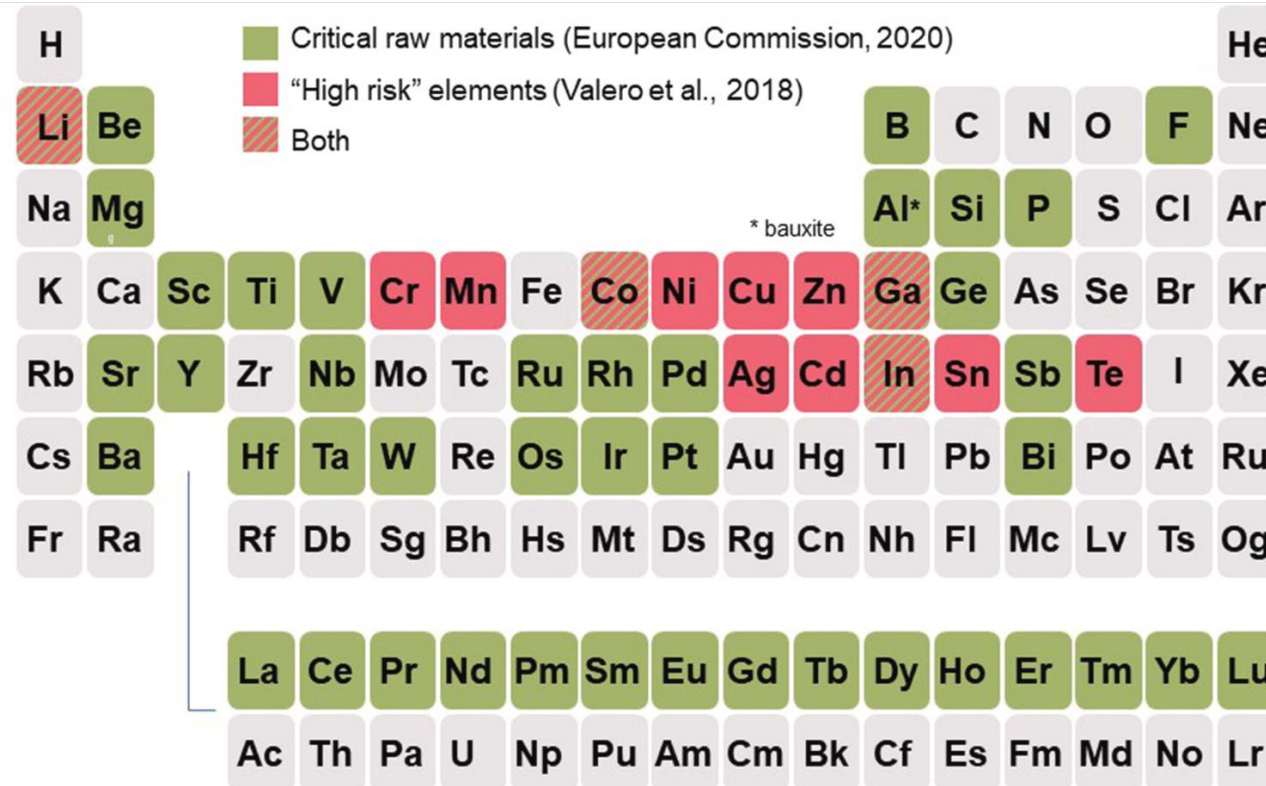


**2023 Smoky Mountain Mobility Conference:**  
**Hybrid Powertrains for Mobility**

**Hugh Blaxill – General Manager and Head of Engineering Services**  
**MAHLE Powertrain US**

**October 23 - 26, 2023**

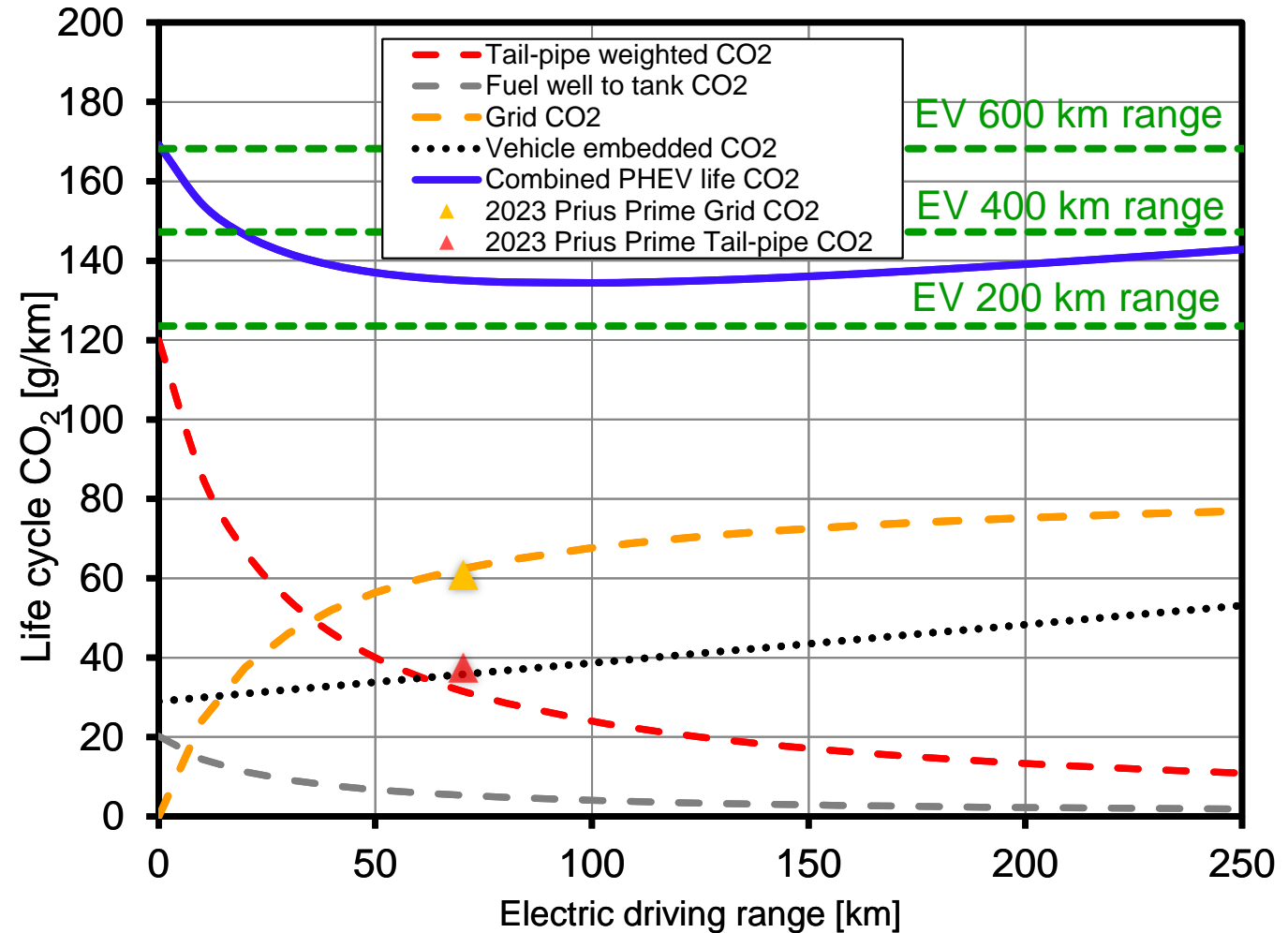




Strategic mineral resources: Availability and future estimations for the renewable energy sector; Calvo, A. Valero

### PHEV – A viable solution

- Range-anxiety free
- Cost disparity
- Charging & power availability
- More efficient use of rare metal
- US avg. electricity CO<sub>2</sub> intensity  
Distributed: 410 g/kWh<sup>1,2</sup>
- Battery embedded  
CO<sub>2</sub> 140 kg/kWh<sup>3,4 avg.</sup>



