offer versatility across different routes but may compromise passenger capacity. Smaller batteries can be used for well-defined routes, especially if combined with fast opportunity charging. Supercapacitors are suitable for urban areas where buses can stop frequently or only cover very short distances.

Both EV types are expected to evolve from variants of conventional bus designs towards tailored platforms.

3

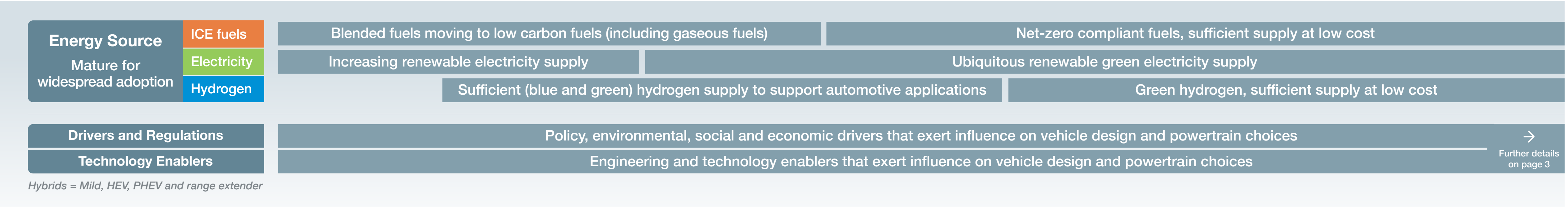
Urban Demand-service BEV

New demand-service urban transit solutions are likely to appear, providing tailored routes for changing passenger needs. Integrating BEV with mature CAV technology could develop in the longer term, offering intelligent route and energy management.

4

Urban Fuel Cell

Offering longer range with less impact on passenger capacity than batteries, fuel cells can work well especially if higher range is required. However, fuel cell stack lifetimes and costs need to improve to make them competitive on a TCO basis.



Energy Source

Mature for widespread adoption

ICE fuels: Blended fuels moving to low carbon fuels (including gaseous fuels) → Net-zero compliant fuels, sufficient supply at low cost

Electricity: Increasing renewable electricity supply → Ubiquitous renewable green electricity supply

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

→ Further details on page 3

Hybrids = Mild, HEV, PHEV and range extender

Long Range Mobility

Roadmap 2020

Bus and Coach

Propulsion Technologies Roadmap

Urban Mobility
Zero tailpipe emissions led

1

Long Range ICE

Increased use of blended and low carbon fuels will continue in a bus and coach fleet whose energy needs are primarily met by diesel. This will need to evolve as CO_2 and NOx requirements increase.

Evolution of ICE provides high efficiency for highway and low (but not zero) emission in cities, running on low carbon fuels.

2

Long Range Zero-emission capable Hybrid

Advanced hybrid ICE running on low carbon fuels provide a combination of long-range travel and short distance zero-emissions control. A modest electric-only range, typically for first and last sections of inter-city journeys, or geofenced zones, allows these vehicles to enter urban settings.

