

The Role Of IC Engines In Future Energy Use

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MAHLE Powertrain

4th Oct 2011

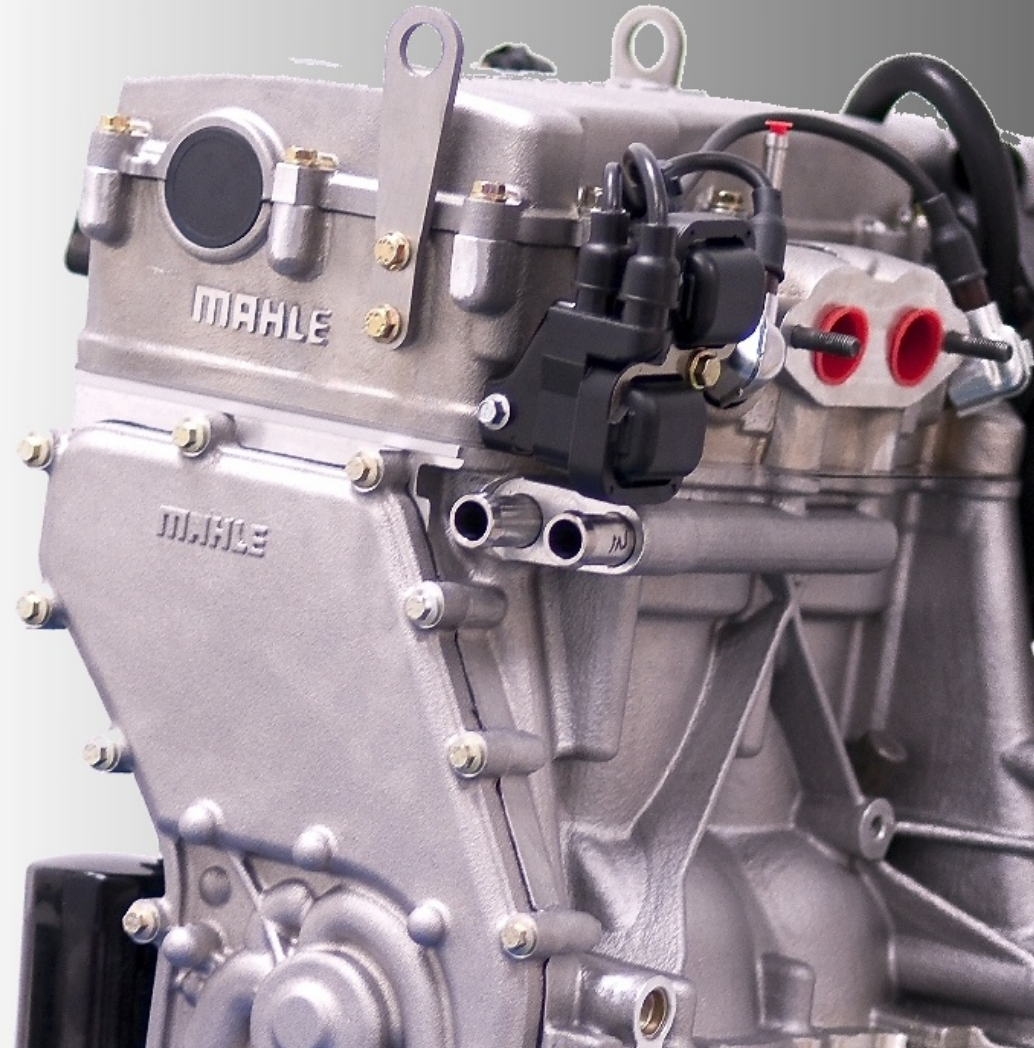


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Contents



- Introduction
- Market Trends and Forecast
- MAHLE Powertrain Research
- Downsizing Challenges
- Range Extending Engines
- Summary



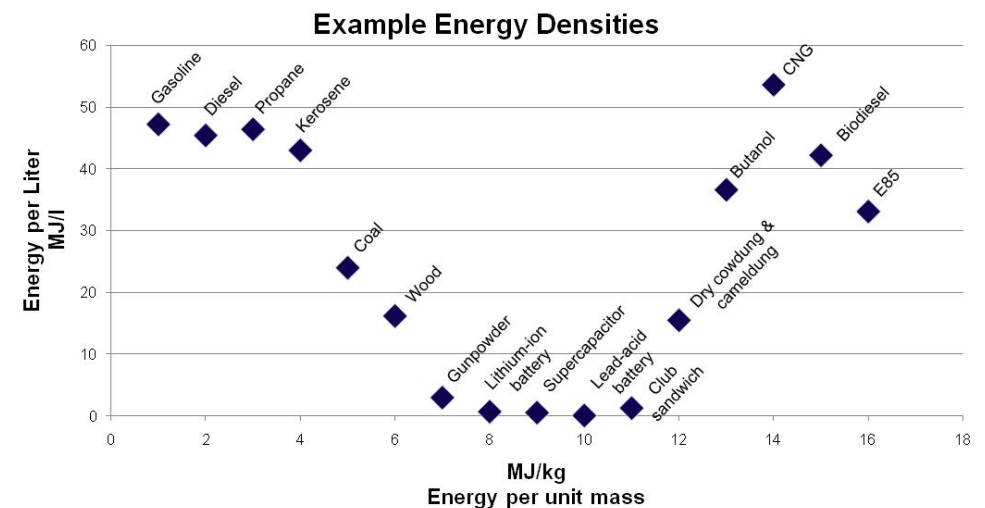
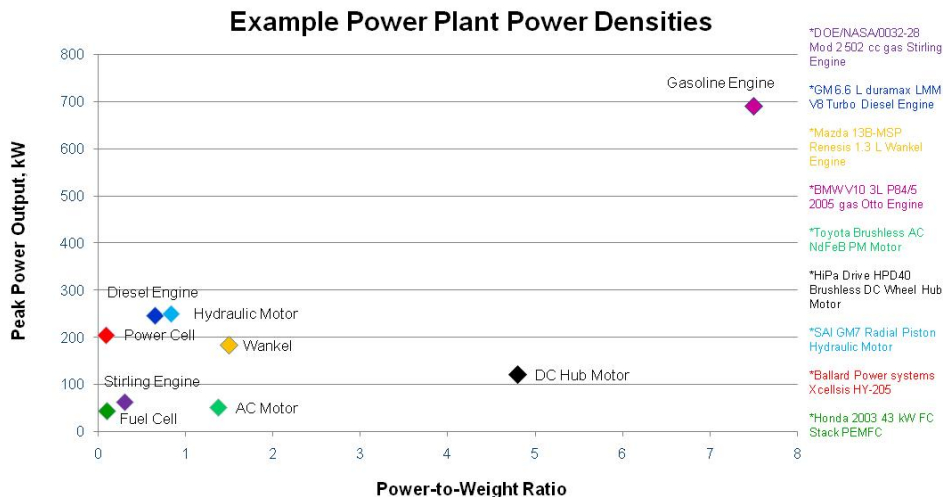
The role of IC engines in future energy use

Introduction

- There is a role for IC engines for future energy use, why ..
 - IC engine has high power to weight ratio
 - Relatively low cost
 - Flexible fuel use
 - Established manufacturing investment
 - Detailed pre existing knowledge
 - **Further development potential**

The IC Engine is not addicted to fossil fuels

WE ARE!



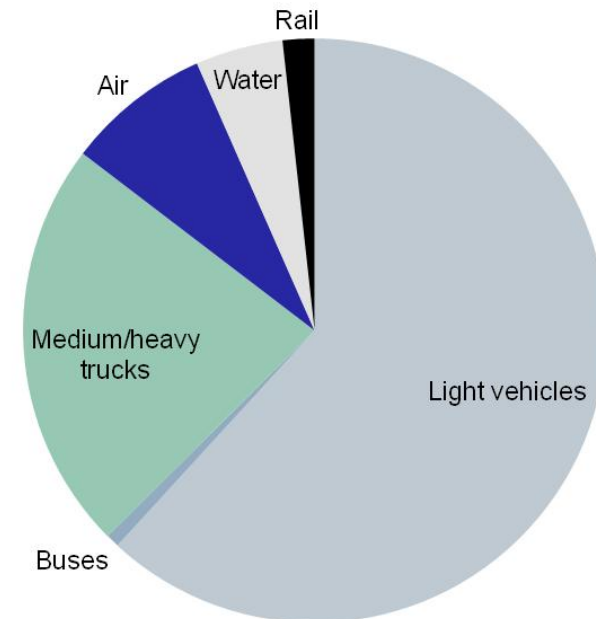
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Where is the role?

- Gas turbines will continue in at least aerospace applications
- Heavy and medium duty and off highway applications using both SI and CI cycles
- Emergency and remote power generation
- Larger capacity residential equipment
- Medium to long range and/or large capacity light duty applications in high efficiency form

How do we get there?

