EFFICIENT POWERTRAIN SOLUTIONS
12 V TO 800 V
RIGHTSIZING ELECTRIFICATION
AUTOMOTIVE SUMMIT 2016
BITEC - BANGKOK
MARKET SHARES 2025
OVERVIEW

North America

<table>
<thead>
<tr>
<th>BEV</th>
<th>FC</th>
<th>HEV</th>
<th>PHEV</th>
<th>MHEV</th>
<th>ICE</th>
</tr>
</thead>
<tbody>
<tr>
<td>84%</td>
<td>1%</td>
<td>0%</td>
<td>2%</td>
<td>1%</td>
<td>3%</td>
</tr>
</tbody>
</table>

EUROPE

<table>
<thead>
<tr>
<th>BEV</th>
<th>FC</th>
<th>HEV</th>
<th>PHEV</th>
<th>MHEV</th>
<th>ICE</th>
</tr>
</thead>
<tbody>
<tr>
<td>76%</td>
<td>1%</td>
<td>4%</td>
<td>17%</td>
<td>1%</td>
<td>3%</td>
</tr>
</tbody>
</table>

ASIA

<table>
<thead>
<tr>
<th>BEV</th>
<th>FC</th>
<th>HEV</th>
<th>PHEV</th>
<th>MHEV</th>
<th>ICE</th>
</tr>
</thead>
<tbody>
<tr>
<td>85%</td>
<td>1%</td>
<td>1%</td>
<td>3%</td>
<td>10%</td>
<td>1%</td>
</tr>
</tbody>
</table>

Japan/Korea

<table>
<thead>
<tr>
<th>BEV</th>
<th>FC</th>
<th>HEV</th>
<th>PHEV</th>
<th>MHEV</th>
<th>ICE</th>
</tr>
</thead>
<tbody>
<tr>
<td>59%</td>
<td>1%</td>
<td>1%</td>
<td>3%</td>
<td>18%</td>
<td>1%</td>
</tr>
</tbody>
</table>

Very Conservative Shares of xEV

Source: IHS Q4 2015
MARKET SHARES 2025
TREND AND TIPPING POINT

Trend Shows significant Increase of Electrification
Past half year ("Dieselgate") and tight future Regulatory push Electrification

Source: IHS Q4 2015
MARKET SHARES 2025
EXPECTED MARKET SHARES

Very Conservative Shares of xEV
MARKET SHARES 2025
EXPECTED MARKET SHARES

- **Migration** from MHEV towards **higher integrated** solutions and HEV on lower voltage to achieve future CO2 and Emission Regulatory. (EU/CN)
- Discussion on **City Access Zones** and especially the precise **definition** is seen as a **decisive factor** for BEV and/or PHEV.
- **Dedicated Hybrid Transmissions** get more into the focus due to higher volumes.
- **BEV Cell prices** are seen **move further down** (today: 145 USD/kWh GM Volt Gen2) and to further **increase the energy density**.
MARKET SHARES 2025 SOLUTIONS

Mild & Micro Hybrid & Ancillary Electrification
Efficiency Hybrid
Battery Electric Vehicle w/o Range Extender
Fuel Cell Electric Vehicle
Plugin Hybrid Electric Vehicle

All degrees of electrification in passenger car, different Customer
MARKET SHARES 2025
RIGHT SIZING VOLTAGE

Rightsizing
Standardization
Market Demand

Battery

Function
Mild & Micro Hybrids & Ancillary Electrification

Efficiency Hybrid

Cost / Complexity

Fuel Cell Electric Vehicle

All degrees of electrification in passenger car, different Customer
CHANGE OF BOUNDARIES
POWERTRAIN ELECTRIFICATION