1) EIA 2021: <https://www.eia.gov/tools/faqs/faq.php?id=74&t=11>

2) Argonne National Laboratory, GREET Model

3) Dale & Hall, ICCT, January 2018

4) McKinsey & Co. Automotive & Assembly Practice, February 2023

# Hybrid Powertrains for Mobility

## Why Hybrid Powertrains – MHD Off-road Applications



### Off-Road Applications

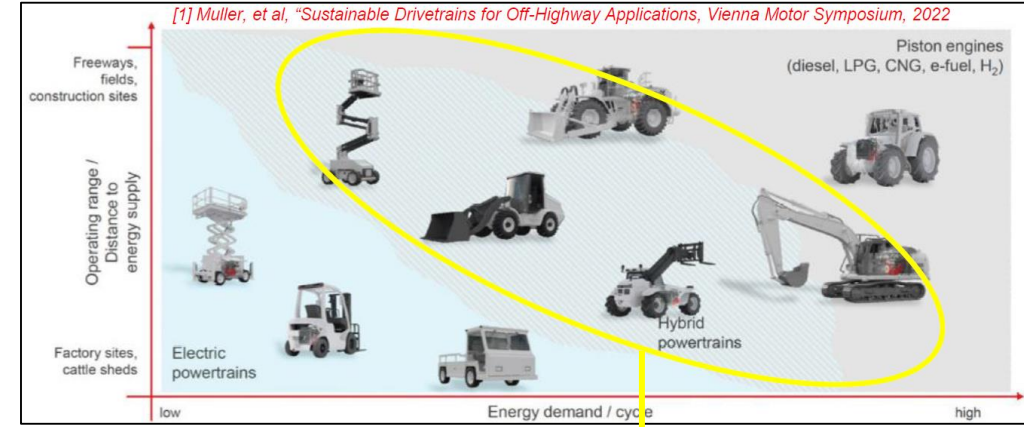
- Construction, Mining, Agriculture, Marine, Military, etc.

### MHD Off-Road Requirements

- High power demands
  - Extended work duration
  - Resilience in harsh environments
  - Rapid torque response
- } Massive energy reservoir

### Drive toward reduced GHG and criteria emissions

- Low carbon intensity fuels (bio-fuel, hydrogen, e-fuel)
- Improve powertrain efficiency
  - Advanced engine technology
  - Advanced powertrain technology (e.g., **hybrid architecture**)