Applications of IC Engines in Transport by Type



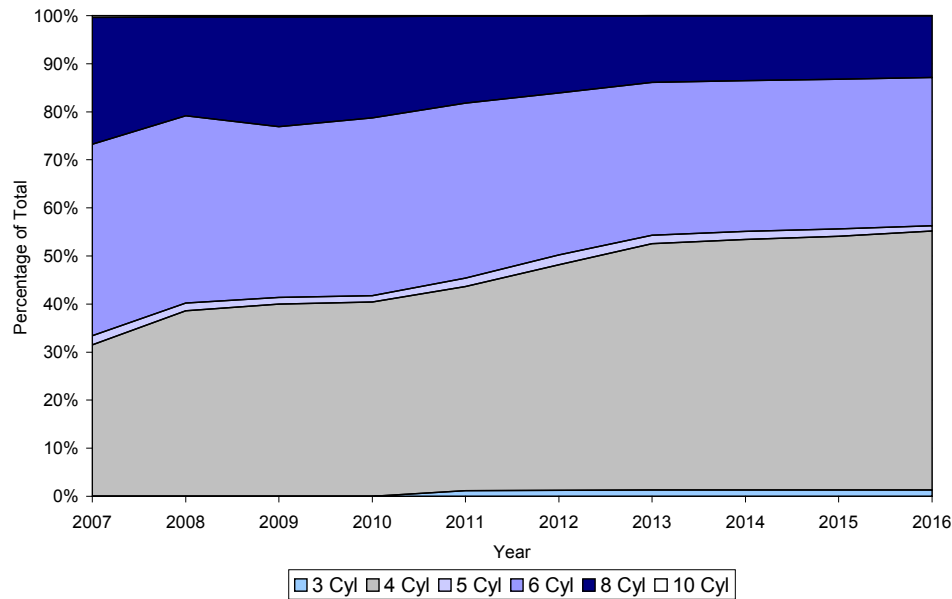
- What fuels?
 - Liquid biofuels and biofuel blends
 - Gaseous fuels

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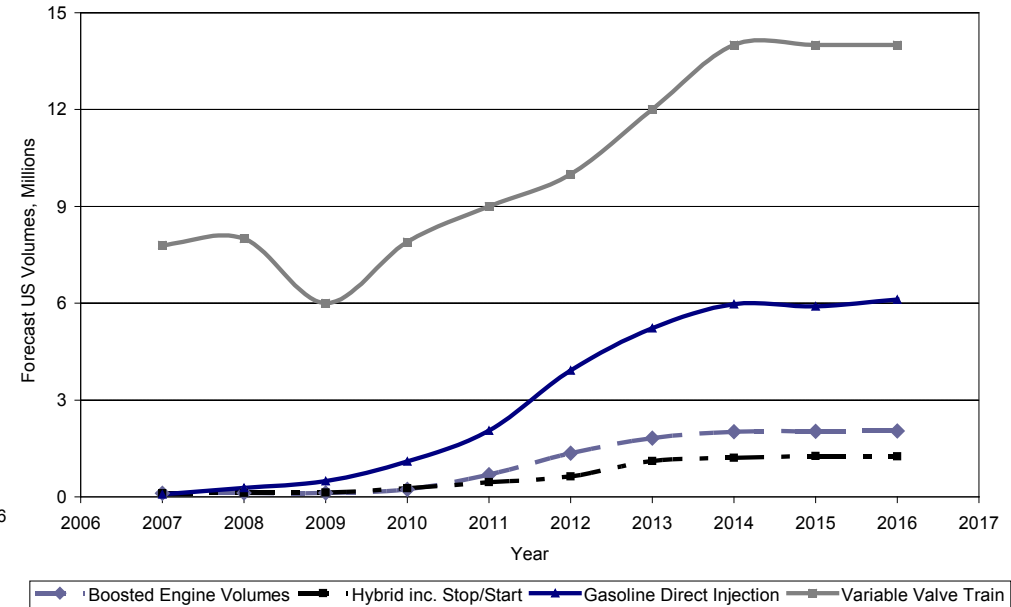
Short Term Forecast



Forecast Volumes of North America Manufactured Engines By Cylinder Number



Gasoline Engine Technology Trends

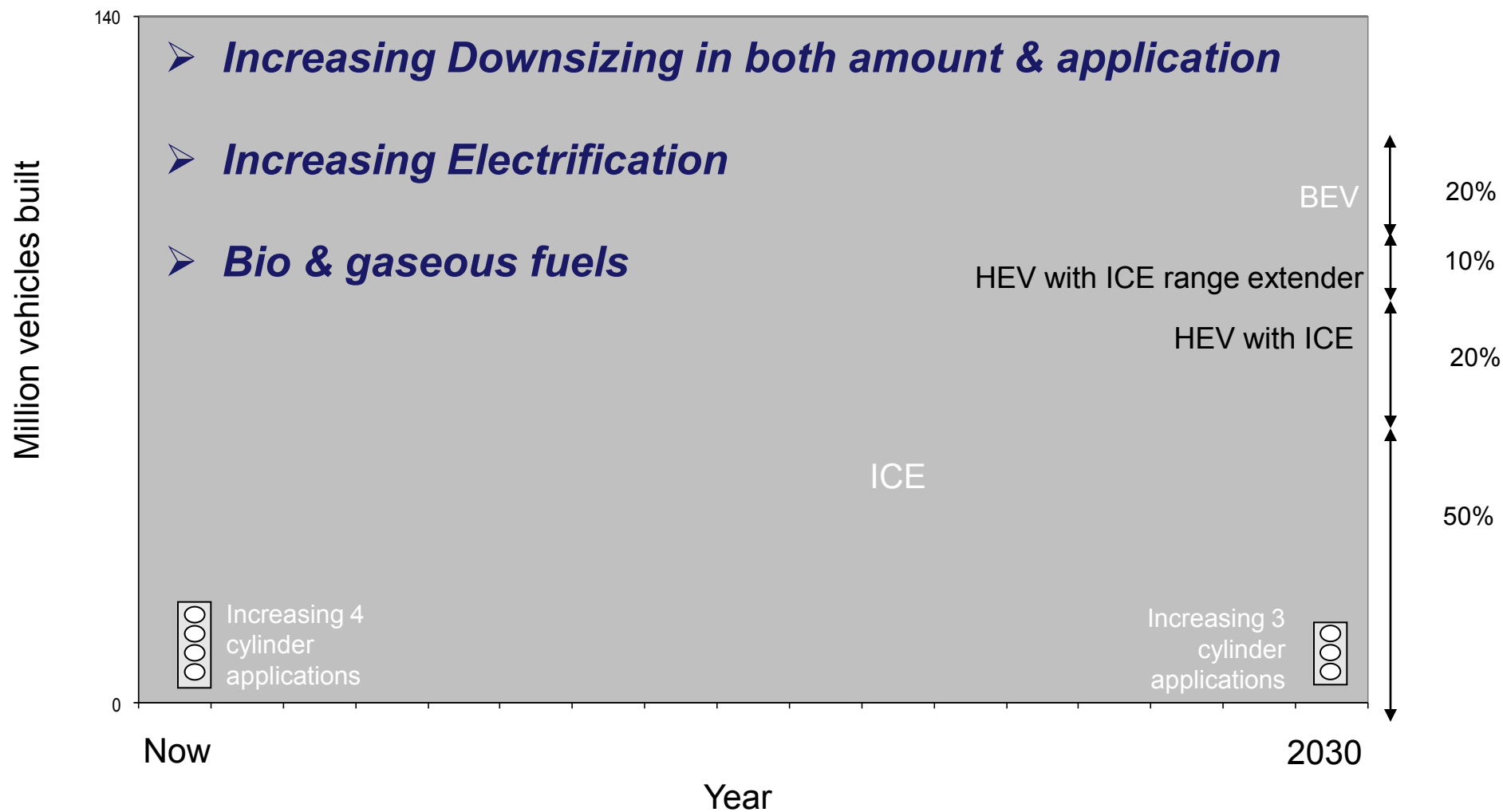


- Increasing volumes of 4 cylinder engines
- Rapid ramp in direct injection and variable valvetrain technologies across all manufacturers
- Start of an increase in downsized applications and hybrid powertrains

Data taken from CSM WW Database Q1 2010

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Longer Term Forecast



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So what is MAHLE Powertrain researching?

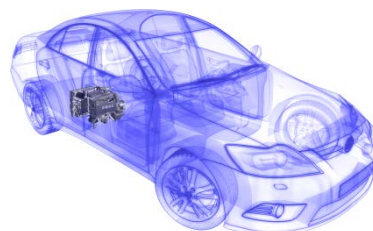


Downsizing



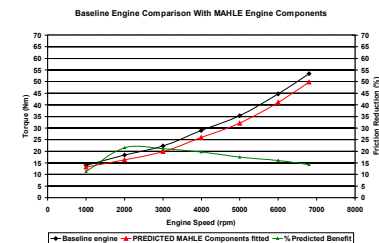
50% downsizing, up to 30% fuel economy

Hybridization



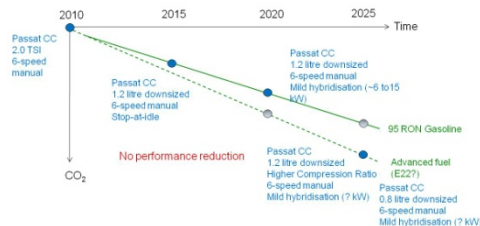
Range extender engine, 30kW power

Friction Reduction



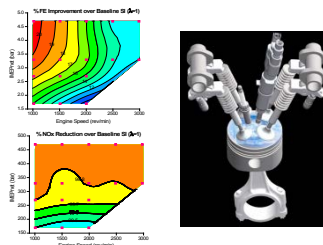
MAHLE low friction components, up to 4% fuel economy saving

Alternative Fuels



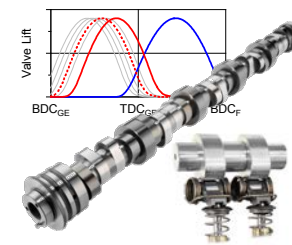
Optimized alcohol blends to suit downsizing applications

Combustion Process



Ultra lean combustion, Controlled auto ignition

De-Throttling



MAHLE CamInCam® Variable valvetrains

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So what is MAHLE Powertrain researching?

