AVL
“Anstalt Fuer Verbrennungskraftmaschinen List” (Institute For Combustion Engines)

Three Divisions …
One Globally Unique Company

Powertrain Engineering

Software

Integrated Powertrain Solutions

Testing

Instrumentation & Test Systems

Advanced Simulation Technologies
AVL POWERTRAIN ENGINEERING AT A GLANCE

- 3750 powertrain development experts
- 7500 AVL employees
- 1500 patents
- 1100 projects per year
- >220 testbeds
- 30 technical centers
- 5 elements of the powertrain
- 62% university graduates
- 65 locations
- 65 years of development experience
Increased Powertrain Diversity: The Five Basic Elements of the Future Powertrain

- Storage capacity
- Energy density
- Recharge time
- Gasoline/diesel
- Valvetrain
- PFI/GDI
- NA/Boosted
- CVT
- DCT
- 8/9/10 Speed
- ECU Complexity
- TCU Complexity

- Torque output
- Voltage requirements
- Efficiency
- ECU Complexity
- TCU Complexity

- Battery
- Electric Motor
- Control System
- Transmission
Increased Powertrain Diversity: The Five Basic Elements of the Future Powertrain

- Storage capacity
- Energy density
- Recharge time
- ...
Increased Powertrain Diversity: The Five Basic Elements of the Future Powertrain

NA PFI Engine with 9 Speed Automatic Transmission

IC Engine
Battery
Electric Motor
Control System

Capability
Fuel Economy Improvement By Transmission Measures

NA PFI
6 speed AT

Energy consumed (WLTC)

BSFC < 240 g/kWh

Vehicle velocity [ km/h ]

Traction Force - N
Fuel Economy Improvement By Transmission Measures

Increased no. of gears

NA PFI
6 speed AT

NA PFI
9 speed AT

BSFC < 240 g/kWh

Energy consumed (WLTC)
Increased Powertrain Diversity: The Five Basic Elements of the Future Powertrain

Turbo GDI Engine with 6 Speed Automatic Transmission
Regional Market Share of Turbocharged Gasoline Engines

- Share of boosted Gasoline engines will dramatically increase especially in Europe
- China higher share than US
- Various GDTI launches also in Japan

→ Downsizing / down-speeding based on boosted engines is already the mainstream technology for FE improvement
Regional Market Share of GDI Engines

- Share of GDI will significantly increase in most major markets
- In Europe and US GDI will become dominating
- China, Korea and Japan expected to gain app. 40% by 2020

Source: IHS Q2/2013
Fuel Economy Improvement With Gasoline Engines - Turbocharging

Turbocharged Engines
Extending area of low BSFC by Boosting and Downsizing
Fuel Economy Improvement With Gasoline Engines - Turbocharging

**NA PFI 6 speed AT**
- BSFC < 240 g/kWh

**Gen 2 TGDI 6 speed AT**
- BSFC < 240 g/kWh

**Energy consumed (WLTC)**

**CHARGING**

- Vehicle velocity [km/h]
- Traction Force [N]
Increased Powertrain Diversity: The Five Basic Elements of the Future Powertrain

Turbo GDI Engine
+ 6 Speed Automatic Transmission

NA PFI Engine with VCT
+ 9 Speed Automatic Transmission

Advanced Turbo GDI Engine
+ 9/10 Speed Automatic Transmission
+ BSG with start/stop

2015

2020 and beyond
Evolution Of Turbocharged GDI

Next generations of TGDI significantly extend sweet spot area

BSFC < 240 g/kWh

Engine Speed

BMEP

Gen 2 TGDI

Gen 3 TGDI

BSFC

Miller Cycle

Schematic
Miller TGDI Democar Golf 7 HiEff

- 1.6l TGDI; 104 kW/4500 rpm
- Cooled Exhaust Manifold
- Increased Compression Ratio
- Miller Cycle
- Cooled Forced EGR (HP)
- Engine min. BSFC <210 g/kWh
- 90 g/km CO2 in NEDC
Evolution Of Turbocharged GDI

- Miller TGDI 6 speed AT
  - BSFC < 240 g/kWh
  - Energy consumed (WLTC)

