ABSL’s COTS Li-Ion Cell Suite Development
2007 NASA Battery Workshop

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Objective

- Explain ABSL’s programs for identifying and qualifying Li-Ion COTS cells for space use.
- Show some of the benefits this approach to space batteries provides.
- Provide a briefing on the current status of ABSL’s next generation COTS cells.
ABSL Space Battery Experience
ABSL has the most launches of Li-ion batteries with 32 spacecraft powered by ABSL batteries without ANY failures
Contracts/Launches “at a glance”

- 6 space qualified cell (3 launched)
  - Lithium-ion secondary
  - Lithium primary
- 32 s/c launched
  - LEO, MEO, GTO, HEO, Interplanetary
  - Including NASA, AFRL, DOE, ESA missions
  - Longest serving LEO Li-ion (6+ years, >30k cycles)
  - Three 10 yr LEOs on orbit
- Contracts for 80+ spacecraft and launchers
  - 2 GEO launches in 2008
  - 1st Launch Vehicle flight in 2008
  - Many more NASA missions, MDA, AFRL, ESA...
U.S. Customers
Rest of the World Customers

- ESA
- KARI
- ISRO
- JAXA
- CSA ASC

Japan Aerospace Exploration Agency
Contents

- ABSL Space Battery Experience
- The ABSL COTS Approach
  - What is the COTS Approach?
  - Process Overview
  - The Details
- ABSL’s Next Generation COTS Cells
ABSL’s COTS Approach is a proven process for providing space qualified Li-Ion batteries using commercial off-the-shelf (COTS) Li-Ion Cells.

- Encompasses everything from identifying candidate COTS cells, to high fidelity design and qualification testing of space batteries.
- Mitigates the risk of using of COTS cells for space applications to provide customer confidence in the end product.
- Leverages the immense size of the commercial industry to provide cutting edge performance and security of supply.
The ABSL COTS Approach

- **Cell Assessment & Qualification**
  - *Identify the best COTS cells to meet future space battery needs and qualify them to space industry standards.*

- **The Cell Suite**
  - *Readily provide a broad range of battery capabilities and security of supply.*

- **Lot Acceptance Testing (LAT)**
  - *Ensuring consistency of cells batch to batch, maximizing the value of comprehensive cell characterization and life test programs.*

- **Life Test Program**
  - *Enabling unmatched EOL performance predictions capabilities.*

- **Standardized Battery Design, Build, & Qualification**
  - *Leveraging the consistency and predictability of ABSL’s COTS cells to efficiently optimize and qualify battery designs for any mission.*
COTS Cell Cycle

Cell Assessment

Cell Qualification

Space Qualified Cell Suite
Cell Assessment

Phase A
All cells under investigation in the Technology Watch

Phase B
Preliminary in-house testing

Phase C
Qualification testing

- Reported datasheet, manufacturer, and 3rd party performance
- Measured performance, project needs, R&D budget
Phase A: Technology Watch Database

![Image of a spreadsheet with various data columns including Diameter, Height, EniWh, Capacity, Energy, Mass, Energy Density, Capacity Density, Volumetric Capacity, Current Density, Volumetric Current, Max Continuous Current, and Max Depth.]

800011.--. ABSL's COTS Li-Ion Cell Suite Development
Phase B: In-House Testing

- All Phase B cells are screened and assessed for consistency and build quality

- Specific test regime depends on the cell, but any test is fair game: performance characterization, temperature sensitivity, safety, etc.

- Lifetesting is initiated as early as possible for promising candidates

- This helps identify the best future mission applications of candidate COTS cells

![Graph showing specific capacity over cycle number for different cell types.](image)
Phase C: Cell Qualification

- Basic Parameters
- Safety
- Environmental
- Characterization
- Endurance
## ABSL Cell Suite

