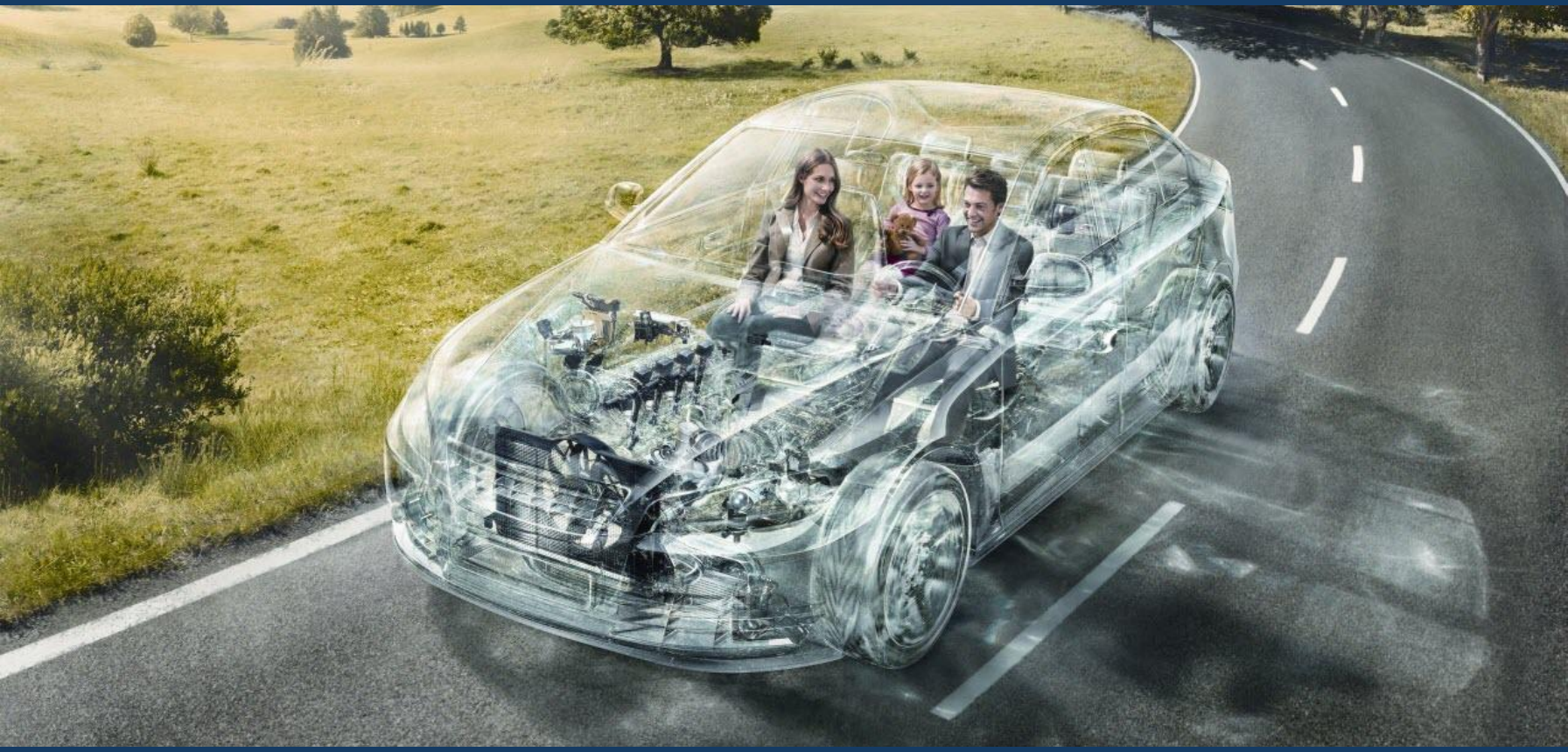
DEER 2012 – Bosch Powertrain Technologies



Hakan Yilmaz

Chief Engineer – Gasoline Systems
Robert Bosch, North America

Gasoline Systems

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DEER 2012 – Bosch Powertrain Technologies

- Bosch Automotive Sector Introduction
- Regulations and Market Trends
- Electrification Overview
- ICE Technologies
- DOE / Bosch Collaboration
- Conclusion

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Bosch: Automotive Technology business sector

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Divisions of Automotive Technology

Gasoline Systems
Injection & Ignition for Gasoline & Alternative Fuels, Air Management, Transmission Controls and Components, Electrification, Controls and Sensors, System and Application Engineering

Diesel Systems
Diesel fuel injection system, Exhaust-gas treatment, Start system

Chassis Systems Brakes
Brake booster, Disc-brake calipers

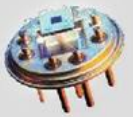
Chassis Systems Control
ABS, ESP

Electrical Drives
Actuation, thermal and wiper systems, steering

Starter Motors and Generators
Products for commercial vehicles, starter motors and generators

Car Multimedia
Navigation system, Car radio, indication instrument

Automotive Electronics
Sensors, Electronic Control Units, Semiconductor, Airbag-control



Automotive Aftermarket
Automobile spare parts, Accessories, test engineering

ZF Lenksysteme GmbH (50 % Bosch)
Steering system for passenger cars and commercial vehicles (including steering pumps and columns)

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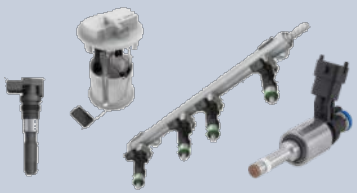
Bosch Gasoline Systems Overview

