Status of the Space-Rated Lithium-Ion Battery Advanced Development Project in Support of the Exploration Vision

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Session [D04]
Advanced Materials, Structures, and Mechanisms
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The NASA Glenn Research Center (GRC), along with the Goddard Space Flight Center (GSFC), Jet Propulsion Laboratory (JPL), Johnson Space Center (JSC), Marshall Space Flight Center (MSFC), and industry partners, is leading a space-rated lithium-ion advanced development battery effort to support the vision for Exploration. This effort addresses the lithium-ion battery portion of the Energy Storage Project under the Exploration Technology Development Program. Key discussions focus on the lithium-ion cell component development activities, a common lithium-ion battery module, test and demonstration of charge/discharge cycle life performance and safety characterization. A review of the space-rated lithium-ion battery project will be presented highlighting the technical accomplishments during the past year.

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Energy Storage Project

- Exploration Technology Development Program ETDP
  - Focused technology development program that address critical technology areas required to implement the Vision for Exploration
- Energy Storage Project – Addresses Batteries and Fuel Cells
- Applications
  - Orion (Crew Exploration Vehicle, CEV)
  - Ares I (Crew Launch Vehicle, CLV) Upper Stage
  - Ares V (Cargo Launch Vehicle, CaLV)
  - Lunar Precursor and Robotic Program (LPRP)
  - Lunar Surface Access Module (LSAM)
  - Earth Departure Stage (EDS)
  - Un-pressurized Rovers and Habitats
  - EVA Suit 2
- Technology development to achieve TRL 6 - phased to meet technology insertion dates

Energy Storage Technology Insertion for Exploration Missions

CEV	PDR: 3/08	CDR: 4/09
CLV/ARES-1	PDR: 5/08	CDR: 7/09
CLV/ARES-5	PDR: FY12 Q3	CDR: FY14 Q1
EVA	PDR: 7/08	CDR: 10/09
EVA Suit 2	PDR: FY12 Q2	CDR: FY15 Q3
LSAM	PDR: FY13 Q1	CDR: FY14 Q2
Surface Sys.	PDR: FY13 Q2	CDR: FY15 Q1

Energy Storage Project Overview

- NASA/Industry/Academia Partnership
  - NASA Centers -GRC – Lead, JPL, JSC, MSFC, GSFC
  - Industry – T/J Technology
  - Grants - University of Texas, Austin, USC, University of Akron, CalTech
  - SBIRs – Giner, Inc; Yardney Technical Products, Inc; T/J Technology, Santa Fe Science and Technology, Inc
- Exploration Mission Energy Storage Requirements and Trade Studies

Exploration Mission Energy Storage Requirements and Trade Studies

- Analysis and assessment of mission power profiles
  - Identify and define energy storage requirements
  - Define where specific fuel cell & battery technologies apply
- Properly size and design the energy storage system to meet those requirements.
- Identify gaps between current performance capabilities and the mission requirements

Exploration Battery Objectives

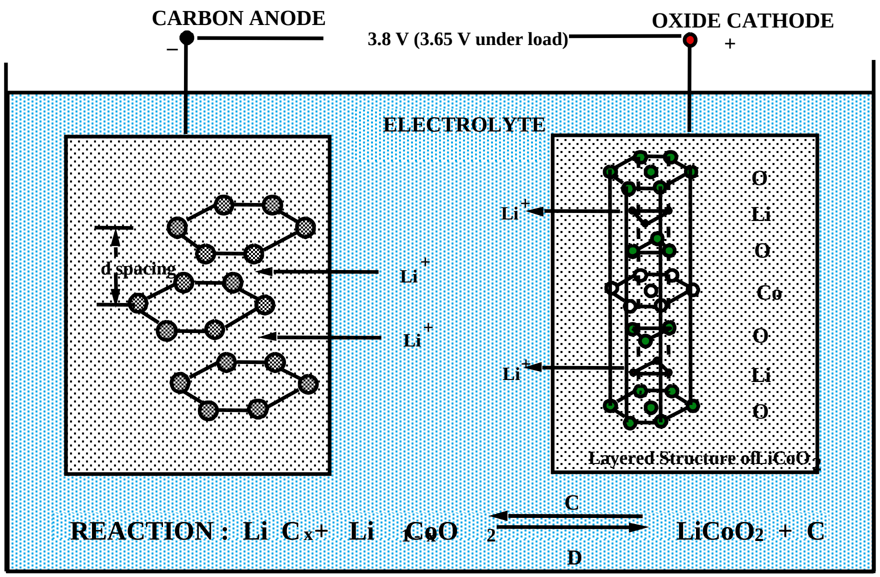
- Develop a common battery module to serve as the building block for multiple Exploration missions
  - Affordability
  - Flexibility
  - Effectiveness
  - Reusability
  - Modularity
- Focus technology development efforts to address technology gaps to meet Exploration specific challenges
  - Human-rated safety
  - Wide operating range
  - Light-weight, low-volume

