E-MOBILITY.

BMW GROUP TECHNOLOGY WORKSHOPS.
FLEXIBLE ARCHITECTURES.
I. PIONEERING

II. ELECTRIFICATION OF CORE PORTFOLIO

III. SCALABILITY AND FLEXIBILITY

electric mobility | December 2017
FLEXIBILITY IS THE KEY FOR E-MOBILITY.
BMW i. FROM “BORN ELECTRIC” TO “ONE PLATFORM SERVES ALL”.

2013 “Born electric”

FROM 2021 ON

One platform fits all powertrain derivatives…

- Combustion engine
- Plug-In-Hybrid
- Pure electric
CONVENIENT INTEGRATION OF THE ELECTRIC DRIVETRAIN IN HIGH CARS.
OUR VEHICLE ARCHITECTURE ENABLES INTEGRATION OF CONVENTIONAL DRIVE TRAINS, PHEVS AND BEVS IN THE SAME MODEL-LINE.

Combustion engine
PHEV-prepared since 2015
PHEV
BEV
Additional BEV-integration starting 2021
COMMON MODULAR SYSTEMS FOR ALL DRIVETRAIN-VERSIONS. INCREASED FLEXIBILITY AND REDUCED INVEST.

Architecture with common components

- Identical driver position
- Interior (cockpit, center console, seats)
- Body
- Firewall, steering, climate control
- Chassis / wheels

Sedan as example

- Plug-in Hybrid
- Electric Vehicle

delta-parts different to conventional drivetrain
CHALLENGES OF BEV INTEGRATION IN LOW VEHICLES.

- Maximum electric range
- Low driving resistance/available energy
- Flat battery with high energy-density and max. length and width
- Optimize battery height and underbody-space
- Moderate increase in height, uncompromised interior

Challenge: Best-in-class driving performances

Adequate Power/Torque

Integration of powerful el. machines in front- and rear-axle. Battery-design with high power-output

Custom-made electric machines and battery

Ideal package, weight and safety
MODULAR E-TOOLBOX.
THE ROAD TO 2025: WIDE ROLLOUT OF PHEVS AND BEVS WITH NEXT GEN OF MODULAR ELECTRIC POWERTRAIN.
GEN3 AND GEN4 UP TO 2020: EMOTIONALISATION OF OUR EXISTING xEV DRIVE TRAIN ARCHITECTURES.

**PHEV P2**
Example: 7 Series

- **+10 kW** electric power
- **+40%** electric range

<table>
<thead>
<tr>
<th>Electric Range WLTP:</th>
<th>0-100 km/h:</th>
</tr>
</thead>
<tbody>
<tr>
<td>33 km</td>
<td>5,4 s</td>
</tr>
<tr>
<td>46 km</td>
<td>5,2 s</td>
</tr>
</tbody>
</table>

**PHEV axle hybrid**
Example: i8 LCI

- **+10 kW** electric power
- **+60%** electric range

<table>
<thead>
<tr>
<th>Electric Range WLTP:</th>
<th>0-100 km/h:</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 km</td>
<td>4,4 s</td>
</tr>
<tr>
<td>50 km</td>
<td>4,4 s</td>
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</tbody>
</table>

**BEV**
Example: i3s

- **+10 kW** electric power
- **+60%** electric range

<table>
<thead>
<tr>
<th>Electric range WLTP:</th>
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<tbody>
<tr>
<td>150 km</td>
<td>7,2 s</td>
</tr>
<tr>
<td>235 km</td>
<td>6,9 s</td>
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</tbody>
</table>
INTEGRATION OF E-MASCHINE, GEARBOX AND POWER ELECTRONIC IN ONE SYSTEM.

Today

E-Machine

Gearbox

Power Electronics

Tomorrow

E-Machine, Gearbox and Power electronics fully integrated

Vehicle Integration

Weight reduction

Increase of power density

Cost reduction

Adaptive production system

New semi-conductor technologies (SiC, GaN)

Securing technological leadership

E-Mobility | December 2017.
OUR FUTURE PHEVs: UNCOMPROMISING CUSTOMER VALUE PROPOSITION.

PHEVs must be refined to offer customers an uncompromising value proposition.

BMW DRIVING DYNAMICS GENES.
BALANCED AXLE LOAD DISTRIBUTION,
LOW CENTRE OF GRAVITY.

LONG-DISTANCE DRIVEABILITY.
LOW FUEL CONSUMPTION AND
LARGE-VOLUME FUEL TANK.

HIGH ELECTRIC RANGE.
INCREASED BATTERY CAPACITY.

MAXIMUM PERFORMANCE.
TUNED ELECTRIC POWERTRAINS.

UTILITY VALUE.
MAINTAINS FULL LUGGAGE VOLUME.

INDUCTIVE CHARGING.
GREATER CHARGING CONVENIENCE.

SEATING COMFORT.
BATTERY INTEGRATION WITHOUT LOSS OF COMFORT.
BATTERY CELL.
BATTERY PERFORMANCE IS THE BASIS FOR SUCCESS OF E-MOBILITY. LI-ION TECHNOLOGY IS THE ENABLER FOR CURRENT ELECTRIC VEHICLES.

