Thermal Propulsion Systems

Industry Challenges 2020-2035+

This document outlines the R&D challenges for Thermal Propulsion Systems across a diverse range of automotive applications. The industry challenges are intrinsically linked with the 2020 Automotive Council roadmaps and should be read in conjunction with the narrative report to provide a context and background to the rationale behind the challenges.

May 2021 | Version 1.0

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An introduction to the industry challenge report

The industry challenges present the technical barriers to commercialising automotive powertrain technology in the short, medium and long term. Developed via a consensus process, this report highlights the most significant technology themes and specific R&D examples to springboard innovation. A list of recommendations on how this content can be taken forward by industry, academia and government is provided below:

Industry

- Review in-house R&D priorities against the industry consensus challenges provided in this report
- Provide guidance to companies wanting to transition into low-carbon automotive propulsion technologies
- Provide a sense-check for start-ups to help guide their technology focus

Academia

- Address the long-term scientific challenges that need to be overcome
- Align internal university research with the needs of the automotive industry
- Build a bridge with industry to execute and industrialise research

Government

- Understand the R&D challenges required to industrialise low-carbon propulsion technologies
- Identify R&D challenges that may require additional funding
- Understand the challenges facing different mobility sectors and adjust policy, strategy and funding support accordingly

A guide to reading the industry challenges

Technology Challenge

A Technology Challenge is a broad issue that OEMs and the supply chain face when commercialising technologies for the automotive industry.

Examples of research topics

Examples of research topics illustrate potential projects that could overcome the Technology Challenge. These are not intended to be an exhaustive list but a snapshot of areas captured in the industry engagement process.

Time horizon

The filled bar represents when research is likely to be completed. For example:

2020-2025 | 2025-2035 | 2030-2035+

Technology Challenge	Examples of research topics	Time Horizon	LDV	HGV & OH	Bus & Coach
Increased efficiency combustion engines (Light Duty Vehicles)	Develop new-generation high dilution combustion solutions (lean burn, high exhaust gas recirculation) with associated ignition systems, controls and air paths that deliver high engine efficiencies.	2020-2025	●	◒	◒
	Develop advanced cylinder de-activation and low friction engine designs		●	◒	◒

Attributes and vehicle applications

The columns refer to the different attributes or vehicle applications related to each technology theme. The dots represent how relevant overcoming this topic would be to each application area.

○ Not relevant ◒ Somewhat relevant ● Very relevant

Technology challenges and research topics

Technology challenges for thermal propulsion systems

The technology challenges listed here represent the highest priority R&D themes that industry and academia regard as critical for innovation.

Increased efficiency combustion engines (Light Duty Vehicles) See challenge	Codes and standards supporting net-zero combustion technologies See challenge
Increased efficiency combustion engines (Heavy Duty Vehicles) See challenge	Combustion engines running on net-zero fuels See challenge
Increased efficiency combustion engines (Sensors, simulation and controls) See challenge	Advanced after-treatment and CO_2 capture solutions See challenge
Dedicated and integrated hybrid powertrains See challenge	Recycling, remanufacturing and circular economy supporting LCA See challenge

LCA = Life cycle assessment

The above challenges are not listed in a prioritised order. They represent all the themes industry and academia regard as critical for innovation.

Thermal propulsion systems – technology challenges and research topics (1/12)

The research topics listed below predominately focus on the **Light Duty Oriented** section of the thermal propulsion systems technology roadmap, with linkages to other themes on the roadmap.