3

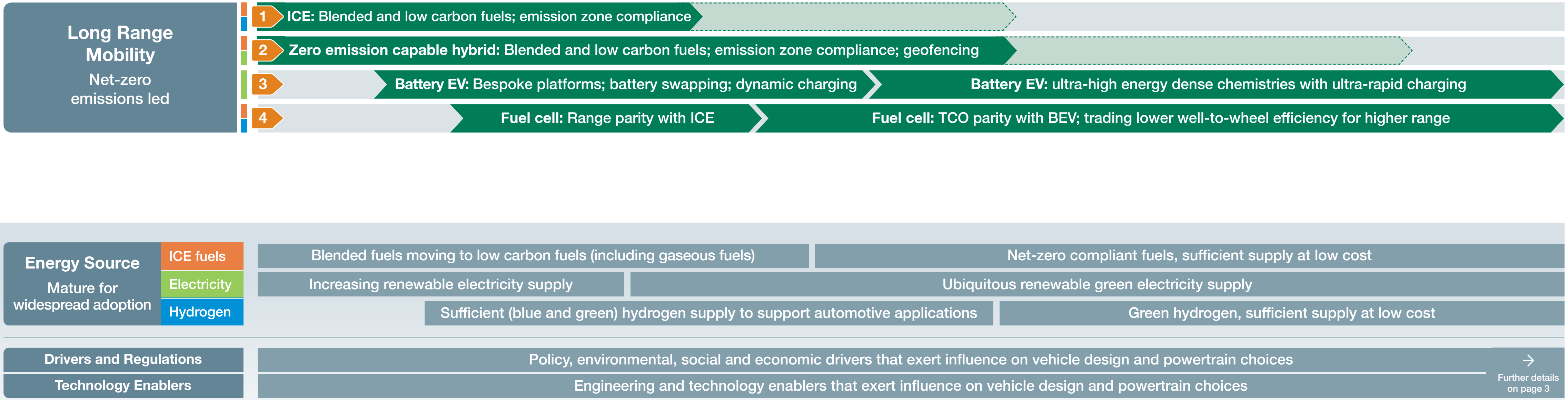
Long Range Battery EV

Battery vehicles may suit longer range vehicles where dynamic route charging or depot solutions like battery swapping become available. As battery chemistries evolve to higher energy densities and charging capability, this will provide opportunities for vehicle design optimisation and increased use.

4

Long Range Fuel Cell

Fuel cells are well-suited to long range travel and in settings where refuelling points are distanced, but longer cell stack lifetimes and lower costs need to be developed and demonstrated to compete on a TCO basis. Less well-to-wheel efficiency than battery vehicles, but able to provide more onboard energy storage for a given weight or vehicle capacity gives these vehicles a benefit.



Long Range Mobility
Net-zero emissions led

1 **ICE:** Blended and low carbon fuels; emission zone compliance

2 **Zero emission capable hybrid:** Blended and low carbon fuels; emission zone compliance; geofencing

3 **Battery EV:** Bespoke platforms; battery swapping; dynamic charging → **Battery EV:** ultra-high energy dense chemistries with ultra-rapid charging

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Roadmap 2020

Bus and Coach

Drivers and Regulations / Technology Enablers

automotive council UK

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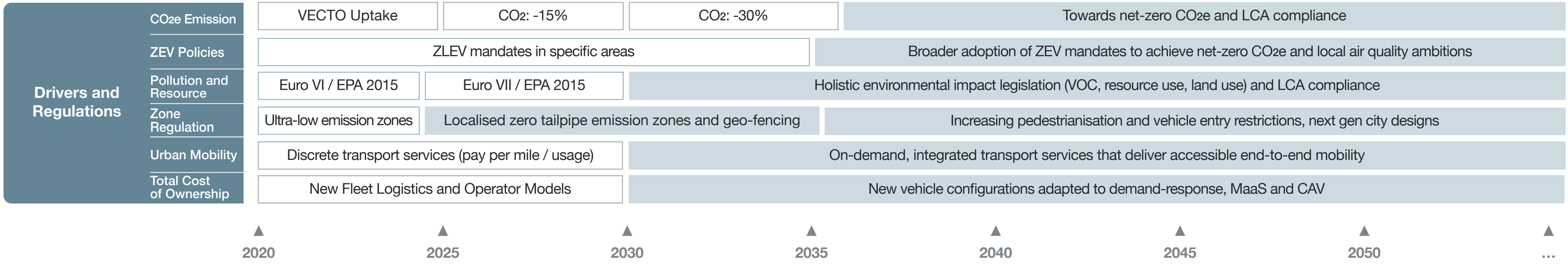
Policy, environmental, social and economic drivers that exert influence on vehicle designs and powertrains

