Overview about Lead–Acid Batteries for Future Automobiles

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Outline

- Electric Vehicle Motivations
- Different Kinds of Electric Vehicles
- Micro HEVs
  - Operating Conditions
  - How LABs can meet these Operating Conditions?
- LABs or LIBs for Micro/Mild HEVs?
- Outlook
Motivation – Why Electric Vehicles in General?

- Local Emissions
- Global Emissions
- Finite Resources
- Generate Jobs, Export
- Diversification of Fuel Sources (D, EU, …)
Technical Tasks

➢ Improvement of fuel economy
➢ Reduction of CO₂ emission

➢ Higher electrical functionality for greater safety and comfort
CO$_2$- Emission Reduction Plan

*new vehicles

- 130 g/km * in stock
- 95 g/km * (COP21 target)
- ~50 g/km *
- ~0 g/km *
- 0 g/km * (COP21 target)

2016 2020 2025 2035 2050

Assistance systems
Semi-autonomous driving
High automatisation
Full automatisation
Autonomous traffic systems
Electric Vehicles

CO2 Emission Reduction Potentials
ICE Losses 1/2

Urban Drive Cycle Energy Balance, 2005 3 L Toyota Camry

Source: Toyota
ICE Losses 2/2

Urban Drive Cycle Energy Balance, 2005 3 L Toyota Camry

Source: Toyota
Possible Savings

- Micro HEV Eliminates
  - Standby 8%
  - Driveline 13%
  - Engine 16%
  - Engine Loss 76%
  - Driveline Losses 3%
  - Aero 3%
  - Rolling 4%
  - Braking 6%

- Fuel Tank: 100%
- Full Hybrid Reduces Plug-in
  - Engine downsizing
  - Decoupling of engine and wheel can eliminate engine entirely
- Micro HEV Reduces

2005 3 L Toyota Camry
# EVs - Functions

<table>
<thead>
<tr>
<th>Increasing Electrical Capability</th>
<th>IC Engine Stop/Start</th>
<th>Brake Energy Recovery</th>
<th>Electric Motor Assist</th>
<th>Pure Electric Drive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Micro-Hybrid</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Mild/Medium Hybrid</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
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<td>Full-Hybrid</td>
<td>✓</td>
<td>✓</td>
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</tr>
<tr>
<td>Plug-In Hybrid</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Range Extender</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Electric Vehicle</td>
<td></td>
<td>✓</td>
<td></td>
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</tr>
</tbody>
</table>

## Additional function

**Coasting**

![Coasting Graph](image)
## EVs - Functions

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<td>✓</td>
<td>✓</td>
<td></td>
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**Additional function Coasting**

![Graph showing acceleration, engine-off coasting, recuperation, and constant driving speed over time.](image)
Technical Tasks

➢ Improvement of fuel economy
➢ Reduction of CO$_2$ emission

➢ Higher electrical functionality for greater safety and comfort
Higher Electrical Functionalities

- Dynamic Roll Stabilization
- Radiator Cooling Fan
- Power Steering
- Front Window Heating
- AC Compressor
- PTC Heater

Power-on time:
- 100%
- 75%
- 50%
- 25%

Power requirement:
- 100W
- 300W
- 500W
- 750W
- 1kW
- 2kW
- 3kW
- 4kW
- 5kW
Higher Electrical Functionalities

- Dynamic Roll Stabilization
- Radiator Cooling Fan
- Power Steering
- Front Window Heating
- A/C Compressor
- PTC Heater

Reduces electrical losses
<table>
<thead>
<tr>
<th>Functionality</th>
<th>Micro Hybrid</th>
<th>Mild Hybrid</th>
<th>Full Hybrid</th>
<th>Plug-In Hybrid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start/stop, regenerative braking</td>
<td>Launch assist</td>
<td>+ Power assist, limited E-drive</td>
<td>+ Extended E-drive</td>
<td></td>
</tr>
<tr>
<td>Launch assist / kW</td>
<td>0</td>
<td>&lt;15</td>
<td>&gt;15</td>
<td>&gt;60</td>
</tr>
<tr>
<td>e-drive range / km</td>
<td>0</td>
<td>0</td>
<td>~2</td>
<td>10-40</td>
</tr>
<tr>
<td>System voltage / V</td>
<td>14 (48)</td>
<td>48-150</td>
<td>&gt;200</td>
<td>&gt;200</td>
</tr>
<tr>
<td>Battery power / kW</td>
<td>2-10</td>
<td>7-20</td>
<td>&gt;20</td>
<td>&gt;20</td>
</tr>
<tr>
<td>Usable battery energy / kWh</td>
<td>0.25</td>
<td>0.25-1</td>
<td>0.7-2.0</td>
<td>5-10</td>
</tr>
<tr>
<td>CO₂ benefit / %</td>
<td>4-7</td>
<td>8-15</td>
<td>15-25</td>
<td>25-50</td>
</tr>
<tr>
<td>OEM on-cost / €</td>
<td>150-700</td>
<td>1,500 -3,000</td>
<td>3,000 - 5,000</td>
<td>6,000 - 10,000</td>
</tr>
<tr>
<td>Spec.Cost CO₂ reduction / €/%</td>
<td>35-100</td>
<td>150-200</td>
<td>200-250</td>
<td>300-500</td>
</tr>
</tbody>
</table>
Light Vehicle Market

