Electrification of Passenger Vehicles
The 48 V Solution

Michael Kozan
Global Technology Shares – One Potential Scenario

Global

Annual Production Volume (Global) – Mio

FCEV
BEV
ICE PHEV
ICE (M)HEV
ICE only

ICE
BEV
FCEV

AVL Prediction 03/2018
Scenario "Medium"
Global

** Fuel Cell:** limited to specific markets

- **BEV:** Dependent on infrastructure, incentives and access restr.
- **Full Hybrid:** Primarily with Japanese OEM’s
- **Mild Hybrid:**
  - 48 V in various configurations P0 – P4
  - Power Increase 15 → 20 → 30 kW
  - ICE utilizes synergies
- **Conventional ICE:**
  - Significantly higher effort for emission compliance (RDE, China6, SULEV xx, ...)
  - “Zero Impact Emission Concepts”

2025 → 50% electrified - still 100 mio ICE’s - high scatter of predictions
Solution Trend

**today**
- Miller, Atkinson

**tomorrow**
- VCR, HCCI, UHP, ..... 
- Extended Miller, Advanced Boosting

Spark Ignited

Extended 48V systems (20→30 kW) as enabler for low emission & CO₂

HCCI. Homogeneous Charge Compression Ignition  
VCR Variable Compression Ratio, UHP Ultra High Injection Pressure

Mild Hybrid as enabler for next refinement level of ICE
Solution Trend

today

**Lean NOx Trap + SCR**

Compression Ignited (Diesel)

**tomorrow**

**Advanced EAS & Temperature Management, Refined Operation Strategies**

**48V**

Extended 48V systems (20→30 kW) as enabler for low emission & CO₂

Mild Hybrid as enabler for next refinement level of ICE
AVL 48V Mild Hybrid Solutions
Roadmap - 3 Generations of functionalities

Add On Solutions
Functionality:
- Low-End Torque Fill
- Boost
- Recuperation (combustion engine off)
- Extended Coasting
- Engine Start (Low Temp tbc.)
- Generating while standstill
- AC - Conditioning while engine off
- Advanced Emission Management

Dedicated Propulsion
Functionality:
- Recuperation (combustion engine decoupled)
- Extended Coasting (Engine decoupled)
- e-Drive (incl. Launch and Creep; e.g. 30 kph)
- Autonomous parking (electrical)
- Engine Start (Low Temp tbc.)

Full Scale EE Ancillaries
Functionality:
- Heating
- Braking
- Steering
- E-Closure
- ...

Roadmap
- today
- 2020
- 2025
Solution Overview 48V (M)HEV

Add On Solutions
Benefit 6 – 12%

- P0 + eSC
  Belt electric Supercharger

Modular & Dedicated
Benefit 12 – 20%

- P0 + P4
  Belt eAxle Parallel Module

- P2

Vehicle Level Auxiliaries
Benefit 3-4%

Roadmap

2017 2020 2025
48V P2 Gasoline Vehicle
CO2 reduction potential in WLTC example

13% CO₂ potential reduction by means of 48V hybridization
- Further 4,4% CO₂ potential reduction by means of additional base engine measures
- Overall WLTC CO₂ reduction up to 20,5%
Electrification of the ICE Features & Options

- Catalyst heating element
- Electrical coolant pump
- Electric Supercharger
- Electric Camphaser
- Elimination of FEAD
- Oil cooler/filter module with e-pump
- 48V 20kW e-Motor
The ideal base engine for 48 Volts
Package Envelope

Additional e-motor drive assembly

- Removal of FEAD and oil pump drive
  - 40mm
  + 20mm
  +60 mm

+/- 0mm
Ideal base engine for 48v
Minimised overall weight increase

Production engine
&
48V electrification

Electrified base engine
&
48V electrification

Integrated solutions will have a mass benefit
Electrification of the ICE Integration
Electrification of the ICE Integration

Fits to current vehicle tooling without major redesign of sheet metal
48V Solutions in the market

Modular

The BSA fuel-saving hybrid functions:
- 48V Water Pump
- Easy start
- Boost up to 2500 rpm
- Energy recovery up to 12.5 kW
- Shifting of the load point
- Coasting with engine off
- extended stop/start with intelligent engine shutoff even at low speeds

