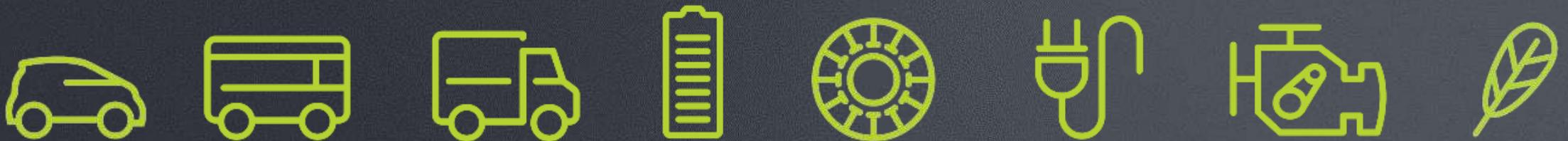


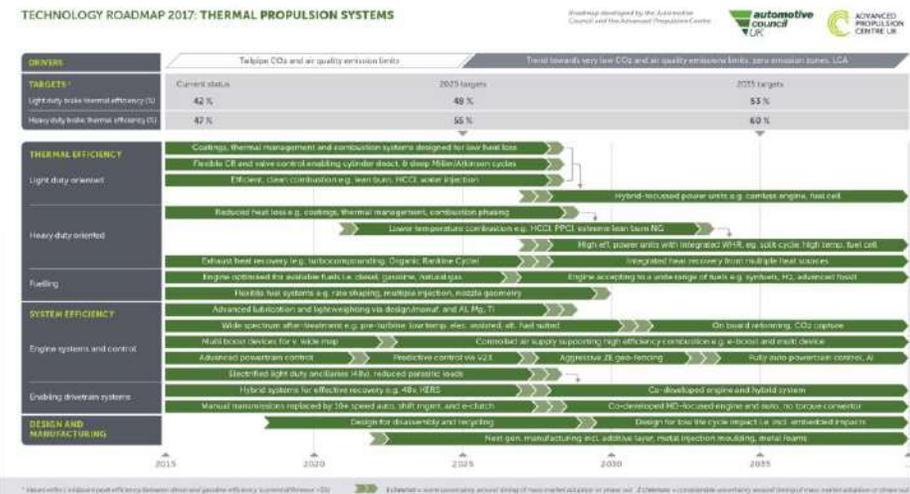
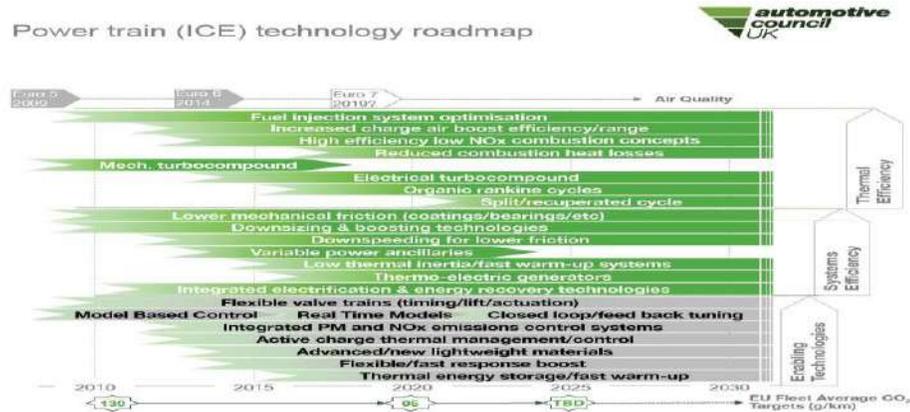


## Thermal Propulsion Systems Roadmap



Updated by the Advanced Propulsion Centre in collaboration with and on behalf of the Automotive Council

# Executive summary: Thermal propulsion systems



- The 2013 roadmap focused on thermal efficiency, system efficiency and enabling technologies that support continued engine innovations.
- The 2017 roadmap builds upon the 2013 approach and recognises that light duty and heavy duty base engines may take different approaches.
- The 2017 roadmap has introduced stretched targets for future light and heavy duty systems, focussing on wider emissions spectrum in order to maintain market relevance and competitiveness.
- The roadmap reflects that thermal propulsion systems are part of a wider powertrain system, and its performance and compliance with regulation is dependent on the integration of pre and post combustion sub-systems.
- Similar to the 2013 roadmap, alternative operational cycles through alternative engine designs and control systems are highlighted in the roadmap.
- There is a stronger recognition of the integration of transmissions and energy recovery devices to further enhance hybrid system performance.

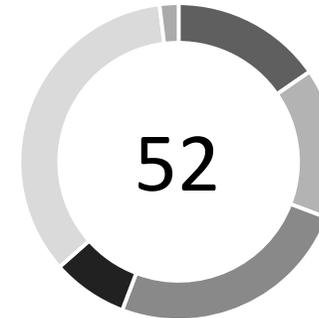
**Update process:** *The 2017 Thermal Propulsion Systems Roadmap was updated via a structured consensus-building process involving 52 experts*



- **A public workshop** was held at the University of Bath on the 31<sup>st</sup> January 2017
- The process was co-ordinated by the **Advanced Propulsion Centre on behalf of Automotive Council**
- The **Advanced Propulsion Centre Thermal Efficiency and System Efficiency Spokes**, supported by an expert Steering Group, helped to shape the roadmap before and after the workshop.

