Development of Large Format Lithium Ion Cells with Higher Energy Density

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Overview

Timeline

• Project start date: Oct. 1, 2011
• Project end date: Mar. 31, 2015
• Percent complete: ~30%

Barriers

• Barriers addressed
  – Increase energy density of lithium ion battery
  – Reduce cost
  – Maintain good cycle life

Budget

• Total estimated project cost:
  – DOE share: $4,986,984
  – Dow Kokam share: $2,431,606
• Funding received in FY11: $1,957,460
• Funding for FY12: $997,560
• Total funding received: $2,955,020

Partners

• Dow Kokam – Project Lead
• Wildcat Discovery Technology (WDT) – Cathode Materials and High Voltage Electrolytes
• Oak Ridge National Lab (ORNL) – Material Characterization
• University of Missouri, Kansas City (UMKC) – Analytical Support
Project Objectives

• To research, develop, and demonstrate Li-ion battery cells that are capable of achieving an energy density of >500 Wh/L and a power density of >500 W/L while maintaining comparable performance standards in terms of cycle life (300-1000 cycles at 80% initial capacity), calendar life (5-10 years), and durable cell construction and design capable of being affordably mass produced.
**Project Approach**

- **Phase 1:** Mobilize Resources, Implement Project Management Plan, Institute Project Controls *(On-going)*
- **Phase 2:** Establish Model & Performance Baseline NMC/Graphite Cell, Establish Baseline Capacity For Cells, Install Equipment *(90% Completed)*
- **Phase 3:** Optimize High Voltage Cell Design and Finalize Materials Development, Scale Up High Voltage Cathode Material, Produce High Energy Interim Cells, Estimate Costs *(40% Completed)*
- **Phase 4:** Develop and Optimize High Capacity Materials and Cell Designs, Produce High Energy Interim Cells, Estimate Costs *(20% Completed)*
- **Phase 5:** Produce And Deliver Large Format Baseline and High Energy Cells *(Not Scheduled to Start Until 2014)*
- **Phase 6:** Verify Achievement of Cost Goals and Develop Commercialization Plan *(20% Completed)*
Performance of 2-Ah Hand-Assembled Baseline Cells

Baseline cells passed all tests; they will be delivered to ANL for testing in April 2013.

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High Capacity Anode Development

- Si-based anodes provide high capacity as claimed
- Matching between anode and cathode is important
- Charging conditions must be optimized
- DK is now testing full cells

Anode Material 1

Anode Material 2
The high voltage material system, CM1/EM1/Graphite, achieved an energy density of ~340 Wh/L in 65X95-mm hand-made cells.
Gas generation continued throughout the cycle life test.
Three-electrode cells showed that the cathode reached >5V during cycling.
Presently:
- Developing improved HVC with higher specific energy
- Evaluating effects of cell resistance by changing electrode design
# High Capacity Cathode Development

## Comparison with State of the Art

<table>
<thead>
<tr>
<th>Metric</th>
<th>NMC LiNi&lt;sub&gt;1/3&lt;/sub&gt;Mn&lt;sub&gt;1/3&lt;/sub&gt;Co&lt;sub&gt;1/3&lt;/sub&gt;O&lt;sub&gt;2&lt;/sub&gt;</th>
<th>LMNO LiMn&lt;sub&gt;1.6&lt;/sub&gt;Ni&lt;sub&gt;0.6&lt;/sub&gt;O&lt;sub&gt;4&lt;/sub&gt;</th>
<th>OLO Li&lt;sub&gt;1.3&lt;/sub&gt;Ni&lt;y&gt;2&lt;/y&gt;Mn&lt;y&gt;0&lt;/y&gt;yCo&lt;sub&gt;2&lt;/sub&gt;O&lt;sub&gt;2&lt;/sub&gt;</th>
<th>HCC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity (mAh/g)</td>
<td>155</td>
<td>147</td>
<td>274</td>
<td>288#</td>
</tr>
<tr>
<td>Gr. Energy (Wh/kg)</td>
<td>590</td>
<td>690</td>
<td>1000</td>
<td>1090#</td>
</tr>
<tr>
<td>Vol. Energy (Wh/L)</td>
<td>2760</td>
<td>3060</td>
<td>4470</td>
<td>4790#</td>
</tr>
<tr>
<td>Rate Performance (% at 1C)</td>
<td>87</td>
<td>95</td>
<td>80</td>
<td>-</td>
</tr>
<tr>
<td>Cycle Life (80% of Initial)</td>
<td>&gt;1000</td>
<td>~700</td>
<td>300</td>
<td>-</td>
</tr>
<tr>
<td>Cost ($/kg)</td>
<td>24-30</td>
<td>~20</td>
<td>~22</td>
<td>~21*</td>
</tr>
</tbody>
</table>