☐ *Defined driver* ▨ *Predicted driver*



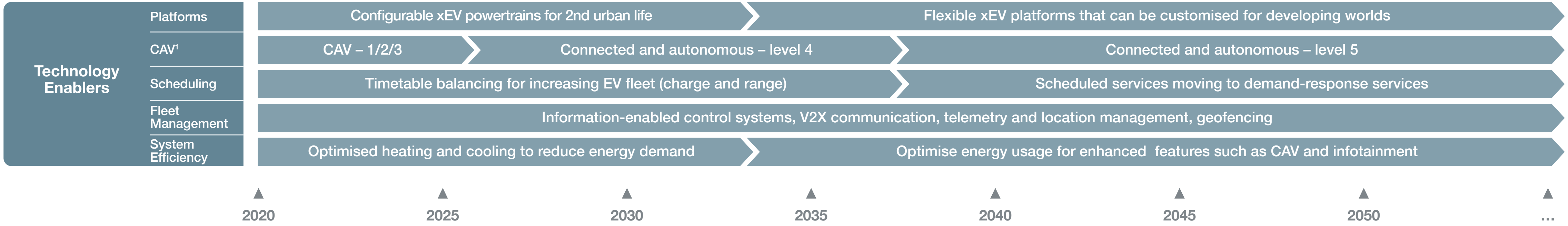
Drivers and Regulations

- CO2e Emission: VECTO Uptake | CO2: -15% | CO2: -30% | Towards net-zero CO2e and LCA compliance
- ZEV Policies: ZLEV 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 | Euro VII / EPA 2015 | Holistic environmental impact legislation (VOC, resource use, land use) and LCA compliance
- Zone Regulation: Ultra-low emission zones | Localised zero tailpipe emission zones and geo-fencing | Increasing pedestrianisation and vehicle entry restrictions, next gen city designs
- Urban Mobility: Discrete transport services (pay per mile / usage) | On-demand, integrated transport services that deliver accessible end-to-end mobility
- Total Cost of Ownership: New Fleet Logistics and Operator Models | New vehicle configurations adapted to demand-response, MaaS and CAV

2020 2025 2030 2035 2040 2045 2050 ...

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

Technology adoption for mass-market applications



Technology Enablers

- Platforms: Configurable xEV powertrains for 2nd urban life | Flexible xEV platforms that can be customised for developing worlds
- CAV[1]: CAV – 1/2/3 | Connected and autonomous – level 4 | Connected and autonomous – level 5
- Scheduling: Timetable balancing for increasing EV fleet (charge and range) | Scheduled services moving to demand-response services
- Fleet Management: Information-enabled control systems, V2X communication, telemetry and location management, geofencing
- System Efficiency: Optimised heating and cooling to reduce energy demand | Optimise energy usage for enhanced features such as CAV and infotainment

2020 2025 2030 2035 2040 2045 2050 ...

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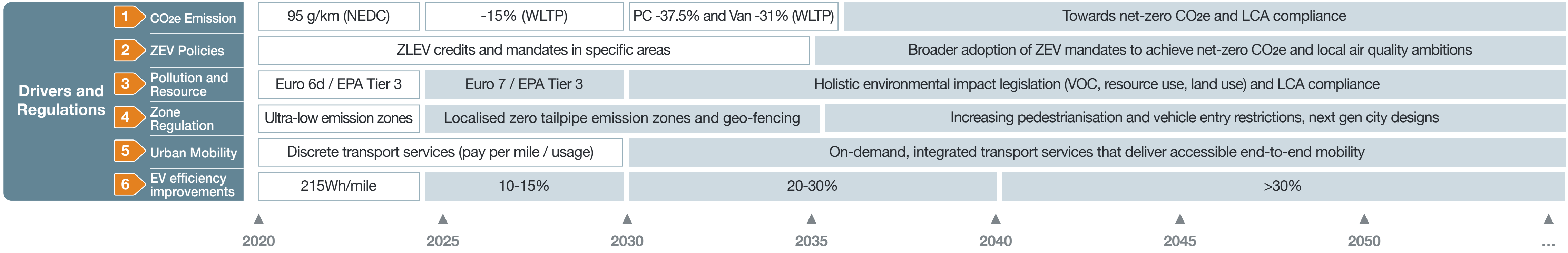
1. Adoption is dependent on supporting roadside infrastructure (incl. V2X, digital networks, data protocols, interconnects). See further details on https://zenzic.io/roadmap/

