Future Powertrain Improvements

Hochschule Esslingen

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Vice President
Corporate Advanced Engineering, Scientific Services
and global TechCenter Coordination
Future Powertrain Improvements

Agenda

- Short introduction of MAHLE
- Scenarios 2020/2025 Global Light Vehicle Powertrain
- Strategy for Fuel Consumption Improvement and Technical Challenges e.g. for Gasoline engines
- Downsizing engine: MAHLE 3 cylinder, 1,2 liter as workhorse to show technologies and their benefits
- Targets correspond to the technical challenges identified by Hyundai-Kia
- Bring it to the Road to experience driving behavior and anticipate Customer view
- Reduce the losses - examples
- Improve fuel economy - examples
- Battery Electric vehicles - examples
- Summary
As a leading global development partner for the automotive and engine industry, MAHLE is working on forward-looking products for new generations of vehicles and mobility concepts.

With its two business units Engine Systems and Components as well as Filtration and Engine Peripherals, the MAHLE Group ranks among the top three systems suppliers worldwide.

As of 2014, the Behr Group—one of the leading OEMs worldwide in vehicle air conditioning and engine cooling—will be integrated into the MAHLE Group as the Thermal Management business unit.

All of the Group’s nonautomotive activities are combined in the Industry business unit. These encompass products from the application areas of filtration, thermal management, and large engines for industrial purposes.

The Aftermarket business unit serves the independent spare parts market with MAHLE products in OE quality.

**Key data:**

- 140 production locations on five continents
- Approximately 65,000 employees
- Planned sales volume of around EUR 10 billion in 2014
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Facts and figures

Long-term trends at MAHLE

Group Management

Sales and Application Engineering

Corporate Advanced Engineering

BU1
Engine Systems and Components

BU2
Filtration and Engine Peripherals

BU3
Thermal Management

BU4
Aftermarket

BU5
Industry

Revenue in Billion Euro


2.4  2.8  3.1  3.2  3.8  4.1  4.3  5.1  5.0  3.9  5.3  6.0  6.2  6.3  10

Headcount in Thousands


28  28  29  30  36  37  39  48  49  37  43  47  49  48  48  65
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Locations

- R&D Centers
- MAHLE Production Sites
- Behr Production Sites
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Facts and Figures
Sales by Region

**Total sales**

<table>
<thead>
<tr>
<th>Year</th>
<th>Total</th>
<th>+23%</th>
<th>2008</th>
<th>2012</th>
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<tr>
<td></td>
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<td>23%</td>
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**Automotive sales**

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<td>5,590</td>
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<td>15%</td>
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<td></td>
<td></td>
<td>15%</td>
<td>23%</td>
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</table>

[in million EUR]  
- Europe
- North America
- South America
- Asia/Pacific

© MAHLE
Future Powertrain Improvements

Research and Development in Tech Centers

Stuttgart

Detroit (Farmington Hills)

Northampton

Shanghai

Tokyo (Kawagoe)

Tokyo (Okegawa)

São Paulo (Jundiaí)
Future Powertrain Improvements

MAHLE product range – more than pistons
Future Powertrain Improvements

MAHLE product applications – more than Automotive
Future Powertrain Improvements

MAHLE

Scenario 2020/2025 Global Light Vehicle Powertrain

Business as usual
Realistic Scenario
Electrification/Hybridization

Estimated: 74 93 103 107 Mio. LV Production

BEV = Battery Electric Vehicle, PHEV = Plug-in Hybrid Electric Vehicle, REEV = Range Extended Electric Vehicle (with ICE), S/S = Stop/Start, Alcohol = E85 & E100

Source 2010/2015: IHS 02/2013
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MAHLE
Scenario 2020/2025 Global Light Vehicle Powertrain

Business as usual

Realistic Scenario

Estimated: 74 93 103 107 Mio. LV Production

Electrification/Hybridization

All are using Internal Combustion Engines

BEV = Battery Electric Vehicle, PHEV = Plug-in Hybrid Electric Vehicle, REEV = Range Extended Electric Vehicle (with ICE), S/S = Stop/Start, Alcohol = E85 & E100