Gasoline Systems – Driving Powertrain

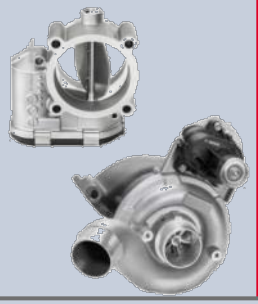
Powertrain Domains

System Integration

Injection & Ignition for Gasoline & Alternative Fuels



Air Management

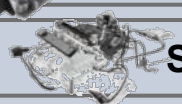


Electrification

Transmission Control & Components

Controls and Sensors

System and Application Engineering



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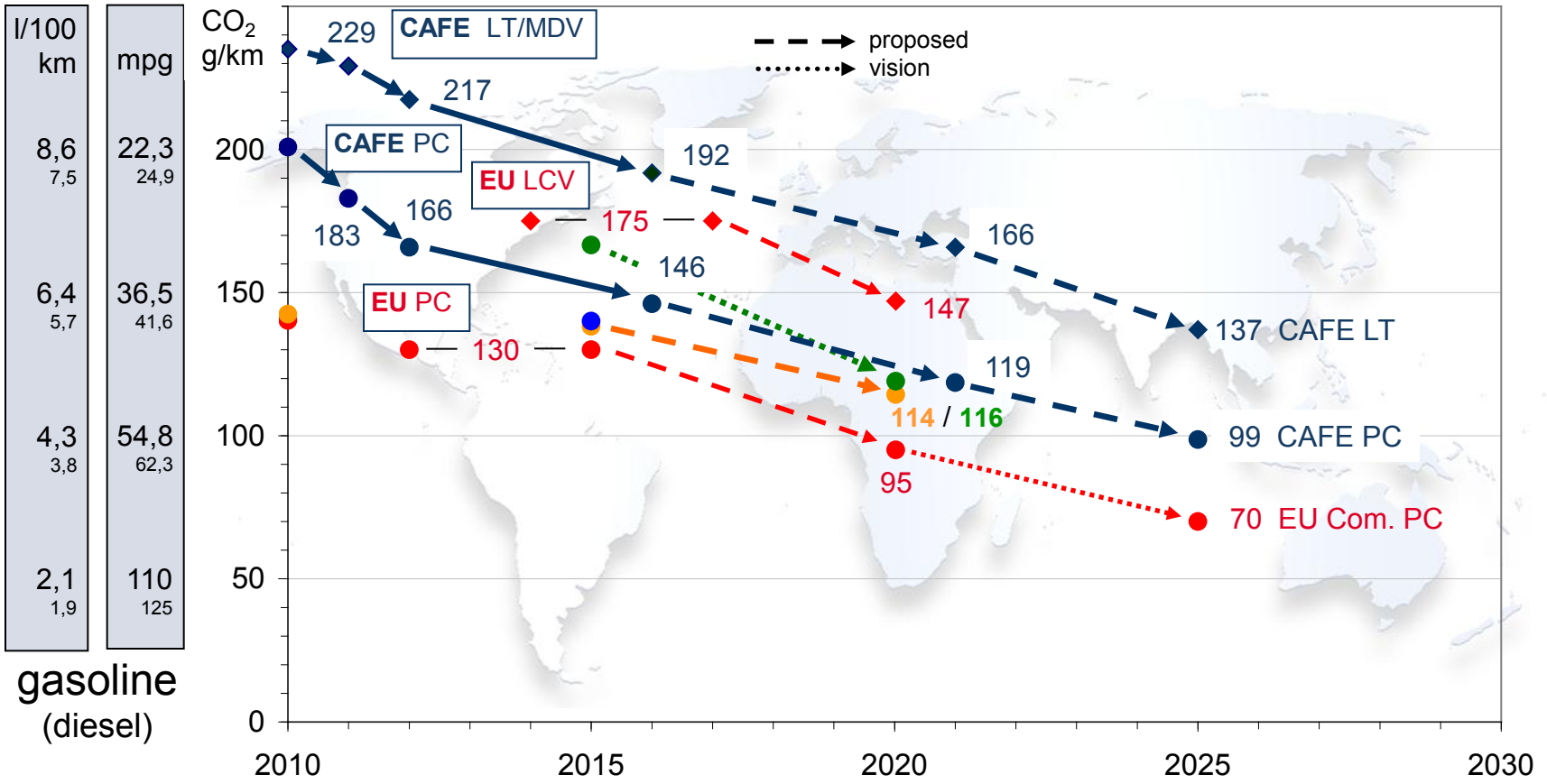
Legislation & Commitments EU US CAFE Japan China Korea



CAFE = Corporate Average Fuel Economy PC = Pass. Cars LT / LDT = Light Trucks (pick-ups, vans, SUVs) MD(P)V = Medium Duty (Pass.) Vehicles LCV Light Commercial Vehicles

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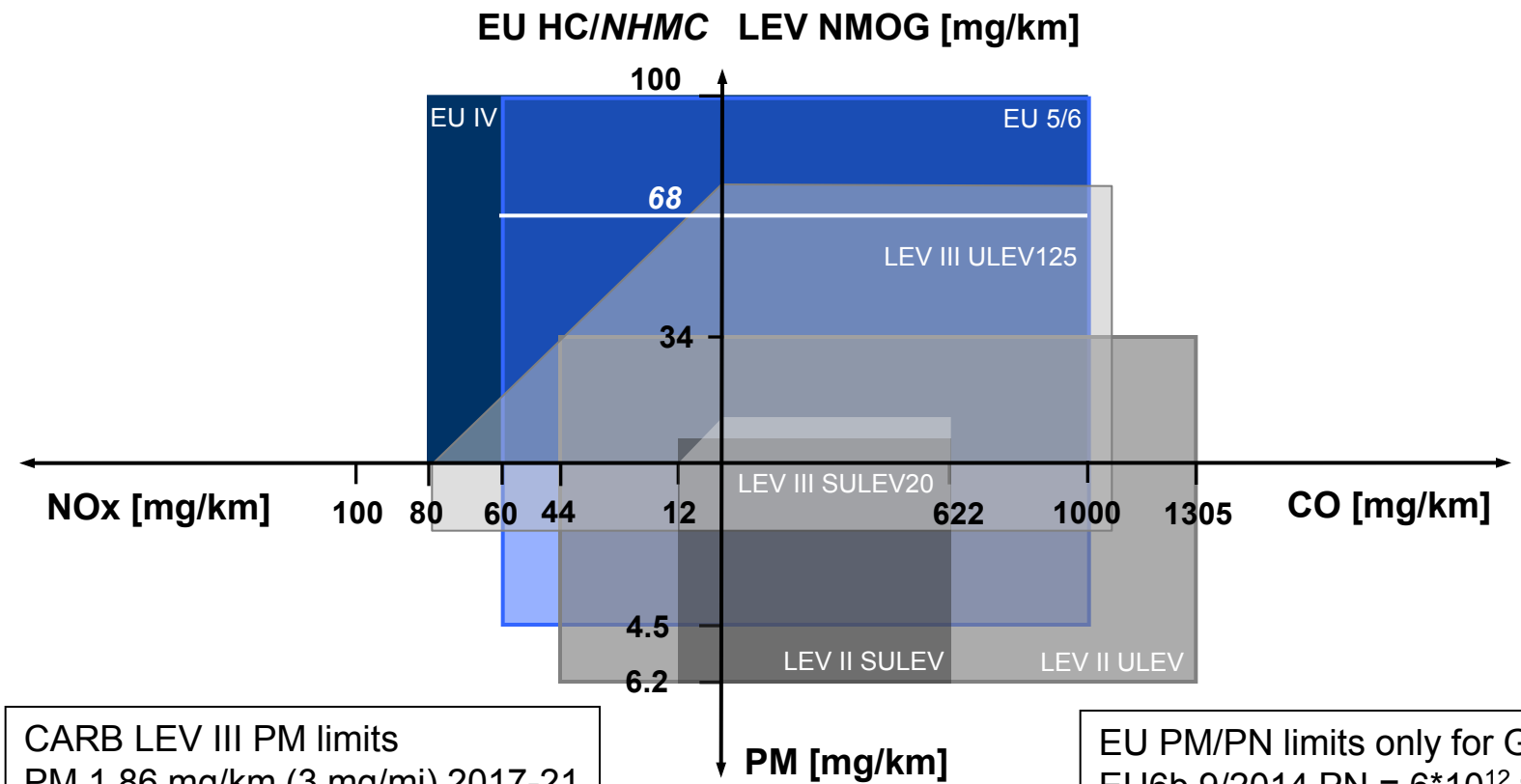
Limit values for SI PC EU IV-6 and CARB LEV II/III



CARB LEV III PM limits
PM 1.86 mg/km (3 mg/mi) 2017-21
PM 0.62 mg/km (1 mg/mi) 2025-28

EU PM/PN limits only for GDI
EU6b 9/2014 PN = $6*10^{12}$ #/km
EU6c 9/2017 PN = $6*10^{11}$ #/km

EU and CARB different test cycles: NEDC resp. FTP75

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Key factors influencing powertrain development

Development of key factors from 2015 to 2020

legislation	**FE legislation**	Reduction 25% / 5years US CAFE: 54.5 mpg in 2025
	NOx legislation	SCR/NSC in all Diesel powertrains (2015: US)
end customer	**EV incentive per vehicle**	Max. $7500[1)] decreasing to $1000 ($3 bn p.a. global 2020)
	Battery price	Decrease from $500kWh to $250/kWh EV with battery leasing increasing from 10% to 30%
	Oil price (inflation adjusted[2)])	Steady increase from 100 to 150 USD/bbl
	Annual mileage	Slow decrease (~10%)
	EV infrastructure	Slow build-up, 2020 major city centers covered
	ICE optimization	OEMs/Suppliers continue optimization until 2020
	Soft Factors	Additional willingness to pay for Green Image, E-Motion, Performance