Drivers and Regulations

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

☐ *Defined driver* ▨ *Predicted driver*



Drivers and Regulations

1 CO_2e Emission: 95 g/km (NEDC) | -15% (WLTP) | PC -37.5% and Van -31% (WLTP) | Towards net-zero CO_2e and LCA compliance

2 ZEV Policies: ZLEV credits and mandates in specific areas | Broader adoption of ZEV mandates to achieve net-zero CO_2e and local air quality ambitions

3 Pollution and Resource: Euro 6d / EPA Tier 3 | Euro 7 / EPA Tier 3 | Holistic environmental impact legislation (VOC, resource use, land use) and LCA compliance

4 Zone Regulation: Ultra-low emission zones | Localised zero tailpipe emission zones and geo-fencing | Increasing pedestrianisation and vehicle entry restrictions, next gen city designs

5 Urban Mobility: Discrete transport services (pay per mile / usage) | On-demand, integrated transport services that deliver accessible end-to-end mobility

6 EV efficiency improvements: 215Wh/mile | 10-15% | 20-30% | >30%

1

CO_2e Emissions

Heavy duty vehicles faced EU tailpipe CO_2 regulations from 2019 (for the first time), with targets set for 2025 and 2030. The EU 2022 consultation is yet to confirm applicability for buses and coaches, but these standards are already being acted on. VECTO is the new simulation tool developed by the European Commission to calculate CO_2 emissions and fuel consumption of HDVs, including buses and coaches.

2

ZEV Policies

Buses commonly operate in ZLEV zones. Increasingly these are changing to ZEV across a number of cities. ZLEV mandates are likely to increase in urban areas, incentivising zero-emission public transport.

Additionally, local jurisdictions impose further environmental and air quality mandates.

3

Pollution and Resource

Pollutant emissions (NOx, HC, CO) from both buses and coaches are regulated by Euro VI (and above) and tiered US EPA standards, for example.

To address public health concerns, urban air quality standards currently attract significant attention. As a result, future regulation based on broader environmental impacts can be expected.

4

Zone Regulation

Some buses need to operate for extended periods in very stringent low- and zero-emissions zones.

The desire for improved air quality in a growing number of cities worldwide is resulting in city-level zero- and low-emission zones, restricting the movement of buses and coaches that are not tailpipe emission compliant.

5

Urban Mobility

A changing city demographic and passenger comfort demands are putting pressure on urban public transport systems. Discrete point-to-point on-demand services are expected to grow but will need new operator and business models to be developed to ensure viability. With maturing CAV technology, more driverless solutions can be expected in urban settings.

6

Total Cost of Ownership

Public transport has to balance customer convenience with affordable prices. High operating costs from new fleet introductions (for zero-tailpipe), depot upgrades and inconsistent passenger numbers are challenging factors for the sector.

New passenger logistics models and opportunities within MaaS, based on EV CAV systems, needs further work to ensure a competitive TCO can be achieved.

Technology Enablers

1

Platforms

Bus platforms are often re-engineered mid-life so an evolution is expected towards platforms that can accept different electrified powertrains over time. This can include later life application in developing countries and designing platforms with 2nd life in mind at inception to improve TCO considerations.

2

CAV

Connected and autonomous vehicles are continuing their progression towards high levels of autonomy, ADAS levels 4 and 5, enabling mobility as a service (MaaS). These are well-suited for EV integration and new mobility solutions.

More information on this is available on the Zenzic roadmaps.