Technology Challenge See all challenges	Examples of research topics	Time Horizon	LDV	HGV & OH	Bus & Coach
Increased efficiency combustion engines (Light Duty Vehicles)	Develop new-generation high dilution combustion solutions (lean burn, high exhaust gas recirculation) with associated ignition systems, controls and air paths that deliver high engine efficiencies.	2020-2025	●	◒	◒
	Develop advanced cylinder de-activation and low friction engine designs		●	◒	◒
	In-cylinder research advancements: • Multiple/split injection strategies to overcome the NOx/carbon trade-off (inc. including understanding problems such as cavitation associated with new injection methods) • Fast cycle by cycle control of homogenous compression ignition • Dilute homogenous combustion – both compression ignition (CI) and spark ignition (SI) • Variable value train control, to control in cylinder events		●	◒	◒
	Improve conventional combustion cycles (e.g., through better valve control, deeper Miller/Atkinson cycles, altering combustion cycles depending on load) to improve thermal efficiency.		●	●	●

Notes: The examples of research topics are intended to provide topics emerging from industry workshops while developing the roadmaps. These are not a complete and exhaustive list and make no reference to priorities within R&D.

○ Not relevant ◒ Somewhat relevant ● Very relevant

Thermal propulsion systems – technology challenges and research topics (2/12)

The research topics listed below predominately focus on the **Light Duty Oriented** section of the thermal propulsion systems technology roadmap, with linkages to other themes on the roadmap.

Technology Challenge See all challenges	Examples of research topics	Time Horizon	LDV	HGV & OH	Bus & Coach
Increased efficiency combustion engines (Light Duty Vehicles)	Hydrogen engines optimised for light duty vehicles, including boosting and associated control technologies for higher efficiencies.	2025-2035	●	◒	◒
	Focussed tribology assessments (friction, lubrication and wear) across the complete powertrain system, looking at sub-system and system gains.	2020-2035	●	●	●
	Multi-zone and adaptive engine pre-conditioning (warm-up) technologies that result in higher efficiencies and improve low temperature operations.		●	●	●
	New engine materials that increase operating pressures / temperatures for alternative combustion cycles.	2025-2035	●	●	●

Notes: The examples of research topics are intended to provide topics emerging from industry workshops while developing the roadmaps. These are not a complete and exhaustive list and make no reference to priorities within R&D.

○ Not relevant ◒ Somewhat relevant ● Very relevant

Thermal propulsion systems – technology challenges and research topics (3/12)

The research topics listed below predominately focus on the **Heavy Duty Oriented** section of the thermal propulsion systems technology roadmap, with linkages to other themes on the roadmap.

Technology Challenge See all challenges	Examples of research topics	Time Horizon	LDV	HGV & OH	Bus & Coach
Increased efficiency combustion engines (Heavy Duty Vehicles)	Develop and prove-out the recuperating split cycle engine for industrial scale-up, targeting high brake thermal efficiency (BTE).	2020-2025	○	●	●
	Develop hydrogen and hydrogen dual-fuel systems (e.g., approx 70% by fuel mix) that result in very-low greenhouse gases and NOx emissions.		○	●	●
	Advanced boosting technologies (steady state and transient) to increase engine performance, including the use of advanced electrical boosting.		◒	●	●
	Implement integrated waste heat recovery (WHR) systems that maximum overall powertrain efficiency.		◒	●	●
	Develop lean burn and closed loop combustion control system, with advancements in homogenous charge compression ignition (HCCI) and other controlled auto-ignition (CAI) combustion systems.		◒	●	●
	New engine materials that increase operating pressures / temperatures, including robust low-cost thermal insulation for hot components (e.g., combustion chambers).		●	●	●
	Robust low-cost high pressure and temperature heat exchangers for waste heat recovery systems, e.g., for recuperators at 70 bar and 800 °C.		◒	●	●

Notes: The examples of research topics are intended to provide topics emerging from industry workshops while developing the roadmaps. These are not a complete and exhaustive list and make no reference to priorities within R&D.

○ Not relevant ◒ Somewhat relevant ● Very relevant

Thermal propulsion systems – technology challenges and research topics (4/12)

The research topics listed below predominately focus on the **Heavy Duty Oriented** section of the thermal propulsion systems technology roadmap, with linkages to other themes on the roadmap.