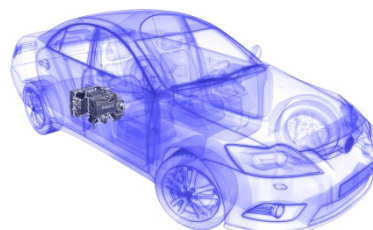


Downsizing



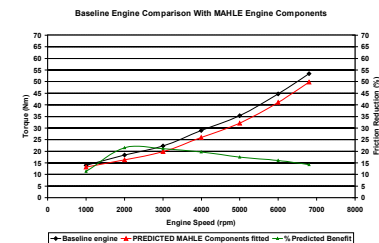
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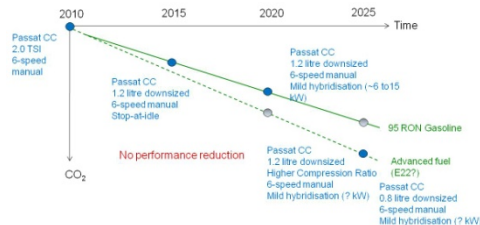
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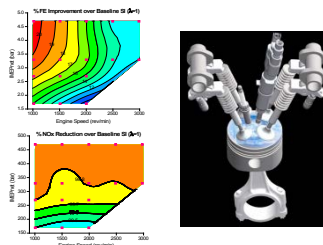
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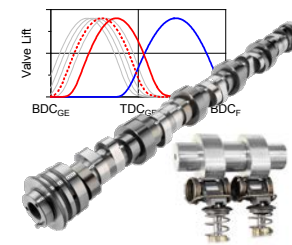
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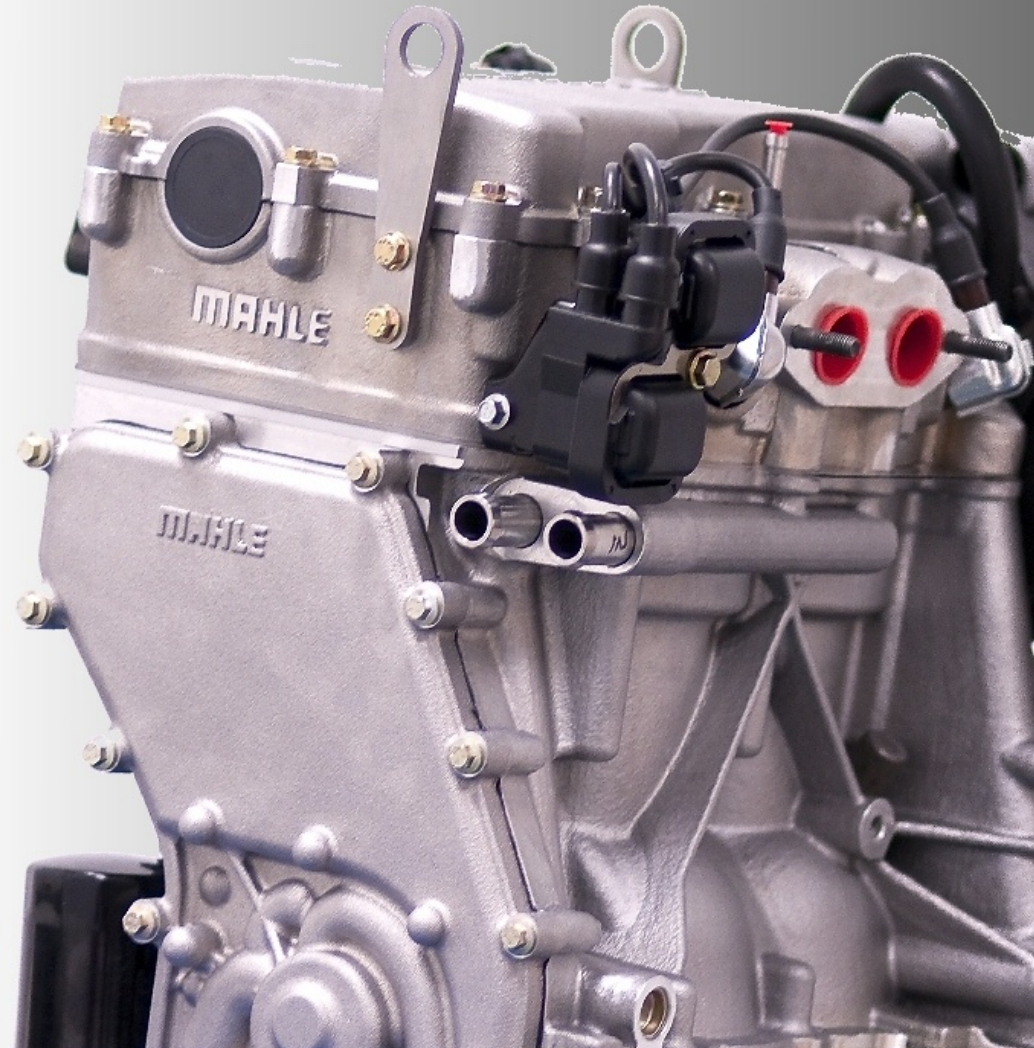
MAHLE CamInCam® Variable valvetrains

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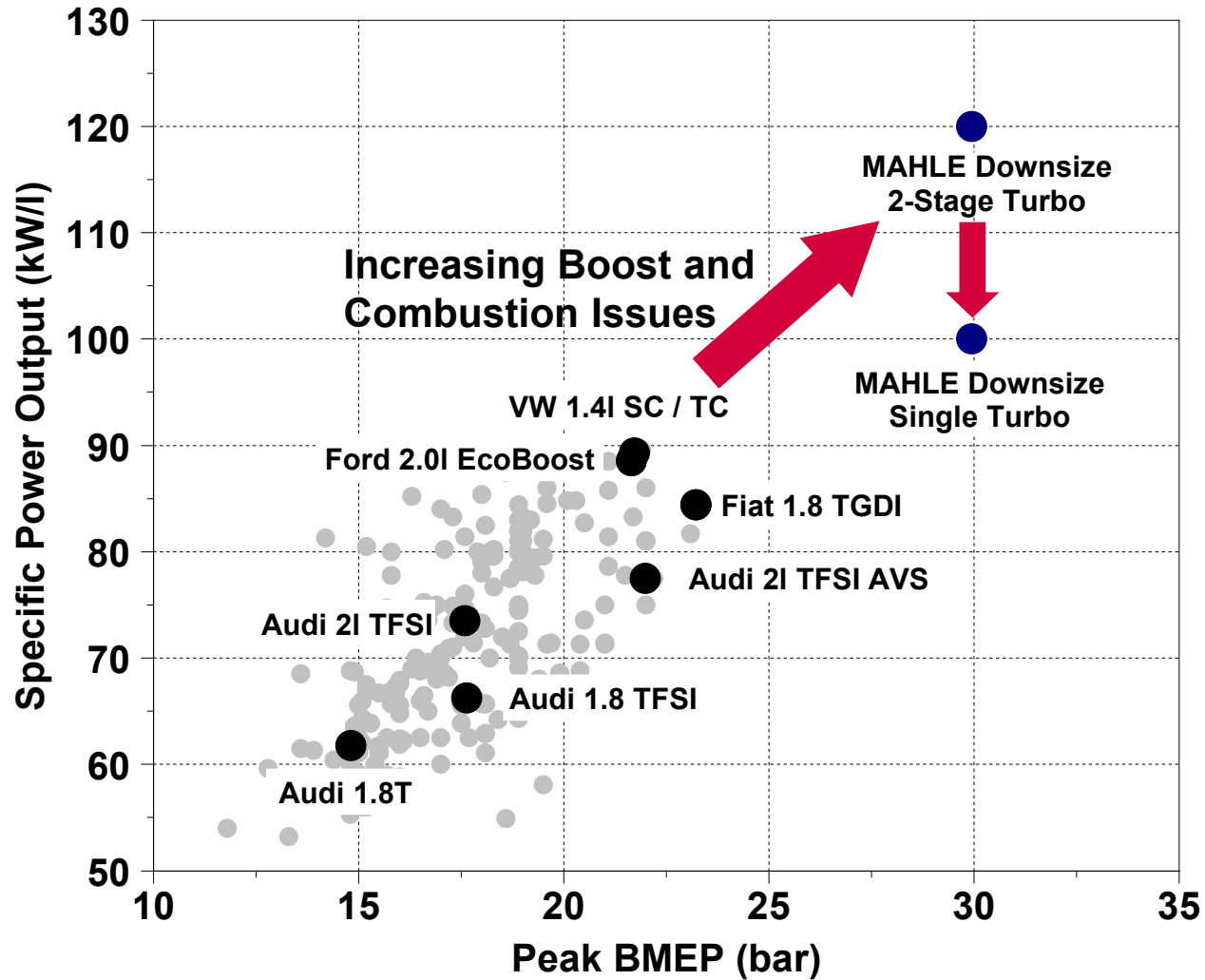
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Gasoline Engine Downsizing

How low can you go?