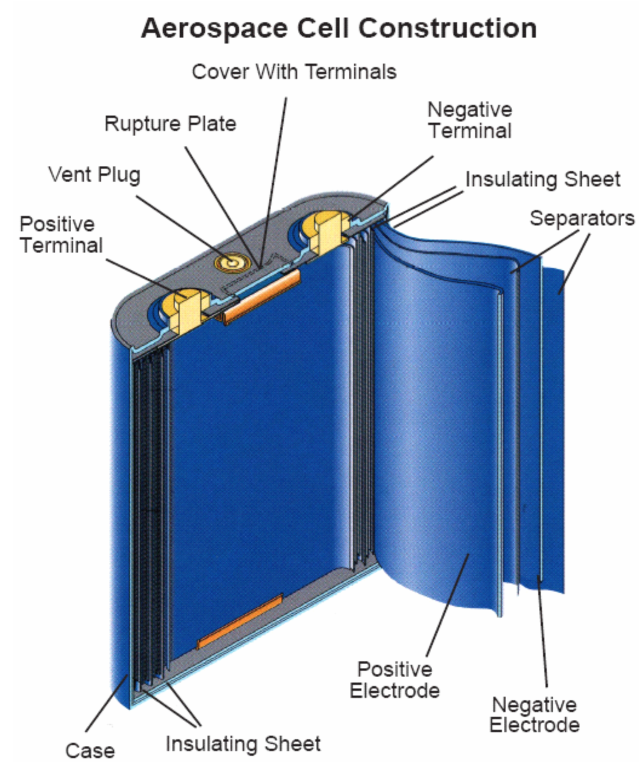
Exploration Battery Development Approach

- Trade Studies
- Parallel Development Efforts
  - Cell level technology development
  - Battery module development
  - Test and demonstration
  - Multi-mission support