1) Incentive paid in 2015, decreasing to $0 until 2025

2) 200 USD/bl in 2020 means 260 USD/bl nominal (at ~2% inflation)

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* CO2 limit for PC in 2017, light trucks 200 g/km

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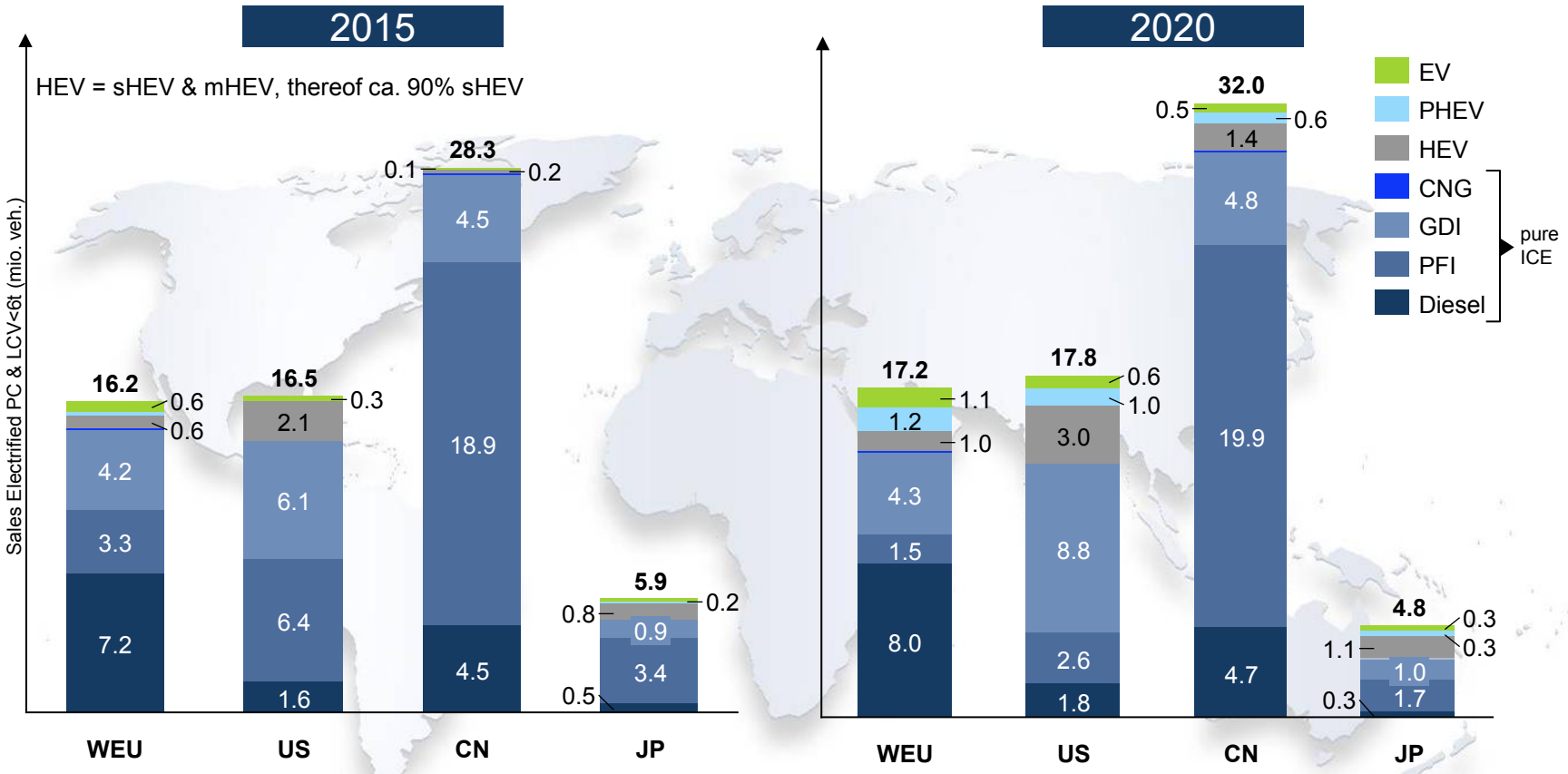
Market Development per Powertrain Type – Sales *



The conventional combustion engine keeps dominating the powertrain the next 15-20 years.
Broad introduction of electrification hindered by system cost and unattractive solutions.

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WEU: EU15 + NO + CH, w/o LU
* Prognosis RB

