BMW GROUP BATTERY CELL TECHNOLOGY.
WE ARE DOING OUR PART.

1.5°C

BEVs in the next 10 years
10 M

Use Phase
-50%
CO₂ per car 2030 vs. 2019

Lifecycle
-40%
CO₂ per car 2030 vs. 2019

Share of secondary materials will increase to 50%
on average per car
IN-HOUSE DEVELOPMENT AND PRODUCTION OF KEY COMPONENTS.
BATTERY CELL IS KEY COMPONENT FOR FUTURE SUCCESS OF BMW.

Battery KPI determine vehicle characteristics

- Range
- Charge time
- Driving power
- Cost

Ca. 40% of total vehicle cost is cost for the battery pack (e.g. i4).

Modul- & System Cost

<table>
<thead>
<tr>
<th>Cost</th>
<th>20%</th>
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<tbody>
<tr>
<td>Battery Cell Cost</td>
<td>80%</td>
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</tbody>
</table>

20% Cell Production Cost
80% Material Cost
LONG TERM COMPETENCE FROM MOLECULES TO CELL AND FROM BASIC RESEARCH TO APPLICATION.

Start build-up of pilot line Parsdorf
Completion 2022

Start build-up of BMW Group Battery Cell Competence Center
Completion 2019

Start dedicated R&D project on battery cell technology
Deep dive, parallel top product development

Start Li-ion development
In particular for i3/i8

FUNDAMENTAL WORKING PRINCIPLES

MATERIALS

ELECTRODES/SUBCOMPONENTS

CELLS
### BMW DEVELOPMENT SPANS OVER EARLY R&D TO CONCEPT PROOF OF BOTH, PRODUCT AND PROCESS. INDUSTRIALIZATION IS DONE WITH PARTNERS.

<table>
<thead>
<tr>
<th>R&amp;D</th>
<th>LAB</th>
<th>PILOT PRODUCTION</th>
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<tbody>
<tr>
<td>&gt; 300 contacts</td>
<td>Material characterization</td>
<td>Industrialization with partners</td>
</tr>
<tr>
<td>43 running projects</td>
<td>Chemistry development</td>
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<td></td>
<td>Recipe development</td>
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<tr>
<td>Institutes</td>
<td>Performance and safety test</td>
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<td>Academia</td>
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<td>Startups</td>
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<td>OEMs</td>
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<tr>
<td>Industry</td>
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**PRODUCT INNOVATIONS**

**PROCESS INNOVATIONS**
COMPLETE VALUE CHAIN AND LIFE CYCLE HAS TO BE CONSIDERED. CLOSED MATERIAL CYCLE FOR BATTERY CELLS IS NECESSARY.

Cobalt and lithium from certified mines in Australia and Morocco. Usage of secondary material.

Production of battery cells with 100% power from renewable sources.

Taking back batteries worldwide at the end of battery life. Enabling second use e.g. in battery storage farms.

Pushing the limits of material recycling and returning materials efficiently into the production cycle.
BATTERY SYSTEM DEVELOPMENT – TRENDS ARE BASED ON TECHNICAL NEEDS BUT ARE ALSO DRIVEN BY REGULATORY MEASURES.

**Present**
- Design: Pack as individual component based on modules and with own structural capability and housing.
- Safety: Mainly based on Chinese regulation: no propagation/battery integrity maintained for >5min in case of a thermal runaway of one cell.
- Sustainability: Own responsibility but no mandatory requirement.

**Trend**
- Design: Higher integration to optimize filling factor/energy per volume e.g. cell-to-pack, cell-to-chassis.
- Safety: Step-wise increase to 40min forecasted. Best solution: “propagation stop”.
- Sustainability: Carbon footprint declaration 2024 on-wards (limit for CO₂ footprint in g/kWh expected); amount of recycle used and recycling rates will become regulated for most relevant materials → in particular driven by EU COM.

Trends/changes in requirements will influence cell technology choice (pouch, cylindrical, prismatic hardcase).
BATTERY TECHNOLOGY ROADMAP – TRANSITION FROM PERFORMANCE/RANGE MAXIMIZATION TOWARDS PORTFOLIO ORIENTED (PERFORMANCE VS. LOW COST).
TRENDS IN MATERIAL AND CELL DEVELOPMENT.

