

# **Electrochemical Energy Storage and Power Sources for NASA Exploration Missions”**

**Richard Baldwin**

**10th Electrochemical Power Sources R&D Symposium  
Williamsburg, VA  
August 20 - 23, 2007**

An overview of NASA’s electrochemical energy storage programs for NASA Exploration missions is being presented at the 10<sup>th</sup> Electrochemical Power Sources R&D Symposium, which is being held in Williamsburg, VA on August 20-23, 2007. This public domain venue, which is sponsored by the U.S. Navy and held every two years, serves as a forum for the dissemination of research and development results related to electrochemical energy storage technology programs that are currently being supported and managed within governmental agencies. Technology areas of primary interest include batteries, fuel cells, and both overview and focused presentations on such are given by both governmental and contractual researchers. The forum also provides an opportunity to assess technology areas of mutual interest with respect to establishing collaborative and/or complementary programmatic interactions.



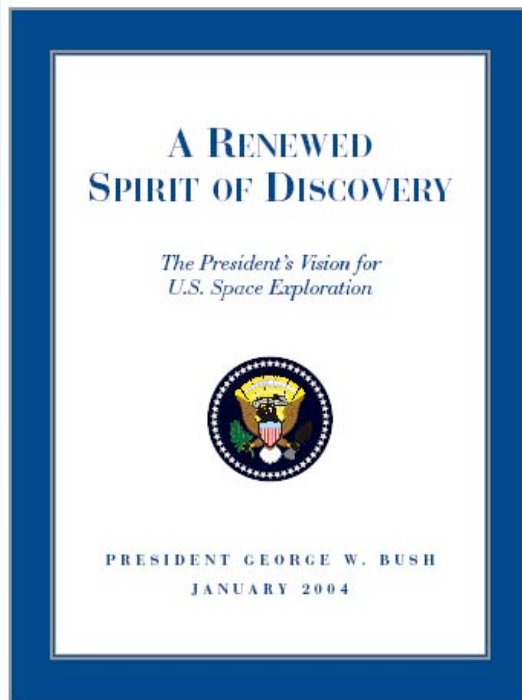
# **Electrochemical Energy Storage and Power Sources for NASA Exploration Missions**

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Williamsburg, VA  
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# National Vision for Space Exploration

**THE FUNDAMENTAL GOAL OF THIS VISION IS TO ADVANCE U.S. SCIENTIFIC, SECURITY, AND ECONOMIC INTEREST THROUGH A ROBUST SPACE EXPLORATION PROGRAM**



Implement a **sustained** and **affordable** human and robotic program to explore the solar system and beyond

**Extend human presence across the solar system**, starting with a human return to the Moon by the year 2020, in preparation for human exploration of Mars and other destinations;

**Develop the innovative technologies, knowledge, and infrastructures** both to explore and to support decisions about the destinations for human exploration; and