Sales PC & LCV<6t (mio. vehicles) *

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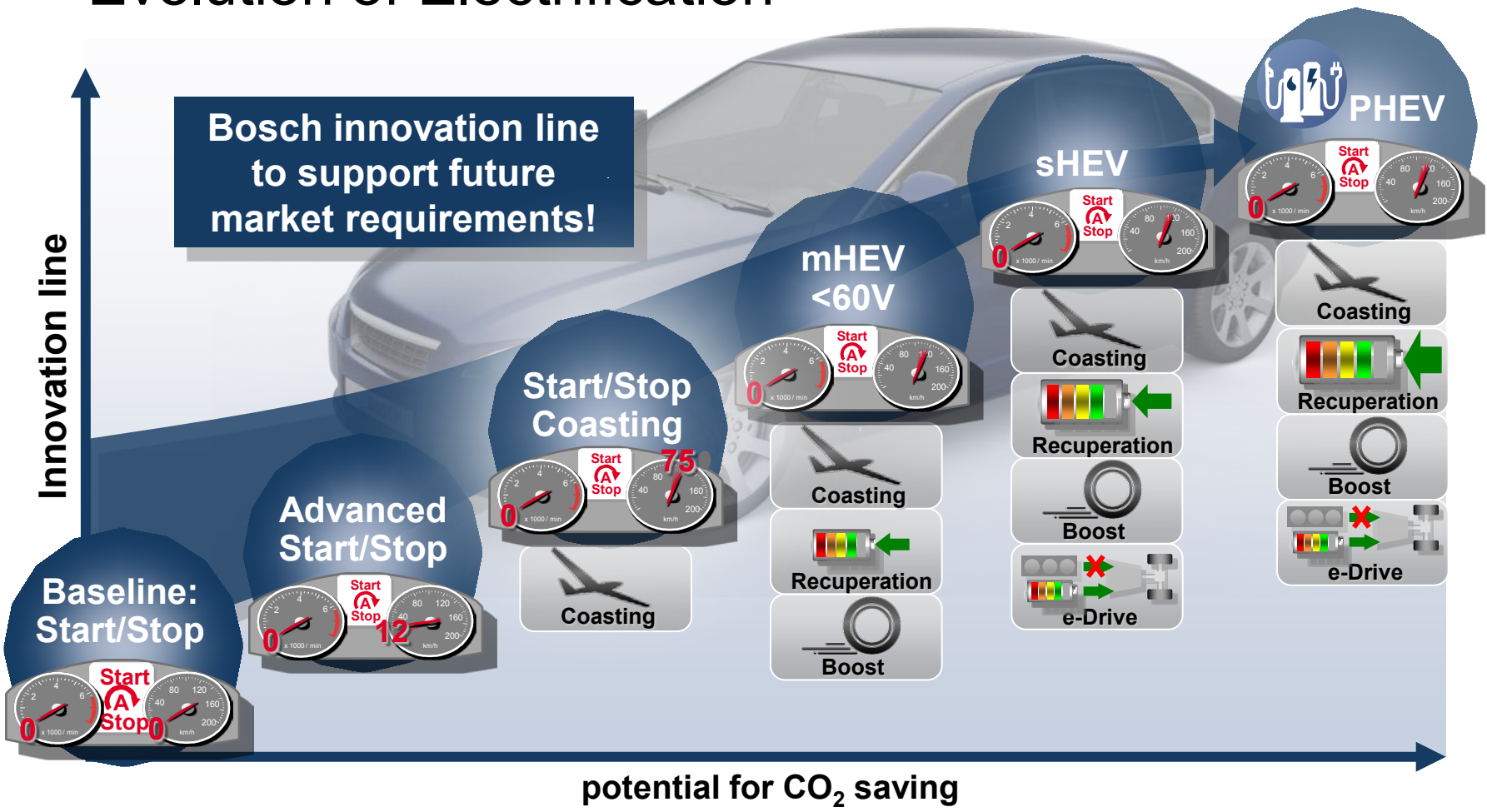
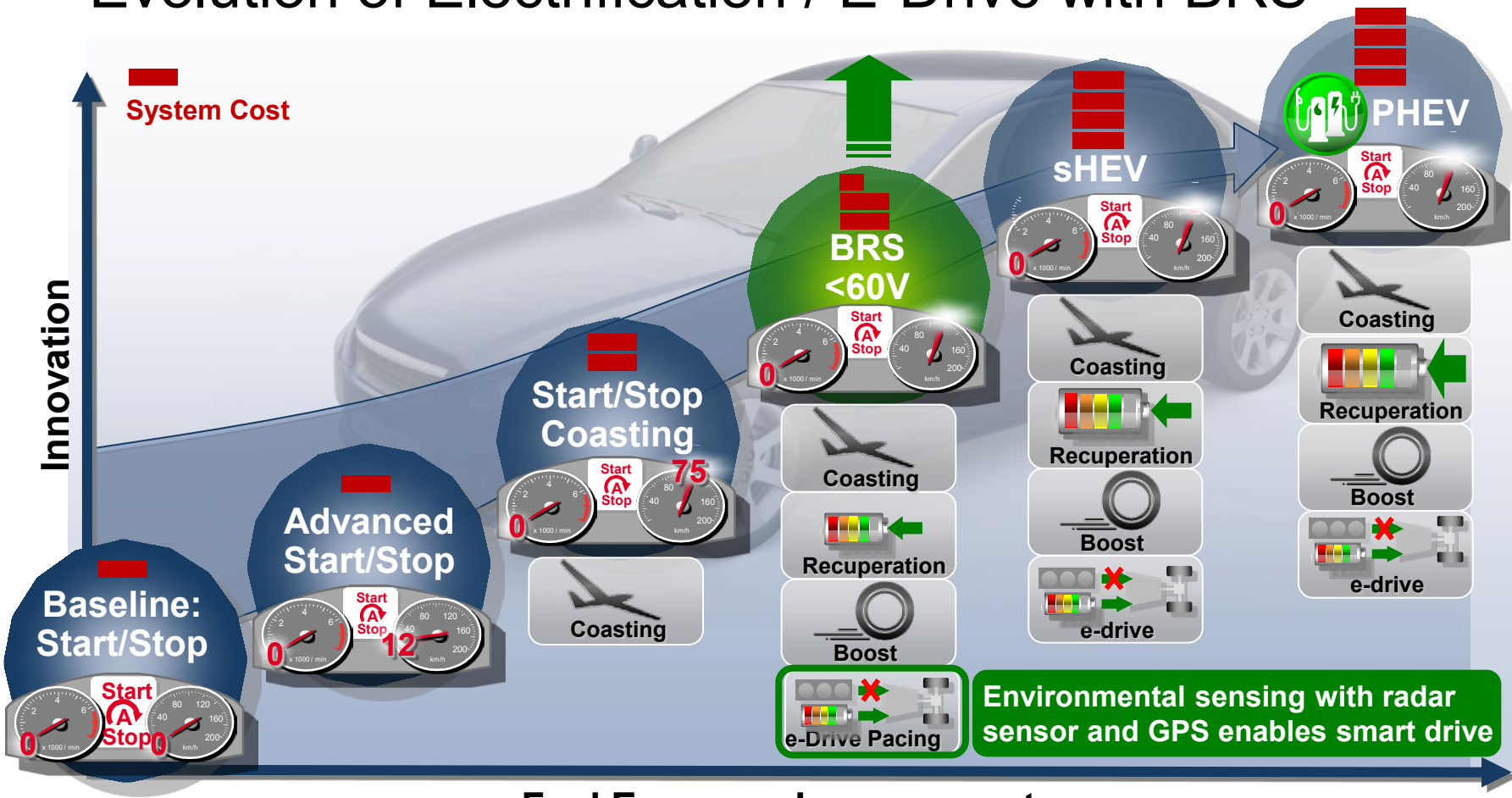
Evolution of Electrification



Evolution of Electrification / E-Drive with BRS



BRS: Boost Recuperation System - sHEV: Strong Hybrid - PHEV: Plug-In Hybrid

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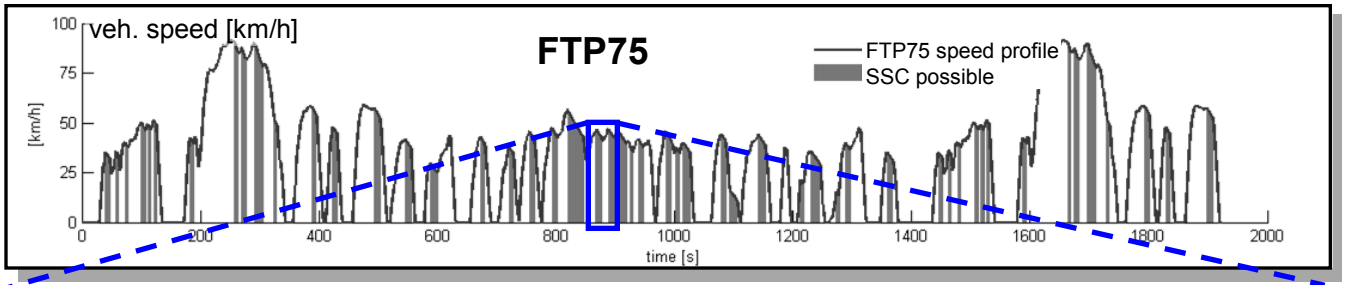
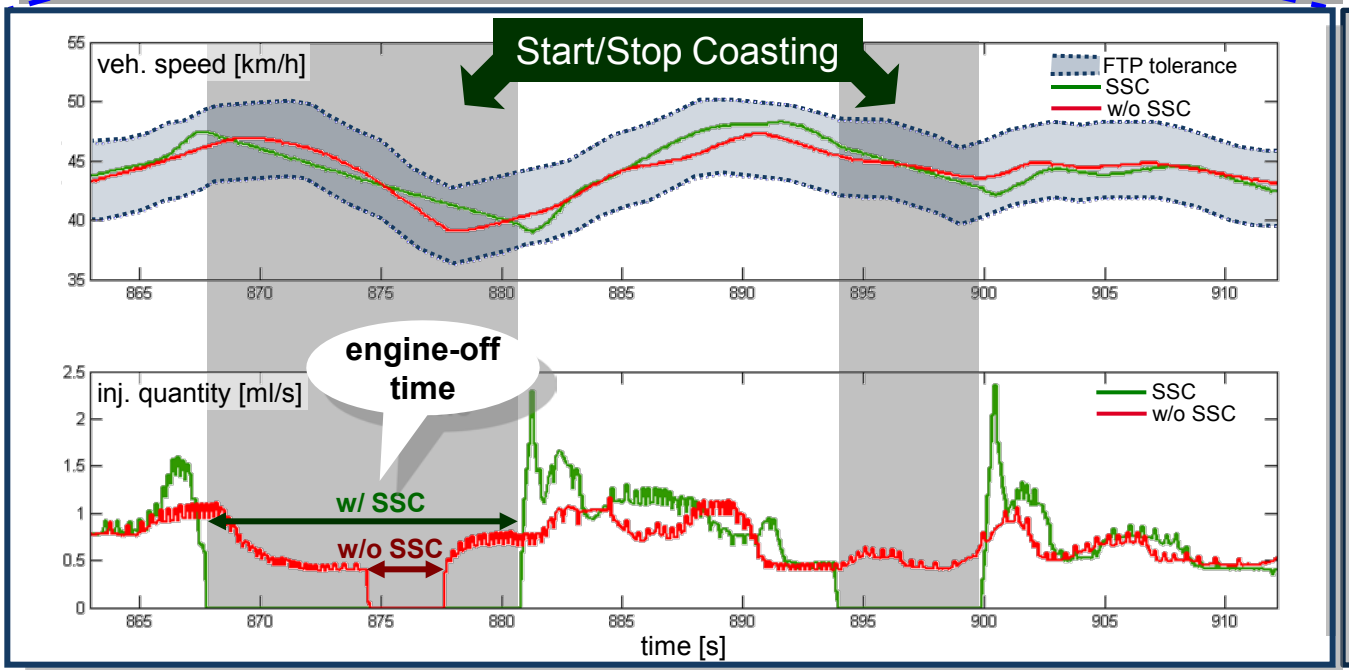
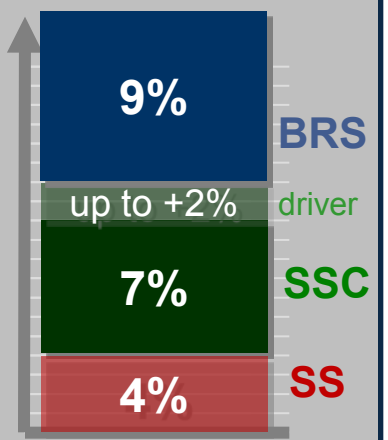
Coasting in FTP75 (measurement)