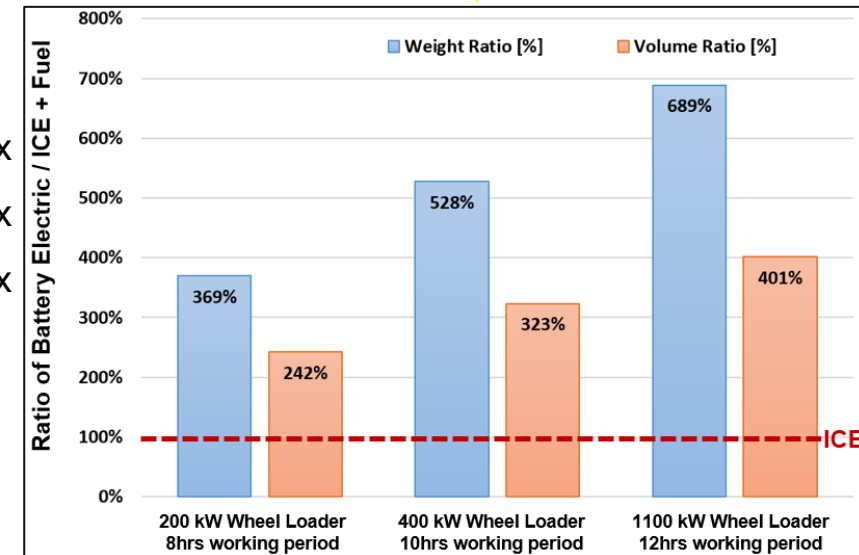


Compare battery-electric MHD powertrains to ICE

Weight: 4x – 7x

Space: 2x – 4x

Capex: 5x - 8x

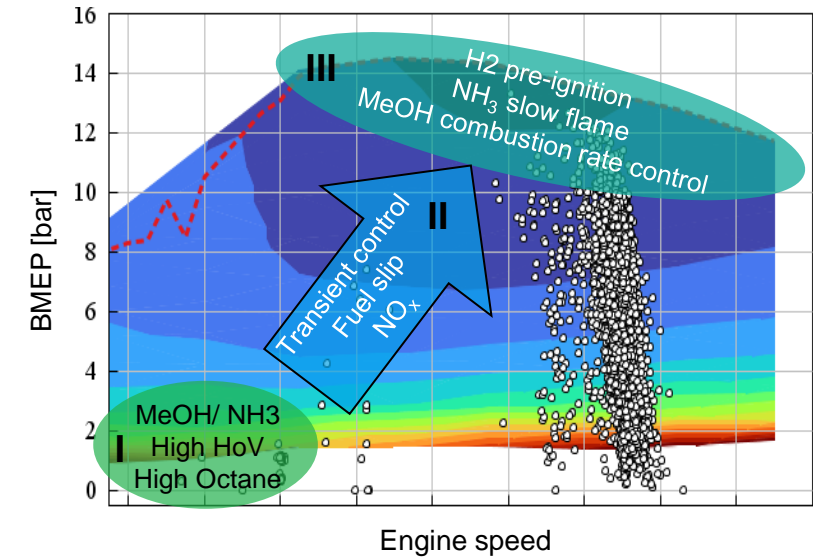


# Hybrid Powertrains for Mobility

## Why Hybrid Powertrains – Alternative Fuel Enabler

Low life-cycle carbon fuel engine is a viable pathway, but challenges exist:

Fuel	Hardware development & integration		Combustion system development		
	Storage	Toxicity	Low load & Idle	Full load	Transient
Ammonia	Pressurized	NH <sub>3</sub> N <sub>2</sub> O	HoV High Octane	Slow flame speed	N <sub>2</sub> O, NO <sub>x</sub> slip control