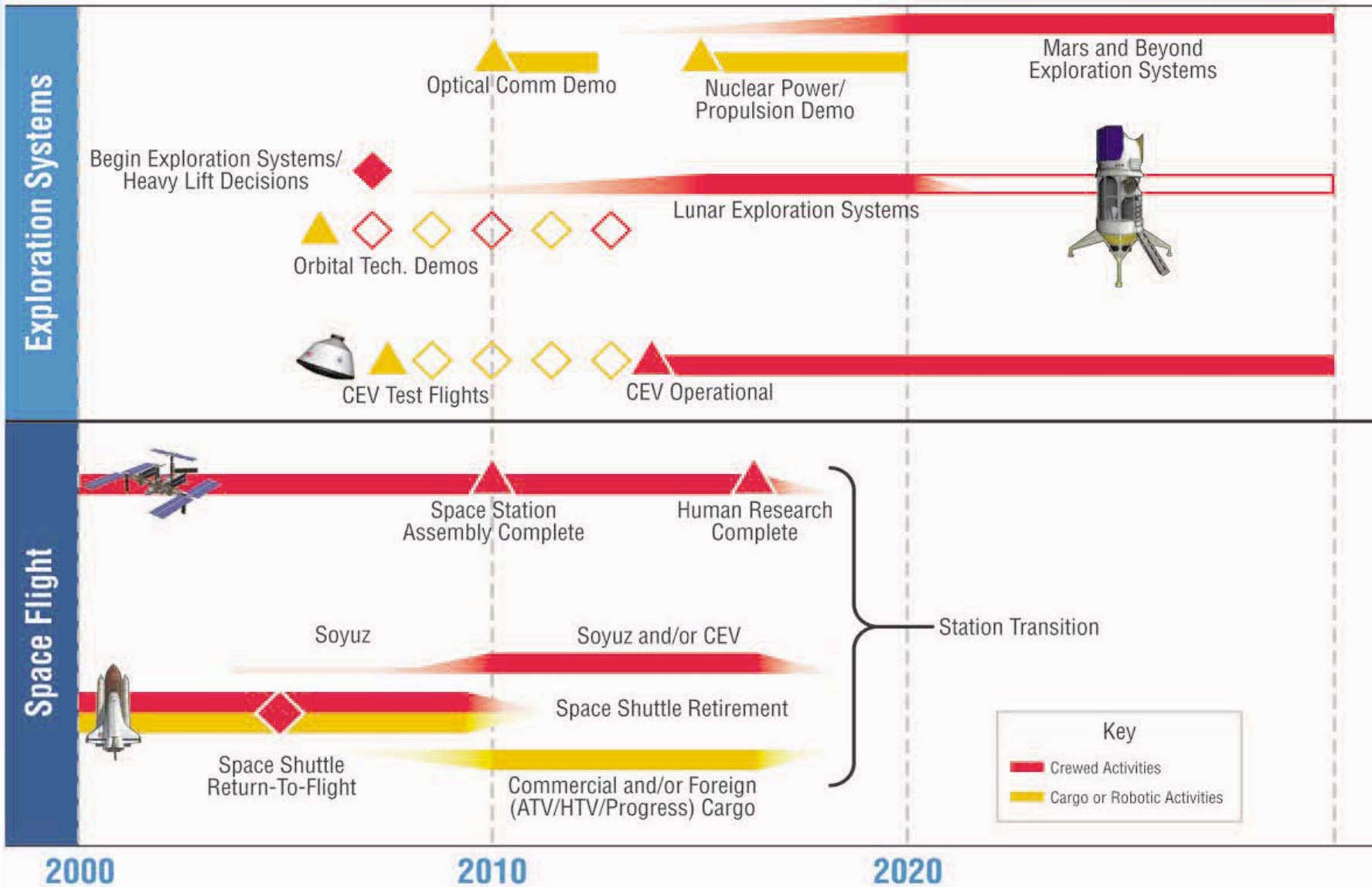
Promote **international and commercial participation** in exploration to further U.S. scientific, security, and economic interests.

# Preparing for Mars Exploration: First Stop, Our Moon

- Use the Moon as a test bed to reduce risk for future human Mars missions
- Advance technology to reduce mission costs and support exploration
- Perform systems testing for reliability in harsh environments
- Expand mission and science surface operations experience
- Build human-machine collaboration to achieve more than either alone
- Break the bonds of dependence on Earth with closed-loop life support
- Develop and test power generation and propulsion
- Invest in common hardware for Moon, Mars, and other Exploration objectives



# Exploration building blocks will provide the capabilities necessary for exploration of the solar system and beyond



# NASA's Exploration Architecture

## Exploration Systems Mission Directorate

Dedicated to supporting the Vision for Space Exploration by developing new capabilities, supporting technologies and foundational research that enables sustained and affordable human and robotic exploration

- **Constellation Program** - Responsible for Orion crew exploration vehicle (CEV) and Ares launch vehicles development projects
- **Advanced Capabilities Division** – Provides knowledge, technology and innovation. Matures, integrates and transitions advanced technologies to Constellation and Robotic missions
  - **Human Research Program (HRP)**
  - **Lunar Precursor Robotic Program (LPRP)**
  - **Exploration Technology Development Program (ETDP)** – Multiple focused projects to develop enabling technologies to address high priority needs for lunar exploration. Matures technologies to the level of demonstration in a relevant environment
    - **Energy Storage Project**