Technology Challenge See all challenges	Examples of research topics	Time Horizon	LDV	HGV & OH	Bus & Coach
Increased efficiency combustion engines (Heavy Duty Vehicles)	Develop variable valves systems that are low-cost and high capability with low energy consumption, suitable for variable control, skip firing and alternative engine cycles (e.g., recuperating split cycle).	2020-2025	○	●	●
	Advanced ignition systems to enable single-fuel operation and engine optimisation (i.e., without the need for dual-fuel).		◒	●	●
	New approaches to thermal recovery, thermal storage and on-board delivery (e.g., electric turbo-compounding, organic rankine cycle (ORC), thermo-electric generators (TEGs), molten salts).		◒	●	●
	New concepts in flexible / adaptable engine systems e.g., skip firing, variable valve systems, variable compression, stroke, etc.		◒	●	●
	Multi-zone and adaptive engine pre-conditioning (warm-up) technologies that result in higher efficiencies and improve low temperature operations.	2020-2035	●	●	●
	Advancements in combustion engines delivering a brake thermal efficiency (BTE) of 55% or greater.	2025-2035	◒	●	●
	Develop new engine concepts running on net-zero fuels that are capable of delivering a BTE of 60% or greater.	2025-2035+	◒	●	●

Notes: The examples of research topics are intended to provide topics emerging from industry workshops while developing the roadmaps. These are not a complete and exhaustive list and make no reference to priorities within R&D.

○ Not relevant ◒ Somewhat relevant ● Very relevant

Thermal propulsion systems – technology challenges and research topics (5/12)

The research topics listed below predominately focus on the **Engine Systems and Control** section of the thermal propulsion systems technology roadmap, with linkages to other themes on the roadmap.

Technology Challenge See all challenges	Examples of research topics	Time Horizon	LDV	HGV & OH	Bus & Coach
Increased efficiency combustion engines (Sensors, simulation and controls)	Improved sensor technologies (better accuracy, more parameters, lower cost) that complements and enhances control software and prognostics • Robustness to drop-in fuels, measurement and diagnostics • Sensors for new fuels or alternate combustion cycles, including adaptions to future Euro 7 requirements	2020-2025	●	●	●
	Advances in engine multi-physics simulation: • Models that can simulate engine combustion, in-cylinder emission formation and after treatment systems for existing and new combustion cycles • Towards 70% virtual testing and verification for thermal propulsion systems	2020-2035			
	Simulation tools for new engine and fuel concepts: • Combustion modelling of net-zero and sustainable fuels • Capability for new engine cycles e.g., recuperating split, double compression-expansion engine (DCEE), etc • Gas injection modelling capability for gaseous fuels • Modelling capability for dedicated and integrated hybrid systems				
	Advanced software controls: • Model based control, new logic and design systems for cyber security • Utilising connected vehicle data for improved powertrain control • AI led, adaptive and collaborative controls, fully connected with infrastructure • Geofencing enabled controlled systems for zero emissions zones • Connectivity, cloud control methodology and telemetry capability				

Notes: The examples of research topics are intended to provide topics emerging from industry workshops while developing the roadmaps. These are not a complete and exhaustive list and make no reference to priorities within R&D.

○ Not relevant ◒ Somewhat relevant ● Very relevant

Thermal propulsion systems – technology challenges and research topics (6/12)

The research topics listed below predominately focus on the **Drivetrain Systems** section of the thermal propulsion systems technology roadmap, with linkages to other themes on the roadmap.

Technology Challenge See all challenges	Examples of research topics	Time Horizon	LDV	HGV & OH	Bus & Coach
Dedicated and integrated hybrid powertrains	Develop dedicated hybrid engines (DHE) for maximum efficiency, low-cost and lowest GhG emissions. Include engine simplification and narrower operating region or dilution for specific vehicle applications.	2020-2025	●	●	●
	Develop efficient and highly integrated dedicated hybrid transmissions (DHT).		●	●	●
	Highly integrated hybrid engines and hybrid transmission design solutions to maximise powertrain efficiency.		●	●	●
	Integration of hybrid engines and aftertreatment systems (e.g., electrically heated catalysts) to maximise CO_2 benefits.		●	●	●
	Combustion engines optimised to battery storage solutions for improved efficiency, power management, battery health (life) and cost.	2020-2035	●	●	●
	Full-sized electric drive systems that enable optimum DHE engine operation without need for emergency power from the engine.		◒	●	●
	Develop off-highway specific hybrid systems to maximise on-board hydraulics, electrical and combustion engine demand-supply mix to maximise CO_2 benefits.		○	●	◒

Notes: The examples of research topics are intended to provide topics emerging from industry workshops while developing the roadmaps. These are not a complete and exhaustive list and make no reference to priorities within R&D.

