NASA's Exploration Technology Development Program Energy Storage Project, Battery Technology Development

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

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Key Performance Parameters for Battery Technology Development

Customer Need	Performance Parameter	State-of-the-Art	Current Value	Threshold Value	Goal
Safe, reliable operation	No fire or flame	Instrumentation/controllers used to prevent unsafe conditions. There is no non-flammable electrolyte in SOA	Preliminary results indicate a small reduction in performance using safer electrolytes and cathode coatings	Tolerant to electrical and thermal abuse such as over-temperature, overcharge, reversal, and short circuits with no fire or thermal runaway***	Tolerant to electrical and thermal abuse such as over-temperature, overcharge, reversal, and short circuits with no fire or thermal runaway***
Specific energy Lander: 150 – 210 Wh/kg 10 cycles Rover: 160-200 Wh/kg 2000 cycles EVA: 270Wh/kg 100 cycles	**Battery-level** specific energy* [Wh/kg]	90 Wh/kg at C/10 & 30 C 83 Wh/kg at C/10 & 0 C (MER rovers)	160 at C/10 & 30 C (HE) 170 at C/10 & 30 C (UHE) 80 Wh/kg at C/10 & 0 C (predicted)	**135** Wh/kg at C/10 & 0 C "High-Energy"** **150** Wh/kg at C/10 & 0 C "Ultra-High Energy"**	**150** Wh/kg at C/10 & 0 C "High-Energy" **220** Wh/kg at C/10 & 0 C "Ultra-High Energy"
	Cell-level specific energy [Wh/kg]	130 Wh/kg at C/10 & 30 C 118 Wh/kg at C/10 & 0 C	199 at C/10 & 23°C (HE) 213 at C/10 & 23°C (UHE) 100 Wh/kg at C/10 & 0°C (predicted)	**165** Wh/kg at C/10 & 0 C "High-Energy" **180** Wh/kg at C/10 & 0 C "Ultra-High Energy"	**180** Wh/kg at C/10 & 0 C "High-Energy" **260** Wh/kg at C/10 & 0 C "Ultra-High Energy"
	Cathode-level specific capacity [mAh/g]	180 mAh/g	252 mAh/g at C/10 & 25°C 190 mAh/g at C/10 & 0°C	**260** mAh/g at C/10 & 0 C	**280** mAh/g at C/10 & 0 C
	Anode-level specific capacity [mAh/g]	280 mAh/g (MCMB)	330 @ C/10 & 0°C (HE) 1200 mAh/g @ C/10 & 0°C for 10 cycles (UHE)	**600** mAh/g at C/10 & 0 C "Ultra-High Energy"	**1000** mAh/g at C/10 0 C "Ultra-High Energy"
Energy density Lander: 311 Wh/l Rover: TBD EVA: 400 Wh/l	**Battery-level** energy density	250 Wh/l	n/a	**270** Wh/l "High-Energy" **360** Wh/l "Ultra-High"	**320** Wh/l "High-Energy" **420** Wh/l "Ultra-High"
	Cell-level energy density	320 Wh/l	n/a	**385** Wh/l "High-Energy" **460** Wh/l "Ultra-High"	**390** Wh/l "High-Energy" **530** Wh/l "Ultra-High"
Operating environment 0°C to 30°C, Vacuum	Operating Temperature	-20°C to +40°C	0°C to +30°C	**0°C** to **30°C**	**0°C** to **30°C**