- Customer Demands
- Vehicle Technology
- Legislation

Engine
Transmission
Electrification
Vehicle
DRIVING EMOTION / FUN TO DRIVE

High Efficiency

- 1,6l TGDI, e-supercharger
- 104 kW/4000 rpm
- FE Target: 90 g/km CO₂

Mild Hybrid + eSC

LEGISLATION & HOMOLOGATION

High Performance

- 1,75l TGDI, e-supercharger
- 400Nm / 3500rpm
- 350HP / 6500rpm (148 kW/l)

(Plug In) - Hybrid

BEV
EFFICIENT POWERTRAIN SOLUTIONS IS HERE TO STAY

- Fleets will remain **predominantly 12 V** due to cost
- 12 V vehicles will have significant impact on **fleet fuel consumption**
- **Innovation** for 12 V vehicles is mandatory
EFFICIENT POWERTRAIN SOLUTIONS
12 V POWER SUPPLY SYSTEM

- After stop/start, Intelligent Power Supply Systems will become standard
- Dual Batteries or pure Li-Ion batteries gaining
  - Charge acceptance and discharge power
  - Denso already sold > 1 Mio 12V Li-Ion batteries
EFFICIENT POWERTRAIN SOLUTIONS
WHY STOP AT 48V?

Significant cost saving...

max. voltage < 60 V
⇒ NO protection against contact required

... at attractive functionality

- 14…16+ kW generating
- 8…12+ kW motoring
- Several hybrid options P1, P2, P3, P4
- Unified VDA-standard
EFFICIENT POWERTRAIN SOLUTIONS
4 DRIVERS FOR 48 V
EFFICIENT POWERTRAIN SOLUTIONS BASIC MILD HYBRID FUNCTIONALITIES

- Start / Stop with comfortable belt-start
- Load Leveling / reduce Load
- Load Leveling / increase Load
- Sailing / Coasting*
- Recuperation
- Pure Electric Driving

*feasible with AT, DCT or e-clutch

Velocity [km/h] vs. Time [s]
## EFFICIENT POWERTRAIN SOLUTIONS
FUNCTIONALITIES ARE SYSTEM DEPENDENT

<table>
<thead>
<tr>
<th>Advanced Stop/Start</th>
<th>Main Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comfort Auto Stop Shutdown Assist</td>
<td></td>
</tr>
<tr>
<td>Comfort Auto Start</td>
<td></td>
</tr>
<tr>
<td>Enhanced Change of Mind</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Torque Split Boost</th>
<th>Main Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>EM** Dynamic Boost</td>
<td></td>
</tr>
<tr>
<td>EM** Efficiency Generation</td>
<td></td>
</tr>
<tr>
<td>eSC Dynamic Boost</td>
<td></td>
</tr>
<tr>
<td>Sailing</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pure Electric Driving</th>
<th>Main Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric Maneuvering</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Recuperation</th>
<th>Main Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coast down recuperation</td>
<td></td>
</tr>
<tr>
<td>Braking recuperation</td>
<td></td>
</tr>
</tbody>
</table>

### Segments

<table>
<thead>
<tr>
<th>A – C</th>
<th>&gt; C</th>
</tr>
</thead>
<tbody>
<tr>
<td>12V</td>
<td>48V</td>
</tr>
</tbody>
</table>

**CO₂ Costs**

**Costs**

- CO₂
- Cost/benefit
- fun2drive
- Comfort

* eSC: Electric Supercharger
** EM: Electric Motor
EFFICIENT POWERTRAIN SOLUTIONS
IMPACT OF FUNCTIONALITY

C-Segment, 4 cyl. TGDI, automatic transmission, NEDC

- Basis w/o STST
- STST + IPSS Regen Brake
- Regen Brake + Boost
- Pwtr. Measures enabled by 48V

New Basis

"Indirect" Benefit

CO₂ Emissions

12 V

48 V

80%

90%

95%

100%
EFFICIENT POWERTRAIN SOLUTIONS
IMPACT OF DRIVING CYCLES

*STST inhibited in China City due to energy balance

C-Segment, 4 cyl. TGDI, automatic transmission
EFFICIENT POWERTRAIN SOLUTIONS
EMISSION & CO2 IMPROVEMENT

- Velocity [km/h]
- CO2 [g]
- NOx [mg]
- BSG [Nm]
- Time [s]

Graphs showing comparisons between Base Vehicle and 48V BSG in terms of emissions and performance.