FTP75
20% SSC share

Fuel Economy Gain



Gasoline Systems

compact class, 1.4l DI T/C, 90kW, 7-gear

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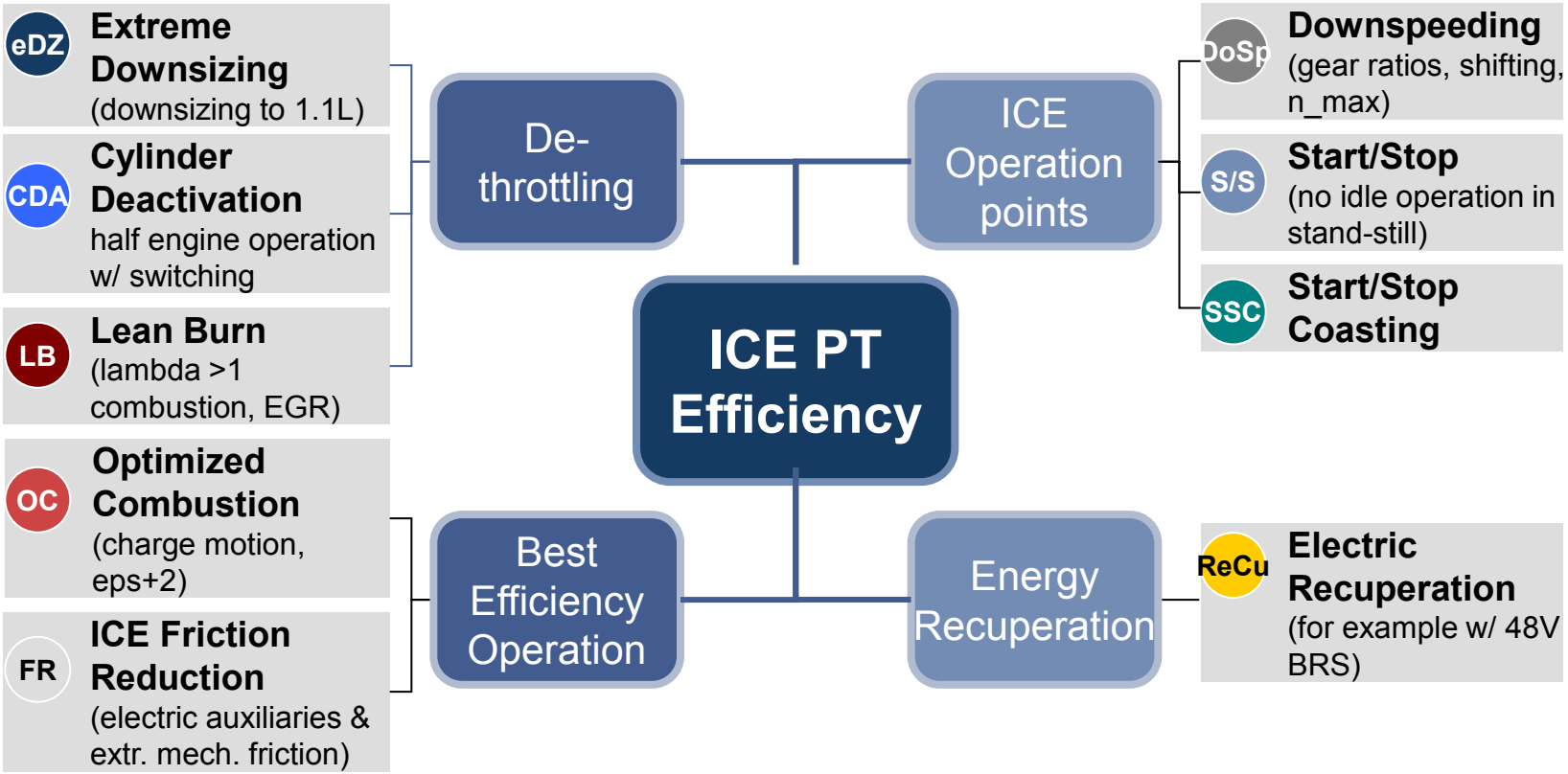
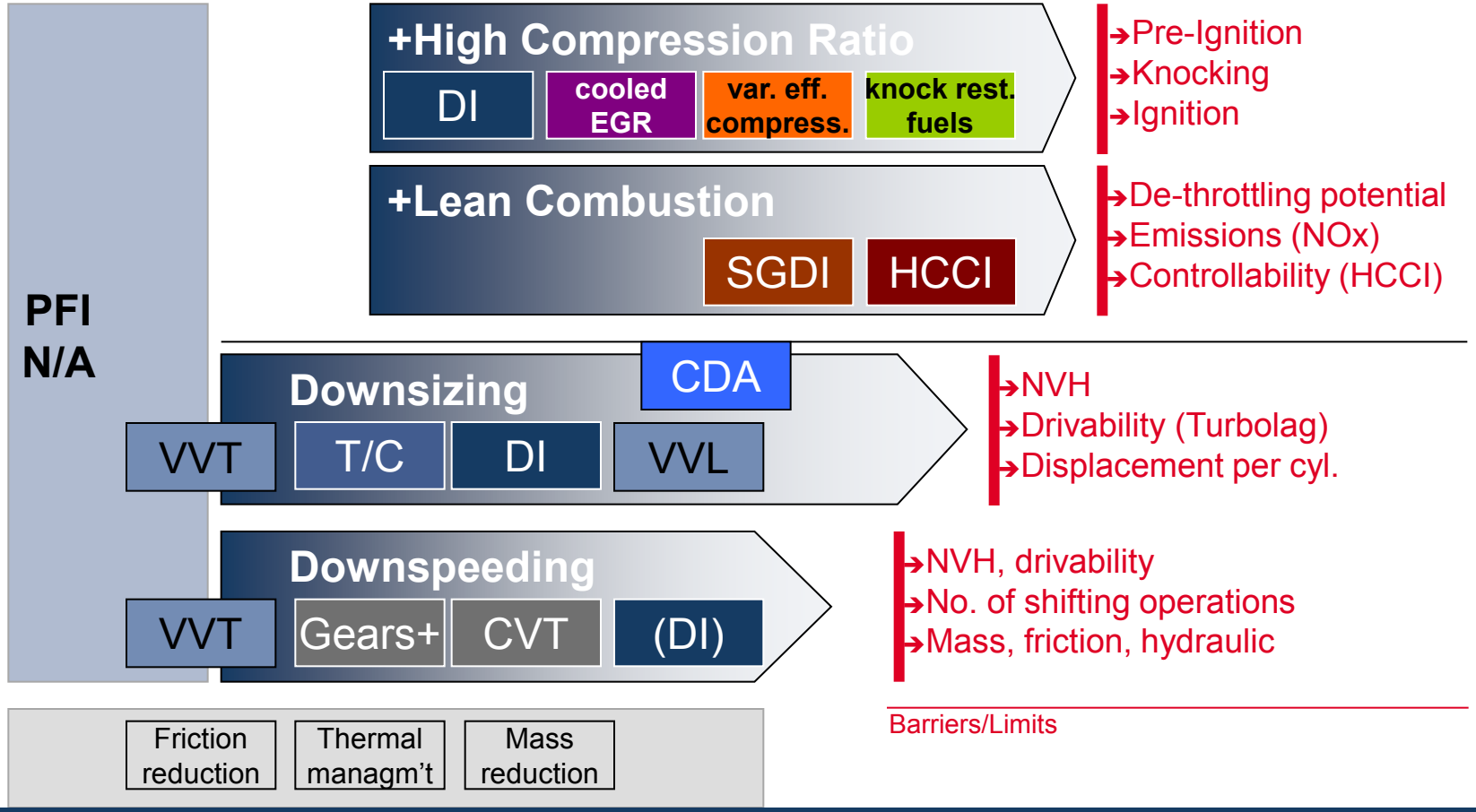
Gasoline engine measures for efficiency

