Fuel Economy – How Do We Get There?

39th Automotive-Petroleum Industry Forum

Dearborn, MI, April 19th, 2016
Dr. Dean Tomazic, Executive VP & CTO, FEV North America, Inc.

Agenda

- **Introduction**
- **Development Trends**
- **Potential Game Changing Technologies**
- **Future Lubricant Requirements**
- **Summary**

The Future of Powertrains
Current Global Situation

Global Mega Trends

Energy Security

Urbanization

Green Themes

Mass Mobilization

Resulting Drivers

Total Cost of Ownership

Legislation

Government Policies
(Taxation, Subsidies etc.)

Powertrain Technologies

ICE

Natural Gas ICE

HEV

HHV

Fuel Cell

MT

DCT

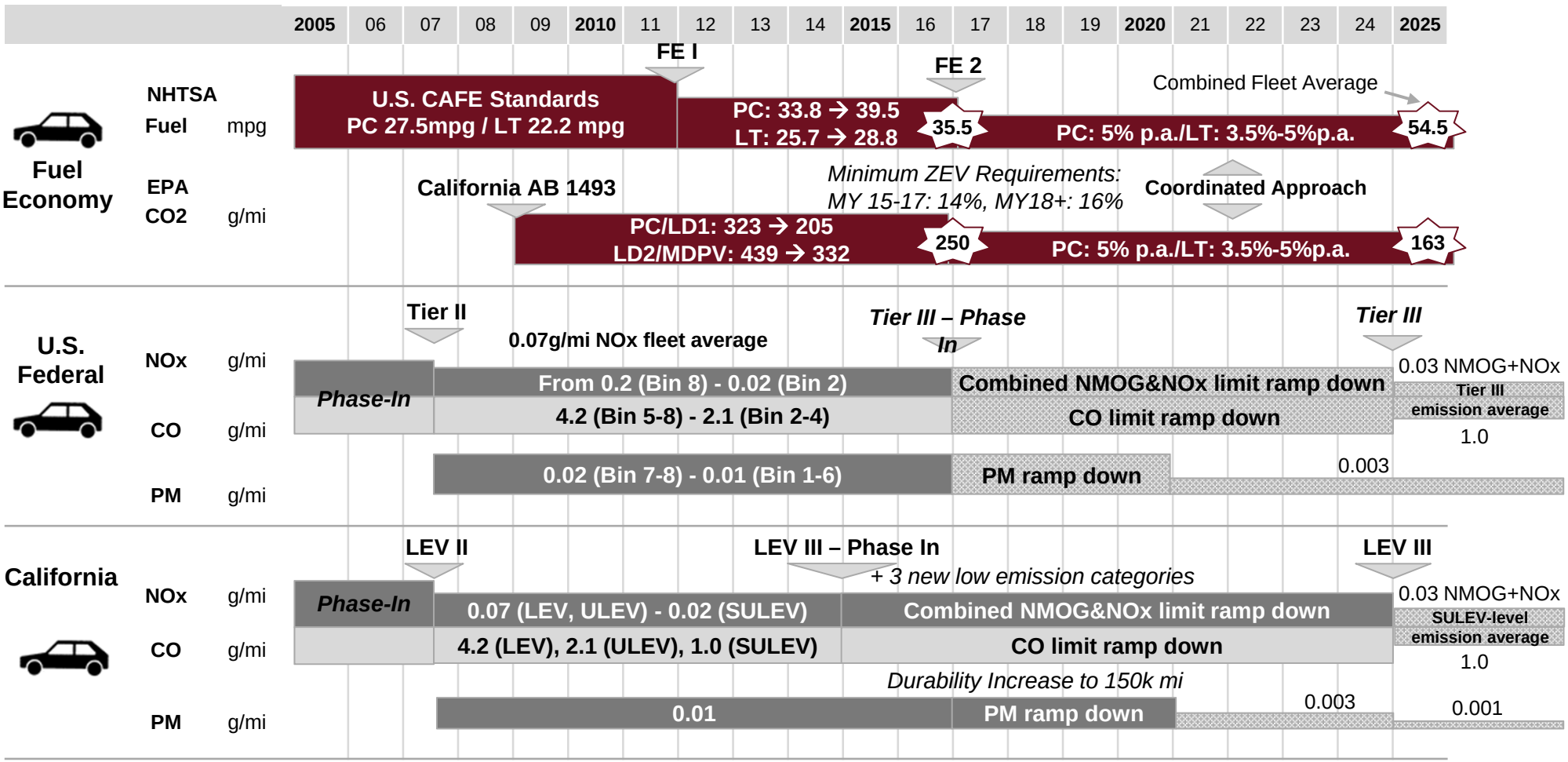
Hybrid

CVT

AT

U.S. Emissions, Fuel Economy, and CO_2 Regulation Overview

U.S. – Passenger Cars and Light Trucks (GVW < 6,000lbs)