Methanol	Cooled	MeOH Formaldehyde	HoV High Octane	Combustion rate control	NO <sub>x</sub> slip control
Hydrogen	Extreme Pressurized	-	-	Pre-ignition	NO <sub>x</sub> control



New/retrofit engines using a dual-fuel strategy is a potential pathway

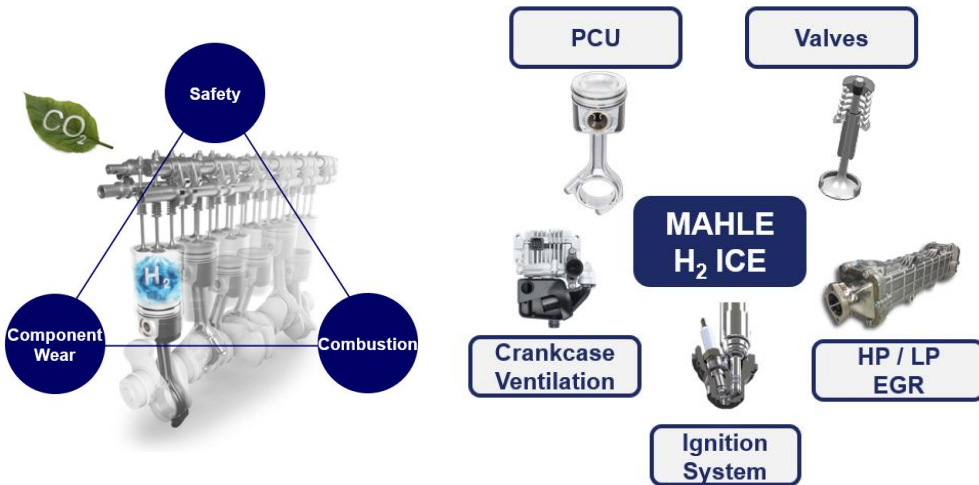
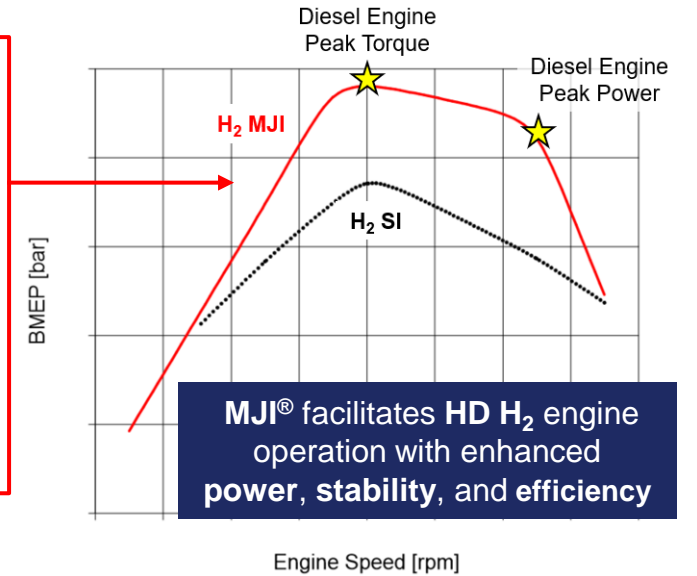
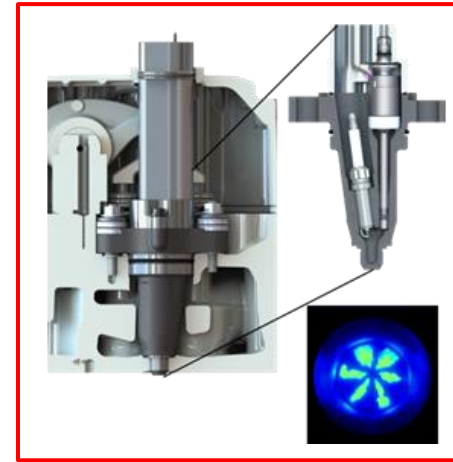
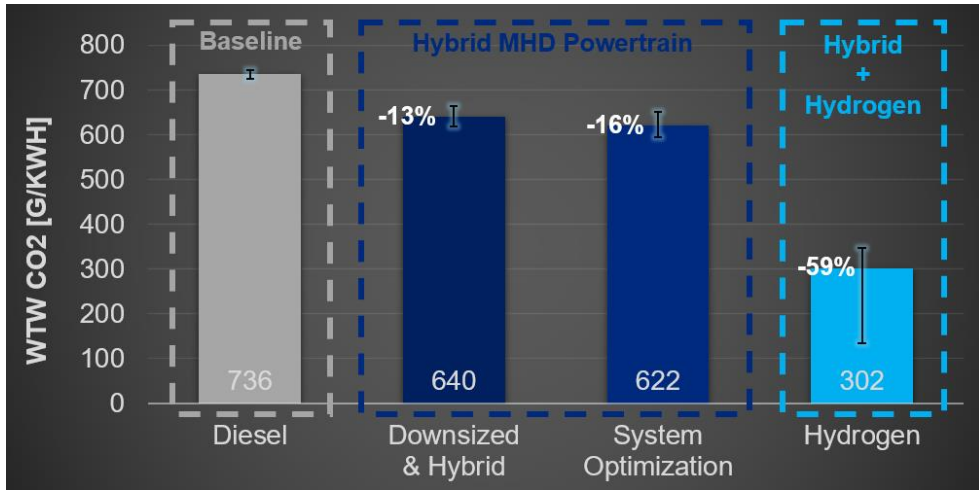
- Require second fuel on board (diesel), increased operational and maintenance complexity, decreased profitability
- Increased carbon footprint