Thermal Propulsion Systems Steering Committee and Workshop Attendees

- Vehicle Manufacturer
- Supplier
- Technology Developer
- Engineering Service Provider
- Research
- Other



Pre-Event Email      1 day workshop with 45 attendees      Post-Event Email

**Pre-event Common Assumptions Briefing**

**Collective Briefing Process**

**Breakout Sessions**

**Post-Event Debrief**

## Technical targets: Mass market adoption of increasingly hybridised vehicles drives challenging cost and performance targets for future thermal propulsion systems

### Drivers of change

- Incremental innovations in thermal propulsion systems has provided steady improvements over a long period, but **bigger changes are required**.
- **Ambitious targets, that are unobtainable with existing engine technology, have been set** to drive significant innovation. These targets must be achieved without compromising customer demands of exceptional cost effectiveness, range requirements, power density and recyclability.
- **Reducing air quality and CO<sub>2</sub>** emissions challenges the current application of all TPS powertrains using conventional fuels. Future sustainable fuels and the associated engine technology are actively being developed, potentially near carbon neutral operation. Air quality and efficiency will remain key drivers.
- **Life cycle measures and materials security** will challenge all propulsion technologies, supporting the acceptability of TPS with suitable performance against these metrics
- For light duty vehicles, TPS will feature in all hybrid vehicles before the potential advent of fuel cell hybrids. **Hybridisation implies a change in the nature of TPS and offers higher efficiencies.**
- For heavy duty the TPS remains core to future propulsion due to the absence of alternatives. **Further improvements to efficiency and emissions are needed, including new fuel types and energy recovery.**

Light Duty	2017	2025	2035
Engine System Brake Thermal Efficiency (%) <sup>1,2</sup>	42	48	53
Tailpipe NOx & Particulates (Mass & Number)	In line with legislated limits	Zero in emissions controlled zones <sup>3</sup>	
Heavy Duty	2017	2025	2035
Engine System Brake Thermal Efficiency (%) <sup>1</sup>	47	55	60
Tailpipe NOx & Particulates (Mass & Number)	In line with legislated limits	Zero in emissions controlled zones <sup>3</sup>	

1) Peak efficiency values shown. Increasingly important to achieve high efficiency across a wider operating range, in keeping with testing cycles based on real world performance

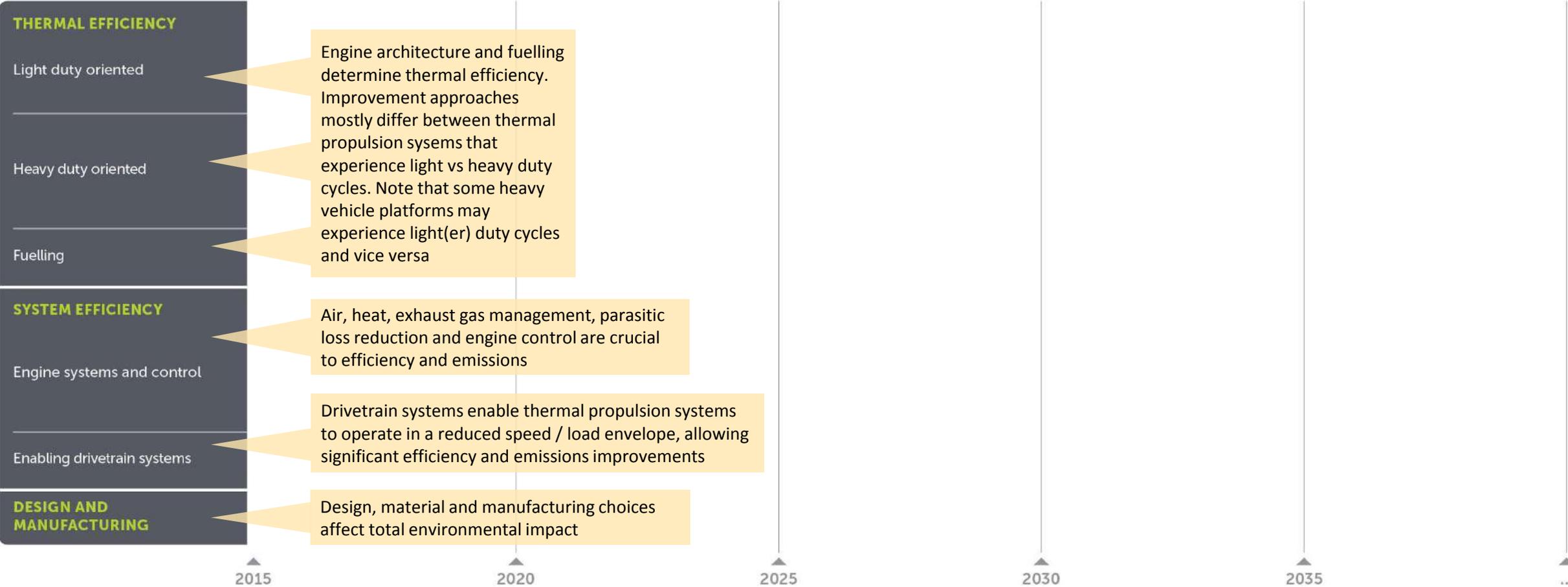
2) Values reflect mid point between diesel and gasoline efficiency (current difference ~5%)