- 2010:
  - Standard Car: 88.5%
  - Micro Hybrids: 10%
  - Mild HEV: 0.5%
  - Full HEV: 1%

- 2020:
  - Standard Car: 44%
  - Micro Hybrid: 50%
  - Full HEV: 4%

~59 Mio LV

reduced

~111 Mio LV

increasing

Light Vehicle Market - Batteries

Light Vehicle Market – Standard Cars

Light Vehicle Market – Micro HEV

What are the operation differences between Batteries for Standards Cars and Micro HEVs?

Regenerative Braking

=> Higher and Dynamic Charge Power

Operating Conditions Changed

=> Partial State-of-Charge
Regenerative Braking \(\Rightarrow\) Higher and Dynamic Charge Power

\textit{Dynamic Charge Acceptance (DCA)}

DCA is quantified as the \textit{average charging current} (charge integral) over recuperation pulses of PSoC microcycling sequences normalized to the battery’s nominal capacity, i.e., A Ah\(^{-1}\).
Problems:

- $DCA < I_{\text{alternator}}$
- $DCA$ is not longtime stable
Partial-State-Of-Charge (PSOC) Cycling Regime

No full charge => no gas development
No full discharge to avoid lifetime reducing => sulfation
Sulfation in Partial State-of-Charge (PSoC) - Charge Potential of Negative Electrode -

PbSO₄

Enhanced by high rate current = HRPSoC

PbSO₄

Source: CSIRO
Possibilities to reduce PSOC-Effects

- Optimization of AM structure => AGM, EFB
- Carbon additives => AGM, EFB
- Avoid high currents for Pb-Negative => UltraBattery
  *High current is absorbed by carbon layer (capacitor function)*
**LABs for Automotive Applications - Applications**

<table>
<thead>
<tr>
<th>Flat plate Monobloc</th>
<th>Flat plate</th>
<th>Flat plate</th>
<th>Spiral cells</th>
<th>Flat plate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flooded batteries</td>
<td>Flooded batteries</td>
<td>VRLA</td>
<td>VRLA</td>
<td>VRLA</td>
</tr>
<tr>
<td>SLI and EFB</td>
<td>Advanced EFB</td>
<td>AGM</td>
<td>AGM</td>
<td>GEL</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cost</th>
<th>FLA</th>
<th>FLA</th>
<th>FLA</th>
<th>FLA</th>
</tr>
</thead>
<tbody>
<tr>
<td>$50-150 , \text{€ kwh}^{-1}$</td>
<td>X 1,3</td>
<td>X 1,6</td>
<td>X 2,5</td>
<td>X 2,8</td>
</tr>
</tbody>
</table>

- **SLI for passenger car:** For microhybrid vehicles with STOP/START.
- **SLI for passenger car for microhybrid vehicles with recuperation only:** For microhybrid vehicles with STOP/START.
- **For microhybrid vehicles with STOP/START:** Taxi, cars with many
- **High Power and deep cycle for special vehicles and construction machines:**
- **Very Deep Cycle:** Board net batteries in vehicles (with seasonal

*Source: M. Gelbke, Ch. Mondoloni, Lead-Acid Batteries for Future Automobiles, ELSEVIER, March 2017, Chapter 5*
OK with LABs
But DCA must be higher and more longtime stable
Light Vehicle Market – Mild HEV

Why not LIBs?

Light Vehicle Market – Micro HEV

Lead-Acid Batteries or Li-Ion Batteries for Micro HEVs?

**Pro LIBs:**
- Specific Energy
- Specific Power
- Usable Capacity
- Lifetime

**Contra LIBs (Pro LABs):**
- Costs
- Deep Temperature
- Recycling
- Safety
Lead-Acid Batteries or Li-Ion Batteries for Micro HEVs?