○ Not relevant ◒ Somewhat relevant ● Very relevant

Thermal propulsion systems – technology challenges and research topics (7/12)

Cross-cutting themes from the thermal propulsion systems roadmap, in support of regulations and standards for new engines and net-zero fuel technologies.

Technology Challenge See all challenges	Examples of research topics	Time Horizon	LDV	HGV & OH	Bus & Coach
Codes and standards supporting net-zero combustion technologies	Fuels standards for future sustainable fuels (listed on the TPS roadmap), including all aspects of storage through to environmental compliance during use.	2020-2025	●	●	●
	Develop fuel safety protocols for future sustainable fuels (listed on the TPS roadmap), covering all aspects of use, storage and dispensing.		●	●	●
	Develop standardisation and harmonisation for control systems (channels, interfaces and protocols) that enable improvements in engine performance.		●	●	●
	Develop harmonised hydrogen storage and dispensing standards, for 350 bar, 700 bar and liquid hydrogen that facilitate infrastructure development.		●	●	●
	Review and develop the VECTO standards to address applicability to non-road vehicles and specialist duty cycles.		◒	●	●
	Development of a harmonised approach to life cycle assessment across all powertrain technologies that addresses a total environmental impact assessments, including; extraction, processing, pollutants, water, land, ecological, eutrophication, pollutants, toxins, etc. . A global approach is required.	2020-2035+	●	●	●

Notes: The examples of research topics are intended to provide topics emerging from industry workshops while developing the roadmaps. These are not a complete and exhaustive list and make no reference to priorities within R&D.

○ Not relevant ◒ Somewhat relevant ● Very relevant

Thermal propulsion systems – technology challenges and research topics (8/12)

The research topics listed below predominately focus on the **Light Duty Oriented and Heavy Duty Oriented** sections of the thermal propulsion systems technology roadmap.

Technology Challenge See all challenges	Examples of research topics	Time Horizon	LDV	HGV & OH	Bus & Coach
Combustion engines running on net-zero fuels	Develop mass-market hydrogen combustion engine concepts, delivering net-zero emissions that meet future air quality standards (e.g., Euro 7 and higher).	2020-2035	●	●	●
	Develop high pressure fuel injection systems for hydrogen gas fuels (at ambient and low temperatures >500bar).		●	●	●
	On-board hydrogen pumping solutions for optimised engine and storage delivery.		●	●	●
	Adapted ICE engines that run on future net-zero fuels; e.g., hydrocarbon e-fuels and syn-fuels (non-drop in fuels are defined on the TPS roadmap)		◒	●	●
	Develop hydrogen storage systems that have high mass to volume storage ratios, designed for hydrogen combustion engines, including; high pressure gas, cold high pressure gas, liquid hydrogen and solid hydrides.	2025-2035+	●	●	●
	Investigate engine concepts for ammonia as a fuel on large heavy goods vehicles; looking at safe storage, on-board odour issues and technologies that can accelerate rate of combustion.		○	●	◒
	Develop specific net-zero combustion systems for heavy goods and off-highway vehicles in use-cases where renewable electricity supply is limited.		◒	●	●

Notes: The examples of research topics are intended to provide topics emerging from industry workshops while developing the roadmaps. These are not a complete and exhaustive list and make no reference to priorities within R&D.