# NASA Mission Applications

## Near-term:

- Orion (Crew Exploration Vehicle, CEV)
- Ares I (Crew Launch Vehicle, CLV)

## Far-term:

- Ares V (Cargo Launch Vehicle, CaLV)
- Lunar Precursor and Robotics Program (LPRP)
- Lunar Surface Access Module (LSAM)
- Rovers, Habitats and EVA



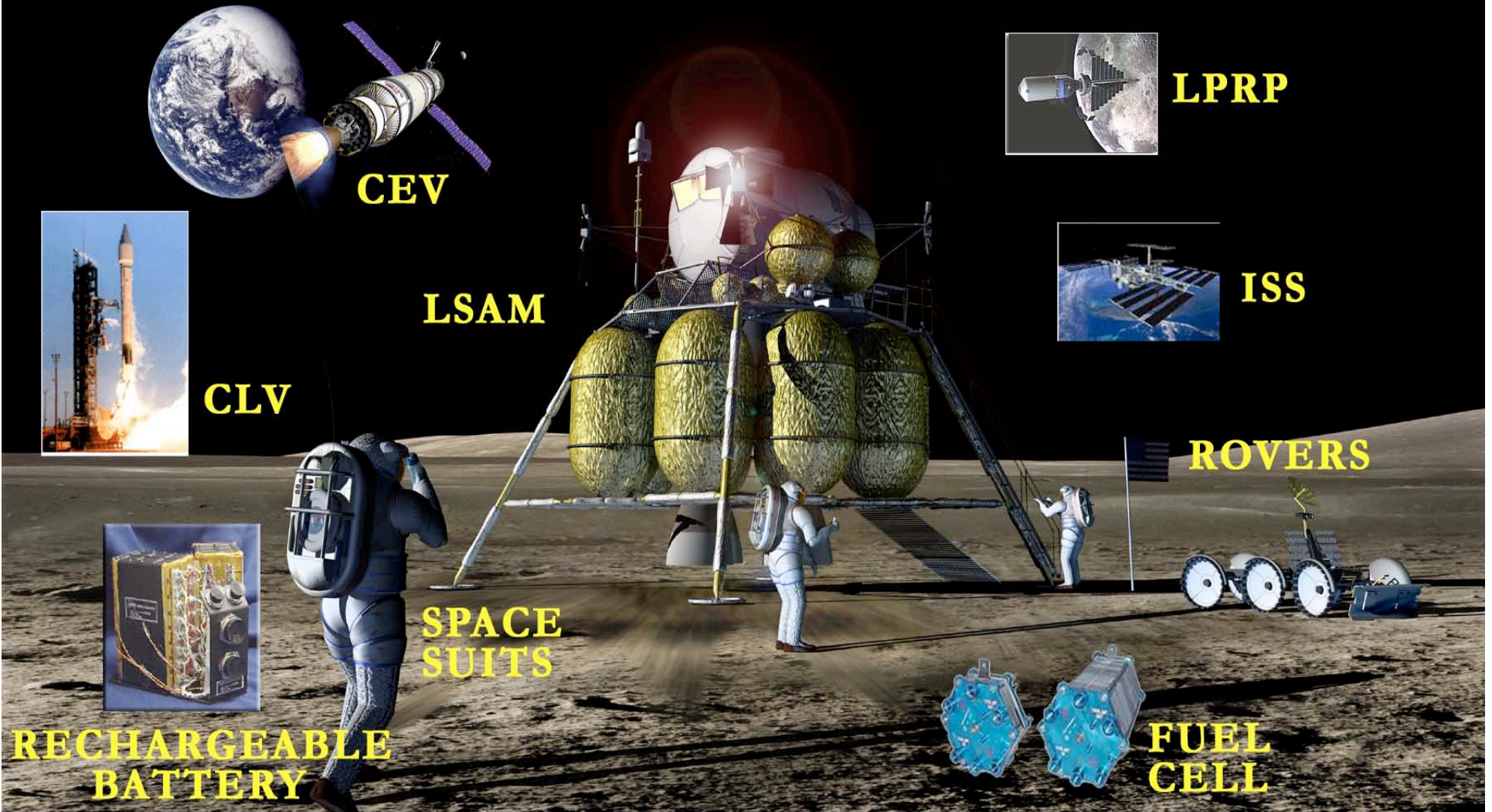
## ETDP Energy Storage Project



## Addresses Development of Advanced Batteries and Fuel Cells

**Maturation of near-term technologies and development of long-lead technologies for lunar exploration missions. Technology development to achieve TRL 6 - phased to meet technology mission insertion dates**

# Energy Storage Technology for Exploration Missions



**NASA Glenn Research Center**

**Jet Propulsion Laboratory**

**Johnson Space Center**

**Marshall Space Flight Center**

**Goddard Space Flight Center**

**Kennedy Space Center**



# Energy Storage Project Overview

## NASA / Industry / Academia Partnerships

- NASA Centers - GRC – Lead, JPL, JSC, MSFC, KSC, GSFC
- Industry – T/J Technologies, Inc., Lockheed Martin, Quallion
- Grants - University of Texas at Austin, USC, University of Akron, Texas A&M, CalTech, Virginia Commonwealth

