DEER 2012 – Bosch Powertrain Technologies

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Chief Engineer – Gasoline Systems
Robert Bosch, North America

Gasoline Systems
DEER 2012 – Bosch Powertrain Technologies

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

Gasoline Systems
## Divisions of Automotive Technology

<table>
<thead>
<tr>
<th>Division</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Diesel Systems</strong></td>
<td>Diesel fuel injection system, Exhaust-gas treatment, Start system</td>
</tr>
<tr>
<td><strong>Chassis Systems Brakes</strong></td>
<td>Brake booster, Disc-brake calipers</td>
</tr>
<tr>
<td><strong>Chassis Systems Control</strong></td>
<td>ABS, ESP</td>
</tr>
<tr>
<td><strong>Electrical Drives</strong></td>
<td>Actuation, thermal and wiper systems, steering</td>
</tr>
<tr>
<td><strong>Starter Motors and Generators</strong></td>
<td>Products for commercial vehicles, starter motors and generators</td>
</tr>
<tr>
<td><strong>Car Multimedia</strong></td>
<td>Navigation system, Car radio, indication instrument</td>
</tr>
<tr>
<td><strong>Automotive Electronics</strong></td>
<td>Sensors, Electronic Control Units, Semiconductor, Airbag-control</td>
</tr>
<tr>
<td><strong>Automotive Aftermarket</strong></td>
<td>Automobile spare parts, Accessories, test engineering</td>
</tr>
<tr>
<td><strong>ZF Lenksysteme GmbH</strong></td>
<td>(50 % Bosch) Steering system for passenger cars and commercial vehicles (including steering pumps and columns)</td>
</tr>
</tbody>
</table>
Global Fuel Economy Regulations

Legislation & Commitments  EU  US  CAFE  Japan  China  Korea

<table>
<thead>
<tr>
<th>Year</th>
<th>CO₂ g/km</th>
<th>mpg</th>
<th>L/100 km km</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2015</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>2020</td>
<td></td>
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<td></td>
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<tr>
<td>2025</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>2030</td>
<td></td>
<td></td>
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</tbody>
</table>

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

gasoline (diesel)

GS/ENS2-Te | Sept 28 2012 | © 2012 Robert Bosch LLC and affiliates. All rights reserved.
Limit values for SI PC EU IV-6 and CARB LEV II/III

<table>
<thead>
<tr>
<th>PM [mg/km]</th>
<th>CO [mg/km]</th>
<th>NOx [mg/km]</th>
</tr>
</thead>
<tbody>
<tr>
<td>EU IV</td>
<td>EU IV</td>
<td>EU IV</td>
</tr>
<tr>
<td>LEV II ULEV</td>
<td>LEV II ULEV</td>
<td>LEV II ULEV</td>
</tr>
<tr>
<td>LEV III ULEV125</td>
<td>LEV III ULEV20</td>
<td>LEV NMOG [mg/km]</td>
</tr>
<tr>
<td>LEV NMOG [mg/km]</td>
<td>LEV NMOG [mg/km]</td>
<td>LEV NMOG [mg/km]</td>
</tr>
<tr>
<td>EU HC/NHMC</td>
<td>EU HC/NHMC</td>
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</tr>
</tbody>
</table>

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 and CARB different test cycles: NEDC resp. FTP75

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

### Development of key factors from 2015 to 2020

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

1) Incentive paid in 2015, decreasing to $0 until 2025  
2) 200 USD/bl in 2020 means 260 USD/bl nominal (at ~2% inflation)

Gasoline Systems  
* CO2 limit for PC in 2017, light trucks 200 g/km
The conventional combustion engine keeps dominating the powertrain the next 15-20 years. Broad introduction of electrification hindered by system cost and unattractive solutions.
Bosch Gasoline Systems Overview - Electrification

Evolution of Electrification

Bosch innovation line to support future market requirements!

