Istanbul, 2nd and 3rd of November 2017
Dr.-Ing. Thomas Hülshorst, Group Vice President Electronics and Electrification, FEV Group GmbH
Connectivity, autonomous driving, shared mobility and powertrain electrification are expected to strongly impact the automotive industry.

CASE – CONNECTED, AUTOMATED DRIVING, SHARED MOBILITY AND ELECTRIFICATION

"Connectivity, autonomous driving, sharing and electric drive systems – each of these four trends has the potential to turn our industry on its head. Yet the real revolution lies in intelligently linking the four trends."

Dr Dieter Zetsche, CEO of Daimler AG and Head of Mercedes-Benz Cars

Source: FEV

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Electrification, mobility and automated driving are expected to be introduced with significant market shares until 2035 time frame.

SALES FORECAST IN MILLION UNITS (BASED ON DMM)

- Pure electric vehicle sales are projected to grow strongly until 2035 driven by
  - Mid-term: governmental regulation
  - Long-term: cost reduction and consumer adoption
- Private ownership projected to remain the dominant source for vehicle sales throughout 2035
- E-Hailing seen as major form of shared mobility
- High level automation (level 3+) is projected to push into market starting from 2025 onwards
- Top-down market introduction from premium to volume applications
- Consumer adoption driven by potential to free up time for productivity increase and social media
- First Level 4 users are expected to be commercial robo-cap fleets for e-hailing

Source: FEV
For European market FEV expects a major shift to plug-in and battery electric vehicles – distribution mainly depending on customer preferences.

FUTURE POWERTRAIN SCENARIOS PASSENGER CAR – VEHICLE REGISTRATIONS

- **FEV Scenario – most likely**
- **Scenario “BEV break-through”**
- **Scenario “PHEV”**

**Future of E-mobility**

**CO₂ fleet emission:**
- <95 g/km*
- <75 g/km*
- <65 g/km*

*: normalized to NEDC
e-gas: gas produced by electricity from renewable energy
Source: FEV

FEV High voltage battery development

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What is THE ELECTRIC CAR of Future Mobility?

Future Mobility will be diverse!
Combination of Individual, Shared and Public Mobility

- Micro cars
- Passenger cars
- High Performance cars
- People Mover
- Public transportation
- Commercial vehicles

Vehicle Hub: Swap the vehicle or the drivetrain!
There is a wide variety of ELECTRIC CARS already today!

Source: KARSAN, BMW, StreetScooter, Imperia, FEV
EV Powertrain System and Components Today:
Still a quite complex and inflexible system for a wide range of applications
The Next Generation EV Powertrain: Modular and Scalable Concepts for Wide Range for Electrified Vehicles

- Highly integrated and connected controls and E/E architecture
  - Powertrain Control Unit
  - Battery Management System
  - Telematics
  - Motor Controller
  - Charging Control

- Highly integrated Electric Drive Unit
  - Electric Motor
  - Transmission
  - Power Electronics

- Highly integrated Battery
  - Modular Battery
  - Cooling / Heating
  - Housing → part of chassis structure
  - Fast charging
The Next Generation EV Powertrain: Modular and Scalable Concepts for Wide Range for Electrified Vehicles

Scaleable “Skateboard” chassis

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Highly integrated and connected controls and E/E architecture
- Powertrain Control Unit
- Battery Management System
- Motor Controller
- Charging Control

Highly integrated Electric Drive Unit
- Electric Motor
- Transmission
- Inverter

Highly integrated Battery
- Modular Battery
- Cooling / Heating
- Housing → part of chassis structure
- Fast charging
How Connectivity Supports EV Powertrain Operation

Assisted

Predictive Cruise Control
Electric Range Optimizer

Connected

Cloud Services
Highly accurate Range Prediction

Electrified

Connected Fast Charging and Thermal Management

Energy consumption comparison:
- Base: 14.5 kWh/100 km
- Optimized: 13.4 kWh/100 km

Energy reduction of 7.3% along evaluated RDE cycle.
Assisted Map based information, ADAS sensors (camera, LiDar) and V2X communication is used to analyse route and traffic flow

<table>
<thead>
<tr>
<th>Objects</th>
<th>Data source</th>
</tr>
</thead>
<tbody>
<tr>
<td>speed limit shield, curvature</td>
<td>map data and camera recognition</td>
</tr>
<tr>
<td>traffic light</td>
<td>V2X communication, camera</td>
</tr>
<tr>
<td>Average traffic speed, traffic jam, etc.</td>
<td>V2X communication, camera, LiDar</td>
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</tbody>
</table>
FEV SMARTDRIVE
The smart vehicle – assisted / connected / electric

Assisted

Optimization of speed trajectory using eHorizon to minimize energy consumption at comparable travel time. → 7.3% energy consumption reduction is achieved at test track (real life driving cycle)!