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

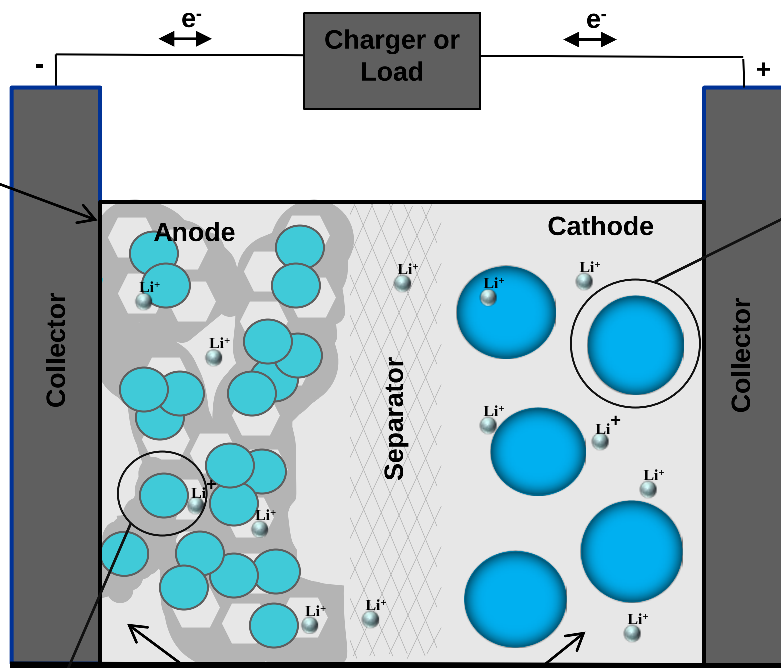
** "Ultra-High Energy" = mixed metal oxide cathode with Silicon composite anode

*** 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.

Revised 9/20/10

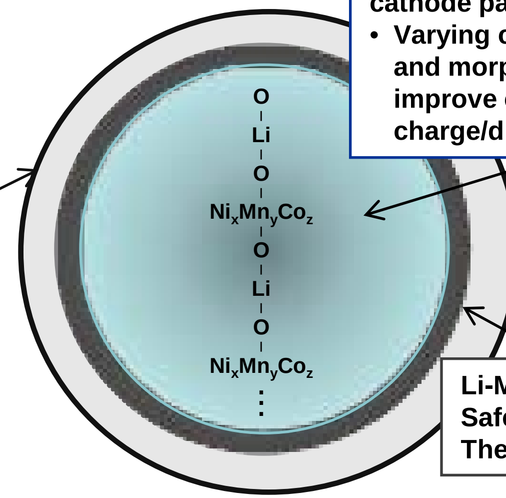
Lithium Ion Battery Technology Development
Advanced Cell Components

Nano-particle based circuit breaker



Layered $Li(NMC)O_2$ cathode particle

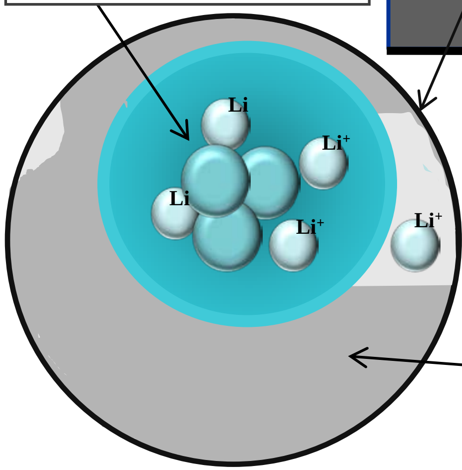
- Varying composition and morphology to improve capacity and charge/discharge rate



$Li\text{-}Metal\text{-}PO_4$ Safety Coating for Thermal Stability

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

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 ($Li[Li_xNi_yMn_zCo_{1-x-y-z}]O_2$) to improve capacity*

Project Transition

Current Project will be phased out Sept. 30, 2010

- Exploration Systems Mission Directorate
  - Exploration Technology Development Program
    - …
    - Energy Storage Project
      Goal: To develop energy storage technologies for Lunar Exploration
    - …

