Electric Vehicle Battery Chemistry and Pack Architecture

High Energy and High Power Batteries for e-Mobility
Opportunities for Niobium
London, England
July 4, 2018
Outline

1) **Global Presentation of A2Mac1**
   By Fabrice Robert, European Sales Engineer

2) **History and types of EVs**
   Hybrids, full electric...

3) **Battery Pack Architecture**
   Battery pack components (housing, cooling, modules, BMS...)

4) **Focus on Battery Cells**
   Battery chemistry and materials

5) **Future of Electric Vehicle Battery**
   What’s beyond Lithium-Ion for tomorrow’s cars?
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GLOBAL PRESENTATION
A2MAC1 presentation - Key figures

6 benchmarking centres worldwide
600+ full teardowns
600,000 parts in storage
28 Mio photos
170+ customers
2.8 Mio pages viewed/month

- Trusted partner to all major OEMs worldwide and suppliers, including steel makers and material producers
- Key reference for competitive analysis in the automotive industry
- Industry leading data management software solution
- Best in class processes for effective data capture
### EV/Hybrid at A2Mac1

**EV/Hybrid perimeter Teardown & properties**
- High Voltage Battery Pack
- Power electronic: Inverter / Charger
- High voltage cables
- HVAC and Cooling system
- E Machine: EV Drive and Transmission
- ECU System management

**Cell Analysis Report**
- Performance testing
- Structural analysis
- Chemical analysis
  - Electrolyte analysis
  - Separator analysis
  - Electrodes analysis

**BMS Report**
- Bill of materials
- Functional Layout detail
- Block Diagram
- Battery Architecture Observations

**Functional Schematics**
- Cabin Heat/Engine Thermal
- HV components Heat exchanger
- HV components & cabling systems
- Battery external cooling
- Battery thermal
- Battery pack electrical
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A look back in history

1859: invention of the lead-acid battery (1st rechargeable battery) by French physicist Gaston Planté

1899: The Jamais Contente sets first speed record over 100 km/h

1902: 1st "mass-produced" electric car (Studebaker Electric)

1910s-1920s: Gasoline powered cars take over the market

1960s-1970s: Renewed interest in electric cars by several manufacturers (1st oil crisis, growing environmental concerns...)

1997: The Toyota Prius I launch is the beginning of a new era for hybrid and electric vehicles

Today, the EV/Hybrid car market is growing thanks to:
- Emissions regulations
- Battery chemistry/performance improving
- New players like Tesla challenging traditional carmakers

➢ Better road infrastructure: longer distances to travel
➢ ICE prices went down with Ford’s mass production
➢ More petroleum discovered, ICE with less noise, smell, vibrations...
Types of Electric Vehicles

- **ICE (Internal Combustion Engine)**
  - Conventional gasoline/diesel engine

- **Micro Hybrid**
  - Start/stop system

- **Mild Hybrid**
  - An electric motor supports the combustion engine for various features

- **HEV (Hybrid Electric Vehicle)**
  - Combustion engine combined with electric motor

- **PHEV (Plug-In Hybrid Electric Vehicle)**
  - High voltage battery can be charged externally
  - Full electric mode available

- **REEV (Range Extended Electric Vehicle)**
  - Vehicle runs on electric motor
  - Combustion engine charges the battery

- **Full EV, or BEV (Battery Electric Vehicle)**
  - Electric motor powered by high voltage battery

### Range/Mileage on pure electric motor
- 0 km
- ≈ 8 km
- ≈ 50-80 km
- ≈ 150 to 500 km

### Size of the battery
- ≈ 1 kWh
  - 10-50 kg
  - (Usually 48 V)
  - ≈ 0.5 to 2 kWh
    - 20-60 kg
    - (≈ 100-300 V)
  - ≈ 4 to 20 kWh
    - 100-200 kg
    - 200-400 V
  - ≈ 20 to 100 kWh
    - 200-700 kg
    - (≈ 350-400 V)
Weight of the Battery Pack

Contribution to the total weight

Battery weight fraction in the vehicle:
- 1 to 3 % for HEV (Hybrid Electric Vehicle)
- 4 to 12 % for PHEV (Plug-in Electric Vehicle)
- 17 to 32 % for EV (full Electric Vehicle)

Source: A2Mac1 database
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The Battery Pack Architecture

Tesla Model 3

Weight = 460 kg (26% of 1766 kg)
Length = 2.15 m
Width = 1.47 m
4 modules, 4416 battery cells
Nominal Voltage = 355 V
Capacity = 217 Ah
Energy = 75 kWh
The Battery Pack Architecture

What’s inside the Battery Pack?
The Battery Pack Architecture

Enclosures

Housing, Enclosure

Metal or plastic “box”
Can be reinforced against impact crash
The Battery Pack Architecture

Battery Modules

46 cells/brick in parallel, 96 bricks in series
(96 S 46 P)
The Battery Pack Architecture