Hybrid system can be alternative fuel enabler, reducing the dependency on second fuel and carbon footprint



# Hybrid Powertrains for Mobility

## Opportunities for H<sub>2</sub> MHD engine development



**SAE** TRUCK & OFF-HIGHWAY ENGINEERING



**Mahle, Liebherr develop active pre-chamber for hydrogen ICE**

2021-11-10 JOHN KENDALL

# Hybrid Powertrains for Mobility

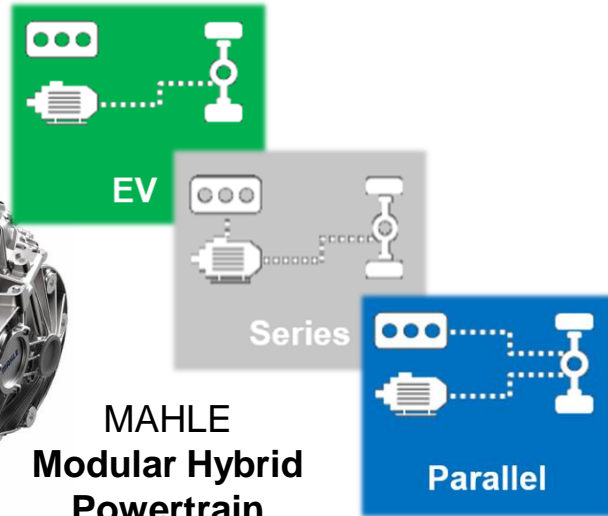
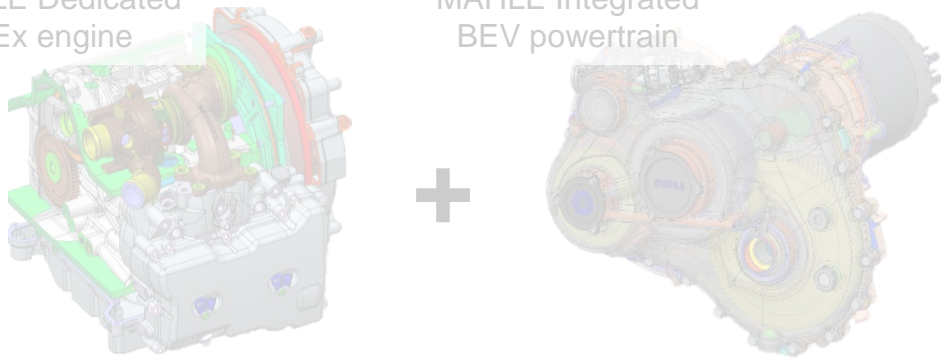
## MPT Electrification – MAHLE Modular Hybrid Powertrain (MHP)