3) Below measureable limits or below ambient (background) levels

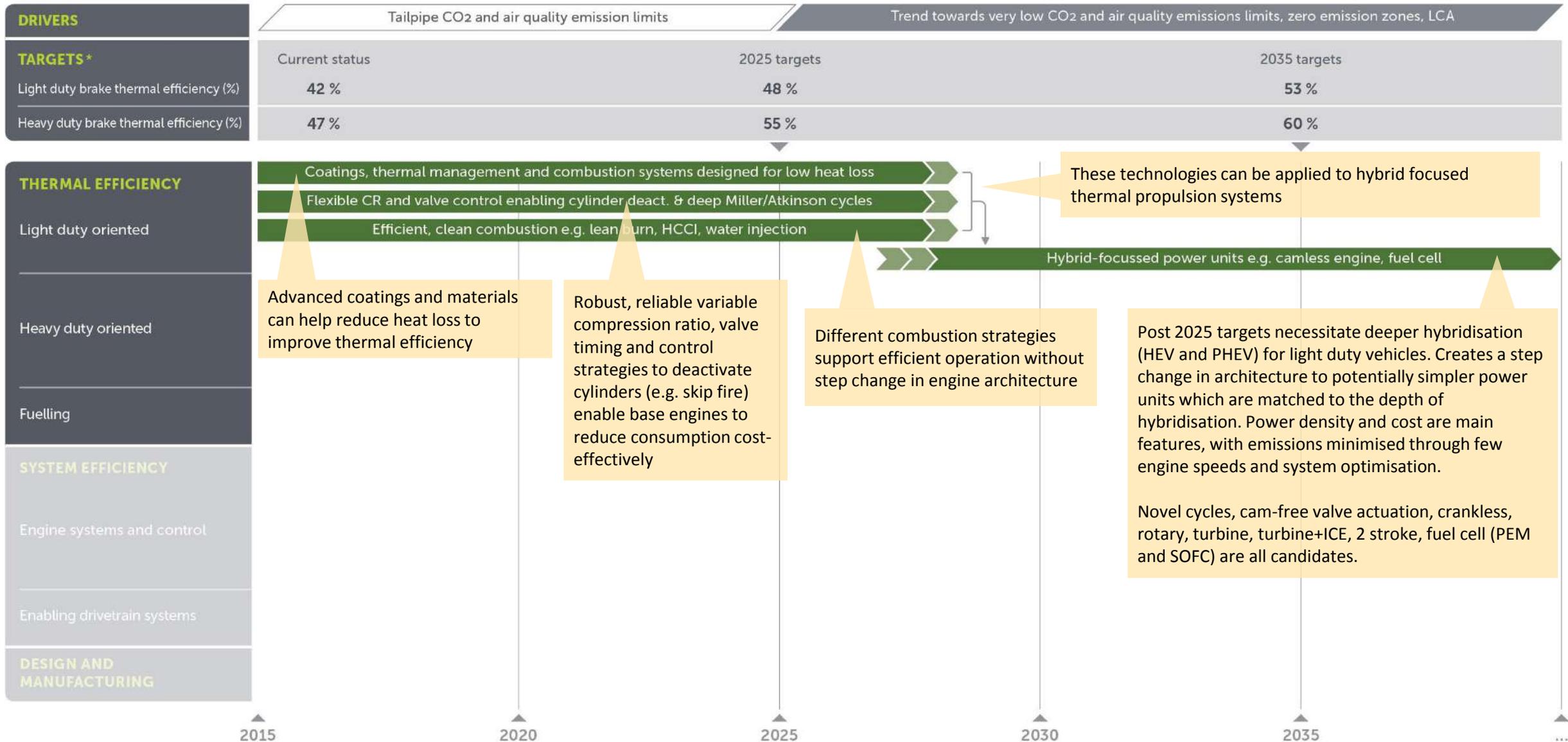


# Technology categories: *To meet tough targets parallel development is needed in thermal efficiency of base engines and efficiency of the wider system*