Lithium-Ion Cell Design

Rechargeable Lithium-ion Cell

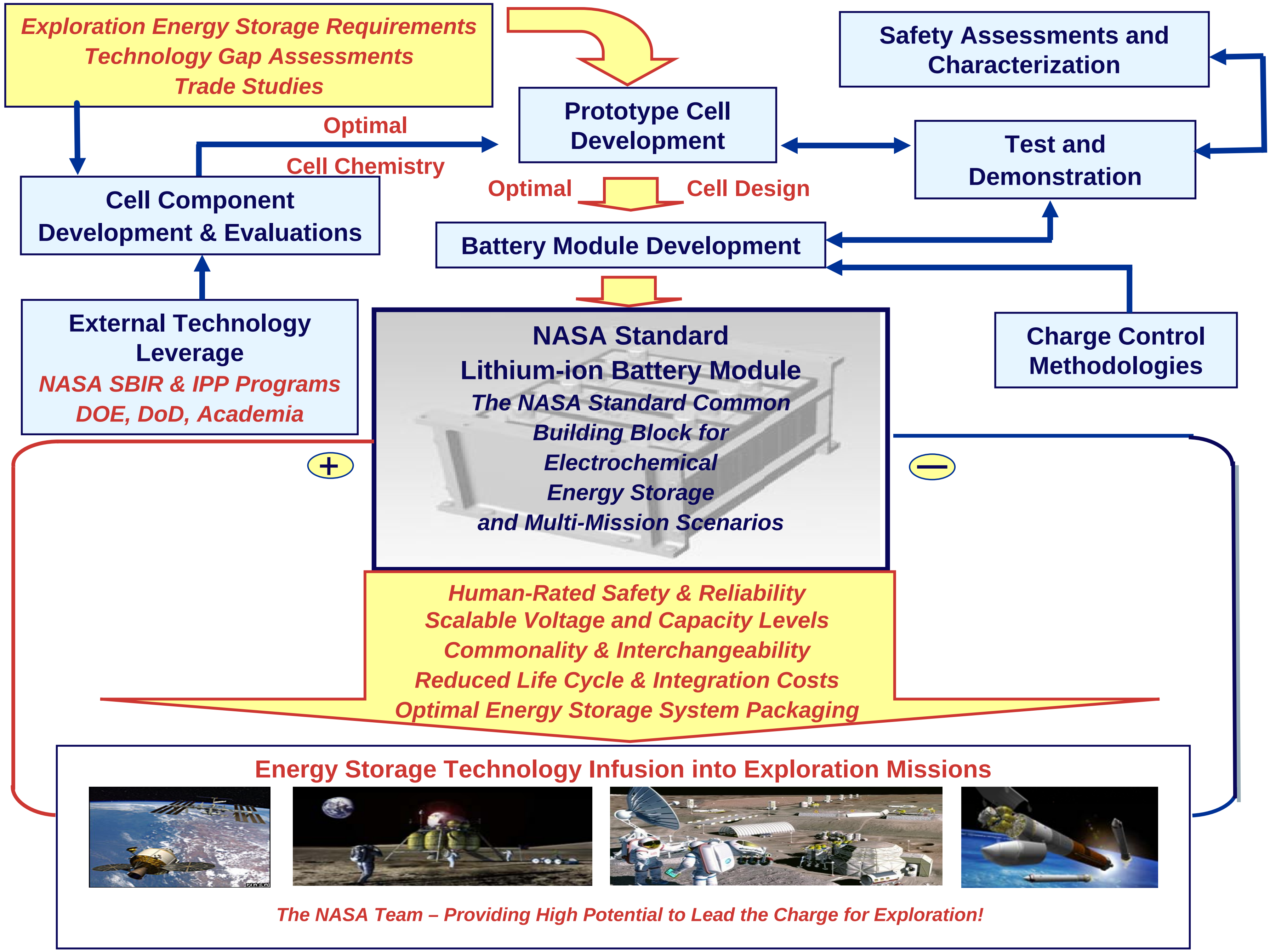




- Li intercalation (solid-state insertion) reactions at both electrodes
- Lithium ion moves from one electrode to the other through electrolyte
  - Organic liquid, polymer or inorganic solid-state electrolyte
- Lithium metal-free

- Configuration: Prismatic, cylindrical or wound-prismatic
- Pouch cells for short-life applications and polymer electrolyte cells

