Baseline Electrochemical Performance of Commercial Lithium-Ion Cells

Heather Barkholtz, Armando Fresquez, Babu Chalamala, and Summer Ferreira
System selection fraught with uncertainty

Problem:

- Performance and safety data
  - Primarily manufacturer-provided data
- Chemistry Selection for an ESS installation must consider
  - Cost
  - Size
  - Safety
  - Application
  - Reliability
  - Oversizing
  - Manufacturer reputation
  - Performance
  - Pack management

Approach:

- Quantify performance with uniform methodology
- Evaluate fundamentals of material stability
- Determine battery failure scenarios and mechanisms
- Validate battery fire suppression techniques

Avoiding accelerated aging or abuse

Current = 20 A (max = 30 A)
Environment = 25 °C
Cell skin Temp = 60 °C

Most packs don’t monitor individual cell skin temperatures.
Unintended abuse condition under ‘normal’ operation.

Pristine Cell

Abused Cell
# Cells and Manufacturer Specs.

<table>
<thead>
<tr>
<th>Cathode Chemistry</th>
<th>AKA</th>
<th>Specific Capacity (Ah)</th>
<th>Average Potential (V vs Li°/Li+)</th>
<th>Max Discharge Current</th>
<th>Acceptable Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LiCoO₂</td>
<td>LCO</td>
<td>2.5</td>
<td>3.6</td>
<td>20</td>
<td>0 to 50</td>
</tr>
<tr>
<td>LiFePO₄</td>
<td>LFP</td>
<td>1.1</td>
<td>3.3</td>
<td>30</td>
<td>-30 to 60</td>
</tr>
<tr>
<td>LiNiₓCoᵧAl₁₋ₓ₋ᵧO₂</td>
<td>NCA</td>
<td>2.9</td>
<td>3.6</td>
<td>6</td>
<td>0 to 45</td>
</tr>
<tr>
<td>LiNi₀.₈₀Mn₀.₁₅Co₀.₀₅O₂</td>
<td>NMC</td>
<td>3.0</td>
<td>3.6</td>
<td>20</td>
<td>-5 to 50</td>
</tr>
</tbody>
</table>

![Battery Images](image)

![Graph](graph)
Evaluating cell chemistries uniformly

Discharge 1C rate  Dsch 5 A rate  Dsch 10 A rate  Test Aborted  Segmented 20 A rate  Segmented 30 A rate

Whole Test

Applied Current (A)  Cell Voltage (V)

1C  5A  10A  20A  30A
$\frac{dQ}{dV}$ elucidates key reactions/changes

graphite  
stage I  $\text{LiC}_6$  
stage II  $\text{LiC}_{12}$  
stage III  $\text{LiC}_{18}$

---

fully charged

---

---

---

---

charge

discharge

---

New peak shape

---

---

Anode de-lithiation occurs within normal operating T regions.

Lithiated Graphite Anode (75% SOC)

- LiC$_{18}$ & graphite
- LiC$_{12}$
- LiC$_{12}$
- LiC$_6$ + LiC$_{12}$
- LiC$_6$ + LiC$_{12}$

Increasing temperature
Decreasing lithiation
Degree of capacity loss varies with T and current

Large contrast in capacity retention
NCA Displays Minimal Self-Heating

Maximum Skin Temperature (°C)

1C 5A 10A 20A

LCO
- 5 °C
- 15 °C
- 25 °C
- 35 °C

NCA

1C 5A 6A

LFP

1C 5A 10A 20A 30A

NMC
Insights into Source of Variation

Determining tradeoffs is clearer with a comprehensive performance evaluation.
References

- https://arstechnica.com/cars/2016/08/tesla-model-s-france-battery-fire/
- “Energy Storage Safety Strategic Plan”

Acknowledgements

- Dr. Imre Gyuk for supporting energy storage safety work
- This work was performed, in part, at the Center for Integrated Nanotechnologies, an Office of Science User Facility operated for the U.S. Department of Energy (DOE) Office of Science by Los Alamos National Laboratory (Contract DE-AC52-06NA25396) and Sandia National Laboratories (Contract DE-AC04-94AL85000).