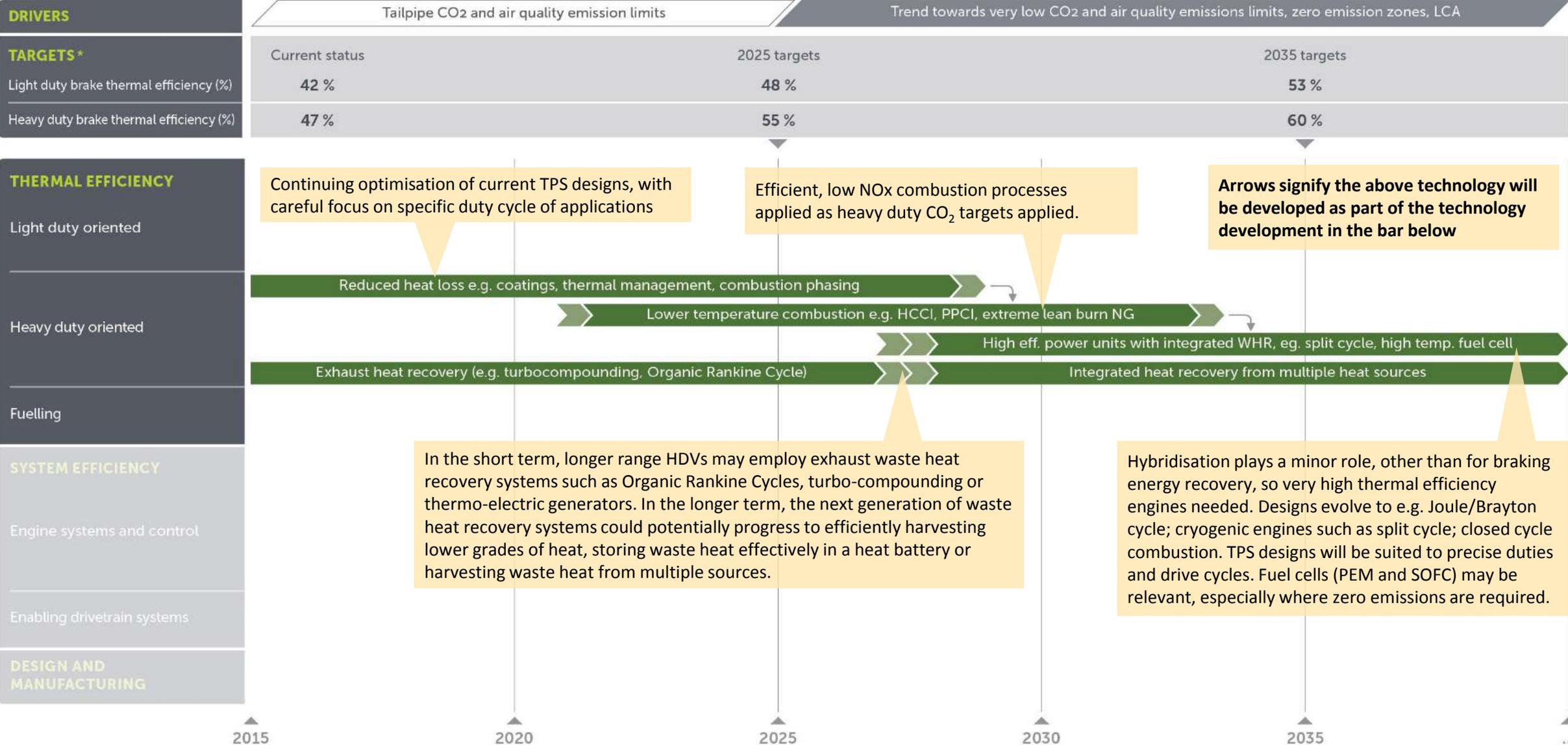
DRIVERS	Tailpipe CO2 and air quality emission limits		Trend towards very low CO2 and air quality emissions limits, zero emission zones, LCA	
	Current status	2025 targets	2035 targets	
TARGETS*				
Light duty brake thermal efficiency (%)	42 %	48 %	53 %	
Heavy duty brake thermal efficiency (%)	47 %	55 %	60 %	