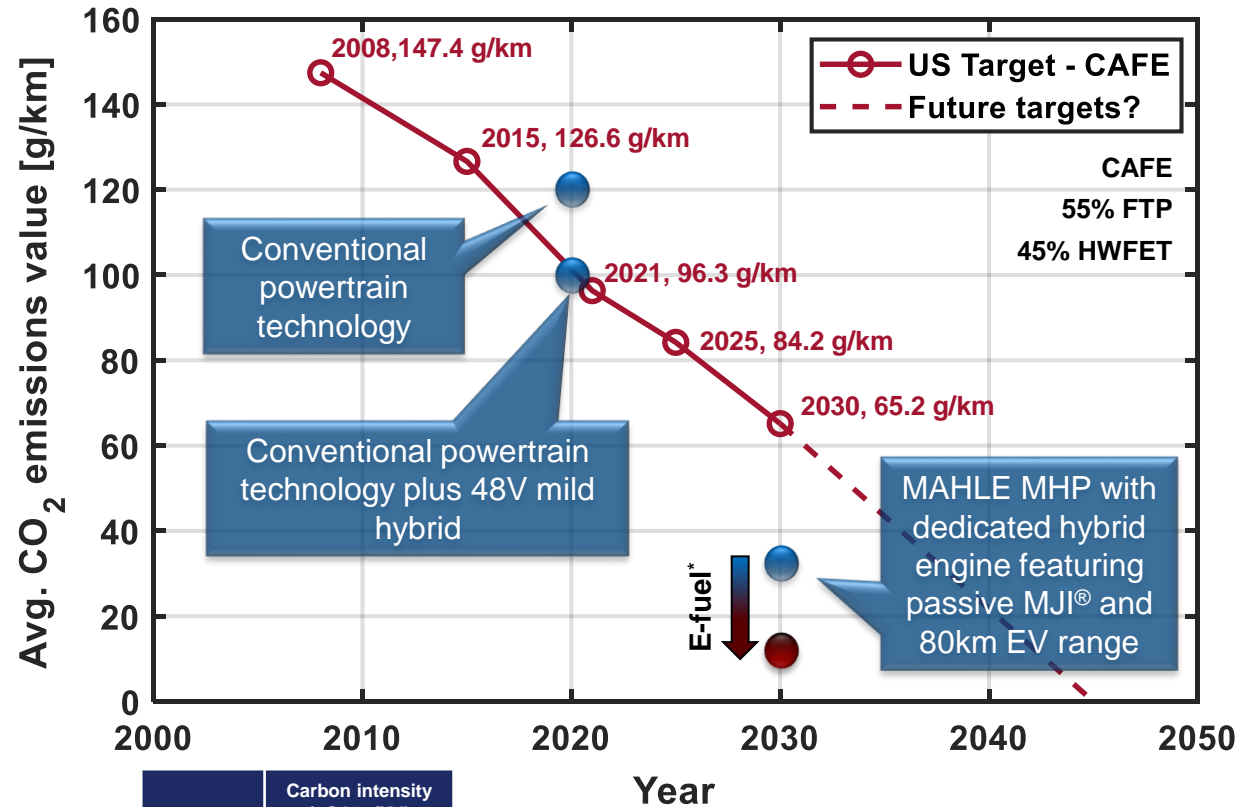
Powertrain

MAHLE Dedicated REX engine

MAHLE Integrated BEV powertrain



Fleet average CO<sub>2</sub> targets, with examples for 1400 kg compact cross-over SUV with various powertrain technologies