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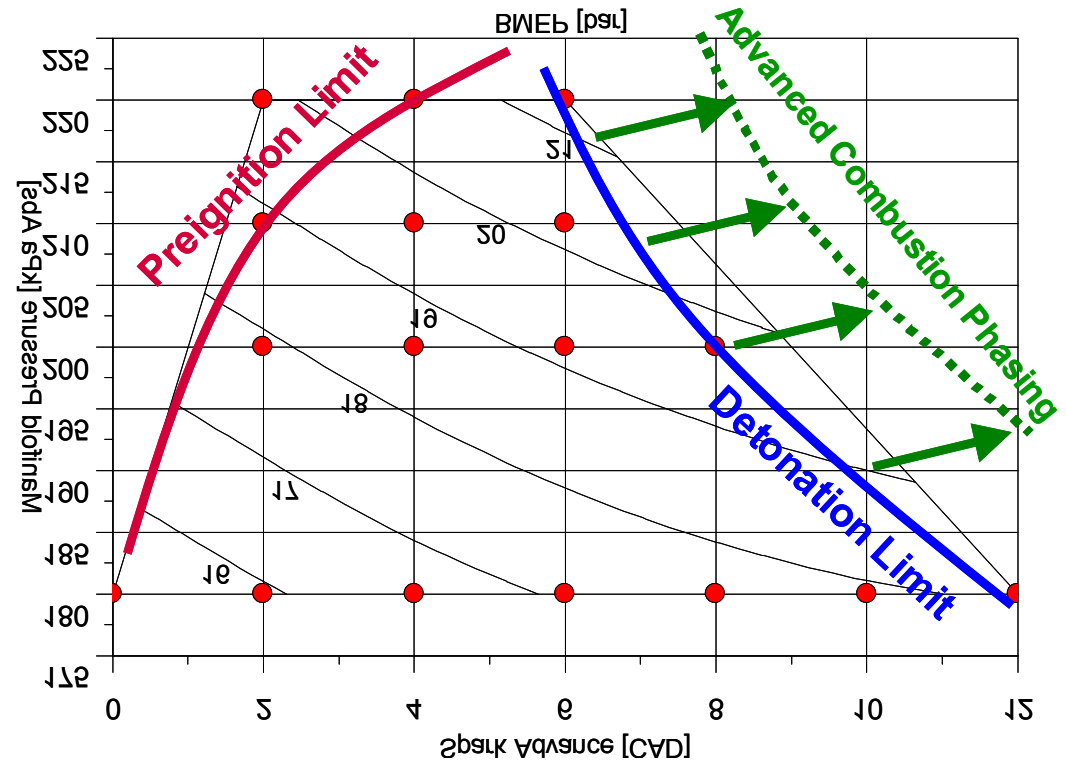
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Downsizing: Unstable Combustion Issues

- Combustion phasing can be retarded due to detonation, which leads to high exhaust valve opening pressures
- Advancing combustion phasing allows higher boost and torque

To achieve this:

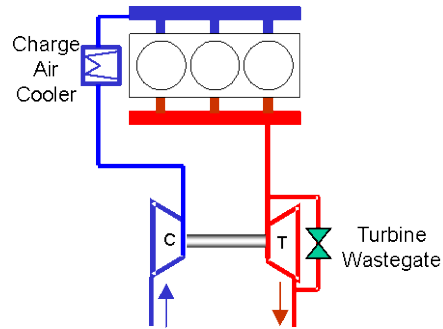
- Turbocharger selection has a strong influence
- Reduced duration exhaust cam has a positive effect
- Optimized exhaust manifold design reduces trapped residuals
- Careful fuel selection
- Combustion chamber is shape-optimized
- Oil consumption is minimized



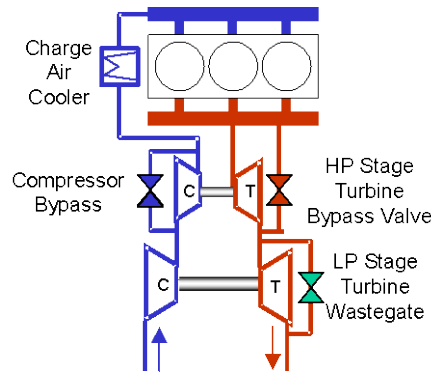
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Boosting Systems