Source 2010/2015: IHS 02/2013

* Relating to Realistic Scenario, LV up to 6t
Future Powertrain Improvements

Customer’s Strategy for Fuel Consumption Improvement and Technical Challenges e.g. Gasoline engines

I. Down-speeding
- Increase Low End Torque
- Transient Response Enhancement

II. Sweet-spot
- Upper throttled and Boosted part load
- Cooled EGR
- Atkinson/Miller

III. Throttled Part load
- Internal EGR strategies
- Dethrottling (late IVC)

IV. High BMEP
- Decrease Enrichment
- WOT Cooled EGR
- Reduced exhaust Gas temp
- Head Integrated Ex-mani
- Active exhaust gas cooling

Fuel Consumption (BSFC)
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Creation of MAHLE 3 cylinder, 1,2l Downsizing engine
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Targets of MAHLE 3 cylinder, 1.2l Downsizing engine

- Reduction of Losses (Friction, Heat, Throttling)
- Power Cell Unit
  (piston, piston rings, piston pins, cylinder liner)
- Cylinder head and valve train
- Thermomanagement
  (Variable coolant and oil management systems)
- Spray guided gasoline direct injection
- Prevent knocking
  - Integrated indirect charge air cooler
  - Cooler Parts e.g. exhaust valve
- Low end torque
  - Turbocharger
  - variable valve timing
  - Exhaust Gas Recirculation cooler
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Create Downsizing Demonstrator vehicle
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Latest Piston Technology for Gasoline Engines

Lightweight and Lowest Friction
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Latest Piston Technology for Gasoline Engines

EVOLITE® Piston Design

- **CO₂-reduction**
  - Increasing thermomechanical loading
  - Reduction of friction losses
  - Reduction of weight

- **Solution: EVOLITE®-Piston**
  - New, load optimized shape of skirt-boxwall-connection to increase its strength
  - Parallel boxwall connection to the crown to reduce crown stresses
  - Thin-walled structure to reduce weight

[Graph showing weight reduction over years for different piston types]

- **EVOTEC® 2**: 240.3 g
- **EVOLITE®**: 219.3 g
Future Powertrain Improvements

Latest Piston Technology for Gasoline Engines
EVOLITE® Piston – Strength and Friction

- Lifetime increased and
- Reduction of friction losses due to combination of structural optimization and skirt profile adaptation

Friction measured in fired engine

<table>
<thead>
<tr>
<th>Speed [rpm]</th>
<th>Δ IMEP [bar]</th>
<th>Δ FMEP [bar]</th>
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<tr>
<td>20</td>
<td>25</td>
<td>0.00</td>
</tr>
<tr>
<td>3000</td>
<td>4000</td>
<td>0.12</td>
</tr>
<tr>
<td>6000</td>
<td>1000</td>
<td>0.12</td>
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</table>

Calculated CO₂-reduction in NEDC: ~0.5 g CO₂/km

1.6l Gasoline Engine (93 kW/l) with external oil, water and fuel conditioning
Engine temperature: 100°C (oil + water)
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Latest Piston Technology for Highest Power Density
Salt Core Cooling Channel
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EVOTEC® SC Piston Design
Temperature field based on RTM- measurement

Example: 1,6 l Turbo Gasoline Direct Injection >90 kW/l

- Temperature reduction at piston crown, 1\textsuperscript{st} ring groove and pin boss (ΔT up to 25K)
- Reduction of the temperature difference between TS and ATS
- Higher structural stiffness and ring land robustness → Less sensitivity for knocking and pre-ignition
- NOx reduced by up to 750ppm in engine operating map
Future Powertrain Improvements