ETDP Energy Storage Project - Lithium-ion Battery Development Task

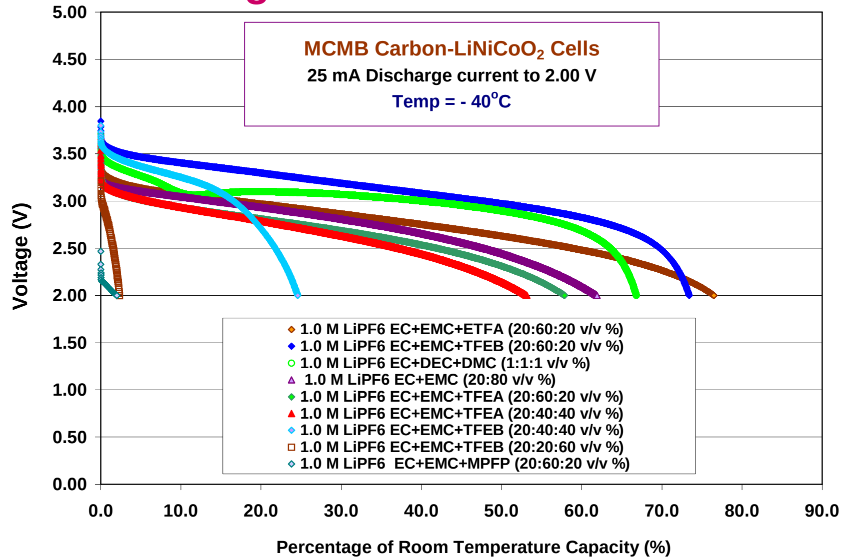


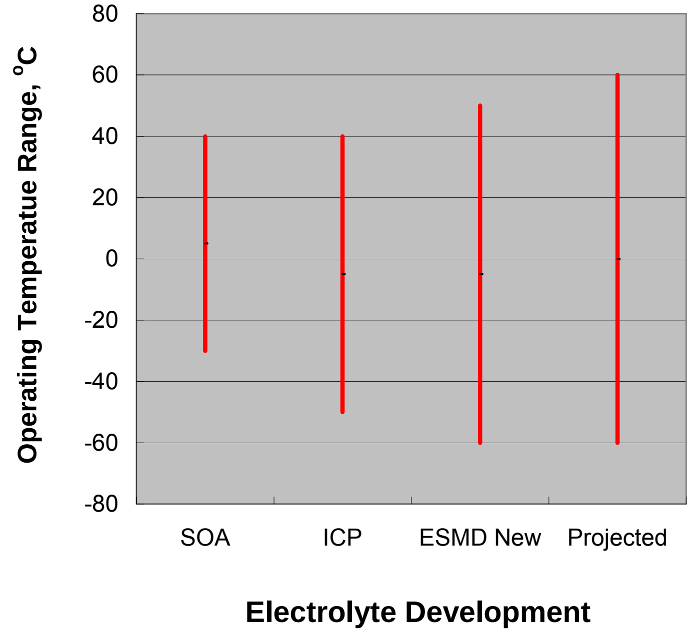
Lithium-Ion Cell Component Development Task

- Electrolytes - Liquid electrolytes, polymer electrolytes
  – Widen operating temperature range
  – Non-flammable solvents to enhance system safety
  – Improved specific energy
- Cathode
  – Improve specific capacity and safety
    - Layered lithiated MnNiCo oxide
    - Lithium iron phosphate
- Anode
  – Silicon composite
  – Carbon:carbon substrate
- Separator
  – Shut-down separator

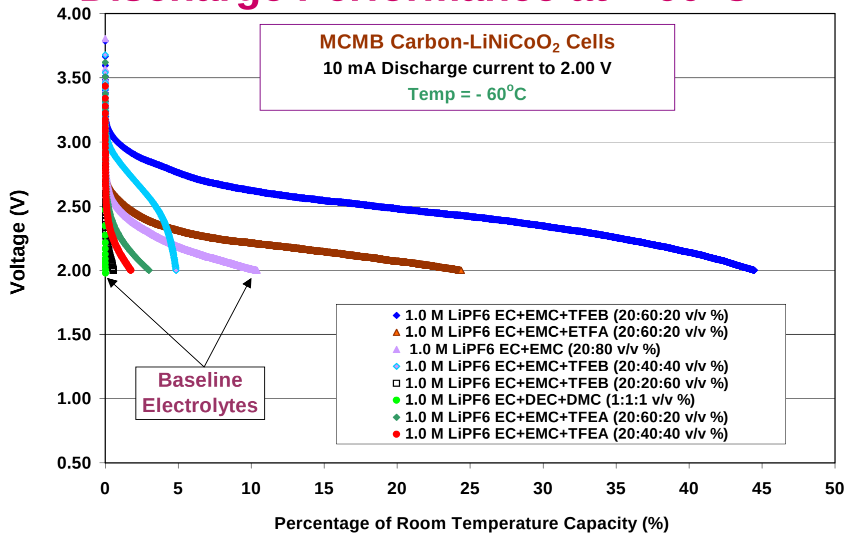
Liquid Electrolyte Development

Discharge Performance at – 40^{o}C





Discharge Performance at – 60^{o}C

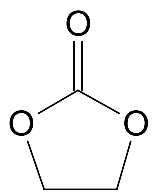


- **Cells containing 1.0 M $LiPF_6$ in EC+EMC+X (20:60:20 v/v %) (where X = 2,2,2-trifluoroethyl butyrate or ethyl trifluoroacetate) deliver superior performance at low temperature compared to previously evaluated electrolytes.**

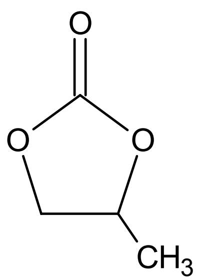
- **Future focus is directed to improving the high temperature resilience of the electrolytes and their safety characteristics (i.e., reducing their flammability)**

Liquid Electrolyte Nomenclature

EC and PC (Film-forming)

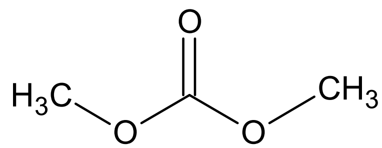


Ethylene carbonate (EC)

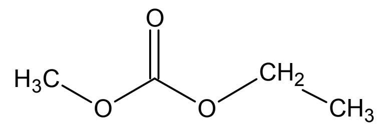


Propylene carbonate (PC)