Source: Delphi, FEV Research

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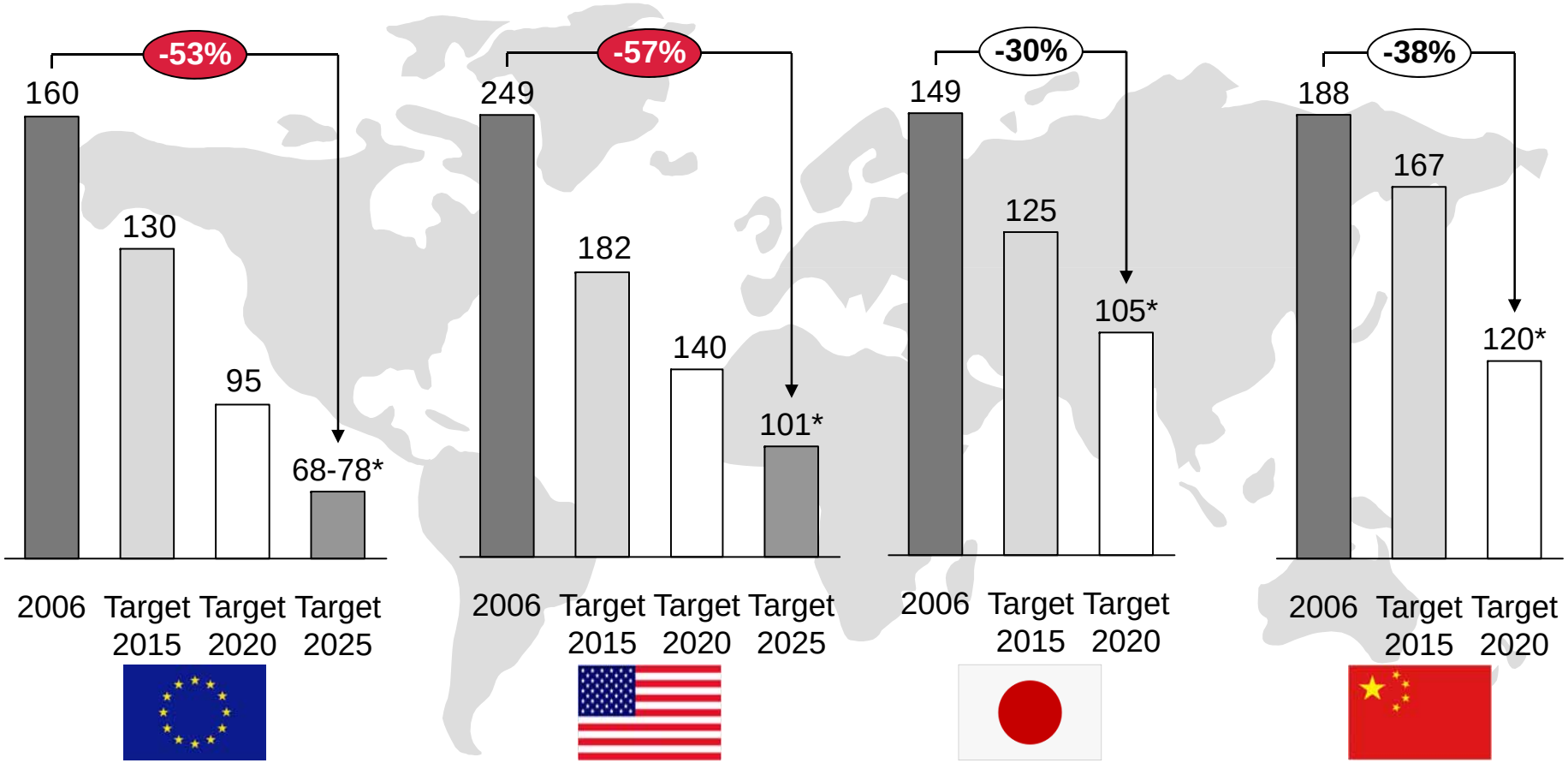
Development Trends
Global CO_2 Emission Targets

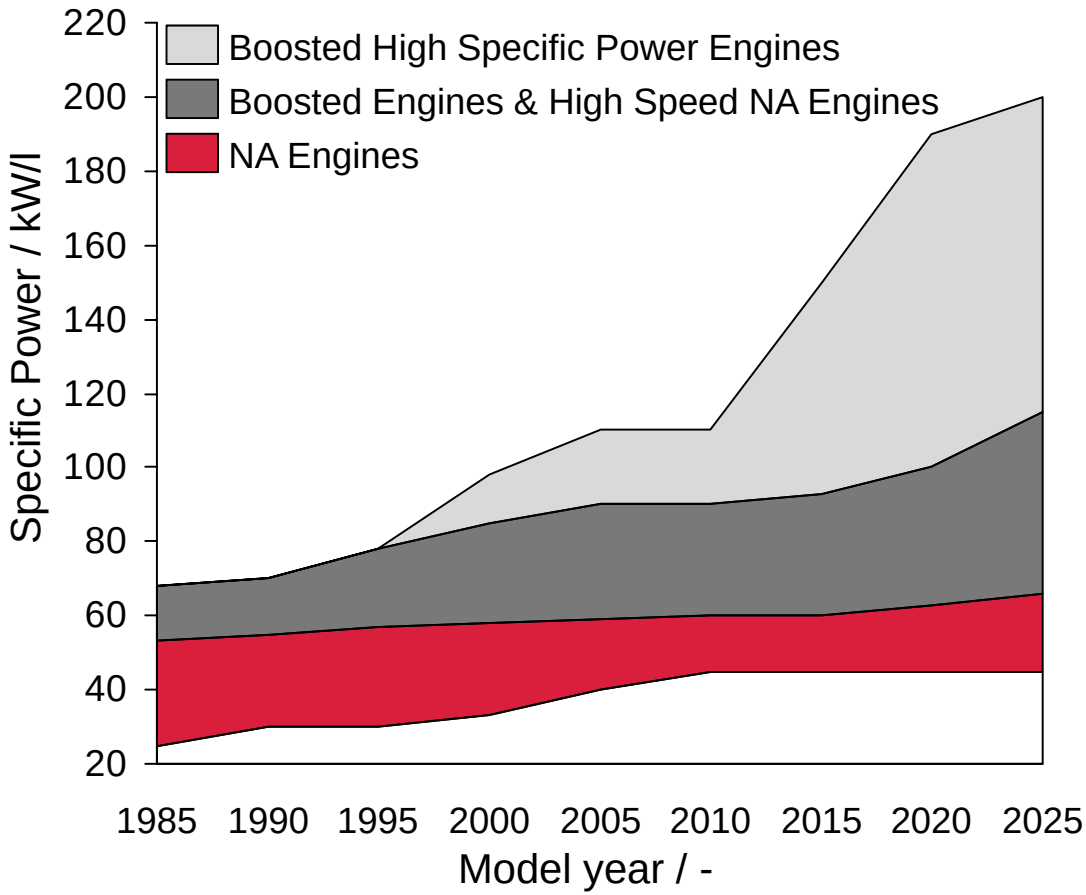
Worldwide regulations for CO_2 reduction – CO_2 fleet targets (g/km) NEDC based