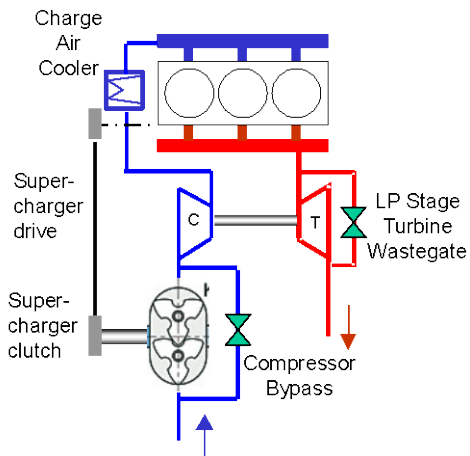
A) Single Turbocharger



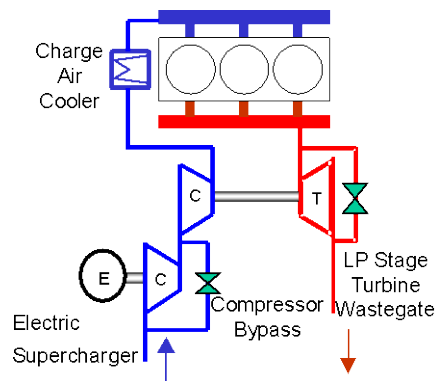
B) 2-Stage Turbocharger



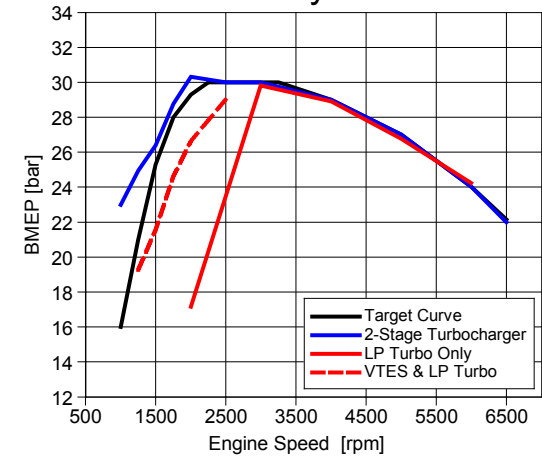
C) Supercharger & Turbocharger



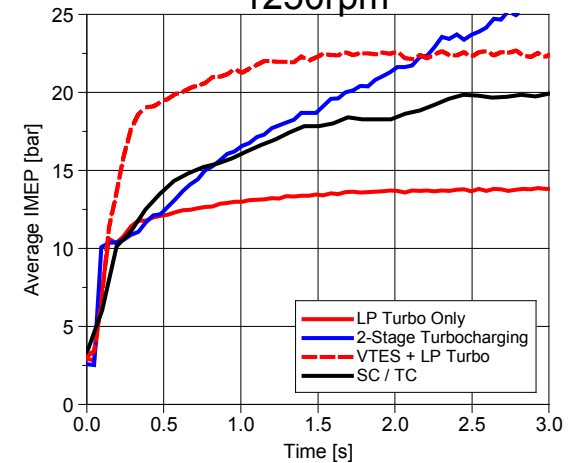
D) Electric Supercharger & Turbocharger



Steady State

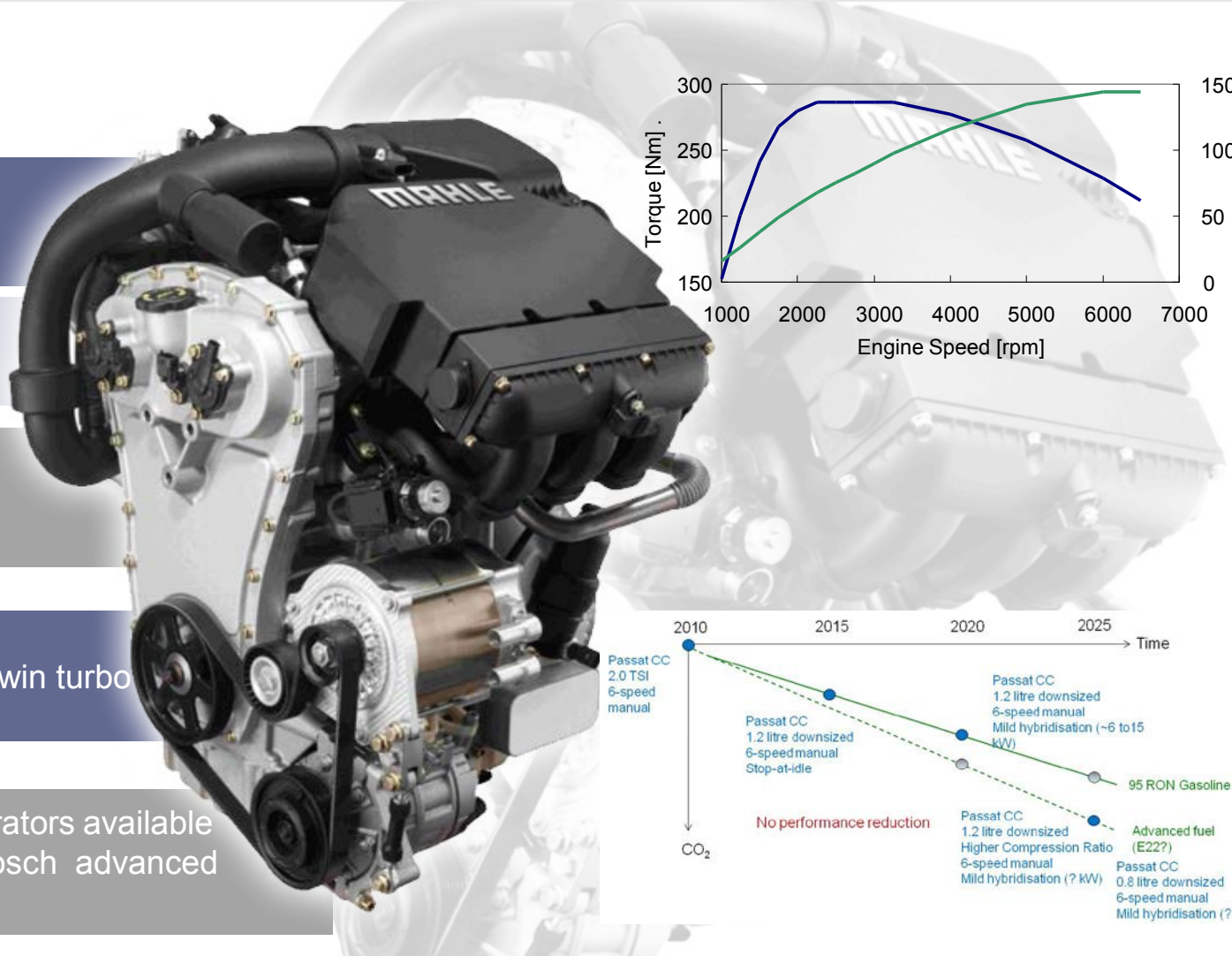


Transient Load Step at 1250rpm



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Next Generation MAHLE Downsizing Engine



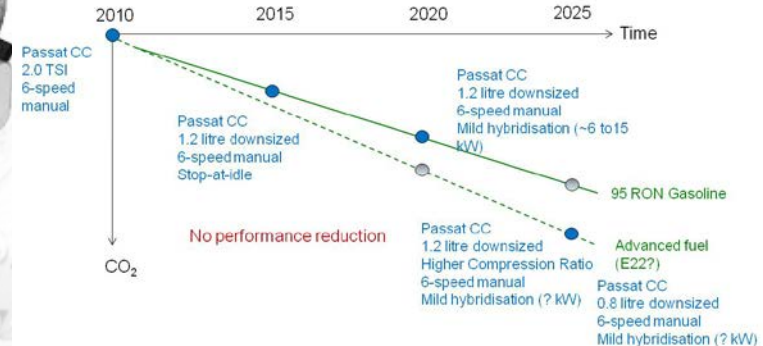
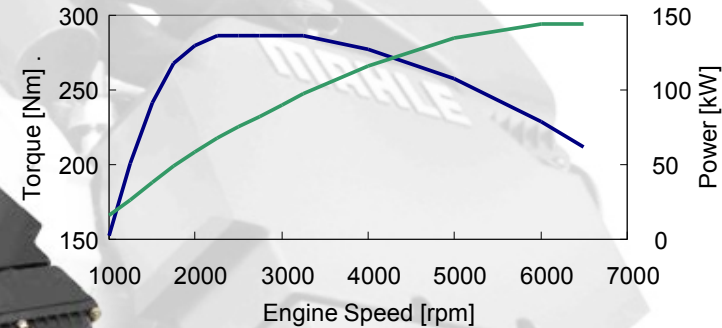
State-of-the-art clean-sheet design for 50% downsized concept DI-3 1.2 L

- 30 bar BMEP +
- 100 kW/l Single Stage Turbo
- 120kW/l Twin Turbo

Up to 30% fuel economy improvement possible with similar performance levels

Excellent low speed torque and transient response with twin turbo configuration

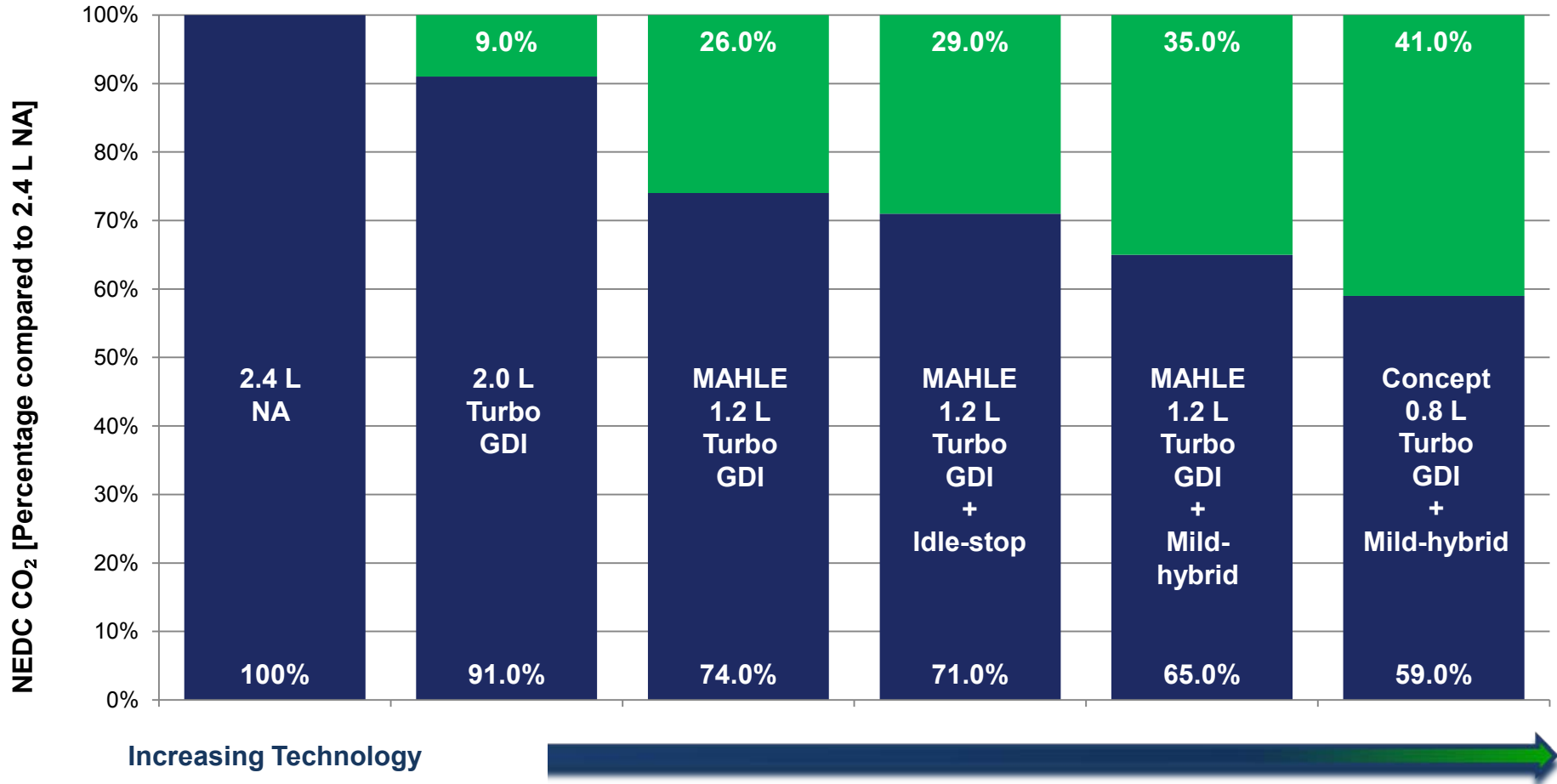
Vehicle and engine demonstrators available
Developed with MAHLE & Bosch advanced components



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Downsizing Electrification Path