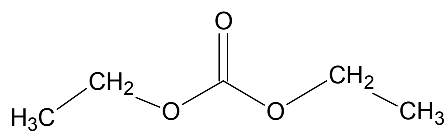
Carbonate co-solvents



Dimethyl carbonate (DMC)

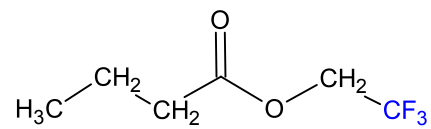


Ethyl methyl carbonate (EMC)

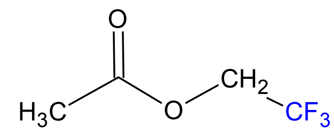


Diethyl carbonate (DEC)

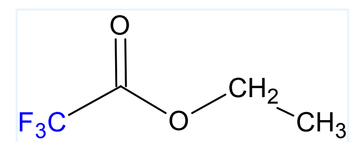
Ester co-solvents



2,2,2-Trifluoroethyl butyrate (TFEB)

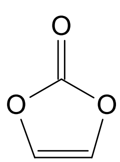


2,2,2-Trifluoroethyl acetate (TFEA)

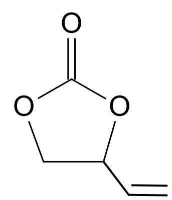


Ethyl trifluoroacetate (ETFA)

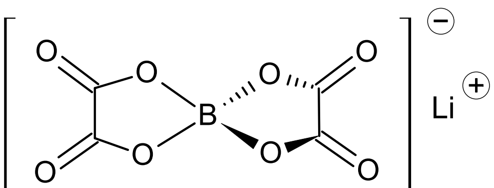
Additives/ New Salts



Vinylene carbonate (VC)

