Powertrain Strategies for the 21\textsuperscript{st} Century: Next Generation Electric Vehicle Strategies

Li-ion Batteries for Electrified Mobility

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Robert Bosch Battery Systems LLC
Bosch Powertrain Electrification – future mobility
Worldwide Footprint

~ 1800 employees working on power train electrification within Bosch group

EM: E-Motor
PE: Power Electronics
BAT: Battery Pack
CELL: Battery Cell
R&D and Production
Global Locations – North America

- Springboro, Ohio Production plant, (50,000+ vehicle packs built since 2006, Li-Ion SOP Nov 2012)
  - Technical and Product Services in place for Aftermarket to support complete Product Life Cycle
  - Approx. 150 employees

- Orion, Michigan Engineering facility (several OEM projects since 2005)
  - Experienced xEV battery pack mechanical, HW-, SW- and systems-engineering
  - On-site development labs, test labs, and validation facilities for Li-ion
  - Approx. 100 employees

Mission:
Produce and Deliver ‘Zero Defect’ Battery Packs ‘On-time’ for Production and Service Customers.
Influence variables on eMobility

- Applications
- Market volume
- Customer expectations
- Requirements

Technology
- Web 3.0
- EV-train

Business models
- Carsharing
- moovel

User experience UX
- KPIs

Infrastructure

Legislation

Megatrends
electrified, automated, connected
Content

- Market requirements for batteries 2020ff – the Bosch view
  - Applications
  - Market volume
  - Customer expectations
  - Battery requirements
  - KPIs

- Technologies to reach the targets
  - Battery cell technologies – until 2020 LIT
  - From 2020: PLIT

- Summary and prospect

- Bosch 48V Mild HEV
## Applications

<table>
<thead>
<tr>
<th></th>
<th>HEV</th>
<th>PHEV</th>
<th>EV</th>
<th>BRS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Generation 1</strong></td>
<td>○</td>
<td>○</td>
<td>○</td>
<td></td>
</tr>
<tr>
<td>(series)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Generation 2</strong></td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>(in development)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electrical range</td>
<td>➤</td>
<td>➤</td>
<td>➤</td>
<td></td>
</tr>
<tr>
<td>Electrical power</td>
<td>➤</td>
<td>➤</td>
<td>➤</td>
<td></td>
</tr>
</tbody>
</table>
| Challenges          | • High power  
                      | • Low cost     | • High performance  
                      |                  | • Cycle life      
                      |                  | • Cost down      | • High energy density  
                      |                  |                  | • Cost down      | • High power  
                      |                  |                  |                  | • Low cost     |
| Technology          | Li-ion (available) | Li-ion (improved) | Li-ion (improved)  
                      |                  |                  | Post Li-ion      | Li-ion (available) |
Market volume

PHEV and EV with strong growth
HEV volume declining

Total vehicle market:

- 2014: 85 mio. vehicles
- 2020: 112 mio. vehicles
- 2025: 125 mio. vehicles

Subject

HEV Hybrid Electric Vehicle
PHEV Plug-in Hybrid Electric Vehicle
EV Electric Vehicle

Vehicle sales PC incl. LCV<6t: Estimation Bosch
Consequences on production capacity

Required battery production capacity

<table>
<thead>
<tr>
<th>Year</th>
<th>HEV</th>
<th>PHEV</th>
<th>EV</th>
</tr>
</thead>
<tbody>
<tr>
<td>2014</td>
<td>8</td>
<td></td>
<td>40</td>
</tr>
<tr>
<td>2020</td>
<td>12</td>
<td>150</td>
<td>600</td>
</tr>
<tr>
<td>2025</td>
<td>11</td>
<td>166</td>
<td>777</td>
</tr>
</tbody>
</table>

Li-ion Consumer 2014

- HEV: Hybrid Electric Vehicle
- PHEV: Plug-in Hybrid Electric Vehicle
- EV: Electric Vehicle
Customer expectations towards an EV

<table>
<thead>
<tr>
<th>Customer expectations</th>
<th>Battery requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Driving range ≥ 350 km</td>
<td>≥ 50kWh&lt;br&gt;200Wh/kg…400Wh/kg</td>
</tr>
<tr>
<td>Good performance</td>
<td>150kW…250kW&lt;br&gt;⇒ P/E ratio 3…5</td>
</tr>
<tr>
<td>Fast charging</td>
<td>250km with 15min charge time</td>
</tr>
<tr>
<td>No battery exchange during vehicle life</td>
<td>80% capacity &amp; performance @ 300Tkm, &gt; 10years</td>
</tr>
<tr>
<td>Reasonable safety</td>
<td>Safety level equal or higher than in vehicle with ICE</td>
</tr>
<tr>
<td>Affordable</td>
<td>Market price target battery: 6,600USD</td>
</tr>
</tbody>
</table>
KPIs: status 2015, market targets 2020 - 2025

Energy Density
Cost
Lifetime
Performance
Quality
Safety
KPIs: status 2015, market targets 2020 - 2025

Energy Density

- Energy density [Wh/kg]
- 2015: ~ Factor 3
- 2020: x 2
- 2025: ~ x 3

Cell | Pack
--- | ---
KPIs: status 2015, market targets 2020 - 2025
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- Bosch 48V Mild HEV
Battery cell technologies