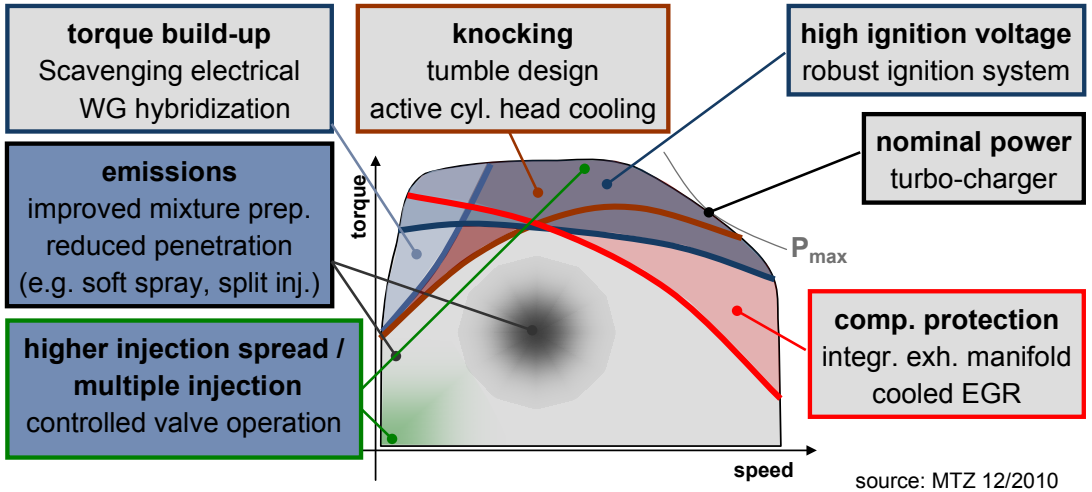


Gasoline Powertrain Fuel Economy Measures



Due to new test cycles and trends towards downsizing and downspeeding, high compression ratios become more important to reduce CO2.

Adv. Combustion Concepts: Challenge and Solution (Fuel Metering)



Downsizing / Displacement Reduction
- wetting (piston, valve)
- oil dilution
- mixture preparation (homogenization)
- spread (idling, catalyst heating, boosted full load)

Lean Burn Concepts (SGDI, HCCI)
- multiple injection >=3
- combustion concept robustness

Solution

Spray-Targeting
- variable hole design
- innovative manufac-turing technologies

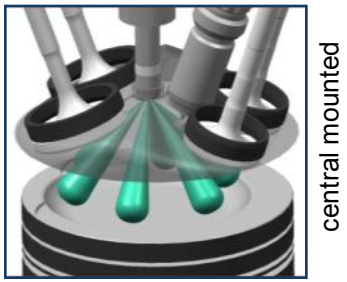
Mixture Preparation
- multiple injection

Adv. Injection Spread
- using ballistic range towards smallest quantities @ 200 bar

Injector Engineering and Advanced Manufacturing

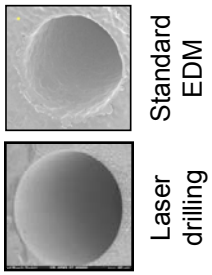
Spray-Targeting

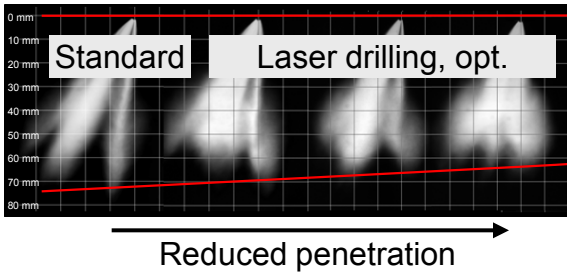
- Better mixture distribution
- Reduced wall wetting
- Optimize valve- spark plug interaction



Laser drilling of spray holes

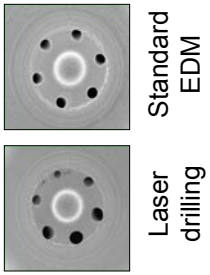
- Better spray break-up
- Increased air-entrainment
- Reduced penetration

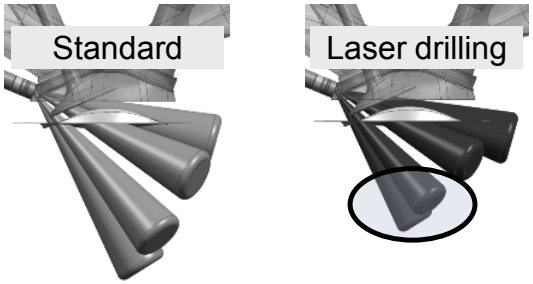




Individual spray beams

- Flexible hole design of single beams
- Improved homogenization
- Reduced wall wetting





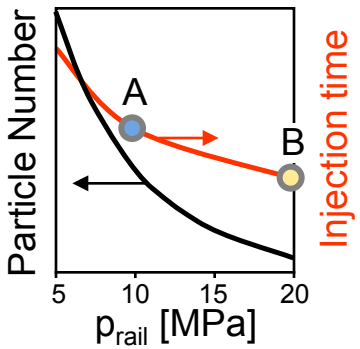
Small quantity injection w/ Controlled Valve Operation

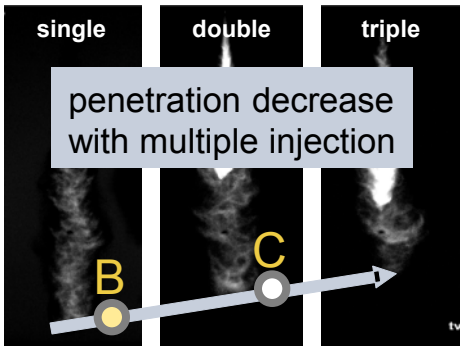
Pressure increase up to 200 bar:

➔ Improvement of mixture preparation with increased rail pressure

Multiple injection:

➔ Penetration reduction with twin- or multiple injection.