○ Not relevant ◒ Somewhat relevant ● Very relevant

Thermal propulsion systems – technology challenges and research topics (9/12)

The research topics listed below predominately focus on the **Light Duty Oriented and Heavy Duty Oriented** sections of the thermal propulsion systems technology roadmap.

Technology Challenge See all challenges	Examples of research topics	Time Horizon	LDV	HGV & OH	Bus & Coach
Combustion engines running on net-zero fuels	Combustion systems that use a combination of bio-fuels and e-fuels that can be tailored to combinations of fuel mix. This related to supply desensitisation.	2020-2035	●	●	●
	Engines and combustion cycles capable of adapting and optimising performance based on fuel or mix used, e.g., advances in fuel sensing.		●	●	●
	Flexible fuel injectors tolerant and adaptable to a wide variety in fuel quality, such as fuels derived from waste. Requires higher durability to accommodate variation in chemical properties.		◒	●	◒
	Advances in variable compression ratio systems for optimised operation over a wide range of fuels.		◒	●	◒
	Low-cost cryogenic pumping systems for liquid natural gas, liquid nitrogen and liquid hydrogen.		◒	●	●
	Low-cost storage systems for liquid natural gas, liquid nitrogen/air and liquid hydrogen.		◒	●	●
	Impact mitigating technologies for alternative fuel combustion systems: • System compatibility and tribology response (lubrication, friction and wear) • Durability and component life improvements		○	●	◒

Notes: The examples of research topics are intended to provide topics emerging from industry workshops while developing the roadmaps. These are not a complete and exhaustive list and make no reference to priorities within R&D.

○ Not relevant ◒ Somewhat relevant ● Very relevant

Thermal propulsion systems – technology challenges and research topics (10/12)

The research topics listed below predominately focus on the **Fuel Systems and After-treatment** section of the thermal propulsion systems technology roadmap.

Technology Challenge See all challenges	Examples of research topics	Time Horizon	LDV	HGV & OH	Bus & Coach
Advanced after-treatment and CO_2 capture solutions	Towards net-zero tailpipe emissions: Develop high efficiency solutions to lower nitrogen oxides, particulate matter, hydrocarbon, and carbon monoxide in low temperature exhausts (150°C).	2020-2025	●	●	●
	Towards net-zero tailpipe emissions: Portable emissions measurement systems (PEMS) for future Euro 7/VII (Diesel and alternative fuels)				
	Towards net-zero tailpipe emissions: Euro-VII mitigation after-treatments (solutions for natural gas, bio-gas, gas-from-waste, ammonia, aldehydes)				
	Towards net-zero tailpipe emissions: Low temperature (below 350^{0}C) oxidation catalysts for methane (for heavy duty vehicles).				
	Highly efficient diesel particulate filter (DPF) and gasoline particulate filter (GPF) solutions for smaller particles (below >23nm).				
	Develop advanced after-treatment control strategies beyond Euro 7/VII requirements with robust on-board diagnostics, including early light-off.				
	Co-optimisation of combustion and aftertreatment system solutions beyond Euro 7/VII, including solutions for hybridised powertrains.				

Notes: The examples of research topics are intended to provide topics emerging from industry workshops while developing the roadmaps. These are not a complete and exhaustive list and make no reference to priorities within R&D.

○ Not relevant ◒ Somewhat relevant ● Very relevant

Thermal propulsion systems – technology challenges and research topics (11/12)

The research topics listed below predominately focus on the **Fuel Systems and After-treatment** section of the thermal propulsion systems technology roadmap.