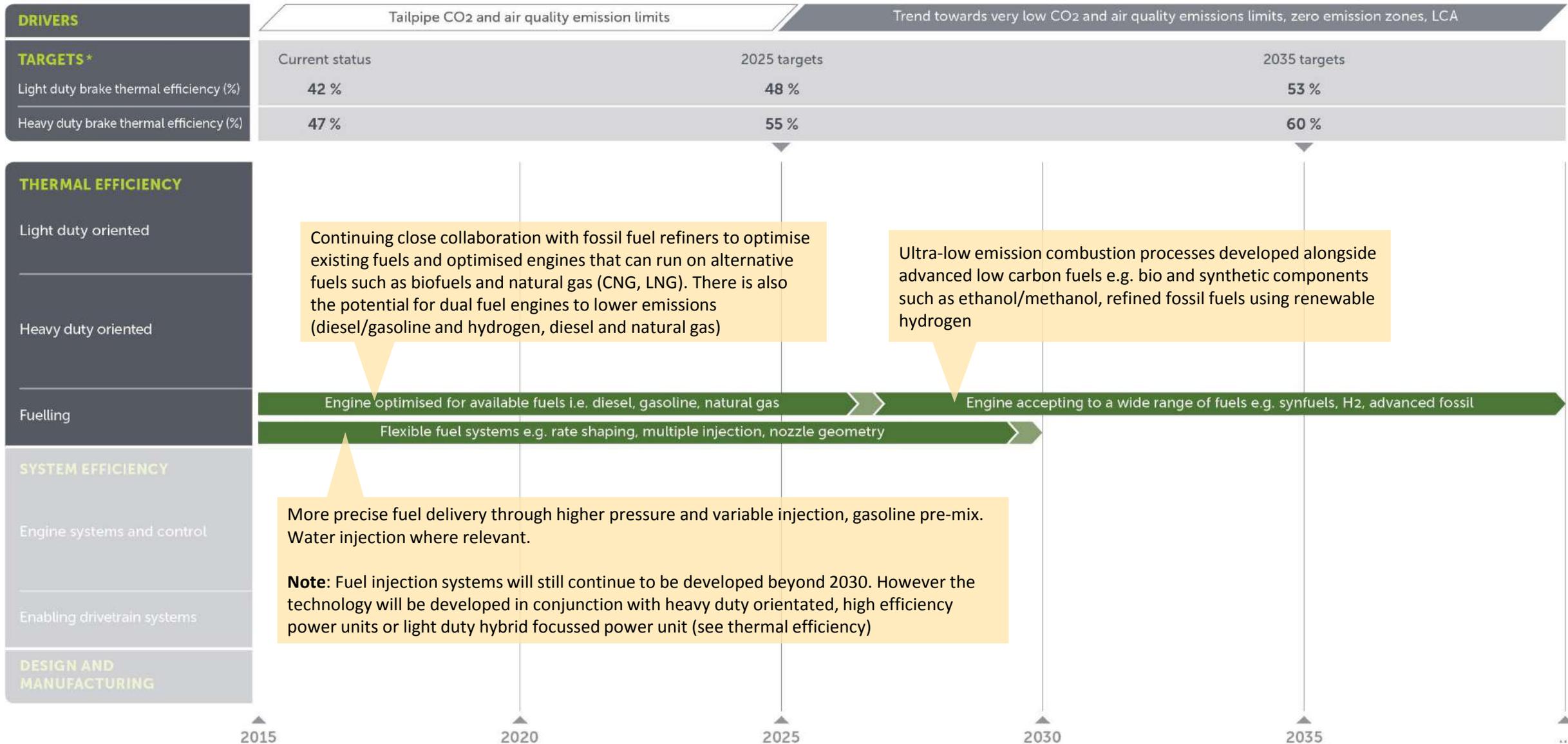
# Thermal efficiency: Existing light duty thermal propulsion systems need to improve, but will reach a point where they transition into hybrid focussed power units for mass market applications



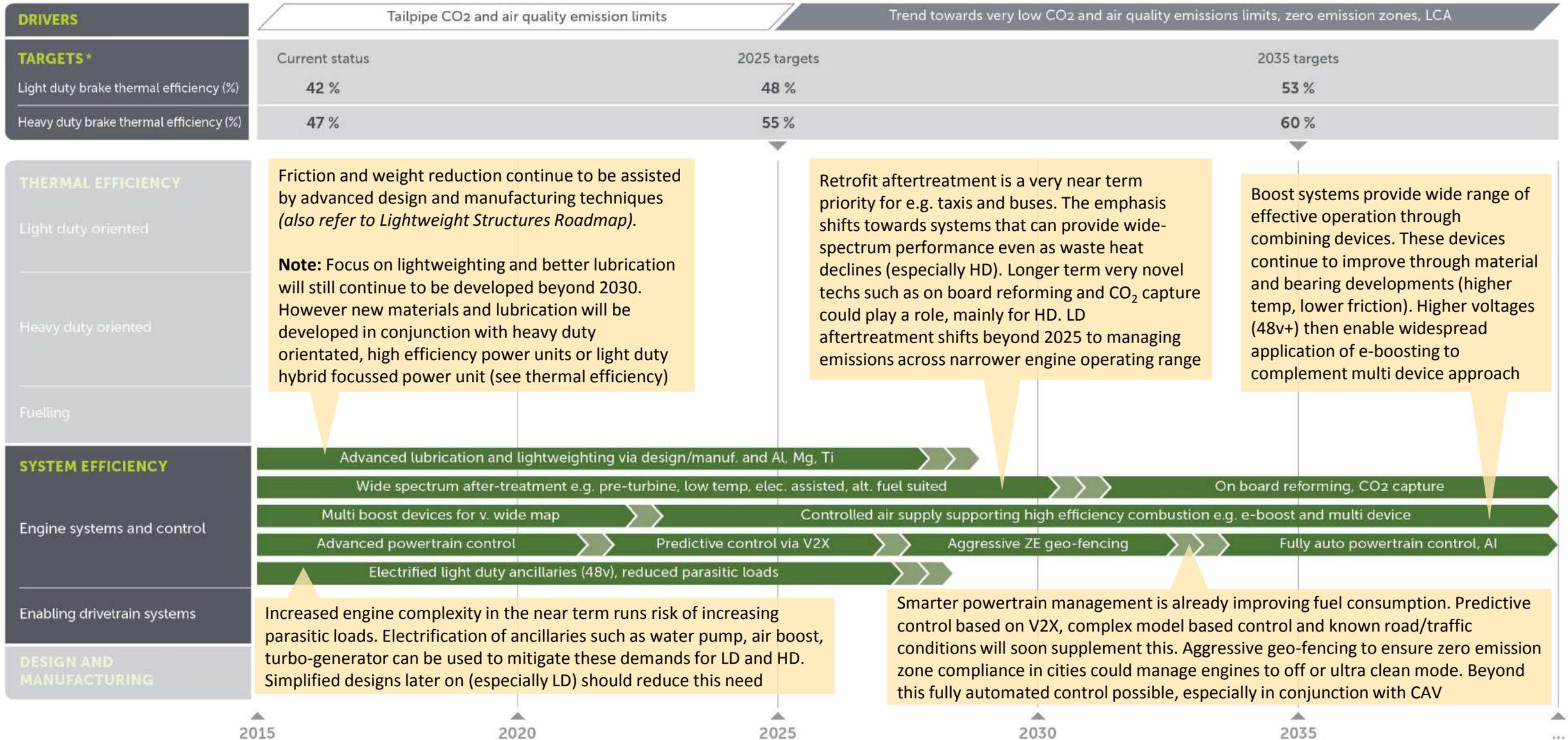
# Thermal efficiency: Heavy duty thermal propulsion systems require continuous improvement to evolve towards very high efficiency