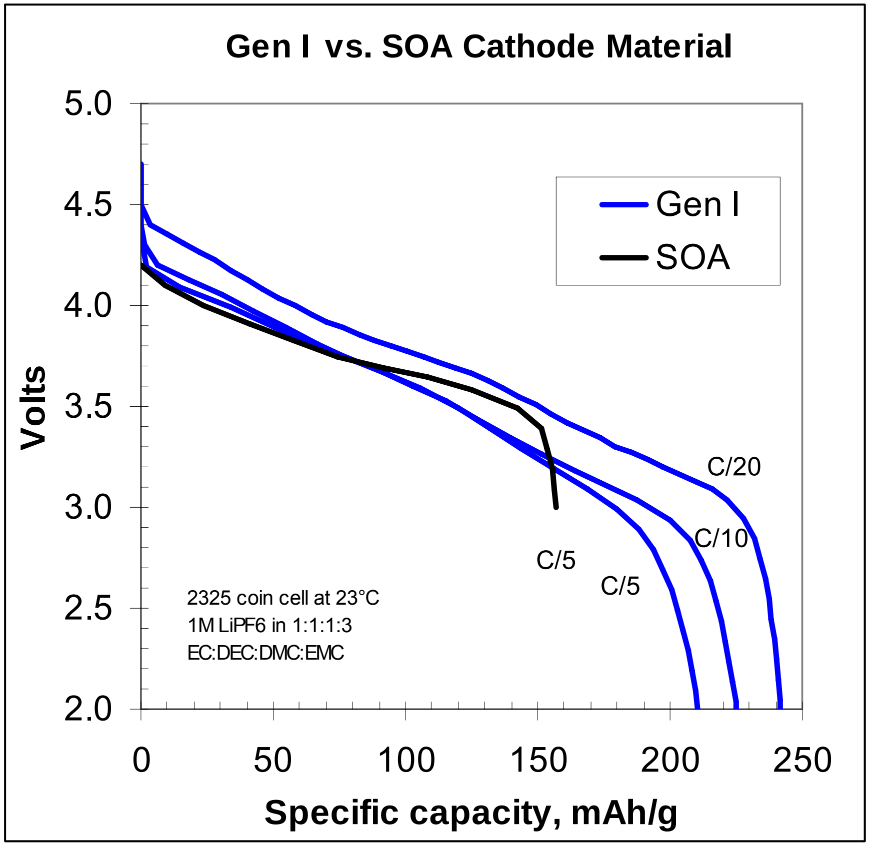


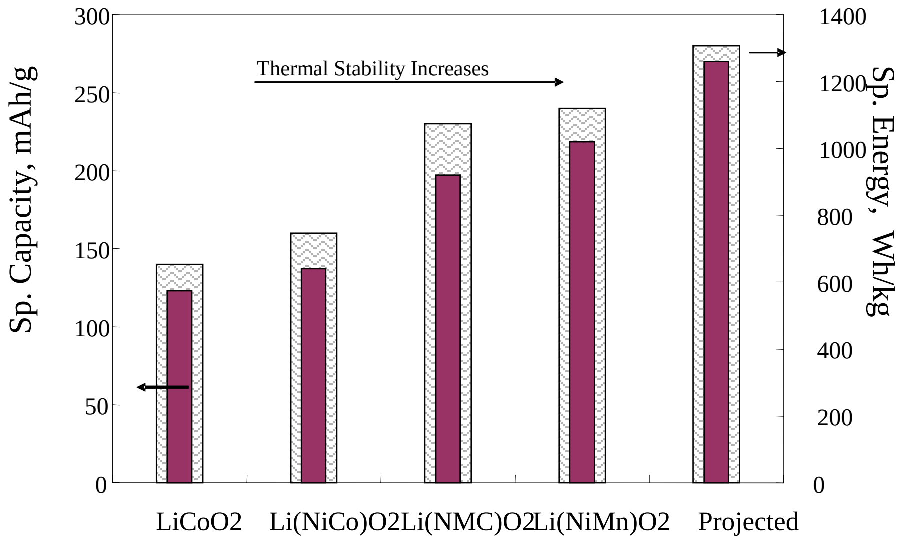
4-Vinyl-1,3-dioxolane-2-one (or vinyl ethylene carbonate)



Lithium bis(oxalato)borate (or LiBOB)

Cathode Development





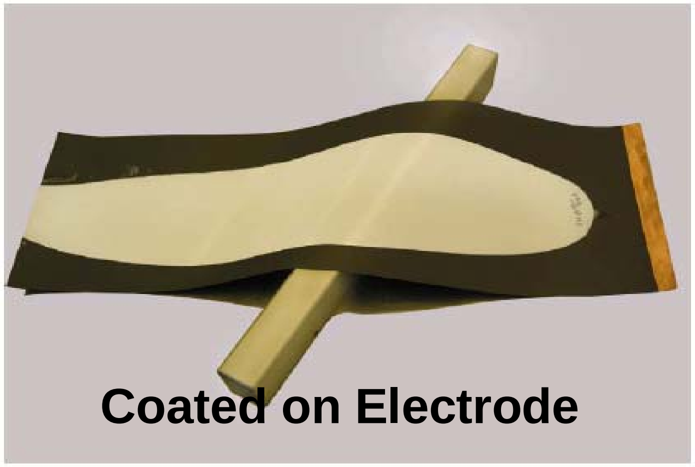
Cathode Material Development

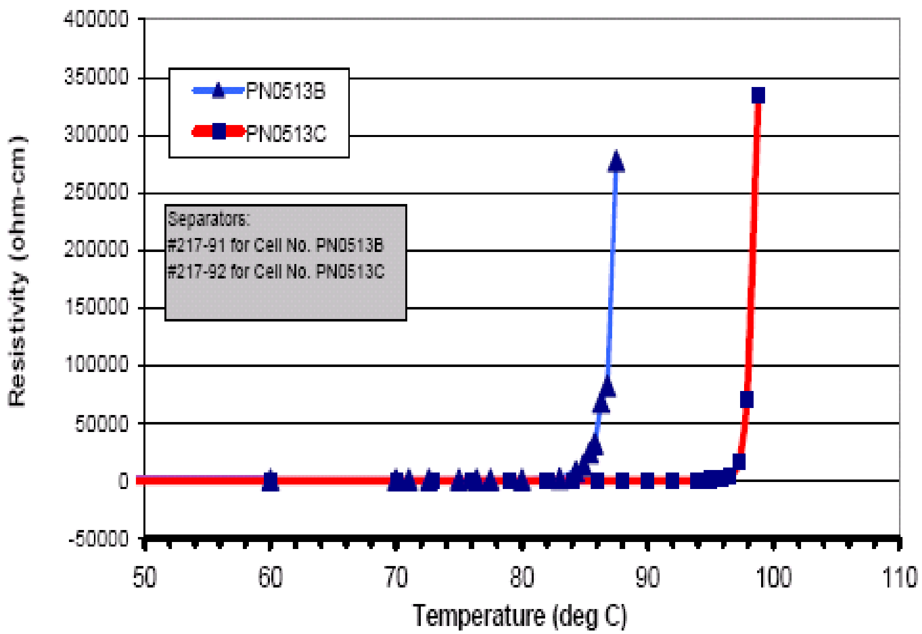
240 mAh/g demonstrated at low rate, up to 210 mAh/g at 5-hour rate (C/5)