Technology Challenge See all challenges	Examples of research topics	Time Horizon	LDV	HGV & OH	Bus & Coach
Advanced after-treatment and CO_2 capture solutions	High efficiency selective catalytic reduction (SCR) systems that can operate over a wide temperature range, designed for super ultra-low emission zones (SULEV).	2020-2025	●	●	●
	Heated (burner) catalytic converter technologies that compete with electrically heated catalysts (EHC), designed to meet Euro 7/VII standards.		●	●	●
	High pressure catalyst solutions, integrated with waste heat recovery systems.		●	●	●
	Reduced precious metal (e.g, rhodium, platinum and palladium) catalyst solutions designed for Euro 7/VII limits.		●	●	●
	Improved Diesel Exhaust Fluid (DEF) dosing control and exhaust aftertreatment systems (EATS) to eliminate N_2O generation.		●	●	●
	Low-cost and compact EATS enabled by reduced transient operation.		◒	●	●
	Create on-board carbon capture solutions, integrated within the powertrain.	2025-2035	◒	●	●

Notes: The examples of research topics are intended to provide topics emerging from industry workshops while developing the roadmaps. These are not a complete and exhaustive list and make no reference to priorities within R&D.

○ Not relevant ◒ Somewhat relevant ● Very relevant

Thermal propulsion systems – technology challenges and research topics (12/12)

The research topics listed below predominately focus on the **Life Cycle** section of the thermal propulsion systems technology roadmap.

Technology Challenge See all challenges	Examples of research topics	Time Horizon	LDV	HGV & OH	Bus & Coach
Recycling, remanufacturing and circular economy supporting LCA	Repurposing existing combustion engine manufacturing assets, equipment and processes to net-zero engine production capability.	2020-2025	●	●	●
	Develop future from waste or bio-materials that are sustainable and carbon neutral.				
	Increase applications and use of remanufactured and re-purposed engines, including high mileage vehicles and fleets.				
	Increased use of recycled material content used in engine production.	2020-2035			
	Implement lower energy demand production facilities that maximise use of renewable energy, e.g. solar, for manufacturing.				
	Development of a harmonised approach to life cycle assessment (LCA) across all powertrain technologies that addresses a total environmental impact assessments, including; extraction, processing, pollutants, water, land, ecological, eutrophication, pollutants, toxins, etc. A global approach is required.	2025-2035+			
	LCA focused engine designs and production methods e.g., greater use of bio-materials, circular supply-chain materials, minimising waste, solvents and toxic chemical use.				

Notes: The examples of research topics are intended to provide topics emerging from industry workshops while developing the roadmaps. These are not a complete and exhaustive list and make no reference to priorities within R&D.

○ Not relevant ◒ Somewhat relevant ● Very relevant

Technology roadmaps

Roadmap 2020

Thermal Propulsion Systems

Technology Roadmap

Technology indicators for 2020-2035 can be seen on page 1

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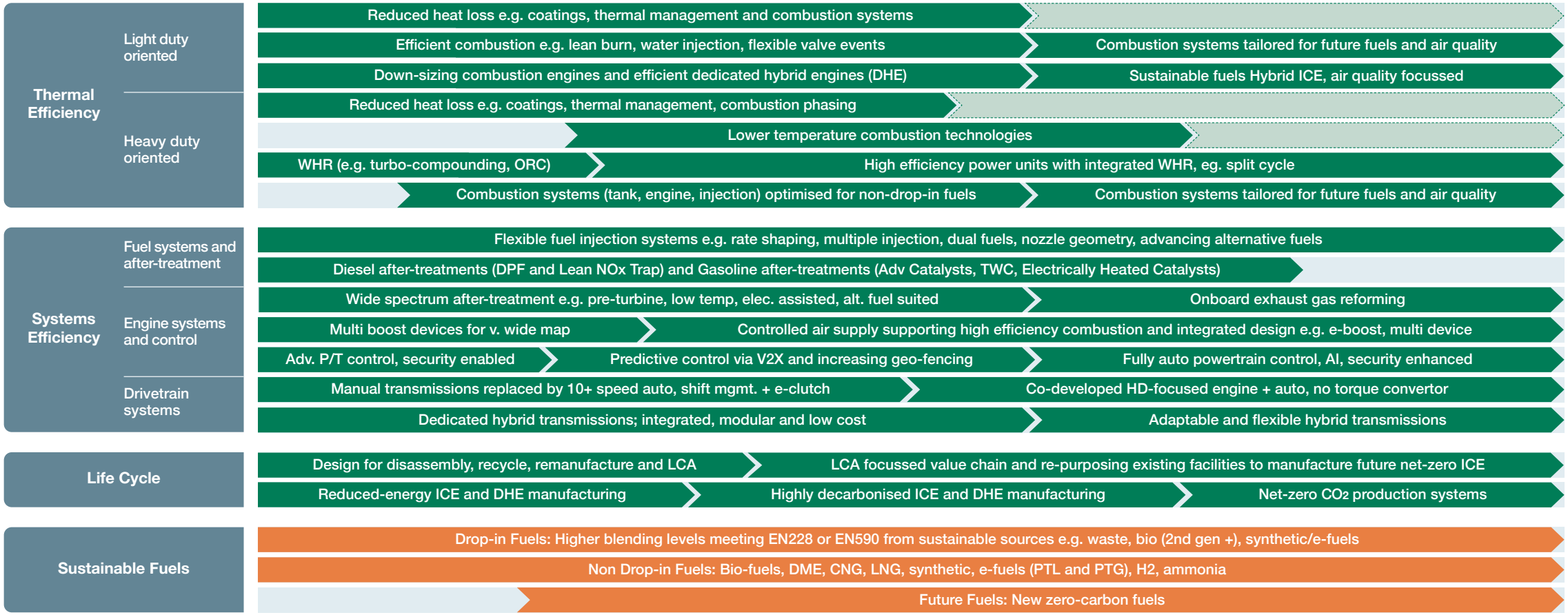
This roadmap represents a snapshot-in-time view of the global automotive industry propulsion technology forecast for mass market adoption. Specific application-tailored technologies will vary from region to region.