**NASA SBIR Program Participants – Infinity Fuel Cell & Hydrogen, Inc., ElectroChem, Inc., Distributed Energy Systems, Giner, Inc., Yardney Technical Products, Inc., T/J Technologies, Inc., Santa Fe Science & Technology, Inc.**

**NASA Innovative Partnership Program (IPP) – T/J Technologies, Inc., ABSL Space Products, Northrop Grumman Space Technology**

**Exploration Mission Energy Storage Requirements and Trade Studies**

**Space-Rated Lithium-ion Batteries Technology Development**

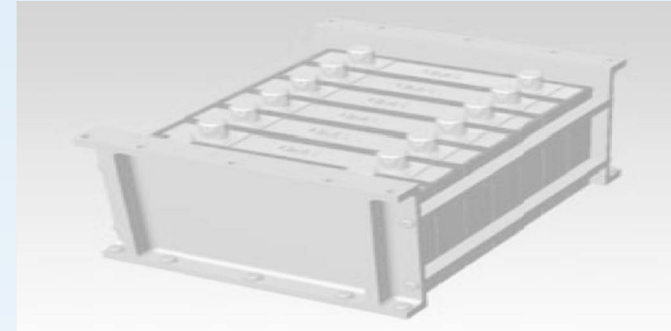
**Fuel Cells for Surface Power Technology Development**



# Space-Rated Lithium-ion Batteries Objectives

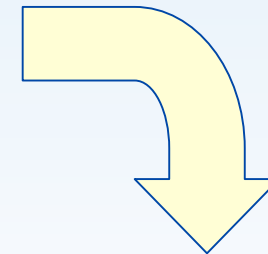
Develop a **common battery module** that addresses technology gaps to meet Exploration challenges

- Human-rated Safety and Reliability
- Wide Operating Temperature Range
- Light-weight / Low-volume



Approach via focus technology development efforts

- Trade Studies and Requirements Assessments
- Cell Component Development
- Test and Demonstration
- Module Development
- Multi-mission Support