* Proposed Target

Development Trends
Gasoline Engines

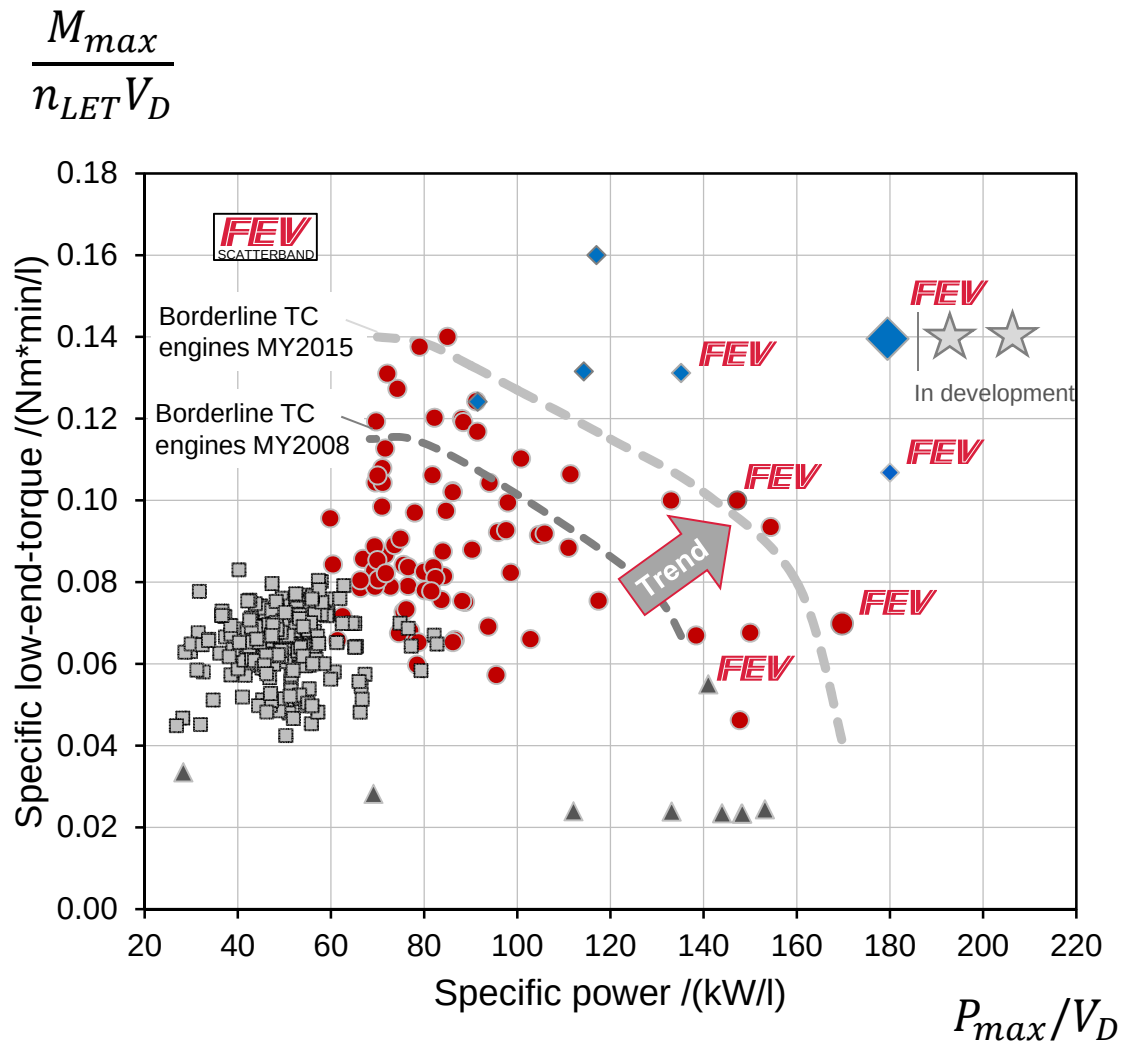
Specific Power: History and Future



- Extrapolation of trend based on ongoing market survey
- Maximum specific power depends on market position of individual OEM
- Mainstream engine of Premium OEM might have higher BMEP than ‘high performance engine’ from large volume OEM
- Additional features for future considered, e.g. variable compression ratio (VCR)

Source: FEV Consulting

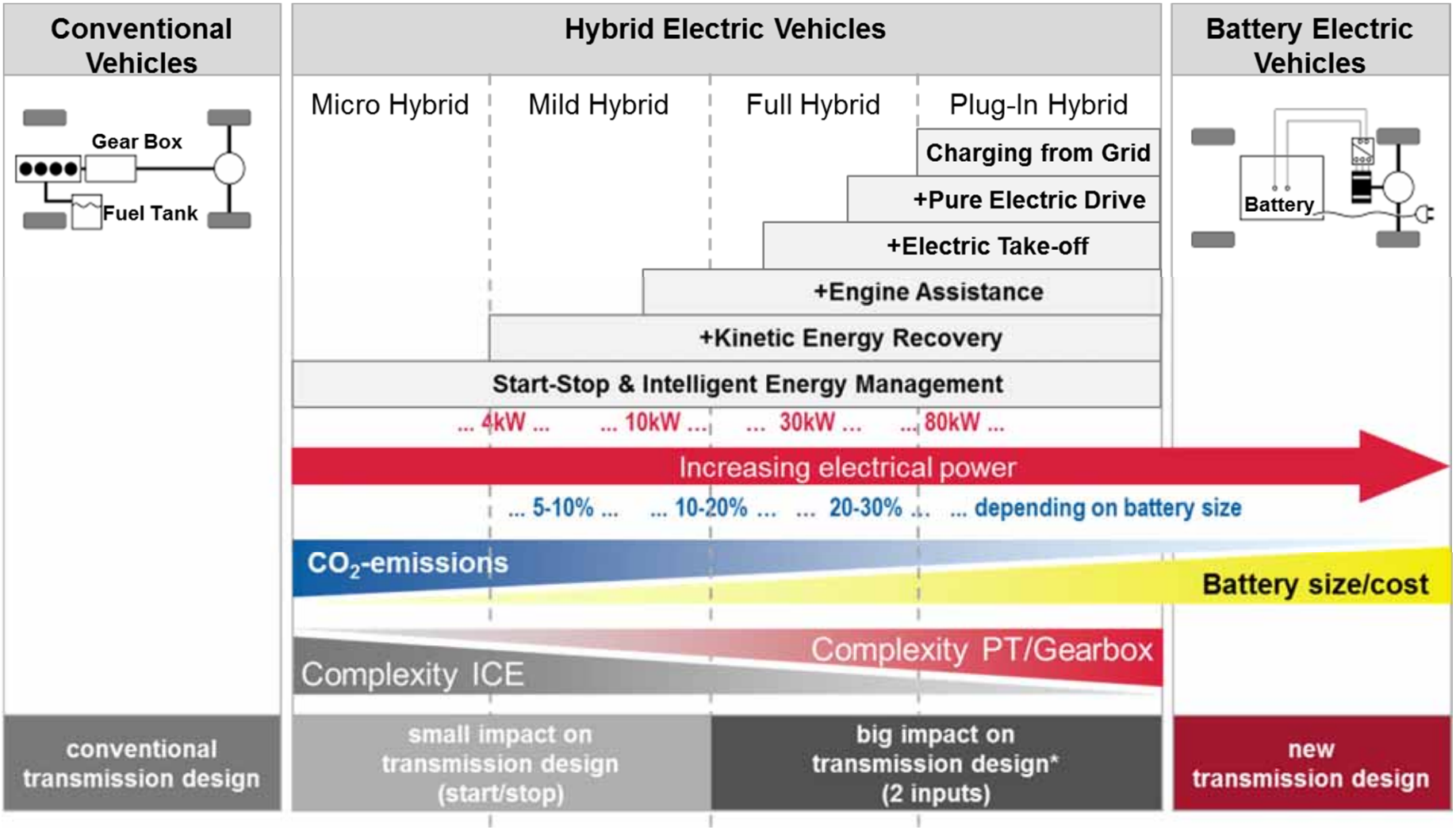
Development Trends
Gasoline Engines



- Trend:
  - Further downsizing
  - High specific power & LET
- Several high performance engines in development at FEV
- Boosting system is key component
- 1-stage boosting limited
- 2-stage boosting to combine high specific power and low-end-torque (LET):
  - TC + eC
  - TC + TC
  - TC + SC