Dark bar: *Technology is in a mass market application. Significant innovation is expected in this time frame*

Transition: *Transitions do not mean a phase out from market but a change of R&D emphasis*

Dotted line bar: *Market Mature – technology has reached maturity. Likely to remain in mass market until it fades out where it's superseded*



Changing powertrain technology options across a range vehicle applications in the short, medium and long term

	Short Term (2020-2025)	Medium Term (2025-2035)	Long Term (2035+)
LDV 	Significant growth in vehicle electrification, to be supported by higher battery energy density, faster charging and lower costs.	Mature battery electric vehicle platforms achieving cost parity with conventional ICE and an increasing number of PEM fuel cell vehicles for long range journeys.	New battery chemistries, based on access to raw materials, LCA focus and low-energy production. Mature fuel cell applications with associated hydrogen infrastructure.
HGV and OH 	Focussed propulsion selection tailored to vehicle type, duty cycle and use case aiming for net-zero carbon emissions; optimised for TCO.	Growth in fuel cells for heavy goods vehicles together with maturing net-zero combustion engines and more efficient BEV platforms.	Emerging catenary transport for certain heavy goods vehicles with collaborative support and infrastructure from government.
Bus and Coach 	Operator specific actions to increase electrification and PEM fuel cells fleet migration.	Mature BEV and fuel cell platforms designed with second use, higher utilisation and increased economic return.	Tailored public transport solutions, new vehicle types and route management for customised journeys.
All vehicle types 	Continued innovation in thermal propulsion systems achieving decarbonisation through net-zero fuels		
	Increasing LCA focus across all activities to deliver environmentally sustainable manufacturing and products		

LDV: Light Duty Vehicle
ICE: Internal Combustion Engine
HGV: Heavy Goods Vehicle
LCA: Life Cycle Assessment
OH: Off-highway
TCO: Total cost of ownership
BEV: Battery Electric Vehicle
PEM: Proton Exchange Membrane

Appendix

Background to the industry challenge report

The opportunities for industry research (and academic)

This report aims to bring industrial research to market-readiness faster, with a fresh approach to R&D challenges, directly linked to the technology roadmaps published by the Advanced Propulsion Centre (APC) on behalf of the Automotive Council UK in 2020.