Baseline: Start/Stop

Advanced Start/Stop

Start/Stop Coasting

mHEV <60V

sHEV

PHEV

Coasting

Recuperation

Boost
e-Drive

potential for CO₂ saving
Evolution of Electrification / E-Drive with BRS

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

Environmental sensing with radar sensor and GPS enables smart drive
Coasting in FTP75 (measurement)

- FTP75 speed profile
- SSC possible

**FTP75 speed profile**

- **Vehicle speed [km/h]**
  - FTP75
  - Start/Stop Coasting

**Fuel Economy Gain**

- FTP75 tolerance
- SSC
- BRS
- driver
- up to +2%
- 9%
- 7%
- 4%

Gasoline Systems compact class, 1.4l DI T/C, 90kW, 7-gear
Gasoline Powertrain Fuel Economy Measures

Gasoline engine measures for efficiency

- **eDZ** Extreme Downsizing (downsizing to 1.1L)
- **CDA** Cylinder Deactivation half engine operation w/ switching
- **LB** Lean Burn (lambda >1 combustion, EGR)
- **OC** Optimized Combustion (charge motion, eps+2)
- **FR** ICE Friction Reduction (electric auxiliaries & extr. mech. friction)

**ICE PT Efficiency**

- **De-throttling**
- **ICE Operation points**
- **Best Efficiency Operation**
- **Energy Recuperation**

**ICE Friction Reduction** (electric auxiliaries & extr. mech. friction)

**Electric Recuperation** (for example w/ 48V BRS)

- **DoSp** Downspeeding (gear ratios, shifting, \( n_{\text{max}} \))
- **S/S** Start/Stop (no idle operation in stand-still)
- **SSC** Start/Stop Coasting
Due to new test cycles and trends towards downsizing and downspeeding, high compression ratios become more important to reduce CO2.
Advanced Fuel Control for Gasoline Engines

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 manufacturing technologies

**Mixture Preparation**
- multiple injection

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

Gasoline Systems
EU6 Requirements & Solutions

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
- 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)
US DOE & Bosch Collaboration in Powertrain

Advanced FFV

Timeline

- K-Off
- M-1
- M-2
- M-3
- M-4

Partners

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

Gasoline Systems

Target Goals:
- Fuel efficiency improvement with E85
- ULEV level emissions with E85
- Ethanol detection & combustion control

Timeline:
- Phase 1
- Phase 2
- Phase 3
- Phase 4

Technological Challenges:
- Power / Comfort / Safety
- Emissions (HC, CO, NOx, PM)
- CO₂-Emissions
- Resources

From Fossil to renewable Fuels

Timeline:
- 10/07
- 01/08
- 04/08
- 07/08
- 10/08
- 01/09
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- 07/09
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From Fossil to renewable Fuels
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.**

Budget & Timeline

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

<table>
<thead>
<tr>
<th>Phase</th>
<th>Start Date</th>
<th>End Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase I</td>
<td>October 2011</td>
<td>October 2013</td>
</tr>
<tr>
<td>Phase II</td>
<td>February 2013</td>
<td>May 2014</td>
</tr>
<tr>
<td>Phase III</td>
<td>May 2014</td>
<td>October 2015</td>
</tr>
</tbody>
</table>

End of Project
Recirculated Exhaust Gas Intake Sensing

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

US Department of Energy  
Robert Bosch LLC  
Oak Ridge National Lab  
Clemson University

Gasoline Systems
**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

**Operation Modes**

- SI + eEGR
- SI
- HCCI w/ spark assist
- FTP75
- HCCI

**Status**

- Prototype engines are operational with simultaneous testing
- First results show combustion concept feasibility
- Single ECU concept is successful
**Bosch Powertrain Systems Technology Focus**

**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.

Gasoline Systems
Bosch Powertrain Systems Technology Focus

Powertrain Architecture and Controls

**Powertrain Sub Domains**
- Chassis
- Electric Drive Transmission Combustion
- Combustion

**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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