NA engines | 1-stage boosted engines | 2-stage boosted engines | Motorcycle engines | FEV under development at FEV

Technology Trends
Hybridization / Electrification / Transmissions



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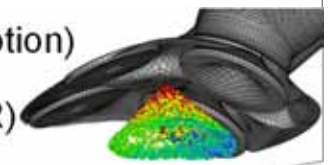
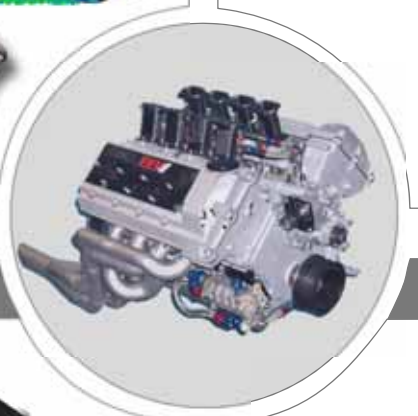
Development Trends
Gasoline Engines

Combustion Efficiency Improvements

- Direct Injection (& Var. Charge Motion)
- Variable Compression Ratio (VCR)
- Miller/Atkinson Cycle
- Controlled Auto-Ignition (CAI)
- Cooled EGR





Reduction of Throttling Losses

- Downsizing
- Boosting
- Cylinder Deactivation
- Variable Valvetrain
- Lean-burn Operation

Electrification/Hybridization

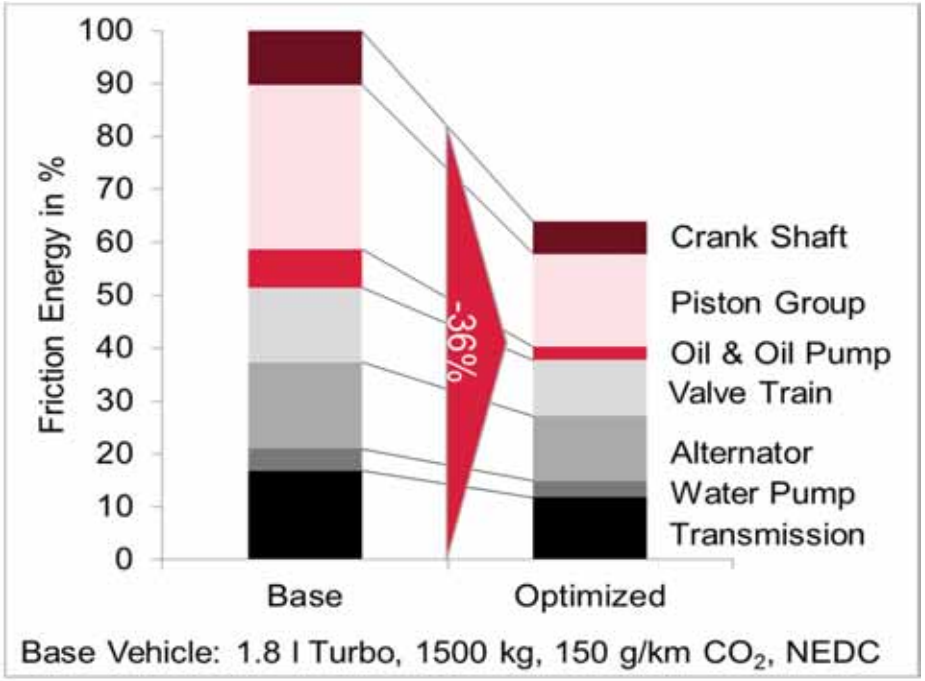
- Micro/Mild/Full Hybrid
- PHEV
- 48V Infrastructure
- Accessory (FEAD) Electrification

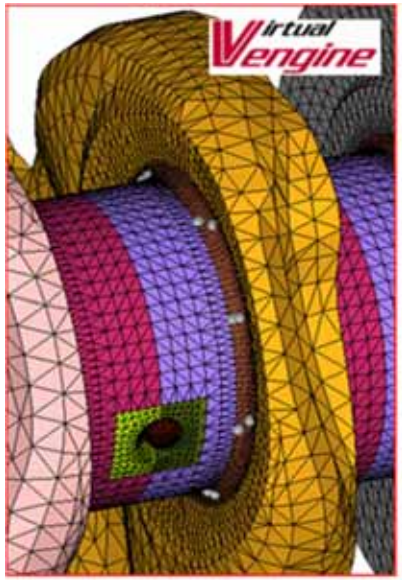
Reduction of Parasitic & Idle Losses

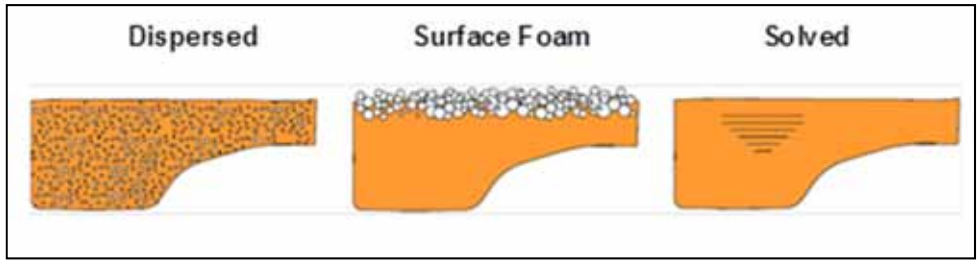
- Friction Reduction
- Stop/Start
- Advanced Thermal Management
- Accessory (FEAD) Electrification

Friction Reduction
Base Engine Design Opportunities

- Friction reduction → Impact on bearing dimensioning → Higher bearing loads
- Discrepancy in bearing load between FE vs. high-power version (LSPI)
- Stop-start (polymer coatings)
- Oil aeration







Development Trends
Gasoline Engines

Example:

Three-Cylinder GTDI

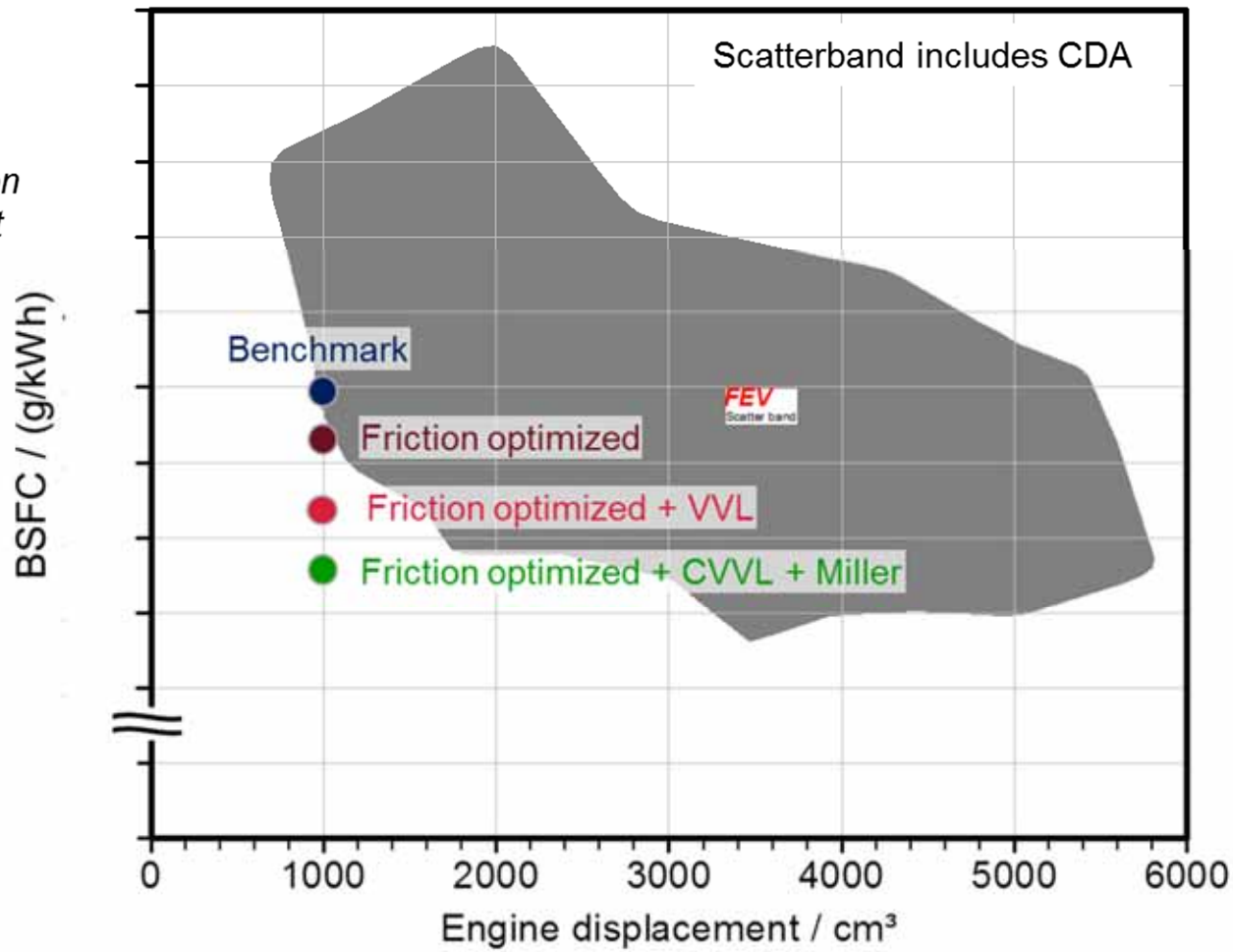
- *Best in class BSFC*
- *Variable valve lift*
- *Friction optimized*
- *State-of-the-art combustion*
- *Optimized air and exhaust management*

Brake Specific Fuel Consumption

norm. to calor. val.=42.5 MJ/kg

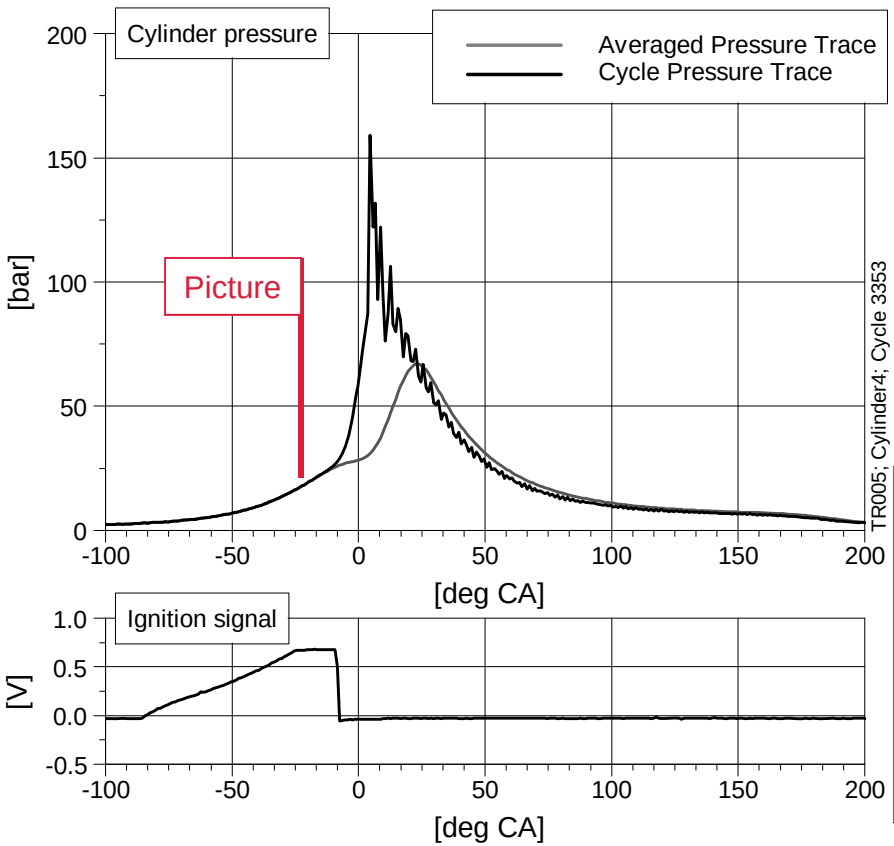
2000 rpm / BMEP = 2 bar

- SI engines
- Production state
- Model year > 1997

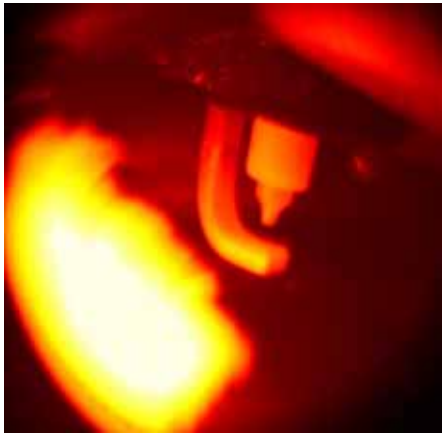


Combustion System Challenges
Gasoline Engine Development: Low-Speed Pre-Ignition (LSPI)

Oil/Cool Temp.:	40 deg C	SOI:	480 deg CA	Pre-conditioning:	Dirty Pre-Conditioning
Intake Temp.:	90/90 deg C	Engine speed:	1600 rpm	Fuel:	Type 1
Lambda Spindt:	1.100	Rail pres.:	120 bar	Spark plugs:	No.1
Exh. backpres.:	50 mbar	Camph. IV/EV:	15/35 deg CA	Inj. orientation:	No.1