For electrification technologies (Electrical Energy Storage, Electric Machines and Power Electronics) the challenges are matched to cost and performance metrics related to electrified powertrains. The Thermal Propulsion System, Lightweight Vehicles and Powertrain Structures and Fuel Cell technology challenges are matched to the relevant product types; light duty, heavy goods and off-highway and bus and coach.

Separate challenges are provided for integrated electric drives within the Electric Machines and Power Electronics reports.

All technology solutions will need a balanced selection from the challenges, specific to each application, and require careful management of their trade-offs.

Industry and academia working together

The report provides a common platform for industry and academia to collaborate in a drive to overcome technology challenges and advance net-zero propulsion systems. Many topics involve fundamental research that can later be industrialised into market-ready products.

Links to the Automotive Council Roadmaps

The industry challenges have been developed to support the net-zero Automotive Council roadmaps published by the APC in November 2020.

The roadmaps and the Industry Challenges report can be used by organisations and institutions to prioritise their research objectives to meet their technology goals.

Developing the industry challenges

Data collection, engagements and validation

The data analysed and shaped into the Industry Challenges report came from several sources:

Roadmap survey responses

We received a total of 130 responses from different types of organisations such as; vehicle manufacturers, SMEs, technology developers, engineering consultancies and service providers, Tier 1, Tier 2 or below, academia, local/national government and research technology organisations. Whilst around 60% of the respondents were UK-based, contributions were also received from Germany, USA, Japan, China, Belgium, and Sweden.

APC competitions insights

Information has been gathered from the APC competitions where specific technical challenges have been highlighted.

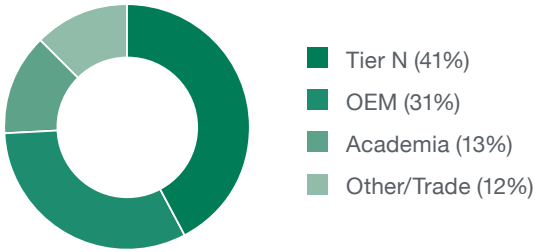
APC Spoke specialists

Data compiled from the survey responses and insights were validated through the APC Spokes. Where necessary more input was provided to fill in specific gaps. The 2017-2018 research challenges were reviewed to include the relevant ones into the new industry challenges list.

Industry workshops

Six events were held, one for each technology area: Electrical Machines, Power Electronics, Electrical Energy Storage, Thermal Propulsion Systems, Fuel Cells and Lightweighting. Industry experts provided feedback on technology challenges and details of research topics for each technology relevant to the product types (Light-duty Vehicles, Heavy Goods Vehicles and Off-Highway, Bus and Coach). A split by organisation type attending the industry challenges workshops is shown below.

Organisation types at the industry workshops



The APC approach to defining the industry challenges

In order to provide a well-informed industry and academia-led propulsion technology list of research challenges that informs and mobilise innovation in propulsion technologies, the APC approached the work as follows:

August 2020 — April 2021

Roadmap workshops and online survey

This was completed prior to the industry challenges workstream and fed into the technology roadmap development - a precursor to the industry challenges.

Our online survey collected data from a wide range of stakeholders by asking experts for specific challenges. These have been analysed according to the main technology themes.

Updated technology roadmaps

These were launched at LCV2020, followed by supporting narrative reports for each technology roadmap detailing context, background data and insights that fed into updated technology roadmaps.

APC Spokes challenges (Academia)

A fresh eyes review of the 2017-2018 research challenges by the APC Spokes provided an up-to-date list for the current report.

Further research topics were added from the roadmap workshops output.

Industry workshops and consensus (Industry)

Six industry workshops were run with roadmaps experts to develop, validate and further populate the examples of the research list.

A draft of the Industry Challenges was provided for comment in order to gather final consensus from the workshop groups.

Industry Challenges published

The report is ready and available to download from the APC website.

www.apcuk.co.uk/technology-roadmaps

Find all the technology roadmaps and industry challenges at

www.apcuk.co.uk/technology-roadmaps

Report authored by Ileana Lupsa, Jon Regnart and Bhavik Shah

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

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