**ANODE MATERIAL**
- Graphite: 360 mAh/g
- Graphite + SiOx: 500 – 600 mAh/g
- Si – C Composite: 1,200 mAh/g

**CATHODE MATERIAL**
- NMC 111: 150 mAh/g
- 532, 622: 180 mAh/g
- 811: 210 mAh/g
- >90% Ni: 230 mAh/g

**RISKS**
- Stability (e.g. Ni-rich materials) and cost (e.g. Si-anodes) of “high performance materials”.
- Materials have to be compatible with electrode and cell design trends.

**ELECTRODE DESIGN**
- Increased loading (limited by power requirement)
- Optimized coating (e.g. reduced uncoated area) (limited by manufacturing tolerances and safety issues)

**CELL DESIGN**
- Increased volume utilization jelly roll to cell (e.g. stacking compared to winding → risk: cost)
- Increased packing density → risk: swelling force
- Reduced Al/Cu foil and separator thickness → risk: handling, safety
- Increased cell size with increased active-/inactive ratio → risk: maintain safety level
MATERIAL AND PROCESS DEVELOPMENT HAVE TO BE DONE IN PARALLEL.

**Typical Challenges/Risks**
- Protective coatings and particle structures can be damaged.
- Final electrode density can not be reached.
- Requirements for cell assembly are not met (e.g. camber effect).

**Counter Measures**
- Coating recipes have to be optimized, e.g. Cathode material powder densities have to be optimized, binder/conducting agents adjusted.
- Substrates foils have to be carefully selected.
- Calendering processes have to be improved.
RENAISSANCE OF LITHIUM-IRON-PHOSPHATE (LFP) – MOTIVATION AND LIMITATION OF LFP FOR LOW-COST APPLICATIONS.

LiMO$_2$ Schichtoxid
e.g. LiNi$_x$Co$_y$Mn$_{1-x-y}$O$_2$ – NCM

LiMPO$_4$ Olivin
e.g. LiFePO$_4$ – LFP

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<tr>
<th></th>
<th>NCM 811</th>
<th>LFP</th>
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<tbody>
<tr>
<td>Specific capacity</td>
<td>200 Ah/kg</td>
<td>158 Ah/kg</td>
</tr>
<tr>
<td>Mean cell voltage</td>
<td>3.68 V</td>
<td>3.22 V</td>
</tr>
<tr>
<td>Specific energy</td>
<td>736 Wh/kg</td>
<td>509 Wh/kg</td>
</tr>
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</table>

LFP material still the same. Optimization of cell and pack design made LFP attractive for entry segment.
ALL-SOLID-STATE BATTERY AS THE NEXT GAME CHANGER.

STATE OF THE ART
LI-ION CELL

Next-gen
Li-metal /solid electrolyte cell (ASSB)

Gr/Si Anode

NMC Cathode

Liquid Electrolyte,
Porous Separator

Lithium-Metal
Anode

NMC Cathode

Solid State Electrolyte
Oxid | Polymer | Sulfid

Main Differentiation
Replace liquid electrolyte by Li-ion conducting solid electrolyte \(\rightarrow\) increase inherent safety
Replace graphite or silicon-graphite anode by Li-metal anode \(\rightarrow\) increase energy density

Potential

- Higher inherent safety level allows for
  - High performance materials
  - Large cell formats
  - Reduced secondary safety measures in the battery pack
- Solid electrolyte allows for innovative cell concepts [e.g. bipolar cells]
- Li-metal anode lead to energy density increase

Challenges

- Pressure necessary to stabilize interfaces and allow for good lifetime
- Different thermal management needed (focus on heating instead of cooling)
- Volume change during charge/discharge for Li-metal anode
- Rate capability for Li-metal anodes
- Robustness of material system in production and over lifetime

High potential in direction of safety and energy density. Cost still unclear but essential. Promises still need to be verified. Industrialization only reasonable after positive concept proof.
THANK YOU FOR YOUR ATTENTION!