TR005; Cylinder4; Cycle 3353

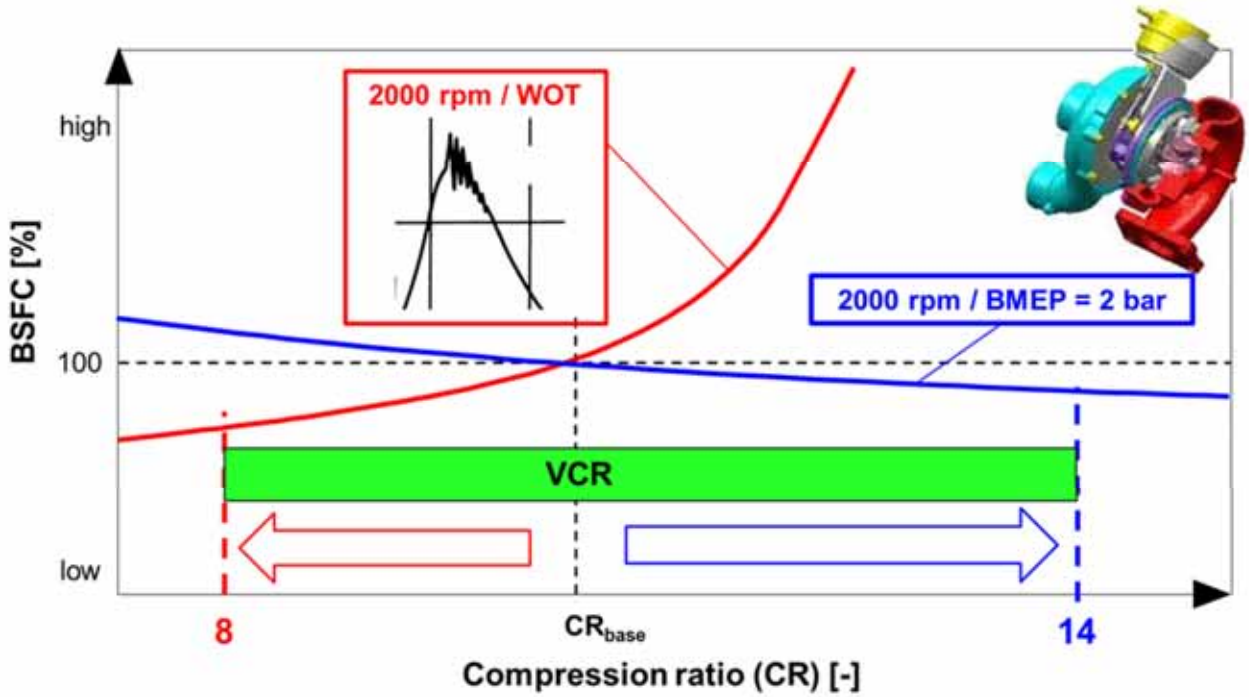


p_{max}	[bar]	158.96
p_{PI}	[bar]	26.51
p_{avg30}	[bar]	31.00
$dp_{max-avg}$	[bar]	127.96
dp_{max-PI}	[bar]	132.45
α_{max}	[deg CA]	4.71
α_{PI}	[deg CA]	-9.29
$\alpha_{SOCavg30}$	[deg CA]	1.71
α_{ign}	[deg CA]	-8.29
$d\alpha_{PI-ign}$	[deg CA]	-1.00
$d\alpha_{PI-SOCavg30}$	[deg CA]	-11.00
$d\alpha_{PI-max}$	[deg CA]	-14.00

Example:

- Picture taken 3 deg CA before spark event
- LSPI event in the middle of the combustion chamber
- Pressure rise 1 deg CA before spark

2-Step Variable Compression Ratio (VCR) Mechanism
Background & Incentive



Key figures

- Conflict of aims:
  - High compression ratio for excellent part load efficiency
  - Low compression ratio for reduced knocking at high / full load
- This trade-off can be solved by systems allowing a variable compression ratio

Source: FEV

2-Step Variable Compression Ratio (VCR) Mechanism
Background & Incentive

Gasoline

- Fuel consumption reduction
- Low End Torque (LET) improvement
- Potential of high knocking resistance for upcoming fuels (E100, CNG) in Bi-fuel applications
- No interference with other thermodynamic measures for fuel consumption
  - Variable valve lift
  - Miller
  - External cooled EGR

Diesel

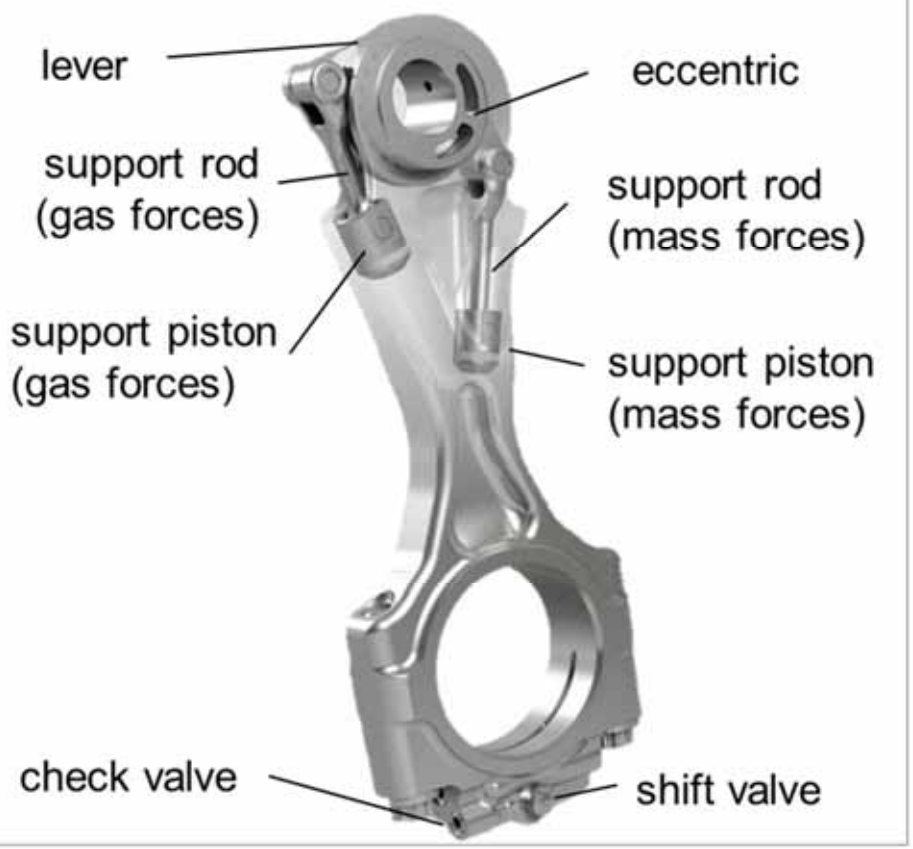
- Low load:
  - High CR for increased efficiency and reduced HC emissions
- Medium & high load:
  - Low CR for reduction of particulate matter emission with constant NO_x
- Full load:
  - Increased rated power / improved efficiency with same peak firing pressure

  or
  - Same rated power enables reduced peak firing pressure to reduce friction by optimized engine design