- CO2 [%] and NOx [%] improvements.
- 13% CO2 reduction indicated.

Confidential

23rd June 2016
EFFICIENT POWERTRAIN SOLUTIONS
EMISSION & CO2 IMPROVEMENT

- Velocity [km/h]
- BSG [Nm]
- CO₂ [g]
- NOₓ [mg]
- Time [s]

- Base Vehicle
- 48V BSG

13% reduction in emissions
EFFICIENT POWERTRAIN SOLUTIONS
EMISSION & CO2 IMPROVEMENT

- Velocity [km/h]
- CO2 [g]
- NOx [mg]
- BSG [Nm]

- Base Vehicle
- 48V BSG

Time [s]

Emissions

AVL
EFFICIENT POWERTRAIN SOLUTIONS
4 DRIVERS FOR 48 V
EFFICIENT POWERTRAIN SOLUTIONS  
ELECTRIC POWER SUPPLY SYSTEM

- Three main trends, pushing 48 V Power Supply System (PSS)
- Fewer opportunities for electrical energy generation
- Increasing continuous power consumption
- More high power consumer
EFFICIENT POWERTRAIN SOLUTIONS
ELECTRIC PSS DESIGN REQUIRED!

Vehicel Measurements

- Gen Power
- Gen Capacity
- DCDC Power
- Boosting Events
EFFICIENT POWERTRAIN SOLUTIONS
ELECTRIC PSS DESIGN REQUIRED!

Power and Energy Analysis
Example: Luxury sedan w/ 48V electric supercharger

- Generator Utilization: P_act/Pmax_act
- Battery SOC Window
- Energy Share eSC: E_eSC/E_electr.

City
Hot city
Race track
Mountain
EFFICIENT POWERTRAIN SOLUTIONS
HYBRID ROAD MAP

48 V Mild Hybrid
HV Full Hybrid

today

CO₂

tomorrow
EFFICIENT POWERTRAIN SOLUTIONS
HYBRID ROAD MAP

48 V Mild Hybrid
HV Full Hybrid
HV Plug-In Hybrid

today

tomorrow

CO₂
Electric driving
Most hybrid vehicle models use standard transmissions or slight modifications thereof (e.g. P2)

- Dedicated Hybrid Transmissions (DHT) will become standard

- Toyota Prius is dominating hybrid volumes already today with DHT

DHT: Transmission not functional w/o e-machine

Market Share 2014

Source: IHS 2014
EFFICIENT POWERTRAIN SOLUTIONS
NEXT GENERATION DHT

-10% CO₂ compared to Powersplit

CO₂ emission in NEDC:
- charge sust.: 79gCO₂/km
- certification: 35gCO₂/km

-10% Piece Cost compared to Powersplit
EFFICIENT POWERTRAIN SOLUTIONS
PERFORMANCE & ENERGY MANAGEMENT

Gasoline

500 km/min
► 40L/min @8l/100km

400V-Tesla-System

9 km/min
► 400 km in < 44,4 Minuten

800V-System

27 km/min
► 400 km < 14,9 Minuten

…Charging Performance
EFFICIENT POWERTRAIN SOLUTIONS
WEIGHT AND INTEGRATION

400 V @ 100 A
800 V @ 100 A

2 x Power output with better repeatability @ 800 V

400V 90mm² 800V 35mm²

...Higher Performance with less weight and lower current
EFFICIENT POWERTRAIN SOLUTIONS
KEY AREAS OF ELECTRIFICATION

For an Exciting, Reliable and Durable Product