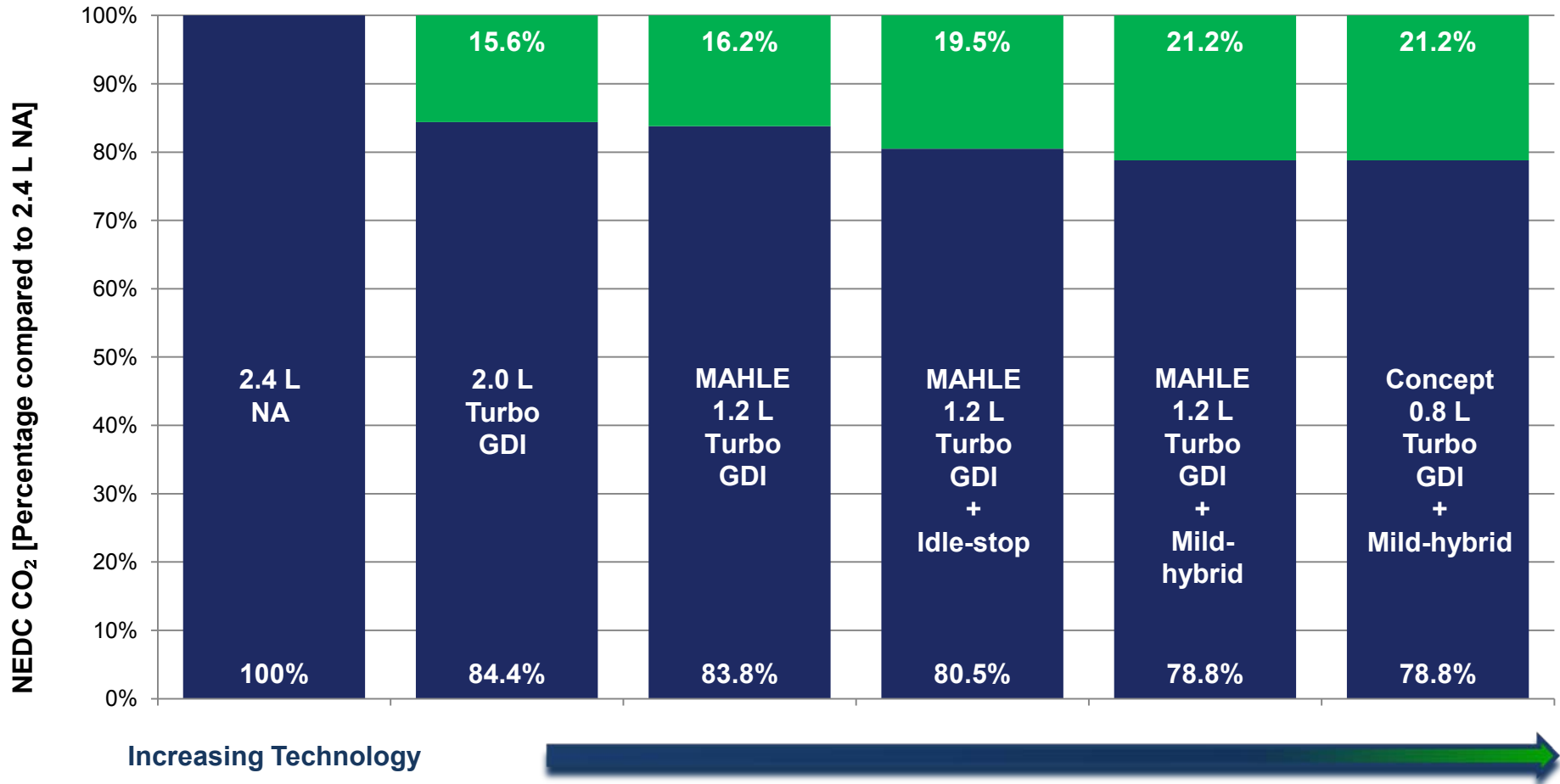
NEDC



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Downsizing Electrification Path

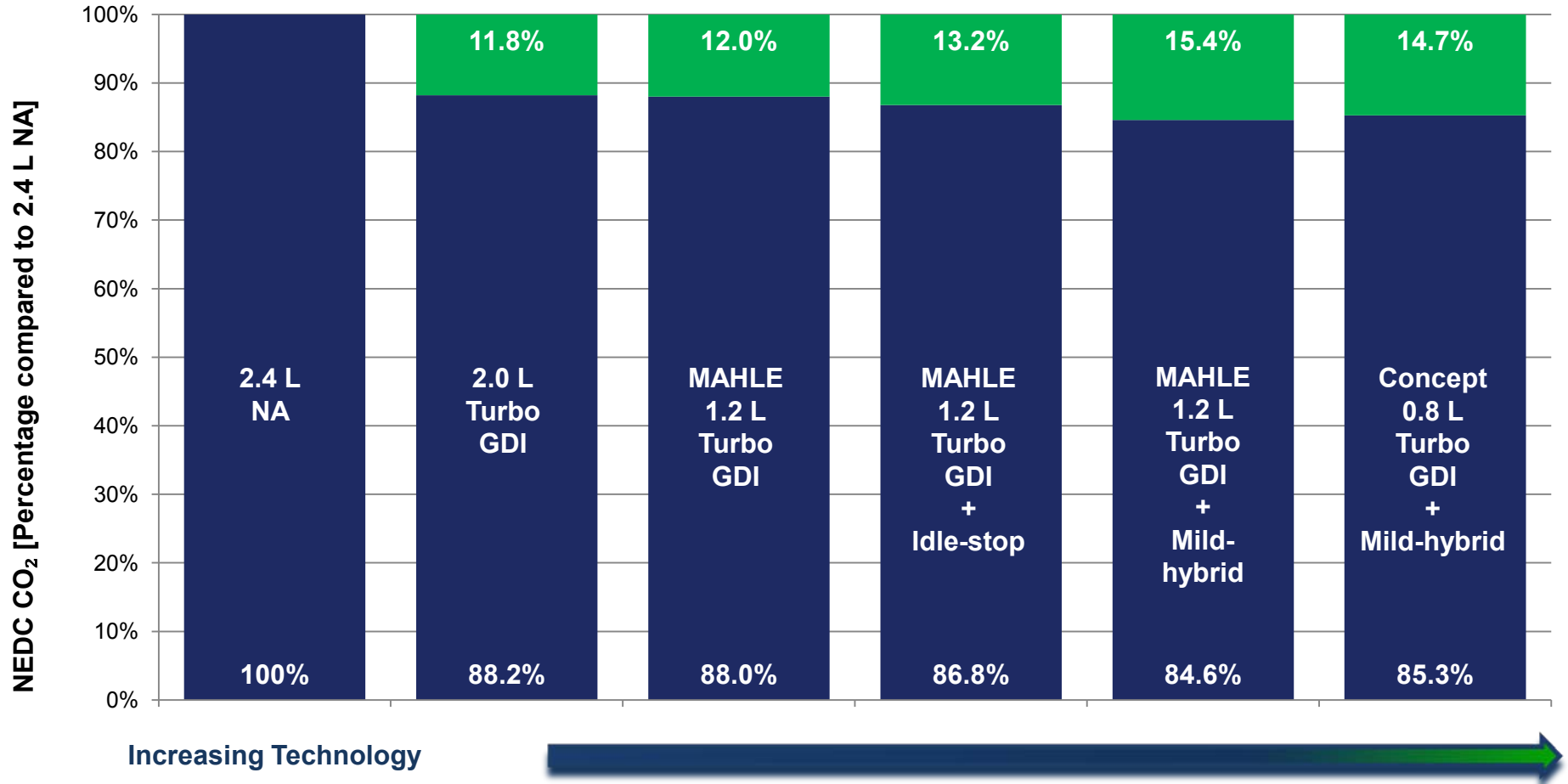
ARTEMIS



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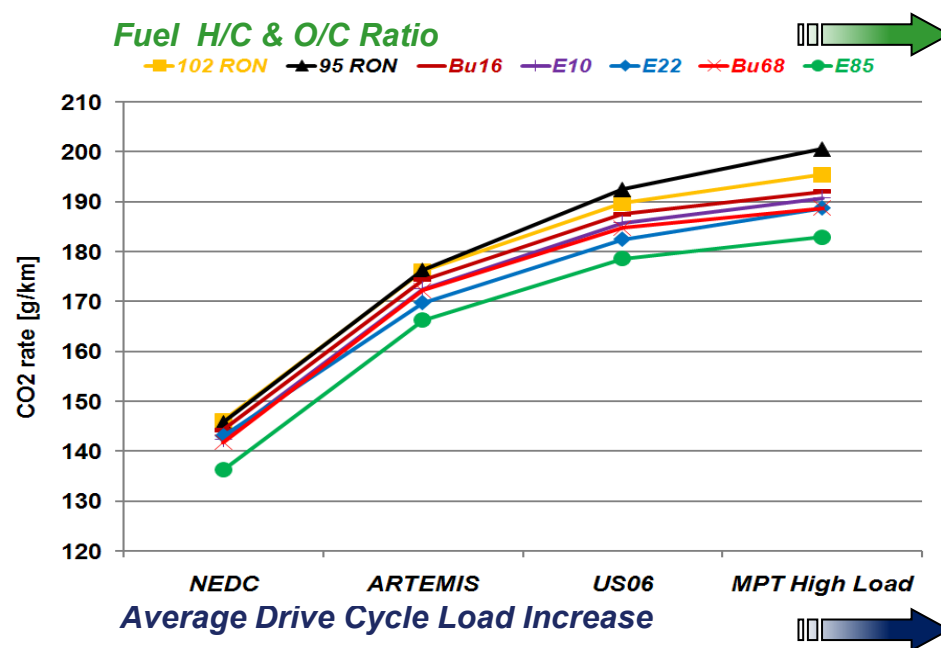
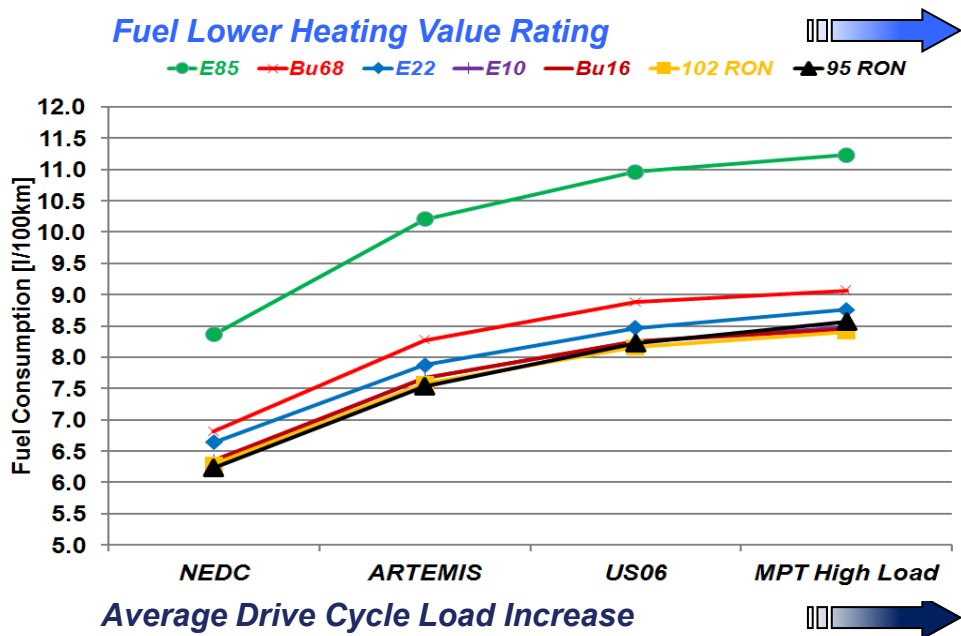
Downsizing Electrification Path