![Graph showing speed and energy consumption comparison](image)
Usage of in-vehicle data for new cloud services like cloud based range prediction, real time traffic or blocked road warning.
Highly Accurate Range Prediction for Electric Vehicles

IN-VEHICLE DISPLAY OF REMAINING RANGE OF ELECTRIC VEHICLE

- Cloud-based range prediction service for electric vehicles
- Based on
  - recorded historical data,
  - driver behavior,
  - relevant vehicle and environment states,
  - traffic information and
  - map attributes
- a range star is calculated
- Test results showed accuracies better than 40m

ICS = intelligent Connection Services

iCU = intelligent Connection Unit
Highly integrated and connected controls and E/E architecture: The FEV LIION Full Function EV Controller, Stage 1

COMBINATION OF FEV BMS AND FEV VCU TO JUST ONE SINGLE CONTROLLER
The Next Generation EV Powertrain: Modular and Scalable Concepts for Wide Range for Electrified Vehicles

Highly integrated and connected controls and E/E architecture
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Highly integrated Electric Drive Unit
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Highly integrated Battery
- Modular Battery
- Cooling / Heating
- Housing → part of chassis structure
- Fast charging
Battery Housing as Part of Integrated Structure of Vehicle to Reduce Overall Weight

PROJECT EXAMPLE: SPORTS CAR

- Electric Vehicles often require all available space for battery package
- Battery housing can be designed as part of the vehicle body structure
- Crash is absorbed also by the integrated structure within the battery pack

Source: Lampo3b Protoscar, TKSE, Imperia

2nd International Automotive Engineering Conference
Despite regenerative braking:

- Linear relationship between energy consumption and vehicle weight:

\[
\frac{1 \text{ kWh}}{100 \text{ km} \cdot 100 \text{ kg}}
\]

- Weight reduction key factor to increase electric driving range

Source: FEV database 2017
Due to continuous development of pouch and prismatic cells next generation cell energy density will catch-up with cylindrical* performance

MARKET TRENDS  CELL SELECTION

<table>
<thead>
<tr>
<th>Applikationen</th>
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<tbody>
<tr>
<td>Samsung prismatic cell 63 Ah:</td>
</tr>
<tr>
<td>□ BMW i3</td>
</tr>
<tr>
<td>□ Change from 63 Ah to 94 Ah cells: 22kWh → 33 kWh, 94Wh/kg → 140Wh/kg</td>
</tr>
<tr>
<td>LG Chem pouch 56 Ah:</td>
</tr>
<tr>
<td>□ Renault ZOE</td>
</tr>
<tr>
<td>□ Chevrolet Bolt</td>
</tr>
<tr>
<td>SK Innovation pouch 37,5 Ah</td>
</tr>
<tr>
<td>□ Kia Soul EV</td>
</tr>
</tbody>
</table>

*) 18650 or 20700 used in Tesla vehicles
Battery Electric Vehicles need scalable, light and ultraflat Batteries at highest specific energy densities

SPECIFIC ENERGY ON PACK LEVEL

Source: FEV database 2017, TBC Battery Packs of Modern xEVs Report (2016)
FEV has developed a very compact low weight EV battery for an European OEM with an outstanding pack factor of 1.5 and ultra-flat design.

**FEV FLAT EV BATTERY**

Sample Picture, not original battery pack

**Key Innovations**
- High intrinsic strength with low weight
- Complex and multifunctional component structures
- Integrated channels for cooling fluid
- Automated joining by glued or cold joint connections
- **Pack factor of < 1.5**
- **Ultra-flat design:** Total height = Cell height x 1.23
  25mm of additional height only, including bottom plate w/ cooling!

**E/E parts**
- Cells: 67%
- Module Housing: 12%
- Pack Housing: 18%

*) Busbars, BMS, wiring, relays
The Next Generation EV Powertrain: Modular and Scalable Concepts for Wide Range for Electrified Vehicles
Introduction to the FEV Electric Drive Unit

INTRODUCTION

- Today there is an increasing demand for electric drive units
- Traditionally built as „gearbox“ and „E-Motor“ and a separate, vehicle mounted inverter
- Next Generation is a highly integrated scalable solution, for front-, rear-, and all wheel application
- Applicable to Hybrid- and Electric-Vehicles
- FEV worked out a highly integrated concept for C/D class, up to light Duty Vehicles