# Theoretical Values * Estimation based on similar process cost of OLO

- Low irreversible capacity and no voltage fade are expected for HCC
- HCC has potential to directly compete with OLO
High Capacity Cathode Development Status

- Screen more than ~2000 materials
- Improve stability to air, capacity, and energy density
- Develop low cost solid state synthesis for HCC
# High Capacity Cathode Development Status

<table>
<thead>
<tr>
<th>Metrics</th>
<th>Theoretical</th>
<th>HCC Baseline</th>
<th>HCC from Primary Screen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity (mAh/g)</td>
<td>288</td>
<td>240</td>
<td>267</td>
</tr>
<tr>
<td>Energy (Wh/kg)</td>
<td>1090</td>
<td>864</td>
<td>977</td>
</tr>
<tr>
<td>Rate Performance (% at 1C)</td>
<td>-</td>
<td>68</td>
<td>77</td>
</tr>
<tr>
<td>Reversible Capacity (%)</td>
<td>-</td>
<td>75</td>
<td>90</td>
</tr>
<tr>
<td>Full Cell Cycle Life (80% of Initial)</td>
<td>-</td>
<td>50</td>
<td>N/A</td>
</tr>
<tr>
<td>Stability</td>
<td>-</td>
<td>Air sensitive</td>
<td>Air stable</td>
</tr>
</tbody>
</table>

- Promising HCC materials are identified by WDT
- WDT is screening for precursors and dopants
Collaboration

- Wildcat Discovery Technologies – Dr. Bin Li
  - Screening of new HVC and HCC materials
  - Screening of dopants to improve material performance
  - Development of synthesis techniques
- Oak Ridge National Laboratory – Dr. David Wood
  - Materials characterization
  - Failure mode analysis
- University of Missouri, Kansas City – Prof. Xiaobo Chen
  - Analytical support
Proposed Work in 2013

- **High Capacity Anode (HCA)**
  - Fabricate and test 2-Ah full cells with HCA as the anode

- **High Voltage Cathode (HVC)**
  - Test improved CM1 in half cells and full cells
  - Search and down-select alternative high voltage electrolytes
  - Combine HVC and HCA in 2-Ah format full cells, deliver to ANL for testing if performance is promising

- **High Capacity Cathode (HCC)**
  - Complete material development and finalize candidate materials
  - Material characterization for physical and electrochemical properties
  - Test the compatibility of HCC and HCA
Program Summary

• Goal: To develop a large format lithium ion cell with energy density > 500 Wh/L
• Approach: Develop 2-Ah format baseline cells using high voltage and high capacity cathodes, in parallel, with high capacity anodes
• Technical accomplishments in 2012:
  – Baseline cells completed, will be delivered to ANL (est April 2013)
  – Si-Based anodes screened and selected, specific capacity >500 mAh/g
  – High voltage cathode demonstrated 340 Wh/L in 64X95-format full cells with graphite anode
  – Development of high capacity cathode material initiated, currently achieved ~250 mAh/g before optimization