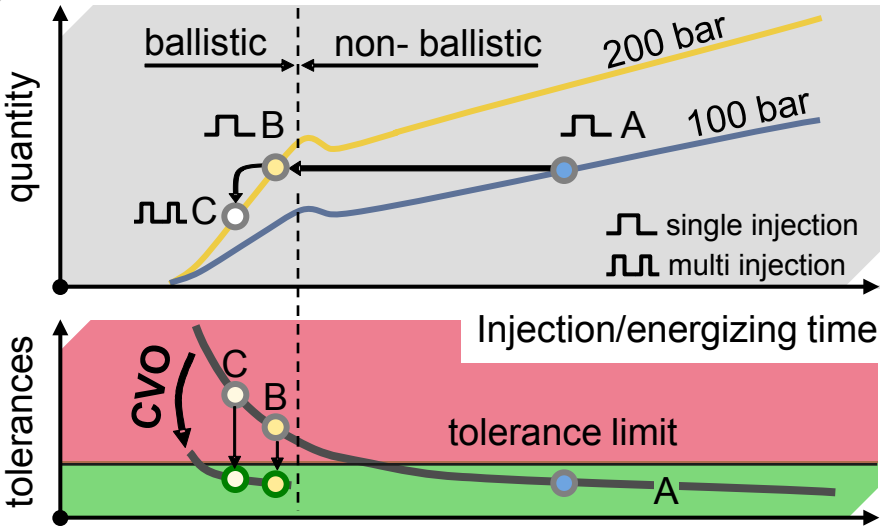




Tolerance requirements:

➔ Increasing quantity tolerances with decreasing energizing time

➔ Adjustment of q_{dyn} tolerances for short energizing times with CVO (*Controlled Valve Operation)



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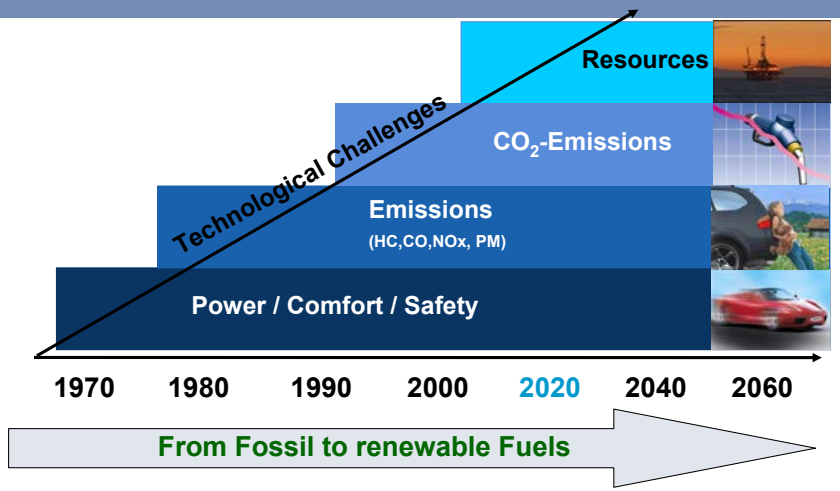
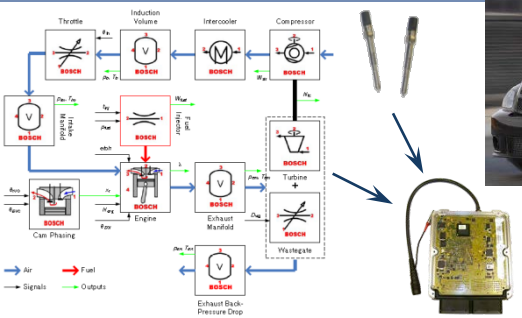
US DOE & Bosch Collaboration in Powertrain

Advanced FFV

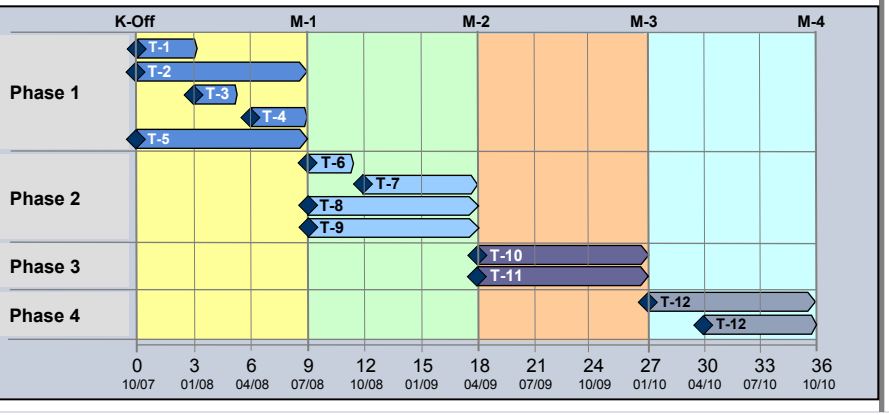


Project Targets



Targets: Fuel efficiency improvement with E85
ULEV level emissions with E85
Ethanol detection & combustion control

Timeline



Partners

- US Department of Energy
- Robert Bosch LLC
- Ricardo, Inc
- University of Michigan, Ann Arbor

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US DOE & Bosch Collaboration in Powertrain

Objective

- Design a Thermoelectric exhaust waste heat recovery system (Thermoelectric Generator) that will provide at least a **5% fuel efficiency improvement for a light-duty vehicle platform.**

Partners

GMZ ENERGY

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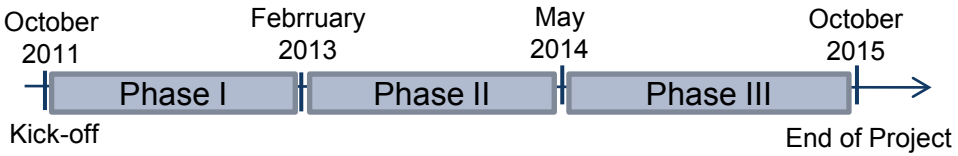
DEPARTMENT OF ENERGY · UNITED STATES OF AMERICA