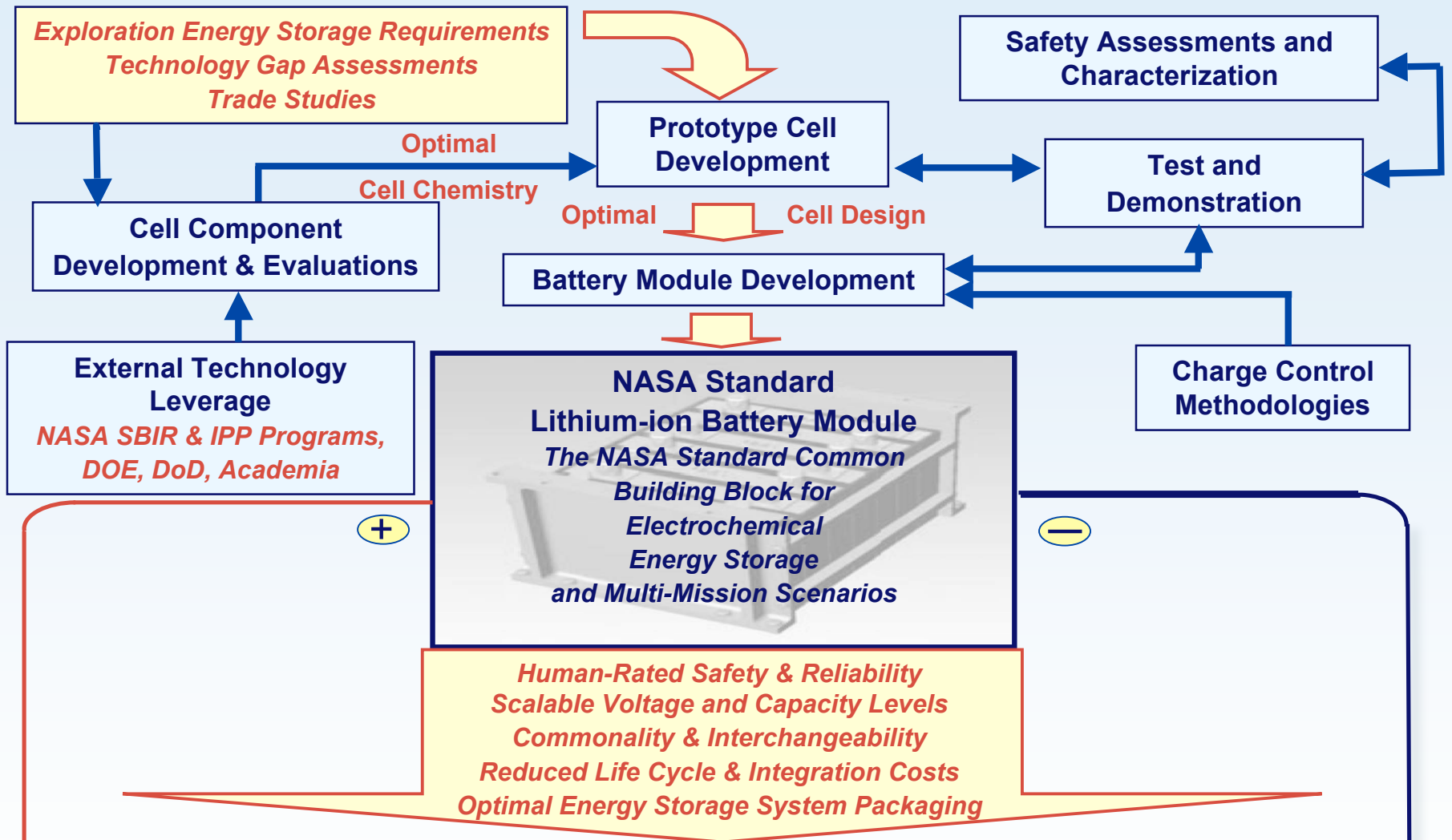


to afford mission-enhancing attributes

- Modularity / Scalability
- Commonality / Flexibility
- Optimal system packaging
- Life cycle & integration cost efficiency