US06



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Fuel Effects: 1.2l Downsizing + Mild Hybrid

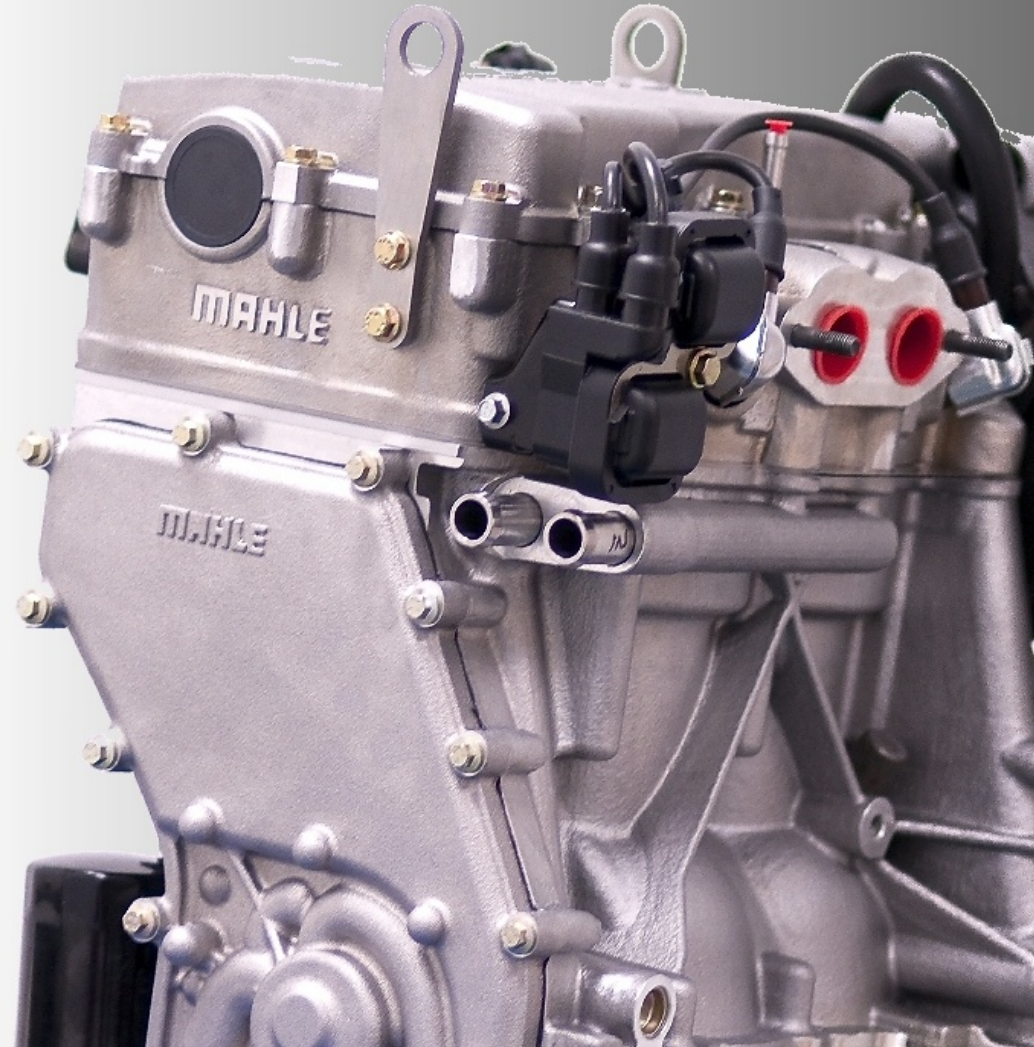


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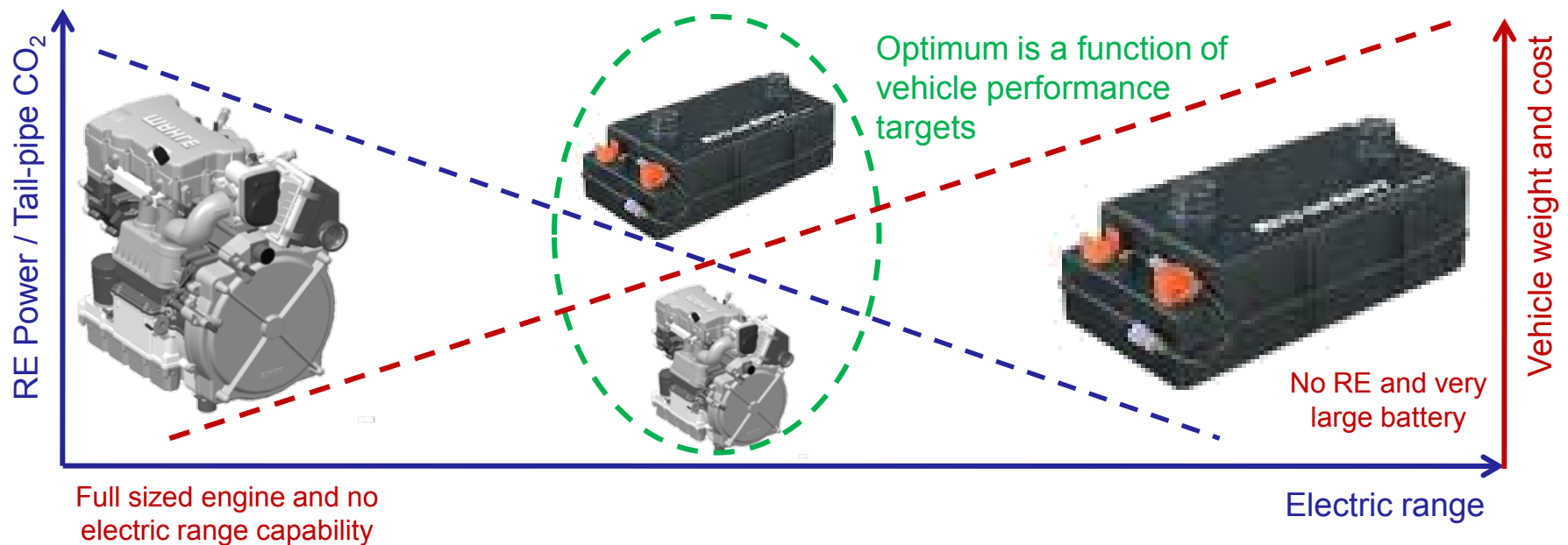


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Introduction - E-REV Concept Description

Extended-Range Electric Vehicle (E-REV)

- Vehicle propelled purely by electric motors with small battery pack (c.f. EV)
 - Typical range of 20 to 100 km using only battery power
 - Battery pack can be charged from residential electrical outlet
- On-board electrical generator (IC Engine or Fuel Cell) can also be used to re-charge battery on the move



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Range Extender - Conflicting Targets - Range / Cost / Weight



■ Baseline – Short Range Electric Vehicle (EV)

- Compact Class
- Range 80 km
- Battery Capacity 15 kWh

Baseline EV



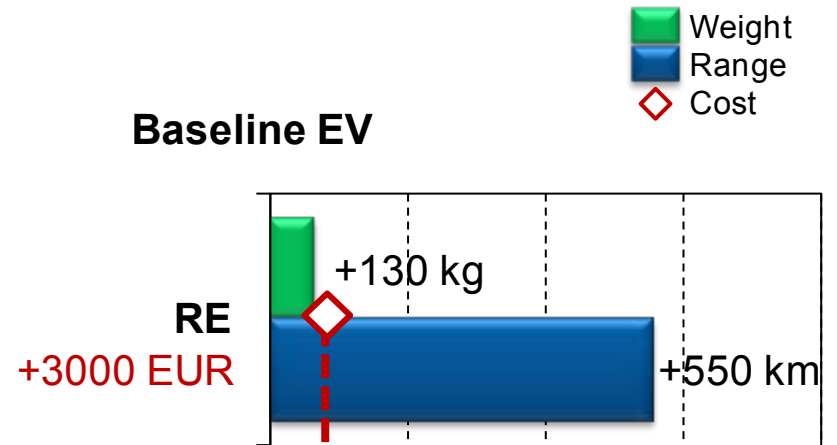
* Battery cost: 500 EUR/kWh

■ Baseline – Short Range Electric Vehicle (EV)

- Compact Class
- Range 80 km
- Battery Capacity 15 kWh

■ Range Extender (RE) (inc. Generator, 40 l Tank, Controller, ...)