- Gen 2 TGDI 6 speed AT
  - BSFC < 240 g/kWh

Refined engine technology
Hybridization allows electric driving at low power requirements where the ICE would otherwise operate inefficiently.
Development Trends TGDI
Specific Power vs. Production Volumes

GASOLINE Turbo DI – Global Engine Production vs. Specific Power

Spec. Power [kW/l]

Units produced

1 Mio
Development Directions
Gasoline Engines

Gasoline Engine

FE-Concepts
Miller+High CR+ext.EGR
BSFC_{min} \geq 200^{\circ} g/kWh
P = 65 - 80 kW/l
BMEP = 17 - 20 bar

Mainstream 2013
BSFC_{min} 235^{\circ} g/kWh
P = 60 - 90 kW/l
BMEP = 17 - 25 bar

“Image / Top Performance“ Concepts
BSFC_{min} > 230^{\circ} g/kWh
P = 110 - 180 kW/l
BMEP = 28 - 30 bar

either - or

*) ... 2l displacement
AVL 2013 High Performance TGDI R&D
200 hp/l Alfa Giulietta

- 1.75l GDI TC Fam B engine reinforced
- Longer exhaust camshaft
- K16 Monoscroll TC
- Valeo Electric Supercharger (12V)
- Flap Exhaust System
- 350 HP / 6500 rpm (148 kW/l)
- 410 Nm / 3500 rpm
AVL 2015 High Performance TGDI R&D
200KW/L

- 1.75l GDI TC Fam B engine
- Reinforced crankshaft, conrods, pistons
- Revised valvetrain
- Biturbo charging with dual compressor
- Electric Supercharger (48V)
- Flap Exhaust System
- 474 HP / 8000 rpm (200 kW/l)
- 416 Nm / 8000 rpm
Variable Compression Ratio – Switchable Con Rod

AVL 2-step VCR conrod

+ Variation of compression ratio by 2-3 units
+ Actuated by main oil gallery pressure
+ Suitable for existing engine architectures
Light-Duty Diesel

U.S. application will only become tougher due to more stringent emissions!

- Diesel has always been the benchmark for efficiency
- Tier 3/LEV 3 emissions will make diesel even more difficult to implement in the US
  - Costs will increase
  - Efficiency may reduce
Increased Powertrain Diversity: The Five Basic Elements of the Future Powertrain

Gasoline Powersplit Hybrid

Electric Vehicle

Range Extended Electric Vehicle

<table>
<thead>
<tr>
<th>Energy Density of Automobile Power Sources</th>
<th>Source</th>
<th>Wh/kg</th>
<th>KJ/kg</th>
<th>Wh/liter</th>
<th>Cost per Wh</th>
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<tbody>
<tr>
<td>Carbon-zinc</td>
<td>36</td>
<td>130</td>
<td>92</td>
<td>$0.31</td>
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<tr>
<td>NiCad</td>
<td>39</td>
<td>140</td>
<td>140</td>
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<tr>
<td>Lead-acid</td>
<td>41</td>
<td>146</td>
<td>100</td>
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<td>NiMH</td>
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<td>Alkaline</td>
<td>110</td>
<td>400</td>
<td>320</td>
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<tr>
<td>Lithium-Ion</td>
<td>128</td>
<td>460</td>
<td>230</td>
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<td>Gasoline</td>
<td>13000</td>
<td>46600</td>
<td>9700</td>
<td>$0.01</td>
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</tbody>
</table>
CO2 Reduction – Sedan in WLTP

Base Engine: 1.4L, 4-cyl, TGDI, Start/stop, smart alternator control

- Engine needs to be operated as close as possible to BSFC min
- BSFC min needs to be improved
- Additional measures required on the vehicle side
- Significant technical challenges lie ahead

<table>
<thead>
<tr>
<th>CO2 – g/km</th>
<th>1.4 TGDI State of Art</th>
<th>US 2025*</th>
<th>EU 2025**</th>
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<tbody>
<tr>
<td></td>
<td>116</td>
<td>88</td>
<td>75</td>
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<tr>
<td></td>
<td>200 g/kWh</td>
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</tr>
<tr>
<td></td>
<td>170 g/kWh</td>
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</table>

*passenger car
**proposed upper limit
Thank You for Your Attention