1882 1972 2013
BMW INHOUSE DEVELOPMENT AND PRODUCTION OF BATTERY MODULS AND PACKS SINCE 2008. FULL COMPETENCE IN CELL DESIGN.

Development and Production Inhouse

xEV Vehicle

Battery Pack

Subsystem/Module

Full Specification and Design Competence

Subcomponents / Electrodes

anode
cathode

separator

Jelly Roll

Cell
BMW CONTINUOUSLY INCREASES CELL COMPETENCE TO ENHANCE THE LEVERAGE FOR REALIZATION OF CUSTOMER RELEVANT INNOVATIONS.
BATTERY DEFINES PERFORMANCE AND COSTS OF ELECTRIC VEHICLES. MATERIALS DOMINATE COST STRUCTURE.

Key Performance Indicators Vehicle → Key Performance Indicators Battery → Cost Structure Battery

- **Battery Cost Structure**
  - Temperature Performance [kW, kWh@ -25°C]
  - Peak Power [kW], 10s, 50% SoC, 25°C
  - Energy Density [Wh/l]
  - Specific Energy [Wh/kg]
  - Lifetime [Cycles, years]
  - Charge Current [A]
  - Safety [hazard level @ abuse tests]
  - Cost [€/kWh]

- **Vehicle Price** ↔ Material Costs & Production Costs
- **Range** ↔ Energy Density
- **Driving Performance** ↔ Power Density (SOC, T-dependence)
- **Charging Time** ↔ Inner Resistance, Max. Current Density
- **TCO** ↔ Life Time
- **Innovation, Attractiveness** ↔ Technology Access, Development Speed

**Graphical Representation**
- Cost share e-drive system:
  - Battery 77%
  - Cells 81%
  - Material 79%
- Typical long range BEV: 49%
SUBSTANTIAL ENERGY DENSITY INCREASE AND COST REDUCTION EXPECTED. HIGHEST POTENTIAL FOR IMPROVEMENT ON MATERIAL LEVEL.

**Integration Levels of Battery**

- **Pack design**: i.e. volume utilisation cell/pack
- **Cell design**: i.e. volume utilisation jelly roll/cell
- **Electrode design**: i.e. loading
- **Material properties**: i.e. specific capacity, discharge curve

**Increasing potential to improve energy density**

**Energy Density and Costs**

<table>
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<tr>
<th>Energy Density</th>
<th>Today</th>
<th>Li-Ion optimization</th>
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<tr>
<td></td>
<td>100%</td>
<td>145%</td>
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<table>
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<th>Costs per kWh*</th>
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<td>100%</td>
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<td>70%</td>
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<td></td>
<td></td>
<td>tbd</td>
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<tr>
<th>Material</th>
<th>NCM 111/C</th>
<th>NCM 622/C</th>
<th>NCM 811/Li</th>
<th>NCM 811/Si-C</th>
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<tr>
<td></td>
<td>Solid state electrolyte</td>
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*Costs per Cell depend on Cell size and might increase on a per Cell basis.*
BMW CONSIDERS TOTAL VALUE CHAIN OF CELL – FROM CRADLE TO GRAVE.

Raw Materials and Refining
- Environmental and social standards
- Raw material optimised for chemistry design
- Use of recycled raw materials
- Securing raw material supply

Cell Design and Production
- Optimised performance/costs based on BMW application
- Securing production capacity
- Reduction CO2 footprint

Battery „2nd Life“
- Cell/module/pack design allows for secondary use
- Application on BMW sites
- Business Models to secure markets

Recycling
- Cell/modul/pack design to foster recyclability
- Development of recycling processes with ability to close material loops
- Securing recycling capacities
INTERNAL CELL HEATING TO IMPROVE LOW TEMPERATURE BATTERY PERFORMANCE IS AN EXAMPLE FOR BMW INNOVATION.

**Concept: Internal Cell Heating**
- Pre-Conditioning: < 30 Seconds
- < 0°C
- > 20°C
- Power Range

**From the Idea to Realization**
- Identification of IP: Start-Up EC-Power, USA
- Joint Development /Proof of Concept
- Test on Industrial Scale incl. **Cell Build at BMW**
- Realization and Test in a Vehicle

**Cell with int. Heating**
- BMW Cell Design

**Modul**
- Modul Design

**Battery**
- Integration in Battery

**Vehicle**
- First BMW Cell in Vehicle
ALL-SOLID-STATE: IMPROVEMENT OF ENERGY DENSITY AND COSTS. BMW EVALUATES AND ACTIVELY DRIVES THE TECHNOLOGY.

### Areas of Activities

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### Selection of Engineering Partner

- Screening and Evaluation of Concept
- Identification of Partner with high Potential
- Joint Development / Proof of Concept

### Material Groups

- **Oxides / Phosphates**
  - Mainly stable
  - Processing
  - Interfaces
- **Sulfides**
  - Processing
  - Interface
  - Stability
- **Polymers**
  - Processing
  - Voltage range
  - Operating temperature

### Electrodes

- **Roll-to-Roll All-Solid-State Electrodes**

### Cell Assembly

- **Cell Stack**

### ASSB Cell

- **1Ah All-Solid-State Cell**
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