- Weight: +130 kg
- Cost: +3000 EUR
- Range: +550 km



* Battery cost: 500 EUR/kWh

■ **Baseline – Short Range Electric Vehicle (EV)**

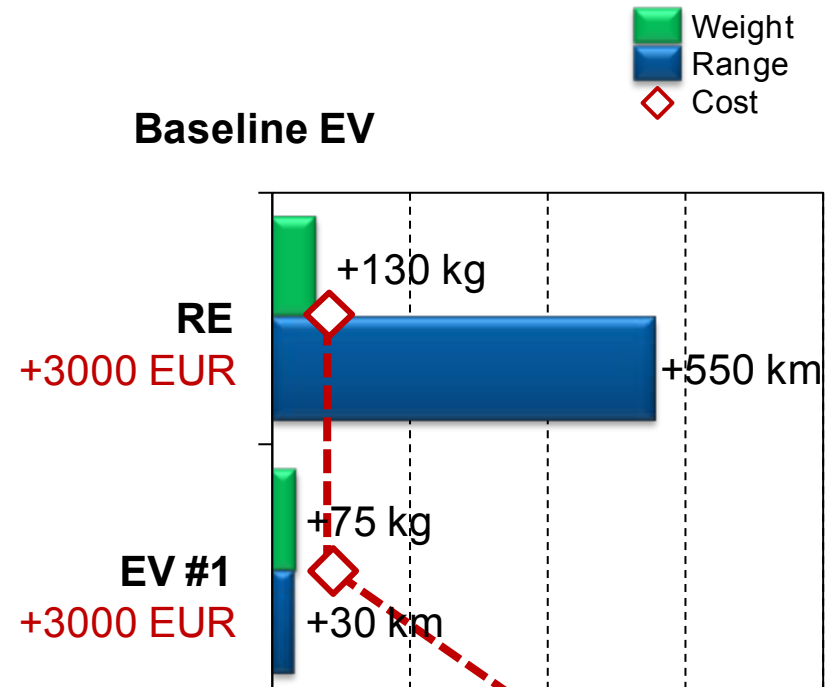
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■ **Range Extender (RE)
(inc. Generator, 40 l Tank, Controller, ...)**

- Weight: +130 kg
- Cost: +3000 EUR
- Range: +550 km

■ **Electric Vehicle #1 (identical additional cost)**

- Weight: +75 kg
- Range: +30 km



* Battery cost: 500 EUR/kWh

■ **Baseline – Short Range Electric Vehicle (EV)**

- Compact Class
- Range 80 km
- Battery Capacity 15 kWh

■ **Range Extender (RE)
(inc. Generator, 40 l Tank, Controller, ...)**

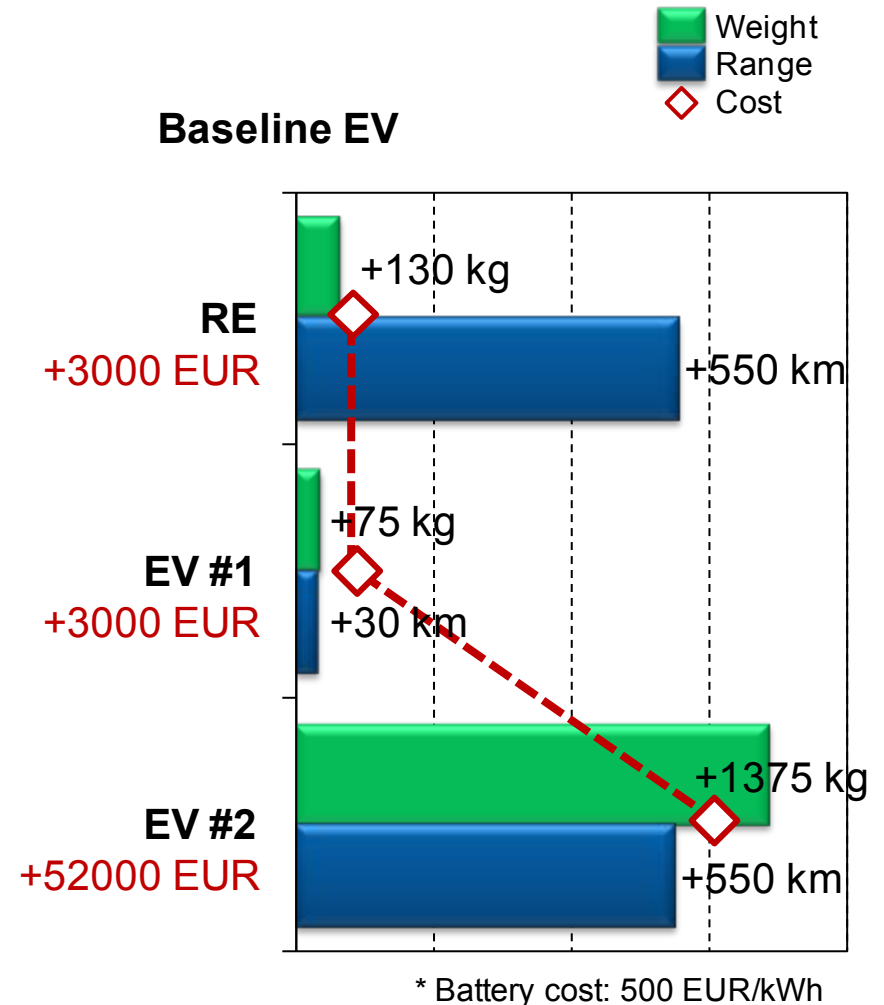
- Weight: +130 kg
- Cost: +3000 EUR
- Range: +550 km

■ **Electric Vehicle #1 (identical additional cost)**

- Weight: +75 kg
- Range: +30 km

■ **Electric Vehicle #2 (identical range)**

- Weight: +1375 kg
- Cost: +52000 EUR



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MAHLE Range Extender Concept

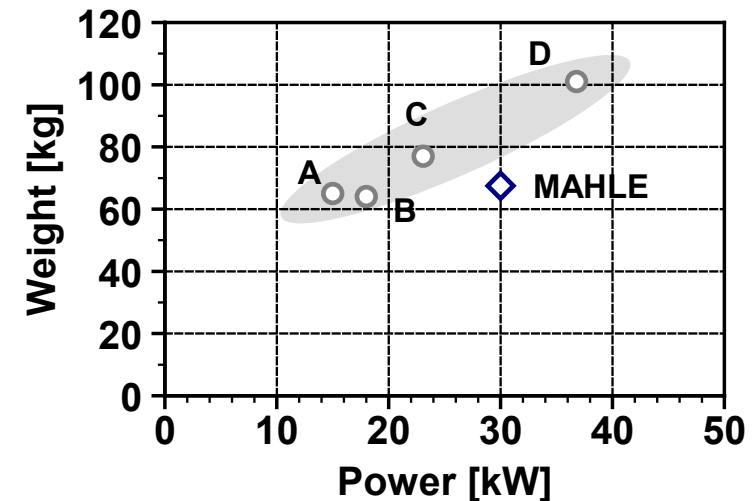
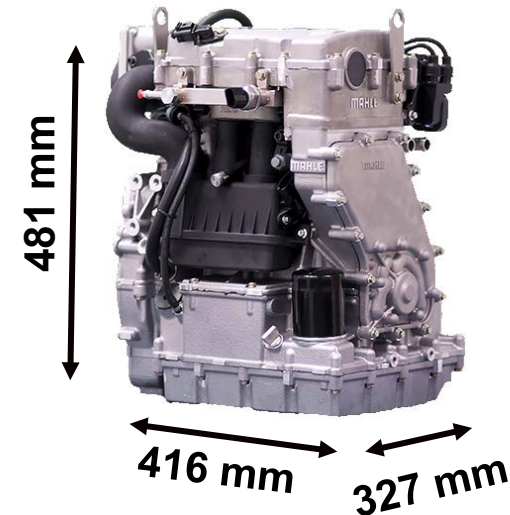


MAHLE Range Extender

- Two-cylinder Inline, 4-Stroke Gasoline
- 900 cm³ Swept Volume
- 30 kW Peak Power at 4000rpm
- Port-fuel Injection ($\lambda = 1$)
- 180°/540° Firing Order
- Flexible Installation

Specific Power

- Power 30 kW
- Weight (incl. Generator) 70 kg
- ➔ Power to Weight Ratio 2.3 kg/kW
(Competitors: 2.75 to 4.3 kg/kW)



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Summary



- There is a role for IC engines in future energy use!
- We will see an increase in downsizing and electrification in light duty applications
- Downsizing needs further technology development, especially in combustion and boosting systems
- Higher alcohol content fuels will support the trend in downsizing via increased octane levels
- Range extenders are very effective energy providers, further efficiency steps can be taken, but cost is a more significant factor

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Thank you for your interest!