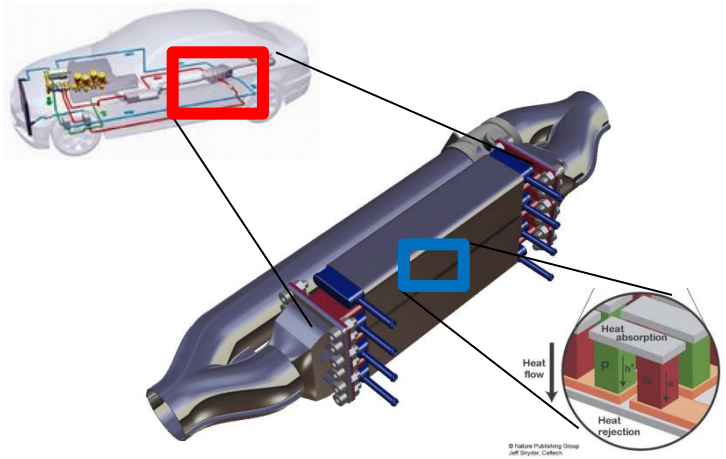
OAK RIDGE National Laboratory

Budget & Timeline

- Total Budget: $11.3 Million
- DOE, National Labs, Academia, Industry participation



Waste Heat Recovery



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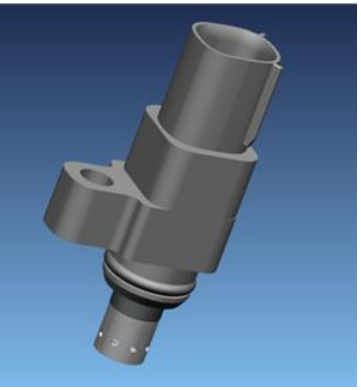
US DOE & Bosch Collaboration in Powertrain

DOE Awarded Project – REGIS

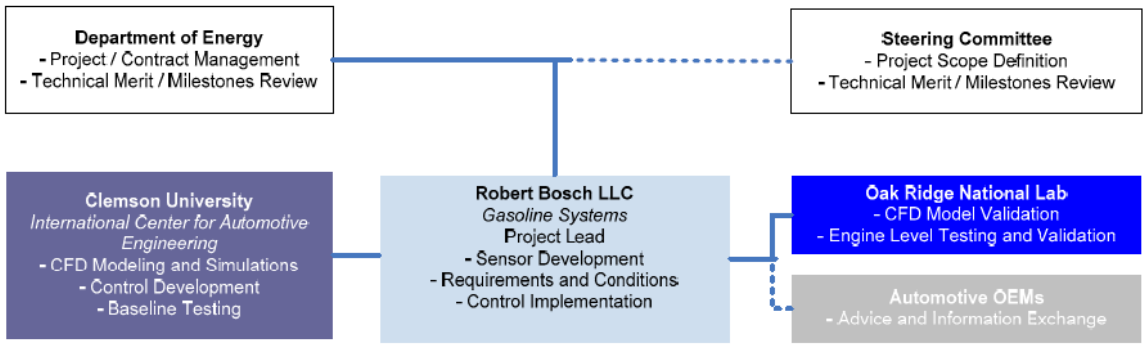


Recirculated **E**xhaust **G**as **I**ntake **S**ensing

Objective of the REGIS project is to develop an Intake Air Oxygen sensor which directly and accurately measures the oxygen concentration in the intake manifold to estimate the external EGR rate in order to improve engine efficiency resulting in reduced fuel consumption while meeting the required U.S. EPA emission standards.

Timeline: 3-year project starting 2012 **Budget:** 4.75 Mio USD

Structure



Partners

US Department of Energy

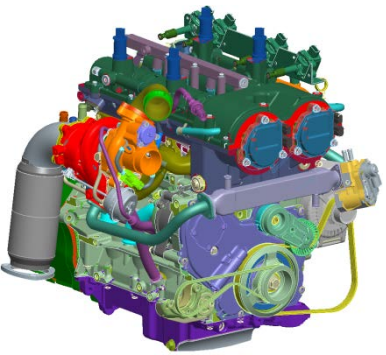
Robert Bosch LLC

Oak Ridge National Lab

Clemson University

US DOE & Bosch Collaboration in Powertrain

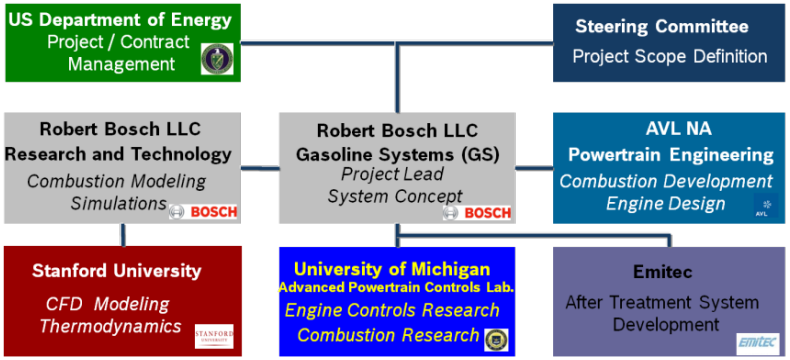
ACCESS



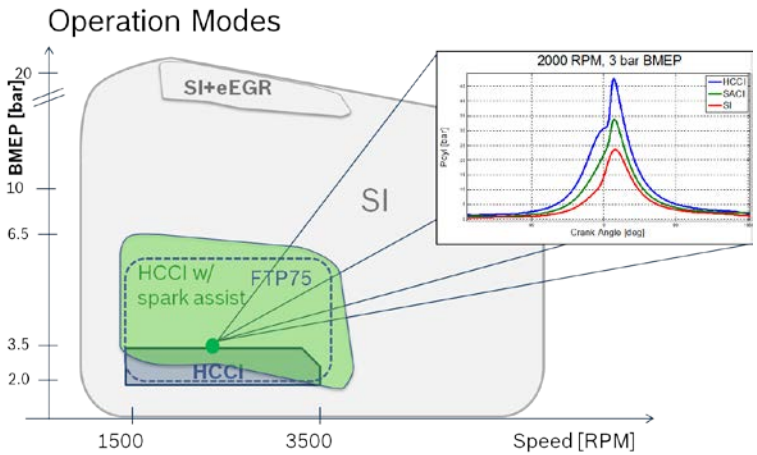
→ Advanced Combustion Concepts – Enabling Systems and Solutions for High Efficiency Light Duty Vehicles
- $24.5 million investment (up to $12 million from Department of Energy)
- 4 year project started October 2010

→ 25+% fuel efficiency improvement compared to a baseline powertrain utilizing advanced combustion concepts complementing the downsizing trend

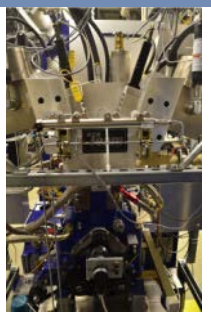
Partners



Concept



Status



- Prototype engines are operational with simultaneous testing
- First results show combustion concept feasibility
- Single ECU concept is successful

Gasoline Systems

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Engineering focus for 2016+

Fuel economy improvement 25% every five years

- MY2016 -- US market
  - Downsizing (DI with Turbo Charging)
  - Vehicle size and weight reduction
  - Start/Stop with automated transmission
  - 8/9 speed transmission
  - (cooled external EGR)
- MY2020+ adds
  - Advanced combustion features
  - 'Affordable electrification' required to meet fuel efficiency targets.
  - Revival of alternative fuels (driven by cost and availability)

The pressure from market and legislation to improve fuel economy accelerates the introduction of technology packages to the ICE.
Optimization of the ICE still offers the best cost/benefit ratio over electrification.

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Powertrain Architecture and Controls

Powertrain Sub Domains

Combustion

Highly efficient combustion concepts

Transmission

Optimized drive train control

Electric Drive

Affordable Hybridization

Chassis

Vehicle Information Management

System Engineering Powertrain

Interlinked control concept for optimized powertrain operation.

Powertrain Control Strategy enhanced by awareness of vehicle environment and driver feedback.

Target → Optimized Powertrain Architecture with "Affordable Electrification"

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