Benefits

- Over 50% improvement in the specific energy over the state-of-art materials
- ~19% mass savings at the battery level
- Thermal stability also improves, which is expected to contribute enhanced cell safety

Separator Development



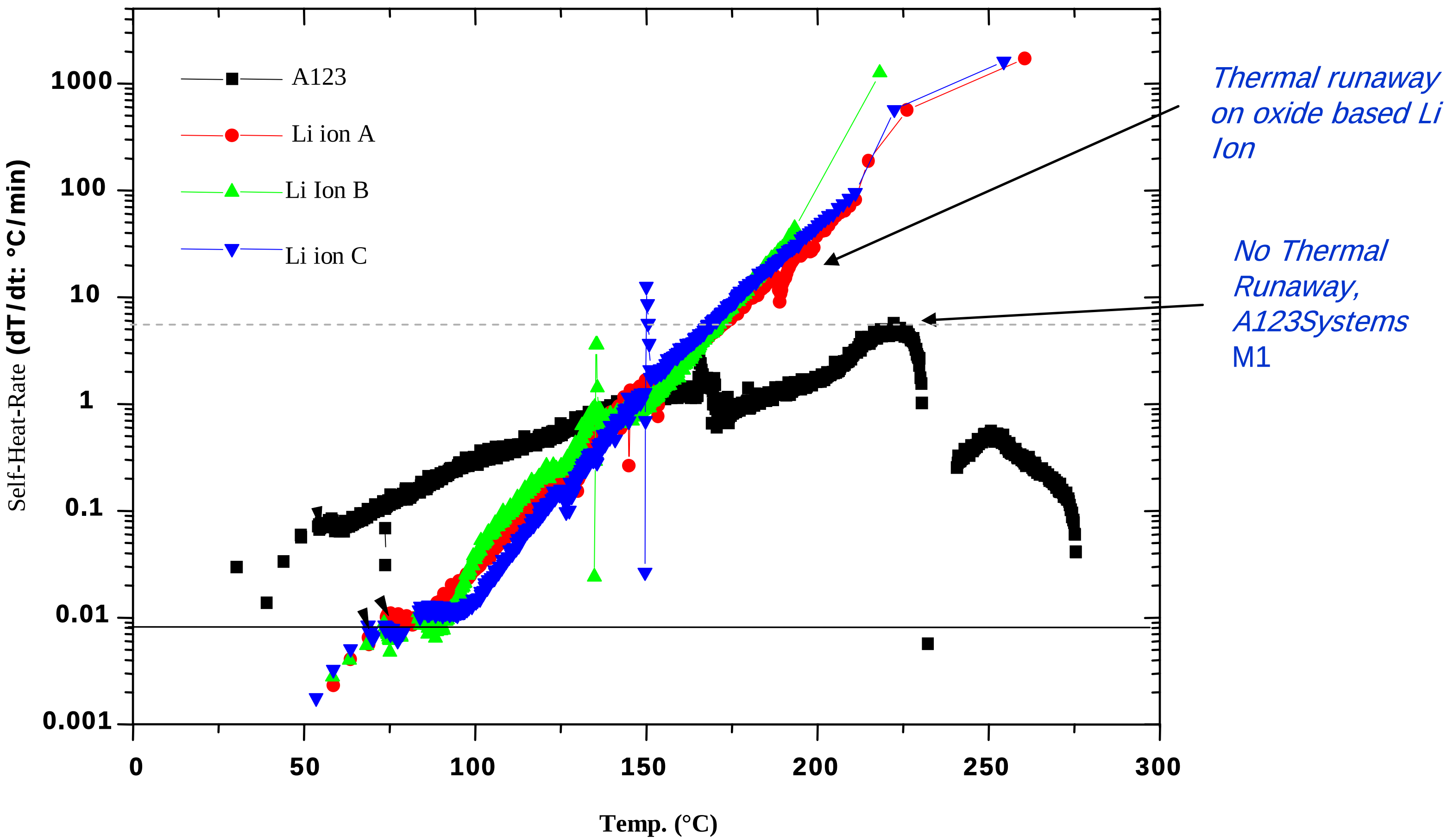


Cells with two different separator compositions that shut down at two different temperatures

T/J Technologies Inc.