Deliver a prototype module at  
TRL 6 by FY11 for infusion into  
LSAM PDR

# ETDP Energy Storage Project – Space-Rated Lithium-ion Batteries Task



## Energy Storage Technology Infusion into Exploration Missions



*The NASA Team – Providing High Potential to Lead the Charge for Exploration!*

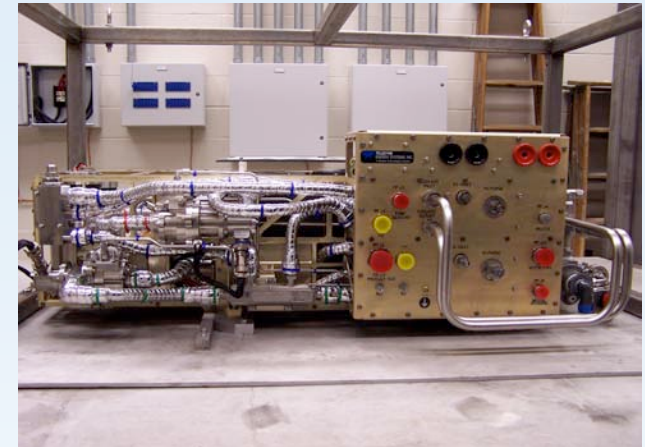
# Fuel Cells for Surface Power Objectives

Develop fuel cells / regenerative fuel cells (RFCs) for Exploration surface power, which encompasses technologies to address unique environmental requirements

- Potable water production
- Provide long mission durations
- RFC's enable near-term implementation of storage for base power (combined with PV)

Approach via focused technology development efforts

- Leverage commercial sector advances
- Flow-through and non-flow-through system technologies
- High-pressure electrolysis
- Balance-of-plant / passive ancillary components



to address three fuel cell classes

- <1 kW for EVA portable life support system
- 8 kW for un-pressurized rovers
- 25 kW for RFC surface power and pressurized rovers

**Demonstrate TRL 6 for RFC systems by 2014**

# **Additional Aerospace Program Areas Being Supported to Enhance Overall Mission Energy Storage Technology Needs**

**Near-term Constellation Program (Orion and Ares upper stage) and LSAM**

- **Systems engineering and integration support**
- **Trade studies – cell/battery chemistry / sizing, power technology options**
- **Cell/battery general, safety and mission-specific performance testing**

**NASA Aeronautics Research Mission Directorate (ARMD) projects**

**Earth-orbiting spacecraft / ISS / satellites**

**Deep-space / planetary probes / surface rover exploration vehicles**

**EVA / spacesuit power systems**

**Dual-use / governmental and commercial technology needs**

**NASA Aerospace Flight Battery Systems Working Group / NASA Engineering and Safety Center (NESC)**

- **Addresses critical battery-related performance / manufacturing issues for NASA and the aerospace community → Lithium-ion battery focus**



# NASA Glenn Electrochemistry Branch

## Battery Development Facilities and Capabilities

### Facilities

- Laboratories with SOA analytical and electrochemical characterization capabilities
- Dry room (600 ft<sup>2</sup>) with 1% relative humidity for handling moisture sensitive materials used in lithium-based batteries
- State-of-the-art battery cycling facilities with >200 independent test channels (1-200 Ahr / 1-50 V)
- Environmental chambers to evaluate performance as a function of temperature (-75 °C to +200 °C)
- Accelerating Rate Calorimeter (ARC)



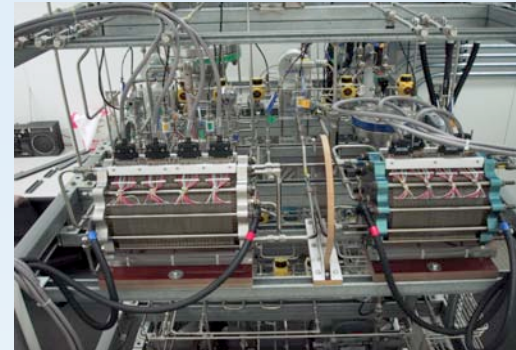
### Capabilities

- Fundamental electrochemical research - component development and characterization with state-of-the-art analytical test capability
- Cell/Battery Design
- Cell/Battery Performance and Life Testing
- Cell/Battery Safety Testing
- Battery Performance Modeling
- Environmental Testing

# NASA Glenn Fuel Cell Development & Evaluation Facilities



**Hydrogen/Air Fuel Cell Test Facility**  
Stack and subsystem testing up to 12 kW  
(Can be modified for other fuels)



**Regenerative Fuel Cell Test Facility**  
Performance evaluation of fuel cell, electrolyzer  
and ancillary components within a closed-  
loop regenerative fuel cell system