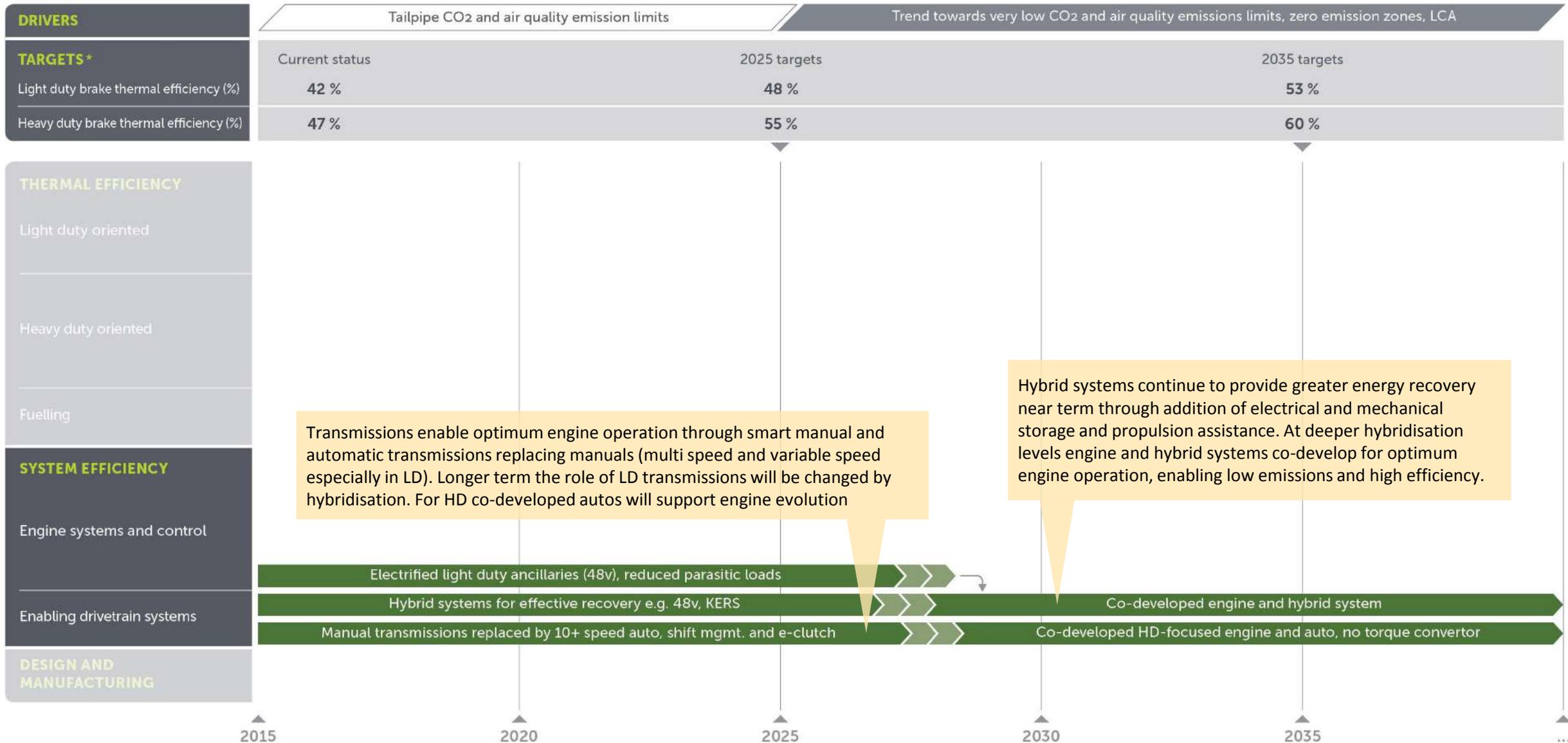
# Thermal efficiency: Both light and heavy duty engines will need to adapt to a wider range of fuels to later also informing the development of fuels