DEVELOPMENT TARGETS

- High Efficiency
- Low Noise
- High Reliability
- Compact Package
- Lightweight Design
FEV Electric Drive Unit
Key innovations to gain a highly efficient and cost effective solution

FEV SOLUTION
- Coaxial design: Low/No axial forces on housing bearings → Low noise radiation
- First generation: Oil cooling and water cooling
- Second generation: Oil only with Si-C inverter
- Reduction gear inside E-Motor rotor as „ring gear-less“ PGS
- Park and neutral shift with one electromechanical actuator → cost reduction
- Total ratio ~ 7.2
- 2 Integrated inverters with water cooling for 6 phase EM
- Outer cooling by water jacket and inner cooling by gear set oil and centrifugal pump

Key innovations over existing technology
- Coaxial design
- New compact reduction gear concept inside EM Rotor
- Advanced system cooling with low power consumption
- Two inverters for cost and fail safe reasons
- Overall ultra-compact design

Note: Some key features are displayed on the next pages
FEV Electric Drive Unit
Features and key innovations for very compact overall package

FEATURES AND KEY REQUIREMENTS (EXTRACT)

- Designed for C/D class vehicle, max weight 2000 kg
- Max. wheel torque 3.500 Nm (Wheel slip limit front axle)
- Peak power 230 kW for 30 s
- Continuous power 100 kW (180 km/h @ 3% inclination)
- Max vehicle speed 200 km/h (Wheel speed max 1.500 rpm)
- System weight (dry) < 85 kg
- Compact solution with E-Motor, Inverter and gear set in one unit
- Integrated park lock and neutral shift with one actuator
- E-Motor max Torque > 500 Nm; max Speed 10.000 rpm
- Lifetime 15 years / 350.000 km
- Efficiency < 90% in test cycle
- Ring Gear-less planetary gear set → extreme low noise radiation
- Low cost architecture
- **Power to weight ratio ~ 3 kW/kg (including inverter and transmission)**
FEV Electric Drive Unit is scaleable to cover a wide range of applications from B segment up to medium duty vehicles.

- 60kW/120kW Single Inverter / 3-Phase Integrated ring-gear less PGS
- 100kW/230kW Double Inverter / Multiphase Integrated ring-gear less PGS
- 150kW/340kW Double Inverter / Multiphase Conventional PGS
Next Generation EV Powertrain
The FEV Approach

Highly Integrated and Scaleable Electric Drive Unit

Modular Battery Pack with High Energy Density and Flat Design

Highly Connected Central Control unit enabling predictive driving strategy and cloud services

Scalable „Skateboard“ Chassis
Key take-aways

Next Generation EV Powertrain

KEY TAKE-AWAYS

- Connectivity, autonomous driving, shared mobility and powertrain electrification are highly interconnected and are expected to strongly impact the automotive industry.

- A wide range of different types of electric vehicles will coexist for individual, shared and public transportation.

- Modular and scalable platforms are needed to deal with diversification in electric vehicles.

- The integration of connectivity and ADAS functionality will help to increase the electric range of EVs by predictive driving strategies and cloud-based highly accurate range prediction.

- Battery will remain the core component for E-Mobility. Modularity and scalability will come together with highly integrated cooling/heating. Battery housing will become a part of the vehicle body structure. Fast charging capability is a key factor for long range EVs.

- Electrical drive units with integrated electric machine, transmission and power electronics will gain a higher market share. Scalable concepts which are applicable to different kind of PHEVs and EVs in different vehicle segments will gain price benefits.

- Skateboard chassis based platforms are likely to be extended to other vehicle segments like light duty vehicles and people mover.
The Next Generation EV Powertrain: Modular and Scalable Concepts for Wide Range for Electrified Vehicles

- Micro car
- Public transportation
- Passenger cars
- High Performance car
- People Mover
- Commercial Vehicles

Source: Karsan, StreetScooter, Local Motors, Imperia, FEV

2nd International Automotive Engineering Conference
The Next Generation EV Powertrain: Modular and Scalable Concepts for Wide Range for Electrified Vehicles

Modular and scalable battery
- Complex and multifunctional component structures
- Battery housing as part of the vehicle body structure
- Crash is absorbed also by the integrated structure within the battery pack
- Highly integrated cooling / heating system optimized for fast charging and all weather conditions

Highly integrated Electric Drive Unit
- Scalable and flexible solution, for front-, rear-, and all wheel application
- Applicable for Hybrid- and Electric-Vehicles
- Compact and lightweight design
- High efficiency at low noise level

Scaleable “Skateboard” chassis
- Applicable to a wide range of vehicles from MicroCar up-to Commercial Vehicles