Integrated

The six-cylinder gasoline engine M 256 features:
- 48 V electrical system.
- Electric auxiliary compressor (eZV) (300ms 0 to 70,000rpm),
- Integrated Starter-Alternator (ISG) provide excellent drivability with no turbo lag.
- Boost (15 kW)
- Almost imperceptible restart of the engine

http://www.greencarcongress.com/2016/10/20161030-benz.html
Electrification Technologies Passenger Cars

Hybrids

- Advantages:
  - Re-Use of & Transition to BEV
- Customer Value:
  - Limited / regional advantage

Source: Toyota
**Electrification Technologies Passenger Cars**

**48V**

**Large**

**Medium**

**Small**

**12V/12V**

**48V P2 / P4**

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**Advantages:**
- Similar fuel consumption as HV
- Lower cost than HV

**Customer Value:**
- Inner city electric driving
- Limited (!) e-Drive

**Challenges:**
- Upgradability of power

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Source: www.schaeffler.com
Making a Difference in the World
Secure City Access for Tomorrow

123g CO2/km

Highest Efficiency Based using ICE Technology

90g CO2/km

E-Axle 20kW, PlugIn 3,3kW

75g CO2/km

Electric Axle 30kW
Electric Range 15 – XX km
E-Speed 65kph

<60g CO2/km (TARGET)

2016

2017

2018
CITY access hybrid
Performance req. 48V systems

- Mild hybrid with 48V is the target vehicle
- Performance requirements in EV mode
- Urban driving
- Single architecture
- Vehicle segments:
  - B/C
  - D/E

High Level Target Settings:
- Inner City Range ~10 – 20 km in NEDC
- Overall system cost at same level of High voltage HEV

Up to **C-Segment** peak power requirement is **25 – 35 kW** for the electric system
**D/E Segment > 45kW**

Modular system design for power and torque scalability especially in the electrical system.
P2 Side Mounted Modules on Transmission

- Maximum flexibility to use different engines and transmissions
- Mechanical and functional integration of A/C compressor
- Easy assembly using pre-tested modules
- Torque transfer via belt, chain drive or helical gears
- Low Voltage Connection Systems
AVL 48V Mild Hybrid Solutions
Powertrain architectures

48V Powertrain architectures

- P0: The e-motor is installed in the belt drive system of the combustion engine.
- P1: The e-motor is fixed to the crankshaft of the combustion engine.
- P2: The e-motor is installed between combustion engine and transmission. A C0 clutch can decouple the engine from the powertrain.
- P3: The e-motor is connected to transmission output
- P4: electrical rear axle.
AVL will identify requirements of P4 module, 48V BSG and battery with help of simulation (fuel consumption & performance) and packaging/mech. integration study.

The selection of the components is driven by the following boundaries:

- Project Targets fuel economy increase tbd.
- Available space for mechanical integration
  - BSG including mounting concept and tensioner system
  - Battery including cooling interface
  - P4 module including mounting concept and interface to rear differential or drive shafts
  - DCDC Converter and Charging System
- Component availability
- Component cost

The final concept will be a result of iterative loops during the concept phase as shown on the following slide.
### 48 V Features and functions vs. architectures

<table>
<thead>
<tr>
<th>Function</th>
<th>P0</th>
<th>P1</th>
<th>P2</th>
<th>P0/P3</th>
<th>P0/P4</th>
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</thead>
<tbody>
<tr>
<td>Advanced stop start</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
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<tr>
<td>Charging at standstill</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Charging at driving</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Recuperation</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Boost</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Sailing</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Coasting</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>eCreep</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Electric drive</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Engine shutdown assist</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Engine stall protection</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
</tbody>
</table>

- **Customer Value/Experience**: Degree of fulfillment
- **AVL**: Logos and graphics

Confidential
System Approach

5,76 kWh

Scaling Range by 13 Cells
Power Output Limited

1 Module 13 Cells = 48V
1 Module 13 Cells = 2.88 kWh

Reduction of losses to less than an quarter

Modular system design for power and torque scalability –
3 Power Levels (M)HEV / City Access
### 48V PHEV Demo
AVL 48V Battery 12s4p configuration

![AVL Battery](image)