Turbocharger Innovations
Gasoline engine

Electric Wastegate Actuator
Future Powertrain Improvements

Turbocharger Innovations

Gasoline engine

Roller Bearings

Up to 70% less friction in bearings

Electric Wastegate Actuator
Future Powertrain Improvements

Turbocharger Innovations
Gasoline engine

Electric Wastegate Actuator

Roller Bearings

Titanium Aluminide TiAl

50% less moment of inertia
## Future Powertrain Improvements

### Turbocharger Innovations

**Diesel engine**

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<thead>
<tr>
<th>Description</th>
<th>374m</th>
<th>376m</th>
<th>378m</th>
<th>380m</th>
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<td><strong>Roller bearings</strong></td>
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<td><img src="image13" alt="Image" /></td>
<td><img src="image14" alt="Image" /></td>
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<tr>
<td><strong>Roller bearings + TiAl</strong></td>
<td><img src="image15" alt="Image" /></td>
<td><img src="image16" alt="Image" /></td>
<td><img src="image17" alt="Image" /></td>
<td><img src="image18" alt="Image" /></td>
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<td><img src="image20" alt="Image" /></td>
<td><img src="image21" alt="Image" /></td>
</tr>
<tr>
<td><strong>Roller bearings + TiAl + VTG 2nd Gen.</strong></td>
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<td><img src="image23" alt="Image" /></td>
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<th>t&lt;sub&gt;80-120 km/h&lt;/sub&gt;</th>
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<tr>
<td>3.5 m</td>
<td>13.4 s</td>
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<tr>
<td>4.8 m</td>
<td>13.3 s</td>
</tr>
<tr>
<td>5.1 m</td>
<td>13.3 s</td>
</tr>
</tbody>
</table>

2.0 l Diesel engine (110 kW) simulated in a Passenger Car @ curb weight of 1800 kg
Less power into auxiliaries: MAHLE pendulum-slider oil pumps

- Pump driven by the shaft connected to inner rotor
- Inner and outer rotor run at same speed (no wear due to sliding vanes)
- Outer rotor with plain bearing in the slider
Future Powertrain Improvements

MAHLE Down Size Engine with pendulum-slider oil pump
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Leadfree Bearings for Stop/Start, Sailing or Coasting Applications

Stop/Start already 10 times more starting cycles

Belt driven Start Stop system:
Main Bearings with Polymer on Aluminium base after 200,000 Start/Stop-Cycles

Uncoated Aluminum Alloy: wear: ~ 35 µm
Polymer coated Aluminum Alloy ~ 5 µm
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Difference in Friction of Piston Ring Pack and Lube Oil Consumption (Diesel engine)

Oil Control Ring
Tangential force

28.0 N ⇔ 17.7 N
\( \Delta F_{\text{engine}} = 41.2 \text{ N} \)

28.0 N ⇔ 13.5 N
\( \Delta F_{\text{engine}} = 58.0 \text{ N} \)

28.0 N ⇔ 9.1 N
\( \Delta F_{\text{engine}} = 75.6 \text{ N} \)
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Relative portion of Friction in Piston Ring Pack will change with test cycle - Gasoline engine

![Friction percentage chart]

- New Worldwide harmonized Light vehicles Test Procedures and Real Drive Emission will bring engine to higher loads and speeds shifting more weight to top ring friction and much less information from strip down engines.

* Low friction ring pack for a Euro 5 1,2 l Turbo Gasoline direct Injection engine with 65 kw/l specific output and 90 bar peak pressure.
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Valve and Seat can help reduce Knocking and save fuel

Influence of Heat Conductivity Valve Seat

- **600 °C**
- **640 °C**

Influence of Heat Conductivity in Valve

- **Solid**
- **Classic Hollow**
- **EvoTherm®**
- **Competitor**
- **TopTherm®**

<table>
<thead>
<tr>
<th>Component</th>
<th>Temperature Range</th>
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<tbody>
<tr>
<td>Solid</td>
<td>760-820°C</td>
</tr>
<tr>
<td>Classic Hollow</td>
<td>700°C-760°C</td>
</tr>
<tr>
<td>EvoTherm®</td>
<td>650°C-720°C</td>
</tr>
<tr>
<td>Competitor</td>
<td>650°C-720°C</td>
</tr>
<tr>
<td>TopTherm®</td>
<td>580°C-630°C**</td>
</tr>
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</table>