Thermal Management System (TMS)
The Battery Pack Architecture

Electrics/Electronics

Electronics
The Battery Pack Architecture

Weight Distribution

Mercedes GLE 550e (PHEV)
- Modules: 86.4 kg (76%)
- Cooling: 8.2 kg (7%)
- Elec.: 5.5 kg (5%)
- Housing: 15.4 kg (14%)
- Total Weight: 113 kg

Tesla Model 3 (EV)
- Cooling: 21 kg (5%)
- Elec.: 11.7 kg (3%)
- Housing: 65.1 kg (14%)
- Modules: 363 kg (79%)
- Total Weight: 460 kg

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Battery Cells Form Factors

**Cylindrical cell**
- Standard sizes: 18650, D, AA...
- Steel casing
- Low manufacturing cost
- High specific energy (Wh/kg)
- Good mechanical stability

**Pouch Cell**
- No standard size, each manufacturer designs its own
- Laminated bag
- High energy density (Wh/L)
- Requires stacking pressure
- Sensitive to moisture and high pressure

**Prismatic Cell**
- No standard size, each manufacturer designs its own
- Aluminum or steel casing
- Good energy density (Wh/L)
- Commonly used in electric vehicles
### Battery Cells (Li-ion): Chemistry and Materials

#### Anode Materials

<table>
<thead>
<tr>
<th>Material Description</th>
<th>Property or Advantage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon (graphite, hard carbon)</td>
<td>Most common anode material</td>
</tr>
<tr>
<td>Graphite with ≈ 1-3 % silicon : C + Si</td>
<td>Silicon brings better specific energy</td>
</tr>
<tr>
<td>LTO (Lithium Titanate Oxide) : Li₄Ti₅O₁₂</td>
<td>High power, high cycle life, safe</td>
</tr>
<tr>
<td></td>
<td>Low voltage, low specific energy</td>
</tr>
</tbody>
</table>

#### Cathode Materials

<table>
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<th>Material Description</th>
<th>Property or Advantage</th>
</tr>
</thead>
<tbody>
<tr>
<td>LCO : LiCoO₂</td>
<td>High specific energy but expensive because of the cobalt (mostly used in portable electronics)</td>
</tr>
<tr>
<td>LMO : LiMn₂O₄</td>
<td>No cobalt but low specific energy and cycle life. Usually blended with NMC (Nissan Leaf, Chevy Volt…)</td>
</tr>
<tr>
<td>NMC : LiNi₁/₃Mn₁/₃Co₁/₃O₂</td>
<td>High specific energy but high cobalt content. Most common cathode material in EVs</td>
</tr>
<tr>
<td>NCA : LiNi₀.₈Co₀.₁₅Al₀.₀₅O₂</td>
<td>Highest specific energy, high specific power. Lower cobalt content than NMC but less safe. NCA has Tesla’s preference (reduced cobalt content in Model 3)</td>
</tr>
<tr>
<td>LFP : LiFePO₄</td>
<td>Long cycle life, high power, very safe but low specific energy</td>
</tr>
</tbody>
</table>

#### Major battery cells manufacturers:

- Panasonic (Tesla)
- Samsung SDI (BMW, VW…)
- A123 (GM, Mercedes…)
- LG Chem (Renault, GM, Volvo…)
- Sanyo, Hitachi, Lithium Energy Japan, Toshiba, CATL…

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Electric Vehicle Battery Chemistry and Pack Architecture
Battery Cells (Li-ion):

The Cobalt Issue

Problem with cobalt:
- Expensive (almost 100 \$ / kg)
- Low reserves (7 million tons)
- Geopolitics

In previous models, cathode material (NCA) was:
\[ \text{LiNi}_{0.8}\text{Co}_{0.15}\text{Al}_{0.05}\text{O}_2 \]

Today’s trend is to reduce amount of cobalt in EV batteries
(NCA and from NMC 111 to NMC 811)

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Battery Cells for Electric Vehicles: Beyond Li-ion and/or better Li-ion

Several new battery chemistries are being studied and developed in laboratories worldwide

**Solid-state Li-ion** → Replaces highly flammable liquid electrolyte by solid electrolyte
Higher energy density and safer
Could be the next generation of EV battery:
Among the major players working on this technology are *Toyota, BMW, Saft* in partnership with *Solvay, Siemens*...

**Titanium Niobiate (TNO)** → TNO is being developed by *Toshiba* to replace LTO as the anode in Li-ion
Higher energy density, fast charging

**Lithium Sulfur** → Uses sulfur as the cathode
Higher specific energy
Main issues: cycle life, sulfur has low conductivity and expands during discharge
Companies like *Oxis energy or Sion Power* try to commercialize Li-S batteries

**Lithium air** → Uses air (oxygen) as the cathode
Highest specific energy
Main issues: cycle life, low power, water and nitrogen filtering
*Samsung* and many research labs work on this technology

**Other** → Na-ion, Mg-ion...
Other improvements in Li-ion: use of graphene, high capacity cathodes, high voltage cathodes...
Thank you very much for your attention!

Any question?

Please don’t hesitate to contact us:
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