A Technical Interchange Meeting was held at Saft America’s Research and Development facility in Cockeysville, Maryland on Sept 28th-29th, 2010. The meeting was attended by Saft, contractors who are developing battery component materials under contracts awarded through a NASA Research Announcement (NRA), and NASA. This briefing presents an overview of the components being developed by the contractor attendees for the NASA’s High Energy (HE) and Ultra High Energy (UHE) cells. The transition of the advanced lithium-ion cell development project at NASA from the Exploration Technology Development Program Energy Storage Project to the Enabling Technology Development and Demonstration High Efficiency Space Power Systems Project, changes to deliverable hardware and schedule due to a reduced budget, and our roadmap to develop cells and provide periodic off-ramps for cell technology for demonstrations are discussed. This meeting gave the materials and cell developers the opportunity to discuss the intricacies of their materials and determine strategies to address any particulars of the technology.
NASA’s Exploration Technology Development Program
Energy Storage Project

Battery Technology Development

Joint Saft America-NRA Contractor-NASA Technical Interchange Meeting on Cell Components and Cell Development

Held at Saft America, Cockeysville, MD
September 28, 2010

Concha Reid and Tom Miller, co-PI’s
Carolyn Mercer, Project Manager
Amy Jankovsky, Integration Manager
## Key Performance Parameters for Battery Technology Development

<table>
<thead>
<tr>
<th>Customer Need</th>
<th>Performance Parameter</th>
<th>State-of-the-Art</th>
<th>Current Value</th>
<th>Threshold Value</th>
<th>Goal</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Safe, reliable operation</strong></td>
<td>No fire or flame</td>
<td>Instrumentation/control-*-\ers used to prevent unsafe conditions. There is no non-flammable electrolyte in SOA</td>
<td>Preliminary results indicate a small reduction in performance using safer electrolytes and cathode coatings</td>
<td>Tolerant to electrical and thermal abuse such as over-temperature, over-charge, reversal, and short circuits with no fire or thermal runaway***</td>
<td>Tolerant to electrical and thermal abuse such as over-temperature, over-charge, reversal, and short circuits with no fire or thermal runaway***</td>
</tr>
<tr>
<td><strong>Specific energy</strong></td>
<td>Battery-level specific energy* [Wh/kg]</td>
<td>90 Wh/kg at C/10 &amp; 30 °C 83 Wh/kg at C/10 &amp; 0 °C (MER rovers)</td>
<td>160 at C/10 &amp; 30 °C (HE) 170 at C/10 &amp; 30 °C (UHE) 80 Wh/kg at C/10 &amp; 0 °C (predicted)</td>
<td>135 Wh/kg at C/10 &amp; 0 °C “High-Energy”** 150 Wh/kg at C/10 &amp; 0 °C “Ultra-High Energy”***</td>
<td>150 Wh/kg at C/10 &amp; 0 °C “High-Energy” 220 Wh/kg at C/10 &amp; 0 °C “Ultra-High Energy”</td>
</tr>
<tr>
<td></td>
<td>Lander: 150 – 210 Wh/kg 10 cycles</td>
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<tr>
<td></td>
<td>Rover: 160-200 Wh/kg 2000 cycles</td>
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<tr>
<td></td>
<td>EVA: 270Wh/kg 100 cycles</td>
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<tr>
<td></td>
<td>Cell-level specific energy [Wh/kg]</td>
<td>130 Wh/kg at C/10 &amp; 30 °C 118 Wh/kg at C/10 &amp; 0 °C</td>
<td>199 at C/10 &amp; 23 °C (HE) 213 at C/10 &amp; 23 °C (UHE) 100 Wh/kg at C/10 &amp; 0°C (predicted)</td>
<td>165 Wh/kg at C/10 &amp; 0 °C “High-Energy” 180 Wh/kg at C/10 &amp; 0 °C “Ultra-High Energy”***</td>
<td>180 Wh/kg at C/10 &amp; 0 °C “High-Energy” 260 Wh/kg at C/10 &amp; 0 °C “Ultra-High Energy”</td>
</tr>
<tr>
<td></td>
<td>Cathode-level specific capacity [mAh/g]</td>
<td>180 mAh/g</td>
<td>252 mAh/g at C/10 &amp; 25°C 190 mAh/g at C/10 &amp; 0°C</td>
<td>260 mAh/g at C/10 &amp; 0 °C</td>
<td>280 mAh/g at C/10 &amp; 0 °C</td>
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<tr>
<td></td>
<td>Anode-level specific capacity [mAh/g]</td>
<td>280 mAh/g (MCMB)</td>
<td>330 @ C/10 &amp; 0°C (HE) 1200 mAh/g @ C/10 &amp; 0°C for 10 cycles (UHE)</td>
<td>600 mAh/g at C/10 &amp; 0 °C “Ultra-High Energy”</td>
<td>1000 mAh/g at C/10 0 °C “Ultra-High Energy”</td>
</tr>
<tr>
<td></td>
<td>Lander: 311 Wh/l</td>
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<td>Rover: TBD</td>
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<tr>
<td></td>
<td>EVA: 400 Wh/l</td>
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<tr>
<td><strong>Operating environment</strong></td>
<td>Operating Temperature</td>
<td>-20°C to +40°C</td>
<td>0°C to +30°C</td>
<td>0°C to 30°C</td>
<td>0°C to 30°C</td>
</tr>
</tbody>
</table>

Assumes prismatic cell packaging for threshold values. Goal values include lightweight battery packaging.