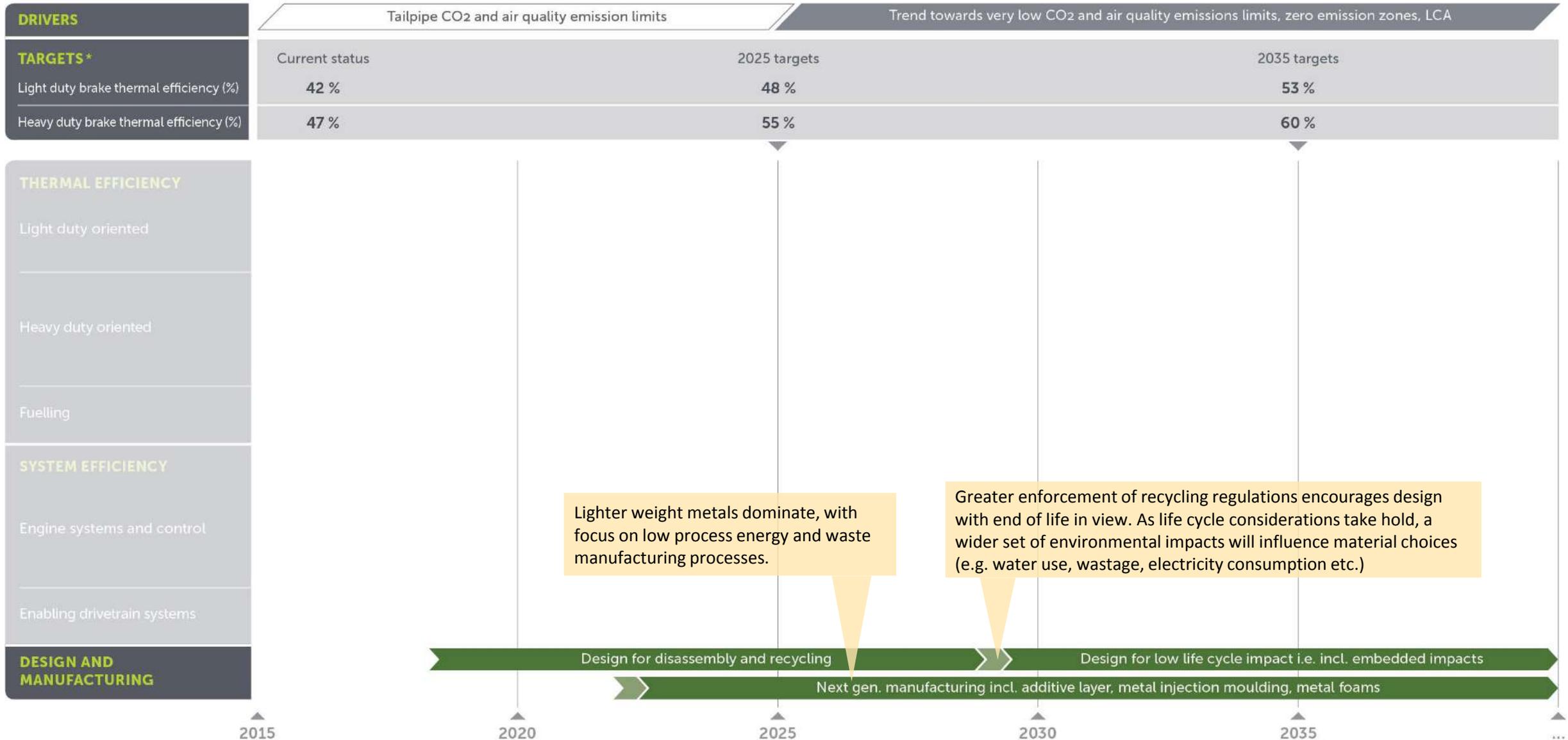
# System efficiency: A wide range of improvements in engine systems and control will support developments in existing engines and the emergence of more novel designs



# System efficiency: *Transmissions and hybridisation are vital enablers for propulsion system efficiency; co-development will allow them to be operated closer to peak efficiency*