**Fuel Cell Development Laboratory**  
Fundamental electrochemical characterization  
and component development  
Capable of testing stack and subsystems up to  
5kW



**Fuel Cell Testing Laboratory**  
3 test cells capable of testing complete fuel cell,  
electrolyzer and regenerative systems  
up to 25kW

# NASA Glenn Electrochemistry Branch Complimentary Facilities and Capabilities



## Imaging and Material Analysis Laboratory

### Surface and Thermal Analysis Capability

- Inductively Coupled Plasma Optical Emission Spectrometer
- Scanning Probe Microscope
- Scanning Electron Microscope Energy Dispersive Spectrometer
- Stereomicroscope
- BET Surface Area Analyzer



## Thermal and Material Analysis Laboratory

Molecular analysis, particle size distribution, thermal property analysis

- Differential Scanning Calorimeter
- Fourier Transform IR Spectrometer
- Thermogravimetric Analyzer (TGA)
- Raman Spectrometer
- Particle Size Analyzer



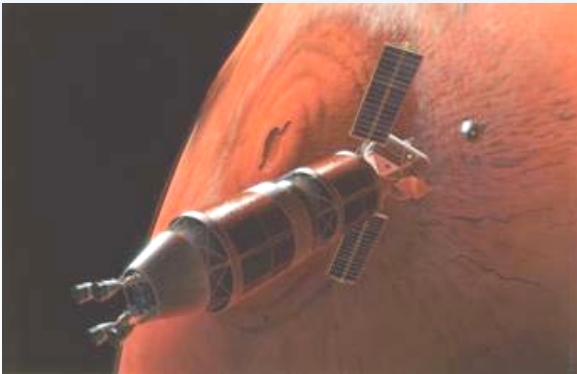


# In Summary...NASA Glenn is Focused on Exploration

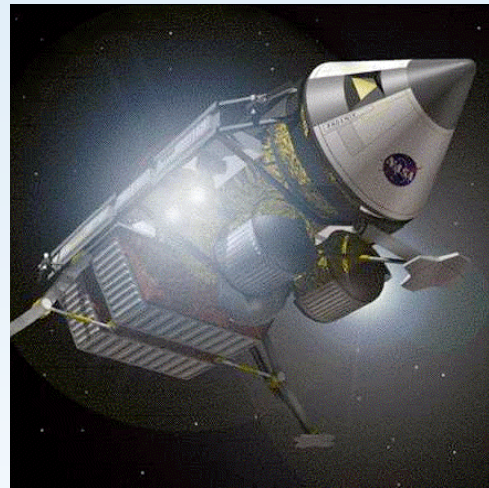
## Unique Combination of Competencies and Capabilities

- Space flight systems development
- Technology development

## Requirements and Systems

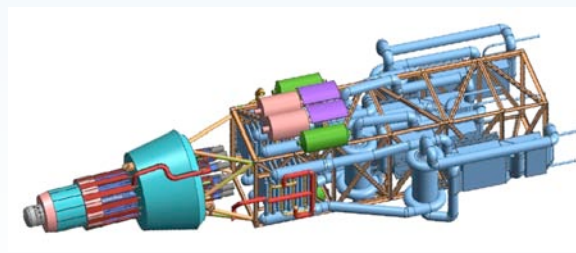


## Constellation



## Exploration Systems R&T

## Prometheus



## Human Systems R&T

...and collaboration is the key to success

## Informational Resources

For current detailed information and for future updates concerning plans and strategies relevant to NASA's missions and partnering opportunities:

[www.nasa.gov/centers/hq](http://www.nasa.gov/centers/hq)

[www.exploration.nasa.gov](http://www.exploration.nasa.gov)

For additional information about NASA Glenn's Space Flight Systems, Advanced Capabilities and Exploration projects:

<http://spaceflight systems.grc.nasa.gov>

For information about specific programs and collaborations with the NASA Glenn Electrochemistry Branch, contact Ms. Michelle Manzo at:

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