Battery Innovations Enabled by Thermal Engineering

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All Climate Battery (ACB™)

same power/life from -40 to 60°C

Fast Charging Battery (FCB™)

10-min charge, 400km range
CAE Tool for Battery Discovery & Innovation

Aid OEMs/battery developers to accelerate product development of low-cost, safe, long-lasting Li-ion batteries for xEVs
Self-Heating Cell Structure

- **Novel cell structure**: Anode + Cathode + Electrolyte + 4th Component: a \( \mu \text{m}-\text{thin} \) Ni foil for rapid self-heating; 2-5\(^\circ\)C/sec or 100-300\(^\circ\)C/min & uniform
- Self-heat in 5-15 seconds & consumes 1-3% battery energy for 20-30\(^\circ\)C temp rise

Temperature Insensitive Battery – All Climate Battery (ACB)

Low-T Power – DCR

2C, 3-sec disch. pulse @100%SOC
NCM523/Gr cell, 33Ah, 200 Wh/kg

\[ \frac{R_T}{R_{RT}} vs. \text{Temperature (°C)} \]

(-20°C, 100% SOC) \(\rightarrow\) (10°C, 97%SOC)
From Breakthrough to Commercialization
In-Vehicle Testing of All Climate Batteries

BAIC EU260 Car, Yutong Luxury Van, & Foton 12m Bus at HaiLaer Winter Vehicle Testing Center in March 2018

Testing Conditions:

• All vehicles soaked in -40°C environment for 72 hours (no plug-in for keeping temperature)
• In 10 min, EVs drive away like normal vehicles (0-100 km/h acceleration, regen, fast charging…)

SUCCESS: All 3 types of vehicles powered by MGL’s ACB batteries PASSED!!!

Courtesy: the Winter Olympic Project of testing ACB technology in vehicles was planned and led by Prof. Sun Fengchun of BIT with active participation from BAIC, Yutong, Foton & MGL
All-Climate Batteries in BMW Cars

INTERNAL CELL HEATING TO IMPROVE LOW TEMPERATURE BATTERY PERFORMANCE IS AN EXAMPLE FOR BMW INNOVATION.

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

**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

Source: [https://www.bmwgroup.com/content/dam/bmw-group-websites/bmwgroup_com/ir/technologie_workshops/Technology_Workshops_E-Mobility.pdf](https://www.bmwgroup.com/content/dam/bmw-group-websites/bmwgroup_com/ir/technologie_workshops/Technology_Workshops_E-Mobility.pdf)
Fast Charging Battery (FCB) – Heated Charging

$h$-cccv: fast heating, cc charge, cv

Yang et al., *PNAS*, 115 (2018), 7266-7271
Guaranteed 15-min Charging at All Temperatures

Yang et al., PNAS (2018).

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**Diagram a**: Graph showing cell voltage (V) over time (min) at various ambient temperatures: 0°C, -20°C, -40°C, and -50°C.

**Diagram b**: Bar chart comparing heating time and total charge time across different ambient temperatures.

**Diagram c**: Graph showing heating current in C-rate over time (sec) at various ambient temperatures.

**Diagram d**: Graph showing surface temperature (°C) over time (sec) at various ambient temperatures.
FCB Cycle Life

15-min charging commercialized, and next goal is 10-min charging

Electrify America will deploy 2,000 350kW fast chargers by the end of 2019

484 new charging sites, split between 17 metro areas and highways in 39 states.
Management-Free Battery (MFB)

- Basic heat transfer knowledge leads to 21x reduction in cooling need.

Consider energy balance for $\Delta T=0$:

$$I^2R_i = hA(T_{cell} - T_\infty)$$

operated at

30°C  $$I^2R_i = hA(30 - 25)$$

60°C  $$\frac{I^2R_i}{3} = \frac{hA}{21} (60 - 25)$$

- Battery management system (BMS) much simplified: estimation of SOC, SOH, SOP is done at a single $T$ by algebraic equations.

- Increase pack energy density by 20-25%, reaching 280-300 Wh/kg at system level. Decrease pack cost by 30%

<table>
<thead>
<tr>
<th>Cell-level ED (Wh/kg)</th>
<th>Cell-System Conversion</th>
<th>System-level ED (Wh/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conv. LiB</td>
<td>400</td>
<td>0.7</td>
</tr>
<tr>
<td>MFB</td>
<td>300</td>
<td>0.9</td>
</tr>
</tbody>
</table>
Summary

- We discovered that a battery is an integrated self-heating and energy-storing electrochemical reactor.
- Thermal stimulation is rapid and energy-efficient, giving rise unprecedented opportunities for battery life, safety, fast charging capability, self-cooling capability, and robustness.
- The self-heating mechanism creates a paradigm shift in energy-power play: on-demand high power vs. stand-by high power.
- Tunable electrochemical interface, enabled by thermal stimulation, opens up infinite opportunities in battery science and technology.