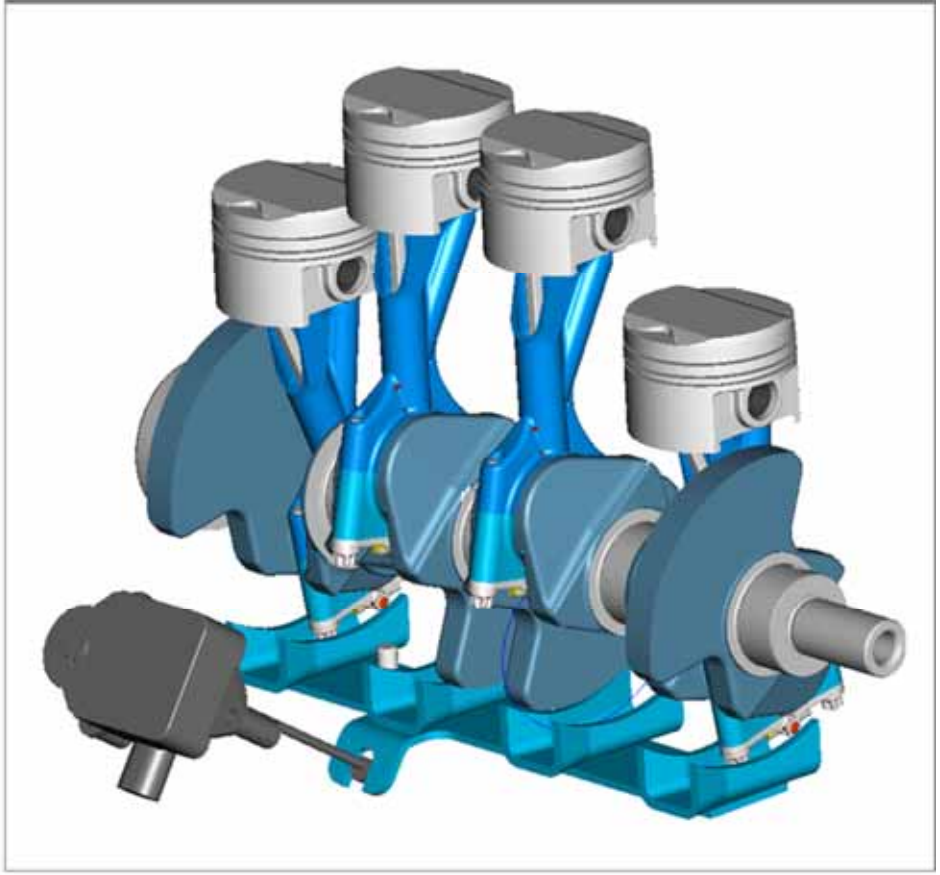
Source: FEV

2-Step Variable Compression Ratio (VCR) Mechanism
Design Features

Connecting rod design

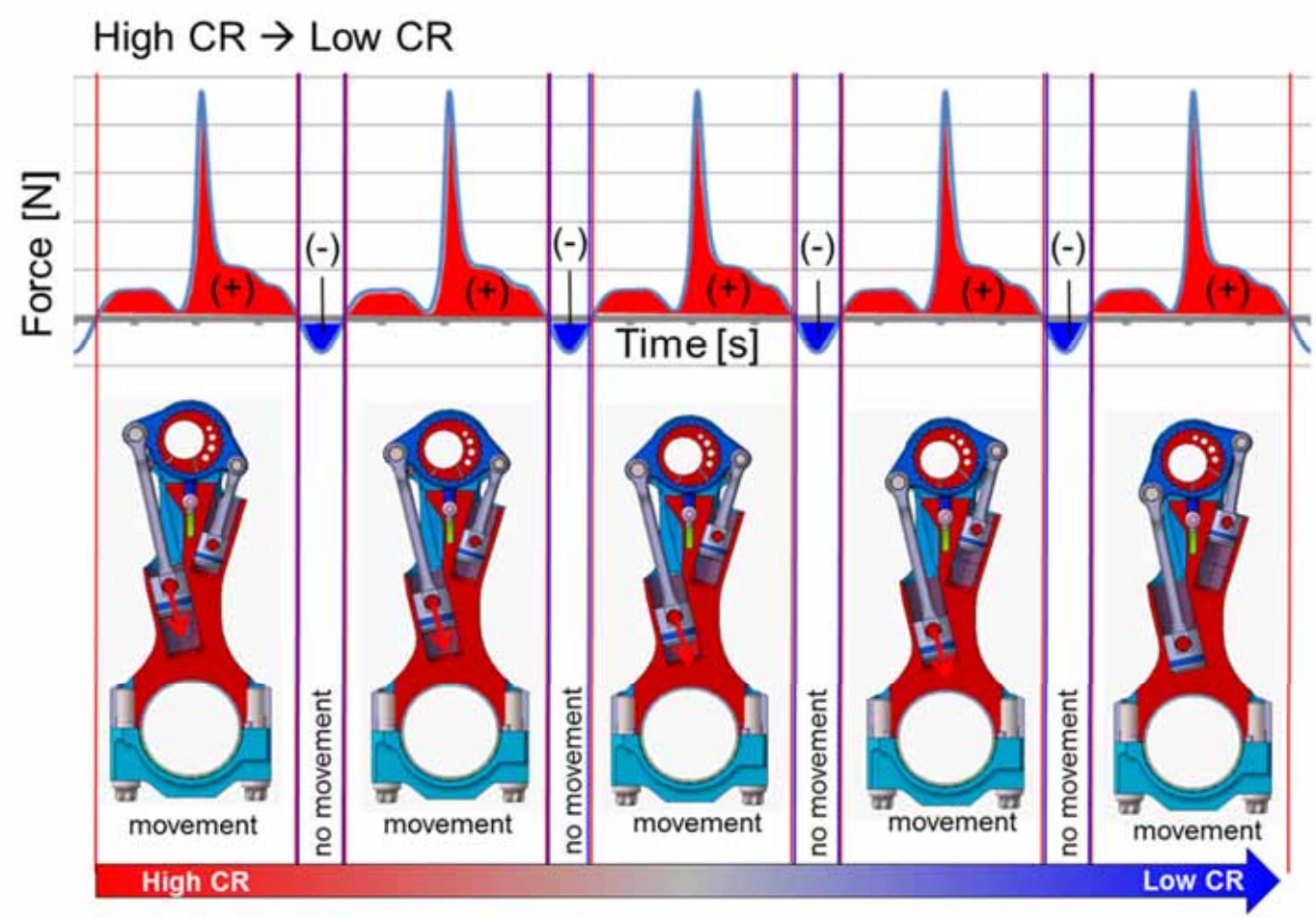


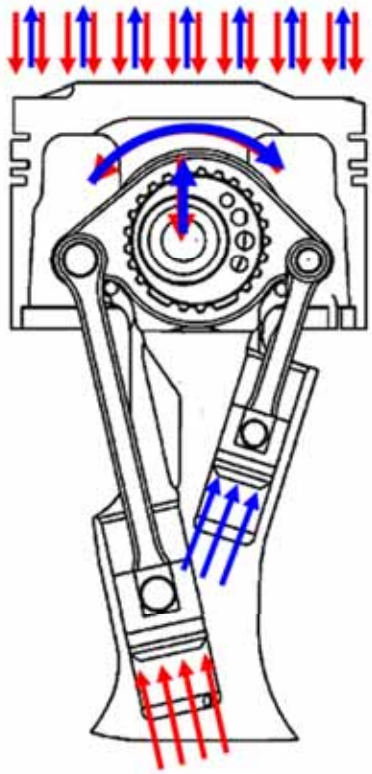
Mechanical actuation



Source: FEV

2-Step Variable Compression Ratio (VCR) Mechanism Functionality





Source: FEV

Development Trends
Transmissions

‘Direct’ Transmission Efficiency Improvements

- High Efficiency Oil Pumps
- Minimized Open Clutches
- Low-Loss Bearings/Seals/Gears
- Low-Leakage Hydraulics
- Low-Viscosity Oils

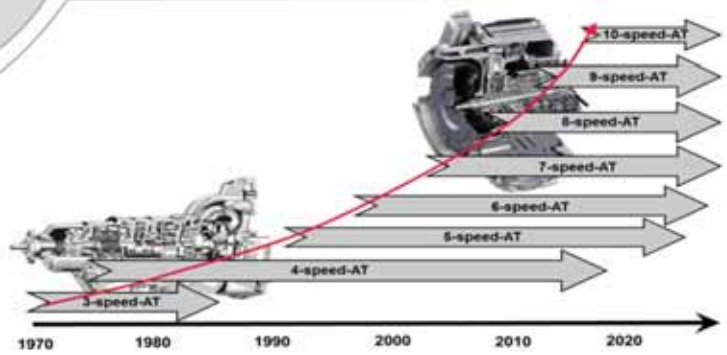
‘Indirect’ Transmission Efficiency Improvements

- Increased Number of Speeds
- Increased Ratio Spread
- Aggressive Torque Converter Lock-Up
- Active Thermal Management

Transmission Types

- Manual/AMT/DCT
- Planetary Automatics
- CVT
- Hybrids

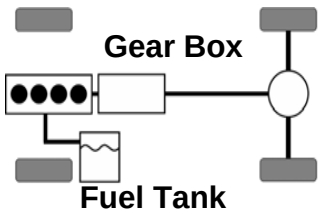
Development Path



Hybridization
Architectural Alternatives

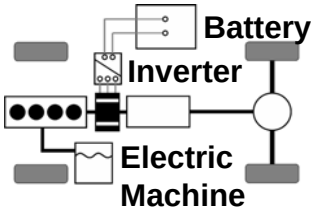
Increasing Degree of Hybridization/Electrification

Conventional ICE-Only Vehicle

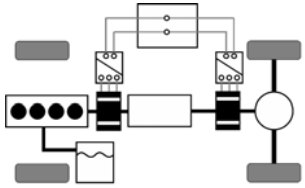


Hybrid Electric Vehicle (HEV)

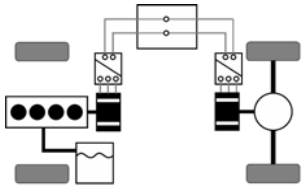
Parallel-Hybrid



Power Split-Hybrid

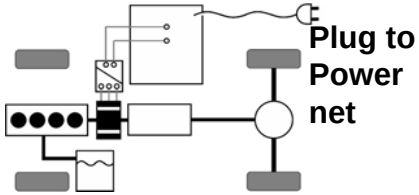


Series-Hybrid

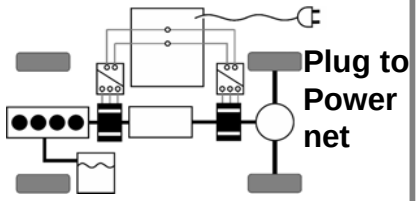


Plug-In (PHEV)

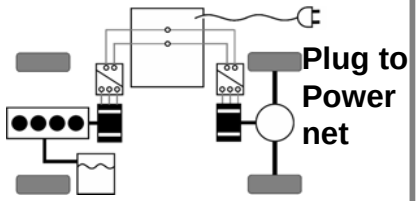
Parallel-Hybrid



Power Split-Hybrid

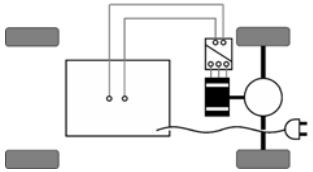


Series-Hybrid

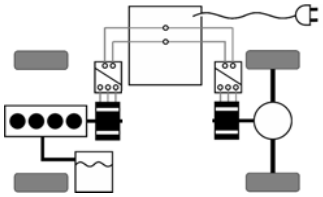


Battery EV (EV)

Electric Vehicle



BEV with REX



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Engine Lubricants
Future Requirements

- Engine
  - Friction reduction → Impact on bearing dimensioning → Higher bearing loads