3

Scheduling

Timetables and services need rebalancing for EV fleets to accommodate charging downtime or more frequent opportunity-charging stops. With fleet sizes and depot charging ports to balance, and electricity tariffs that may favour night-time charging, operators have to strike a balance to accommodate EV technology within established bus and coach routes. In future, fixed scheduling could move to demand-response in some settings.

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

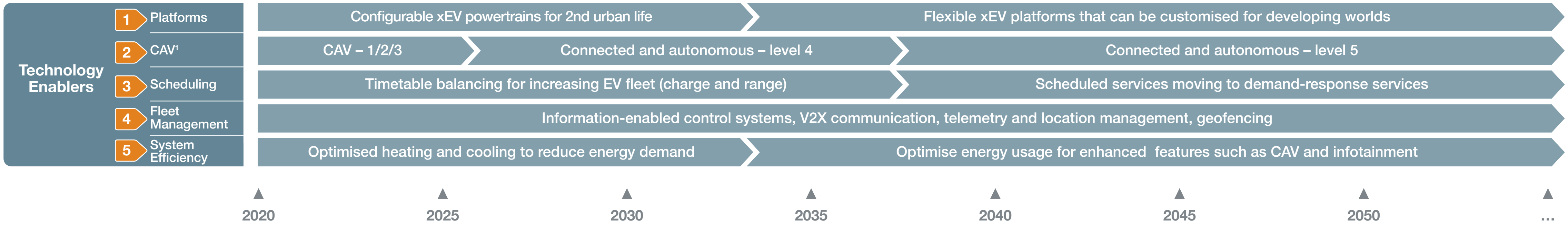
System Efficiency

Bringing efficiency measures to on-board comfort and convenience features, especially driver and passenger heating and cooling, is beneficial to reducing the demand from the on-board energy supply. HVAC systems typically consume >50% of the energy on-board electric buses for seasonal temperature control.

Increasing personal device charging, infotainment and CAV functions will demand further auxiliary battery power.

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

Technology adoption for mass-market applications



Technology Enablers

1 Platforms: Configurable xEV powertrains for 2nd urban life → Flexible xEV platforms that can be customised for developing worlds

2 CAV[1]: CAV – 1/2/3 → Connected and autonomous – level 4 → Connected and autonomous – level 5

3 Scheduling: Timetable balancing for increasing EV fleet (charge and range) → Scheduled services moving to demand-response services

4 Fleet Management: Information-enabled control systems, V2X communication, telemetry and location management, geofencing

5 System Efficiency: Optimised heating and cooling to reduce energy demand → Optimise energy usage for enhanced features such as CAV and infotainment

Glossary

Glossary

Abbreviation	Explanation
ADAS	Advanced Driver Assistance Systems
BEV	Battery Electric Vehicle
CAV	Connected and autonomous vehicle
CCS	Carbon capture scheme
EV	Electric vehicle
GhG	Greenhouse gas
HDV	Heavy-duty vehicle
ICE	Internal combustion engine
LCA	Lifecycle assessment
LDV	Light-duty vehicle
MaaS	Mobility as a Service
TCO	Total cost of ownership
ZEV	Zero-emission vehicle
ZLEV	Zero- and low-emission vehicles

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This is an industry consensus roadmap facilitated by the APC

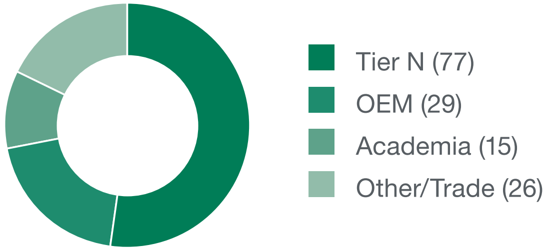
Summary of engagements during the 2020 roadmap refresh

Spread of companies that participated in the refresh

109 industry organisations participated in Workshops and Interviews

38 additional industry organisations participated via the Online Survey

Total engagements 147 Industry Organisations



A global view with international participation

Austria
Belgium
England
Germany
Netherlands
Scotland

Singapore
Sweden
Switzerland
United States
Wales
Japan