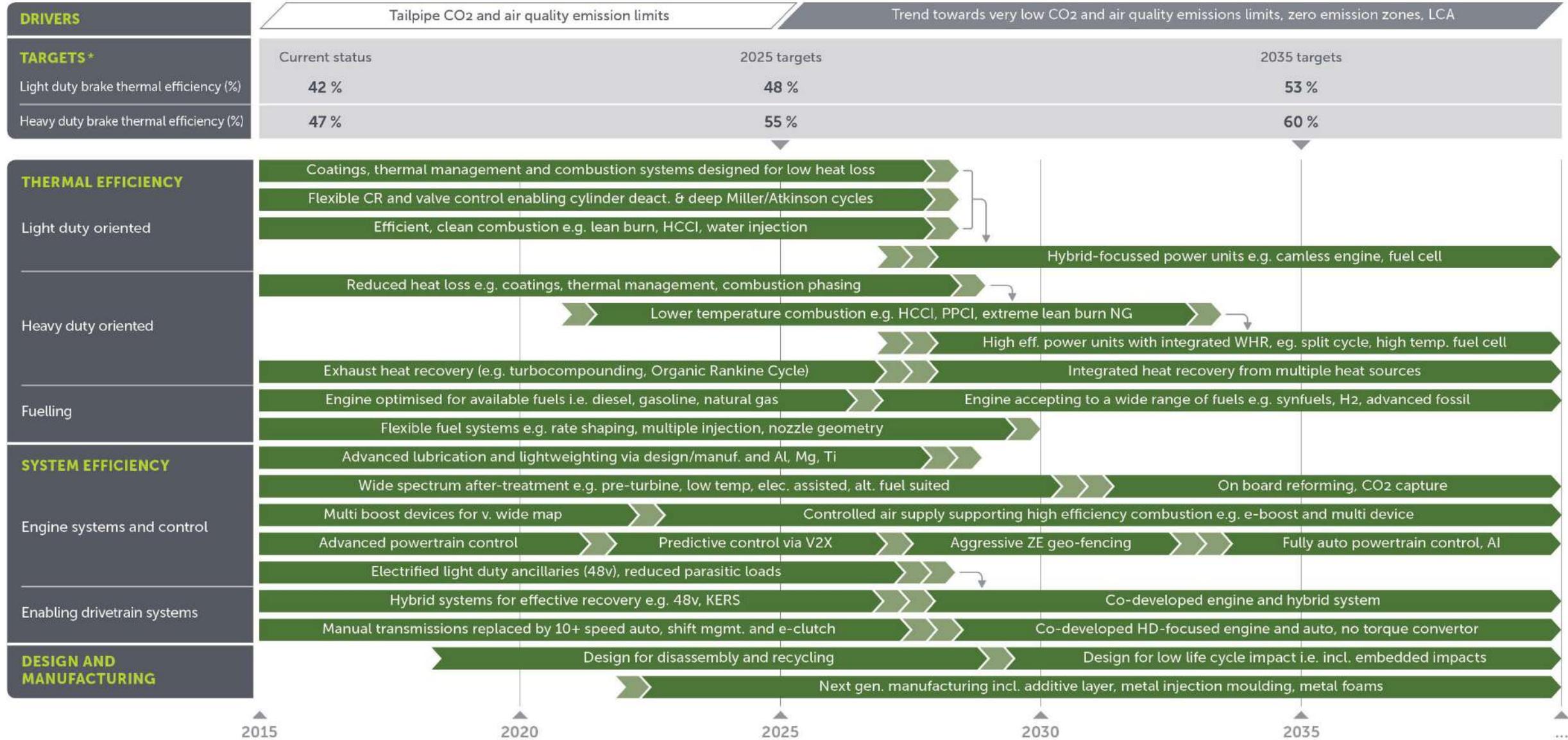


# Design and manufacturing: *Design approaches, materials choices and manufacturing technologies must all evolve to support other technology developments and drivers*



# TECHNOLOGY ROADMAP 2017: THERMAL PROPULSION SYSTEMS

Roadmap developed by the Automotive Council and the Advanced Propulsion Centre



\* Values reflect midpoint peak efficiency between diesel and gasoline efficiency (current difference ~5%)



1 chevron = some uncertainty around timing of mass market adoption or phase out 2 chevrons = considerable uncertainty around timing of mass market adoption or phase out

## **Glossary:** *Explanation of acronyms and terms not described in the roadmap due to space constraints*



- **BTE (Brake thermal efficiency)** - *Brake thermal efficiency represents, in percentage terms, the amount of energy converted into useful mechanical work by a base engine at the crankshaft (excludes transmission and driveline losses)*
- **HCCI (Homogeneous charge compression ignition)** – *A combustion cycle in which well-mixed fuel and oxidizer (typically air) are compressed to the point of auto-ignition at conditions that do not form emissions*
- **KERS (Kinetic energy recovery systems)** – *Systems that can recovery waste energy (i.e. from braking)– these can be electrical, mechanical, hydraulic or pneumatic systems.*
- **LCA (Life cycle analysis)** – *Identifying the total environmental impact of a given product.*
- **NG (Natural gas)** – *An alternative fuel source to petrol and diesel, examples are liquefied natural gas (LNG) and compressed natural gas (CNG).*
- **PCCI (Partially-premixed compression ignition)** – *A hybrid combustion system where the majority of the fuel burns lean (similar to an HCCI engine) but part of the fuel still burns in a diffusion flame*
- **TPS (Thermal propulsion systems)** – *A thermal propulsion system is a device that integrates an engine or fuel cell with thermal and / or electrical systems to manage power delivery to the wheels and recover waste energy to improved performance and efficiency. The key feature of a TPS is that the primary energy is stored chemically (rather than electrochemically like in a battery)*
- **V2X (Vehicle-to-X)** – *Vehicle-to-X refers to an intelligent transport system where all vehicles and infrastructure systems are interconnected with each other.*
- **WHR (Waste heat recovery)** – *Technologies that can capture waste heat from base engines (i.e. from the exhaust) and convert it into useful energy.*