Fuel consumption at full load

- **3 - 6%**

2.0 l T-GDI, 155 kW
Future Powertrain Improvements

Low Friction Camshaft
Roller/Needle Bearing Camshaft

Two effects:
Less friction and
Less oil to pump

Polymer cage with bumpers
Axial pre-positioning and Low noise contribution

Bearing outer ring
Closed single piece ring, Needle bearings for small radial packaging space (Ø 30mm)

Shrink fitted cam lobe
MAHLE’s clean assembly process (use of fully finished components)

Heat treated shaft or tube
Local hardening on the raceway to resist superficial and subsurface stresses
Future Powertrain Improvements

**Behr Enthalpy Storage Tank (BEST)**
Cold Start under less friction due to higher temperature

- **Cold Start**
  - **Higher Temperature**

**Graph Details:**
- **Time:** 60 sec
- **Temperature:** 60°C
- **Media temperature in BEST**
- **Media temperature in engine cooling circuit**

**Lines:**
- **Thick line w BEST**
- **Thin line w/o BEST**
Future Powertrain Improvements

Cam In Cam Technology = concentric camshafts
Pumping loss, low end torque, Emission

60°CA phasing of inner cam shaft against outer camshaft with conventional cam phaser

Simple and cost effective solution for continuously variable valve opening duration

- Gasoline – intake side CIC
  - Fuel economy improvement in low and mid/high loads

- Diesel – intake side CIC
  - Improvement of emissions and part-load fuel economy

- Gasoline (4-cyl.) – exhaust side CIC
  - Significant improvement in low-end torque and reduction in fuel consumption of up to 2.5% over the NEDC drive cycle and up to 2.1% over a representative real-world drive
Air intake modules with integrated indirect charge air cooler

Overview of different cooling concepts

- Direct charge air cooler
- Indirect charge air cooler
- Integrated indirect charge air cooler (i²CAC)
- Integrated cascaded charge air cooler

‘Less space in the package’

‘Less pressure loss’

‘higher cooling performance’
Future Powertrain Improvements

Charge Air Cooler

Package Pressure drop Cooling power

10 % less fuel consumption

Break specific Fuel Consumption in g/kWh*

Plenum Air Temperature [°C]

Turbine In Temp. Limit

*High Load (5000 rpm, 24 bar BMEP)
Both systems deliver value
Under real driving conditions

Up to 5% benefit
in Fuel Consumption

Depending on …

…degree in downsizing

and

…driving habits
Future Powertrain Improvements

Battery Electric vehicles
Creation of a MAHLE Range Extender engine

- Best Concept for Range Extender
- Operate and control RE beside electric motor
- Generator / Battery / DC/DC Converter
- Thermal Management
- Start/Stop Operation, acoustics
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Battery Electric vehicles
Creation of a Range Extender Demonstrator
Future Powertrain Improvements

Battery Electric vehicles
Battery Thermal Management Solutions

- Coolant solution
- Refrigerant solution
- Air solution

- Coolant plate (& TIM)
- Chiller
- Plate heater
- Refrigerant plate (& TIM)
- HVAC module
- PTC heater

MAHLE International GmbH, Uwe Mohr, 2013, October 16
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Battery Electric vehicles
Efficient Heating by Heat Pump Solutions

Cabin heating (& cooling):
Heat pump refrigerant cycle

Battery heating (& cooling):
Thermo electric heat pump

Up to 8 kW
Driving range reduction 15 instead of 45%

Up to 2 kW
Driving range reduction 15 instead of 45%
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Summary

- Taking the challenges by putting future technologies early into demonstrators
- Checking the benefits of products from the customer viewpoint
- Checking benefits versus alternatives and drawbacks in other aspects
- Validate product ideas with their benefit against their total cost in the system/vehicle
- You have seen only some examples for internal combustion engines
- You have seen only some examples for alternative powertrains
- A whole bunch of technologies are possible and only a few are worthwhile to go into series
Future Powertrain Improvements

Thank you for your kind attention

Questions?