- Market until 2020 dominated by Li-ion Technology (LIT)
- Energy density in 2020 already close to the technical limit of LIT
- Post Li-ion Technologies (PLIT) with potential for higher gravimetric and volumetric energy densities in combination with improved safety
- EVs w/ SOP > 2020: PLIT with solid state electrolyte very promising
PLIT cell technologies

- **Terminology**
  - **Li-ion Technology (LIT)**
    - Lithium in both electrodes mainly intercalated
    - Structure of electrodes hardly changed due to intercalation
    - Li-ions migrate free via (liquid) electrolyte
  - **Post Li-ion Technology (PLIT)**
    - At least one electrode not intercalating lithium
    - Acronym PLIT often used as synonym for Li-Sulfur and Li-Air technologies
    - Cells with metallic Lithium anode are counted among PLIT
PLIT cell technologies, examples

### Li-Sulfur Technology
- **Anode**
- **Separator**
- **Electrolyte**
- **Cathode**

- **Discharging**
  - Metallic lithium
  - Mixture of sulfur and carbon particles with binder

- **Charging**
  - Metallic lithium
  - Solid state electrolyte

### Li-Air Technology
- **Anode**
- **Separator/Electrolyte**
- **Cathode**

- **Discharging**
  - Metallic lithium
  - Solid state electrolyte
  - Mesoporous carbon

- **Charging**
  - Metallic lithium
  - Solid state electrolyte
  - Metal fluoride

### Solid State Cells
- **Anode**
- **Separator**
- **Cathode**

- **Discharging**
  - Metallic lithium
  - Solid state electrolyte with active material

- **Charging**
  - Metallic lithium
  - Solid state electrolyte with active material

### Cells with conversion cathode
- **Anode**
- **Separator**
- **Electrolyte**
- **Cathode**

- **Discharging**
  - Metallic lithium
  - Solid state electrolyte

- **Charging**
  - Metallic lithium
  - Metal fluoride
Solid state cells, status Bosch

- Bosch acquired Californian battery technology company **Seeo**
- Engineering prototype cells available

<table>
<thead>
<tr>
<th>Seeo DryLyte™ Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Anode</strong></td>
</tr>
<tr>
<td><strong>Separator</strong></td>
</tr>
<tr>
<td><strong>Cathode</strong></td>
</tr>
<tr>
<td><strong>Electrolyte</strong></td>
</tr>
</tbody>
</table>

Technology very promising: Lifetime > 1000 cycles reached with LFP cathode, operating temperature 80..100°C
Solid state cells, Safety

- Safety test results (LFP cathode, Li metal anode)

<table>
<thead>
<tr>
<th>Test</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crush</td>
<td>No smoke or flames</td>
</tr>
<tr>
<td>Penetration test</td>
<td>No smoke or flames</td>
</tr>
<tr>
<td>Short circuit test</td>
<td>No smoke or flames</td>
</tr>
<tr>
<td>Thermal shock</td>
<td>No smoke or flames</td>
</tr>
<tr>
<td>Over-discharge</td>
<td>No smoke or flames</td>
</tr>
<tr>
<td>Overcharge</td>
<td>No smoke or flames</td>
</tr>
<tr>
<td>Thermal stability</td>
<td>Stable up to 180°C</td>
</tr>
</tbody>
</table>

Intrinsic safety of Seeo technology is a big advantage
Summary and prospect

- Li-ion technology will dominate the market until 2020
- Li-ion technology technical feasible for EV and PHEV
- Technical limit of automotive Li-ion expected @ ~350..400Wh/kg
- Post Li-ion with potential to further increase energy density and to reduce cost
- Solid state cells for EV expected to be ready for series past 2020

PLIT with high chance for game changer
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Bosch 48V Mild HEV

Evolution of Electrification

ICE Dominant  HEV Dominant

Baseline: Start/Stop

Advanced Start/Stop

48V Systems

Coasting

Recuperation

Boost

e-drive entry

Further improvement of cost-benefit ratio plus feeling of electric driving

CO₂ potential

sHEV: ‘Strong Hybrid Electric Vehicle’; electric motor operation independent of engine state; typically operating at VDC>120

sHEV

PHEV

Baseline: Start/Stop

Advanced Start/Stop

48V Systems

Coasting

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e-drive

Further improvement of cost-benefit ratio plus feeling of electric driving

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Powertrain Scenarios – 48V

BRS 48V shows considerable market growth

Vehicle sales PC incl. LCV<6t

**Total market**

- **2014**: 0.0 mio.
- **2020**: 3.1 mio.
- **2025**: 11.3 mio.

**BRS 48V** Boost Recuperation System

1) Estimation Bosch
Increasing Total System Power Required to Achieve Operation

- Limited Change wrt. Today
- Brake Actuation Electrical Power Increased
- EPS Power Increased in coord. w/ Brakes
- Further EPS Power Increase Longer Duration
- Duration after system electrical failure
- Deceleration & extended travel to a safe place

Time to Stop

Driver take-over

Standstill in current lane

Standstill in rightmost lane

Standstill in emergency lane

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Bosch 48V HEV

Summary

- 48V seen as a bridge to a higher voltage future
  - Main focus is on easy to integrate belt-machines
  - Other topologies considered, but with a later implementation (post 2021)
  - Cost effective CO₂ reduction the main driver

- Power-net requirements may drive manufacturers towards 48V solutions
  - Highly Automated Driving will require redundant and powerful actuation systems pushing charging systems to their limit

- New concepts may change the landscape
  - SSC could be one path where a non-traditional strategy that delivers real-world fuel savings may also drive the need for redundant power-net capability
THANK YOU