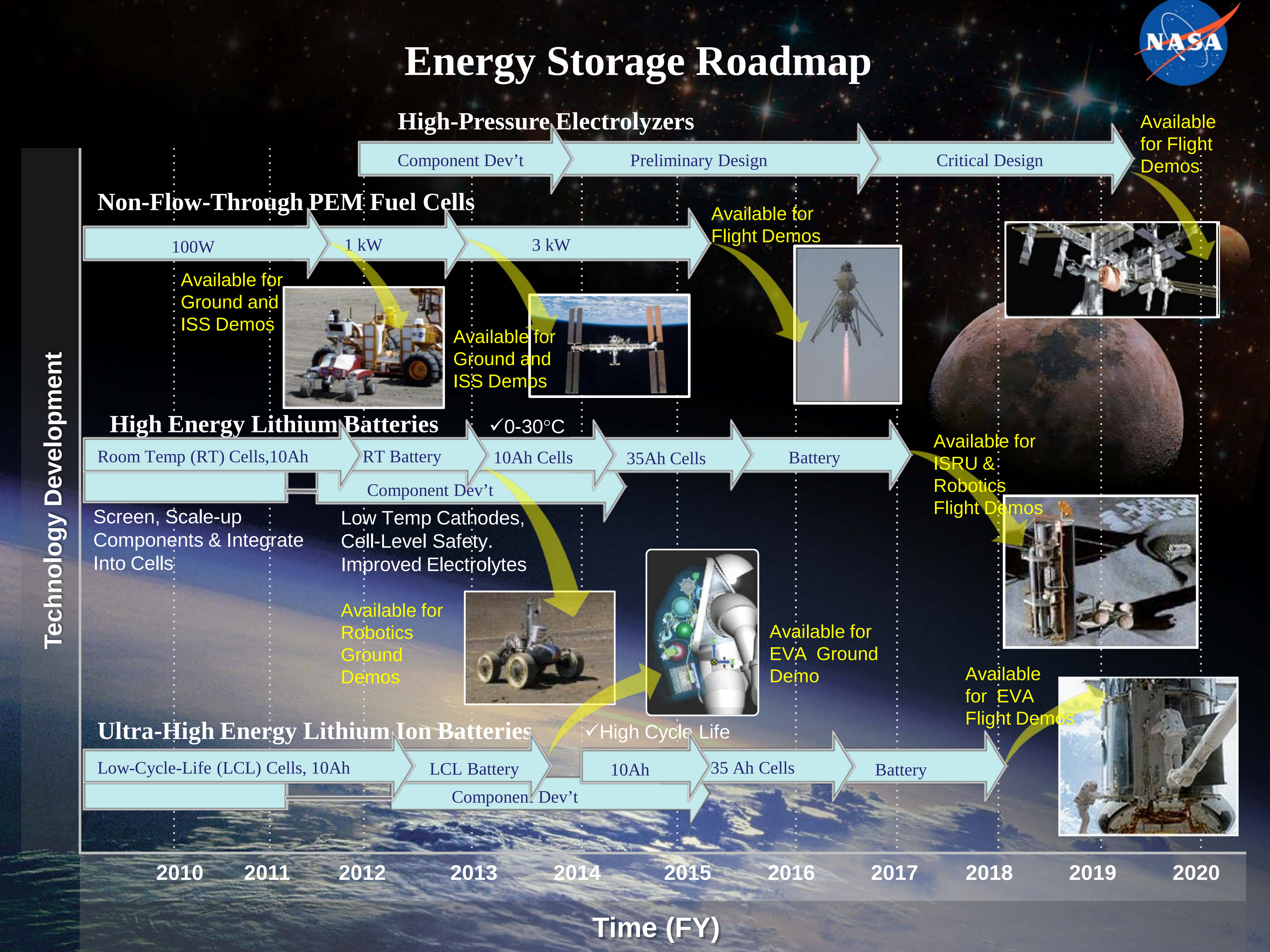
New Project as of October 1, 2010

- Exploration Systems Mission Directorate
  - Enabling Technology Development and Demonstration
    - …
    - High Efficiency Space Power Systems
      Goal: To provide abundant and low-cost power where it is needed for power-rich exploration
    - …

Notional Schedule for DD Cell Builds in FY10-FY11

Hardware Description	Notional Schedule	Comments
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
NASA
High-Pressure Electrolyzers
Component Dev't
Preliminary Design
Critical Design
Available for Flight Demos
Non-Flow-Through PEM Fuel Cells
100W
1 kW
3 kW
Available for Ground and ISS Demos
Available for Ground and ISS Demos
Available for Flight Demos
High Energy Lithium Batteries
✓0-30°C
Room Temp (RT) Cells,10Ah
RT Battery
10Ah Cells
35Ah Cells
Battery
Component Dev't
Available for ISRU & Robotics Flight Demos
Screen, Scale-up Components & Integrate Into Cells
Low Temp Cathodes, Cell-Level Safety. Improved Electrolytes
Available for Robotics Ground Demos
Available for EVA Ground Demo
Available for EVA Flight Demos
Ultra-High Energy Lithium Ion Batteries
✓High Cycle Life
Low-Cycle-Life (LCL) Cells, 10Ah
LCL Battery
10Ah
35 Ah Cells
Battery
Component Dev't
Technology Development
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Time (FY)