* Battery values are assumed at 100% DOD, discharged at C/10 to 3.0 volts/cell, and at 0°C operating conditions

** “High-Energy” = mixed metal oxide cathode with graphite anode

** “Ultra-High Energy” = mixed metal oxide cathode with Silicon composite anode

*** Over-temperature up to 110°C; reversal 150% excess discharge @ 1C; pass external and simulated internal short tests; overcharge 100% @ 1C for Goal and 80% @ C/5 for Threshold Value.
Lithium Ion Battery Technology Development
Advanced Cell Components

Nano-particle based circuit breaker

Silicon nano-particles alloy with Li during charge, lose Li ions during discharge
- Offers dramatically improved capacity over carbon standard

Advanced electrolyte with additives provides flame-retardance and stability at high voltages without sacrificing performance.
Example: LiPF$_6$ in EC+EMC+TPP+VC

Porous, elastomeric binder allows ionic transport and accommodates large volume changes during charge/discharge cycling
- Functionalized nanoparticles adhere to binder without blocking reactive silicon surface area

Layered Li(NMC)O$_2$ cathode particle
- Varying composition and morphology to improve capacity and charge/discharge rate

Li-Metal-PO$_4$ Safety Coating for Thermal Stability

Improving Cell-Level Safety
- Nano-particle circuit breaker, flame-retardant electrolytes, and cathode coatings to increase the thermal stability of the cell.
Goal: no fire or flame, even under abuse.

Providing Ultra High Specific Energy
- Silicon-composite anodes to significantly improve capacity; elastomeric binders and nanostructures to achieve ~200 cycles
- Novel layered oxide cathode with lithium-excess compositions (Li[Li$_x$Ni$_y$Mn$_z$Co$_{1-x-y-z}$]O$_2$) to improve capacity
Current Project will be phased out Sept. 30, 2010

Energy Storage Project
Goal: To develop energy storage technologies for Lunar Exploration

New Project as of October 1, 2010

High Efficiency Space Power Systems
Goal: To provide abundant and low-cost power where it is needed for power-rich exploration
<table>
<thead>
<tr>
<th>Hardware Description</th>
<th>Notional Schedule</th>
<th>Comments</th>
</tr>
</thead>
</table>
| DD cell: MPG-111 anode, NCA cathode  
34P cell: MPG-111 anode, NCA cathode | DD Delivered: Spring 2010  
34P Delivered: July 2010 | Baseline chemistry |
| DD cell: MPG-111, anode Toda NMC cathode  
Saft’s Space electrolyte (2 builds)  
JPL Gen-2 electrolyte (2 builds)  
Tonen 16 micron separator | Begin: Sep 2010  
Cells Delivered: Jan 24, 2011 | High Energy Cells (HE)  
4 variants x 6 copies  
Variations:  
2 cathode loadings &  
2 electrolytes |
| DD cell: MPG-111 and best available components (if any are better) | Begin: Feb 2011  
Cells Delivered: Jun 2011 | HE  
2 variants x 6 copies |
| DD cell: advanced cathode (UT Austin, NEI Corporation or PSI-coated NMC), MPG-111, baseline or JPL electrolyte | 24-mo cathode delivery: Jan 2011  
Begin cell: Mar 2011  
Cells delivered: Aug 2011 | HE  
2 variants x 6 copies |
| DD cell: Silicon anode, advanced cathode (UT Austin, NEI Corporation or PSI-coated NMC), Saft baseline or JPL electrolyte | Begin: Apr 2011  
Cells Delivered: Sep 2011 | Ultra High Energy Cells (UHE)  
2 variants x 6 copies |

DD cell: ~10Ah cylindrical
Energy Storage Roadmap

High-Pressure Electrolyzers
- Component Dev’t
- Preliminary Design
- Critical Design

Non-Flow-Through PEM Fuel Cells
- 100W
- 1 kW
- 3 kW
- Available for Flight Demos

High Energy Lithium Batteries
- Room Temp (RT) Cells, 10Ah
- RT Battery
- 10Ah Cells
- 35Ah Cells
- Available for EVA Ground Demo

Ultra-High Energy Lithium Ion Batteries
- Low-Cycle-Life (LCL) Cells, 10Ah
- LCL Battery
- 10Ah Cells
- 35 Ah Cells
- Available for ISRU & Robotics Flight Demos

- 0-30°C
- Available for Robotics Ground Demos
- High Cycle Life
- Available for EVA Flight Demos

- Screen, Scale-up Components & Integrate Into Cells
- Low Temp Cathodes, Cell-Level Safety, Improved Electrolytes
- Available for Ground and ISS Demos

- Component Dev’t
- Available for Ground and ISS Demos

Time (FY)
- 2010
- 2011
- 2012
- 2013
- 2014
- 2015
- 2016
- 2017
- 2018
- 2019
- 2020