Lithium Iron Phosphate: Inherently Safe Chemistry

Accelerated rate calorimetry test



Lithium-Ion Cell Component Development

- Component Demonstration - Cell Fabrication and Evaluation
  - Identify most promising component developments
  - Scale-up materials production
  - Fabricate small production lots to evaluate performance
    - Acceptance, Characterization, Abuse, Life cycle
  - Destructive Physical Analysis to investigate failure modes
    - Provide recommendations for cell design improvements for next cell generation
- Identify preferred cell design features for specific Exploration missions

Lithium-Ion Battery Module Activities

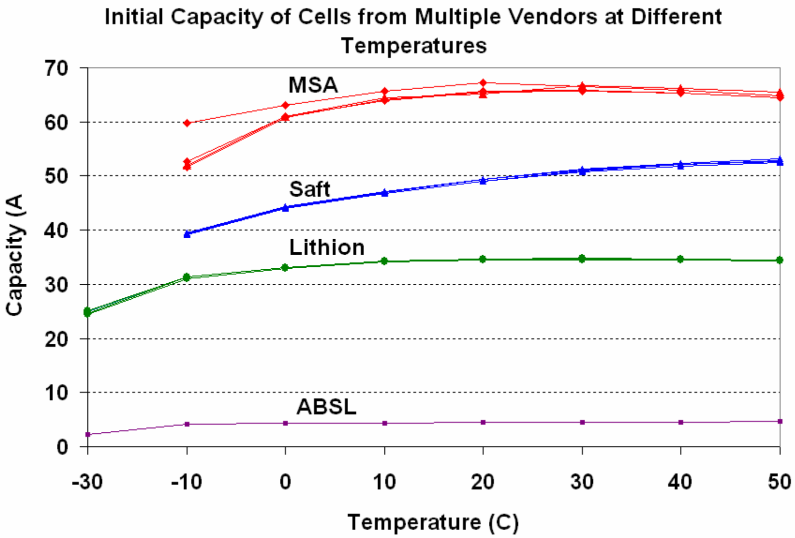
- Conduct lower-level trade studies to determine battery commonality among Exploration Missions
  - Drivers include voltage, ampere-hour capacity, cycle life, thermal considerations, structural loads, and commonality
- Develop common battery module design that meets performance requirements
  - Power, thermal, and data interfaces are controlled
  - Module can accept lithium-ion cells from multiple vendors
  - Component formulations can be customized to meet specific performance goals
- Fabricate and qualify battery module
  - Integrate charge control circuitry and software with the module
  - Conduct acceptance level testing
  - Perform environmental qualification testing to attain TRL 6

Li-Ion Test and Demonstration

- Evaluate SOA technology in Exploration Specific Operational Profiles
  - Develop database to define performance capabilities
  - Develop models to aid in performance predictions
  - Evaluate battery safety and reliability
- Evaluate cell component advances developed as part of this project
- Define and perform acceptance and qualification testing for Li-ion battery module

Cycle Life Verification Testing

- **Background**: This subtask originated from the Lithium-ion Cell Test Verification Program under the former NASA Aerospace Battery Program.
- **Objectives:**
  – Develop a statistical model to predict the performance and cycle life of Li-ion batteries operating at a specified set of mission conditions
  – Assess performance characteristics and lifetime of lithium-ion cells
  – Characterize products from multiple vendors over a range of temperatures, end-of-charge-voltages, and depth-of-discharges



Li-Ion Multi-Mission Support

- Damage Control Model for Li-ion Batteries
  - Interactions between temperature, charge voltage, depth-of-discharge
  - Determine instantaneous damage from life cycle data
  - Establish optimal charge profile
- NASA Aerospace Battery Workshop
  - Jointly sponsor annual workshop addressing current battery issues and developments
  - Hosted by Marshall Space Flight Center
- Rover Demonstration planned for late FY07

Battery Summary Remarks

- Energy Storage Battery Development Effort
  - Directed at development of a common battery module
    - Common chemistry, handling and operational procedures
    - Interchangeable modules
  - Allows introduction of technology advances that address gaps between SOA and Exploration specific mission requirements
  - Leverages numerous existing efforts
  - Addresses needs of human-rated systems
- Targeted developments for insertion into Constellation and Exploration missions