#### 12s4p Configuration

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal Voltage</td>
<td>44 V</td>
</tr>
<tr>
<td>Nominal Energy</td>
<td>10.6 kWh</td>
</tr>
<tr>
<td>10s Discharge Current</td>
<td>1600 A</td>
</tr>
<tr>
<td>30s Discharge Current</td>
<td>1144 A</td>
</tr>
<tr>
<td>Continuous Discharge Current</td>
<td>508 A</td>
</tr>
<tr>
<td>10s Charge Current</td>
<td>608 A</td>
</tr>
<tr>
<td>30s Charge Current</td>
<td>540 A</td>
</tr>
<tr>
<td>Continuous Charge Current</td>
<td>200 A</td>
</tr>
<tr>
<td>Weight (Module)</td>
<td>52 kg</td>
</tr>
<tr>
<td>Volume (Module)</td>
<td>27 L</td>
</tr>
<tr>
<td>Gravimetric Energy Density</td>
<td>203 Wh/kg</td>
</tr>
<tr>
<td>Volumetric Energy Density</td>
<td>392 Wh/L</td>
</tr>
</tbody>
</table>

*All values at 25°C.*
Final electric machine model: Requirements and simulation checklist

<table>
<thead>
<tr>
<th>E-machine design</th>
<th>Requirement</th>
<th>Simulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active stack length</td>
<td>≤200mm</td>
<td>150mm</td>
</tr>
<tr>
<td>Stator outer diameter</td>
<td>≤200mm</td>
<td>190mm</td>
</tr>
<tr>
<td>E-machine torque (S2)</td>
<td>≥135Nm</td>
<td>134.5Nm</td>
</tr>
<tr>
<td>E-machine torque ripple at max. torque (S2)</td>
<td>≤15%</td>
<td>16.6%</td>
</tr>
<tr>
<td>E-machine power (S2)</td>
<td>≥31kW</td>
<td>32.5kW</td>
</tr>
<tr>
<td>E-machine power (S1)</td>
<td>≥5kW</td>
<td>26.6kW</td>
</tr>
<tr>
<td>E-machine power factor</td>
<td>≥0.9</td>
<td>0.939</td>
</tr>
<tr>
<td>E-machine max. speed</td>
<td>≥10500rpm</td>
<td>10500rpm</td>
</tr>
<tr>
<td>Copper fill factor with 0.8mm diameter copper wire</td>
<td>≤42%</td>
<td>40.1%</td>
</tr>
<tr>
<td>Inverter DC voltage</td>
<td>≤48V</td>
<td>48V</td>
</tr>
<tr>
<td>Inverter maximum power</td>
<td>≤35kVA</td>
<td>34.6kVA</td>
</tr>
</tbody>
</table>
### Key System Attribute Targets

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>City Access</td>
<td>Sellable value inner city driving.</td>
</tr>
<tr>
<td>Agility</td>
<td>Boost performance even at low temperature.</td>
</tr>
<tr>
<td>Modularity</td>
<td>3 Power Levels and Full Hybrid system for larger vehicles</td>
</tr>
<tr>
<td>Emission</td>
<td>Support even at low temperature</td>
</tr>
<tr>
<td>Weight</td>
<td>Less than 60kg additional weight for City Access PHEV</td>
</tr>
<tr>
<td>Cost</td>
<td>Lower than an high voltage HEV</td>
</tr>
</tbody>
</table>
48V Solutions – Summary

- **48V standard by 2020+** for Europe and China and NA.
- The **predominant** volume will be **48V BSG** solutions with 12kW.
- Integrated solutions expected to be introduced beyond 2020 starting form top segment.
  - Power level expected to move from **15kW towards 30 kW**
  - New architectures will move to transmission side or will be transmission integrated family concepts
- **Strong focus on modular solutions 25+kW**
  - P0/P4 e-axles
  - P2 parallel hybrids + starting device
  - P0/P3
- **48V Architectures are cost effective solutions between 12 V and High Voltage Hybridization.**
  - Cost of 30% of PHEV (¥85,000 to ¥125,000)
  - Ability to re-use common vehicle parts (Engines, Transmissions) with modular designs for hybrid and non-hybrid versions, or use current tooling
THANK YOU
Questions?
48V PHEV Demo
AVL 30kW e-Axle

190mm diameter, 150mm length, 48VDC, 680Arms, N30UH

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**Power, W**

**Torque [Nm]**

**Speed [rpm]**

Torque, S2, 20°C
Torque, S1, 20°C
Power, S2, 20°C
Power, S1, 20°C