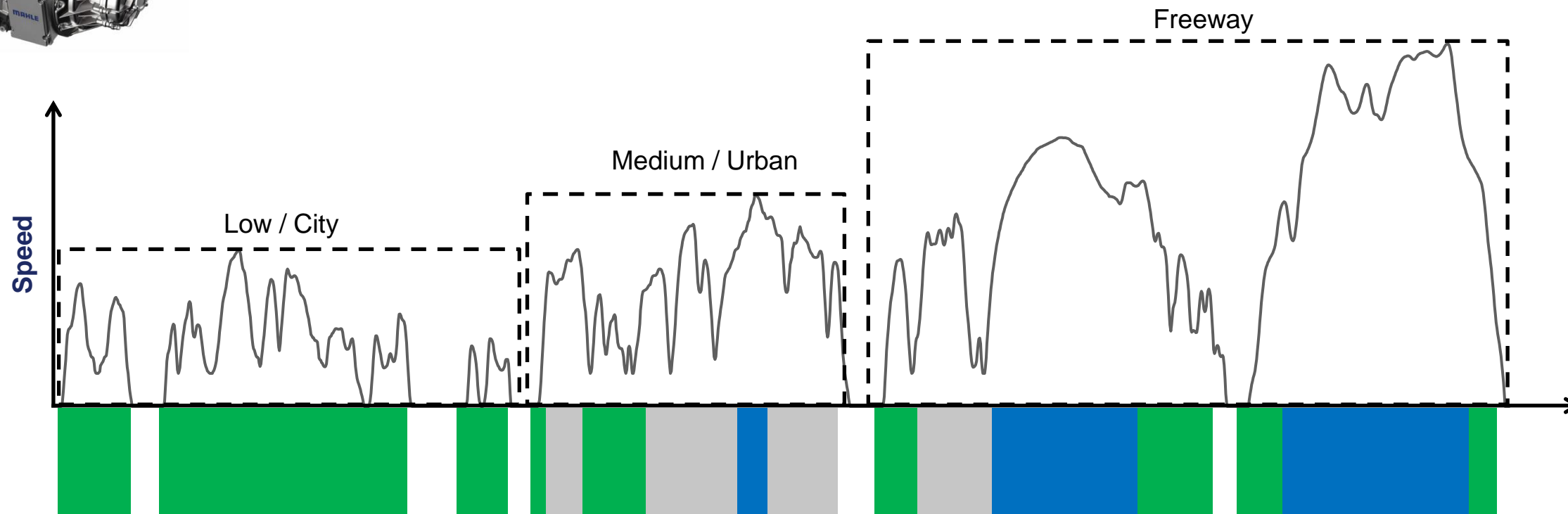
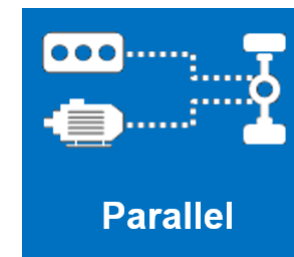
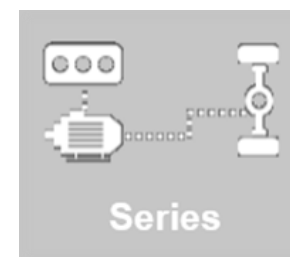
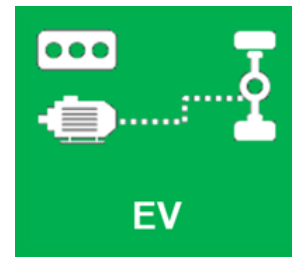


	Carbon intensity (gCO <sub>2</sub> e/MJ)
Gasoline	91
E-fuel	25-45 <sup>1</sup>

1) NZTT, U.S. DRIVE Net-Zero Carbon Fuels Technical Team Analysis Summary Report, Sep 2021