Pro LIBs:
- Specific Energy
- Specific Power
- Usable Capacity
- Lifetime

Mass reduction ~ 15 kg/kWh

LIB 100 Wh/kg => 60 Ah, 13 V = 0.78 kWh => 7.8 kg
LAB 40 Wh/kg => 70 Ah, 12 V = 0.84 kWh => 21 kg
Lead-Acid Batteries or Li-Ion Batteries for Micro HEVs?

**Pro LIBs:**

Specific Energy
Specific Power
Usable Capacity

**Lifetime**

- *Lifetime LIB (NMC, LFP, NCA) ~ 10 years*
- *Lifetime LIB (LTO/LFP) ~ 20 years*
- *Lifetime LAB ~ 5 years*

*>2 x lifetime increase*
Contra LIBs:

Costs

Deep Temperature

Recycling

Safety

Lead-Acid Batteries or Li-Ion Batteries for Micro HEVs?

Source: ALABC Consortium
Lead-Acid Batteries or Li-Ion Batteries for Micro HEVs?

Contra LIBs:
- Costs
- Deep Temperature
- Recycling
- Safety

<150 $/kWh are possible 2020-2025

\( \sim 2 \times \text{cost increase} \)

Lead-Acid Batteries or Li-Ion Batteries for Micro HEVs?

Contra LIBs:

- Costs
- Deep Temperature
- Recycling
- Safety

~2 x power decrease (@ -30 °C)

Lead-Acid Batteries or Li-Ion Batteries for Micro HEVs?

**Contra LIBs:**

- Costs
- Deep Temperature
- Recycling
- Safety

~2 x power decrease (@ -30 °C)

*LTO better, passive/active heating*

SELF-HEATING All Climate Battery (ACB) - via Ni-Foil

-20 °C => 0 °C, 12.5 sec, 3 % energy consumed

Lead-Acid Batteries or Li-Ion Batteries for Micro HEVs?

Contra LIBs:

Costs

Deep Temperature

Recycling - economy, technically possible

Safety

Lead-Acid Batteries or Li-Ion Batteries for Micro HEVs?

Contra LIBs:

Costs
Deep Temperature
Recycling
Safety  - inherent problem (high energy), safe system approach

Active and Passive Devices lead to Safe Systems

Safety is a System Approach

Material  Cell  Module  Pack  Battery

Not all materials are thermally stable

Increasing Number of Safety Devices

- burst membrane
- internal cell fuse
- protection circuit
- etc.
- mechanical cover
- cell voltage +
- T-sensor, etc.
- fuse
- balancer
- main switch, etc.
- BMS
- battery case
- cooling, etc.

Lead-Acid Batteries or Li-Ion Batteries for Micro HEVs?

Pro LIBs:

Specific Energy, specific power, usable capacity - 15 kg/kWh mass reduction
Lifetime - >2 x lifetime increase

Contra LIBs:

Costs - ~2 x cost increase
Deep T. - ~2 x power decrease (@ -30 °C), LTO better, passive/active heating
Recycling - economy, technical possible
Safety - inherent problem (high energy), safe system approach
Light Vehicle Market – Micro HEV
Also with Li-ion Batteries

Li-Ion Battery Impact on Lead-Acid Battery Automotive Business

When will there be a significant (5% market share) impact of LIB

Source: N. Maleschitz, Exide
Lead-Acid Battery or Li-Ion Battery?

- Answer depends strongly on the progress in R&D of LABs

**Problem**
- LAB is a mature system, therefore no government R&D support
- Stronger R&D commitment of LAB Industry/ALABC

**EU directive on End-of-Life Vehicle 2000/53/EC**
bans several materials (Pb, Hg, Cd, etc) from use in vehicles.
But LABs have an exemption (because no competitor), which is reviewed every five years

*Thielmann, A. et al., 2014: Energiespeicher für die Elektromobilität, Fraunhofer ISI*
Summary

- Batteries for standard cars - Standard SLI LABs
- Battery for Micro HEVs - EFB/AGM LABs, LIBs started for premium class cars
- Battery for Mild HEVs - LIBs; EFB/AGM LABs in dual battery systems with LIBs or supercaps

- LABs  Pro:  Costs - 2 x cost decrease vs. LIBs
  Con‘s:  DCA values and their longtime stability, low R&D effort

- LIBs  Pro:  Specific energy/power, usable capacity; ~15 kg/kWh mass reduction vs. LABs
  Lifetime - >2 x lifetime increase vs. LABs;
  High R&D effort
  Con‘s:  Costs, 2 x cost increase vs. LABs
Thank you for your Attention!

Ulm (Germany)