  - Discrepancy in bearing load between FE vs. high-power version (LSPI)
  - Higher operating temperatures (oil and coolant)
  - Low viscosity desired during start up (rapid warm-up)
  - Piston skirt lubrication (honing pattern)
  - Piston ring tension reduction (friction, blow-by, oil consumption)
  - HLA's, VVL, stop-start, etc.
  - Fuel in oil entrainment (dilution) w/ DI engines (E10-100)
  - Oil aeration
  - Variable oil pumps (2-step or continuous)

- Transmission
  - Friction reduction → Impact on bearing dimensioning → Higher bearing loads
  - Separate oil pump (stop-start)
  - Higher operating temperatures ('fill for life')
  - Accelerated warm-up (cold start)
  - Optimized gear geometries
  - Etc.

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Summary

- **The industry is facing multidimensional challenges from a legislative, economic and societal perspective. Technical solutions must satisfy all of these requirements to succeed in the marketplace.**

- **Technologies to meet future requirements are either already available or under development. However, different markets have different requirements and hence different technical solutions.**

- **Due to these requirements, the variability of different powertrain types will continue to increase resulting in the need to also adapt fuels and lubes accordingly.**

- **A ‘one fits all’ solution becomes more and more unlikely due to the vast differences among the different powertrains and the way they will be used in the market.**

- **The main challenge remaining is to develop a cost efficient powertrain portfolio that meets legislative requirements and is accepted by the customer despite fluctuating fuel prices.**