# Hybrid Powertrains for Mobility

Example: MAHLE MHP in a C-segment compact SUV



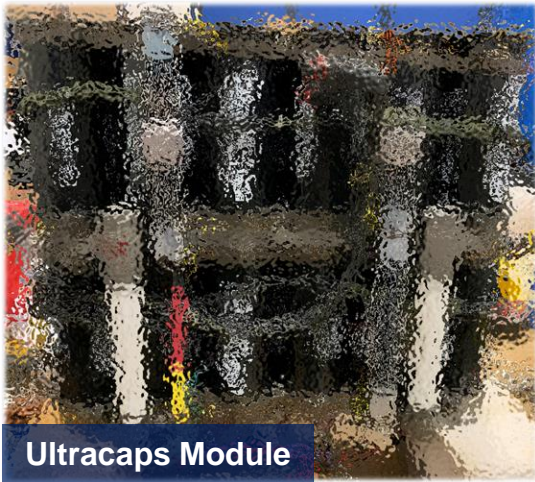


# Hybrid Powertrains for Mobility

## MPT Electrification – 48V High Power Hybrid Module



Powertrain



Ultracaps Module

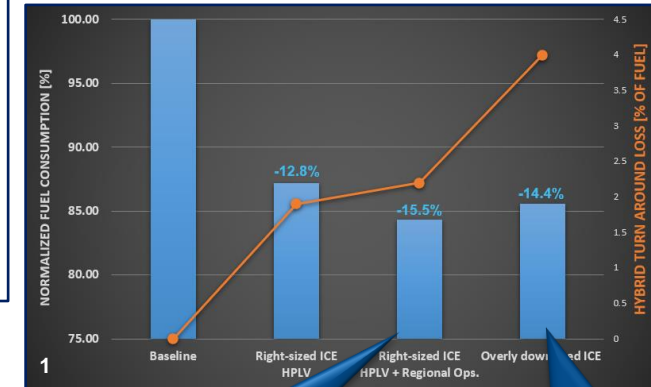
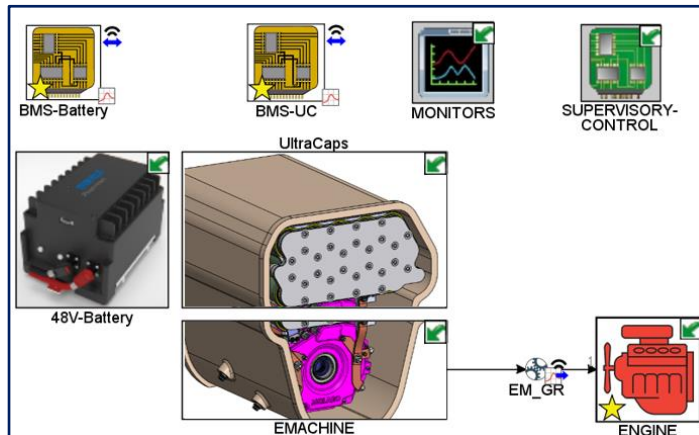


48V Battery Pack



48V HP Motor

### MAHLE 48V High Power Hybrid Module



Appropriate engine downsize improves fuel economy (~16%)  
With additional NOx emissions reduction (~13%) by transient assist

Excessive downsize could be harmful due to turnaround losses

1) Yan et. al., 48V High Power Hybrid..., ASME ICEF 2023

# Hybrid Powertrains for Mobility

## Research & Development Opportunities

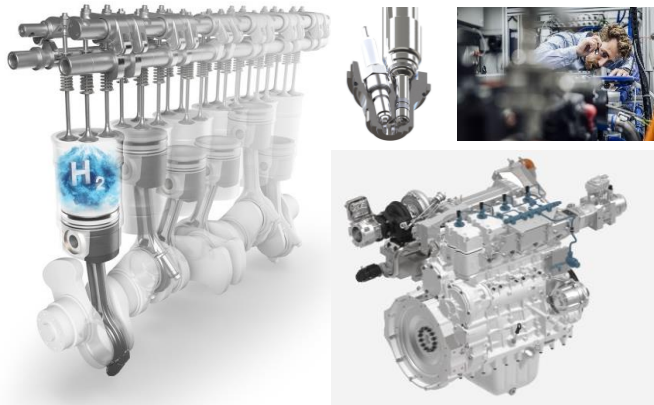
### Hybrid + Alternative Fuels

Geely Tests Full Methanol Hybrid Sedan in -40C, 2023



<https://zgh.com/media-center/news/2022-03-17/?lang=en>

Alternative fuel engines development



### Hybrid for Off-road Applications

Powertrain Electrification via EM



Working Device Electrification

Marine Electrification



UAV Electrification





**MAHLE**

*Powertrain*

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