<table>
<thead>
<tr>
<th>Cell</th>
<th>Energy Density</th>
<th>Attributes</th>
<th>Space Qualified</th>
<th>Space Proven</th>
<th>Space Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABSL18650HC</td>
<td>130 Wh/kg</td>
<td>Excellent and Characterised Cycle Life</td>
<td>✔</td>
<td>✔</td>
<td>All space programs</td>
</tr>
<tr>
<td>ABSL18650HR</td>
<td>100 Wh/kg</td>
<td>Very high current delivery &gt;10 C</td>
<td>✔</td>
<td>2008</td>
<td>High Power</td>
</tr>
<tr>
<td>ABSL18650LV</td>
<td>174 Wh/kg</td>
<td>High Energy Density, low temp performance</td>
<td>✔</td>
<td></td>
<td>Low temp, mass pushed</td>
</tr>
<tr>
<td>ABSL33111PR</td>
<td>450 Wh/kg</td>
<td>High energy and structural integrity</td>
<td>✔</td>
<td>✔</td>
<td>Primary batteries</td>
</tr>
<tr>
<td>ABSL 26650HC</td>
<td>120 Wh/kg</td>
<td>Excellent cycle life</td>
<td>✔</td>
<td>✔</td>
<td>Retired</td>
</tr>
<tr>
<td>ABSL 18650LVF</td>
<td>175 Wh/kg</td>
<td>High Energy Density</td>
<td>✔</td>
<td></td>
<td>Retired</td>
</tr>
</tbody>
</table>
The Cell Suite: ABSL 18650HC

- **Description:** A proven, long-life COTS cell with excellent energy density.

- **Qualification:** The best characterized and understood Li-Ion cell for space, qualified to a broad range of temperatures and vibration environments to meet the needs of nearly any mission.

- **Lifetesting:** A wide range of varied parameters across both storage and operational conditions have been tested.

- **Heritage:** 30 missions flown, and more than 6,000 cell years in space without failure

The HC cell has been employed in batteries ranging from several Ah to more than 100 Ah.

An unrivaled amount of in-house testing and flight heritage make the HC the most predictable Li-Ion cell available for space.
The Cell Suite: ABSL 18650HR

- **Description:** An extremely robust, high power cell for satellites and launch vehicles.
- **Qualification:** Focus on high rate characterization, qualified to extremely harsh temperature and vibration environments.
- **Heritage:** World’s first space-qualified 270V Li-Ion battery set to fly in 2008.
- **Characterization:** Extensive testing has proven that the HR is an excellent cell choice for high power applications.

Employment of the HR cell in ABSL’s 270V TVC battery is crucial to providing the required performance.
The Cell Suite: ABSL 33111PR

- **Description**: US manufactured high rate, high energy density (450 Wh/kg) Lithium Sulfuryl Chloride primary COTS cell.

- **Qualification**: Qualified for the rigorous vibration environment of atmospheric re-entry missions.

- **Heritage**: Successfully completed the FOTON-M3 Earth return mission in September, 2007
COTS Cell Cycle

- Cell Assessment
- Cell Qualification
- Initial Cell Screening
- Lot Acceptance Testing
- Cells Manufactured and Shipped
- Space Qualified Cell Suite & Stock
Lot Acceptance Testing (LAT)

- Build variability is the key risk for using COTS cells.
- LAT = Zero-tolerance mini-qualification program
- Ensures predictable performance batch to batch.
Life Test Program

Life Test

Initial Qual

Batch 1 + LAT

Batch 2 + LAT

Batch N + LAT

Life Test Program
Life Test Program

- A wide range of varied parameters across both storage and operational conditions are tested
  - Storage
    - Temperature
    - SOC
  - Operational:
    - Orbital profiles
    - Temperature
    - DOD
    - Charge/Discharge rate
    - Charge management regimes

8 years of storage data

70k+ cycles of operational data
Stockpiling

- Assured access to cells is critical
- Short Term (0 to 3 years)
  - ABSL buy 10k’s of cells at a time maintain rolling stock
  - Last-time buy agreements
- Long Term (3+ years)
  - Cell stockpiling
  - Cell selection
  - Diverse cell suite
  - Commitment to qualify new cells
In addition to performing a LAT on a sample of each batch, all cells are screened twice. The first screening is on receipt of the cells from the manufacturer, the second is just before use of the cells. This approach allows two opportunities to identify cells with abnormally high self-discharge rates.
Standardized Battery Design

- Battery performance is highly dependant on the complex interplay of electrical, thermal, and structural design aspects.
- For optimal results, all three disciplines must be approached collectively through iteration.
- Strong expertise in all aspects is critical for excellence.

![Diagram showing interplay of Electrical Design, Structural Design, and Thermal Design]
Comparison against in-orbit telemetry shows a high degree of accuracy for complex mission profiles and long mission durations.
Standardized Battery Design

- **Electrical Design**
  - LIFE
  - BEAST
- **Structural Design**
  - CAD Design
  - Battery Configuration
- **Max Deflection & Stress**
  - Cell Level Vibration
  - Random Vibration
- **Modes & Frequencies**
  - Natural Frequencies & Mode Shapes
- **Worst Case Loading**
- **EOL Capacity & Resistance**
  - DOD
  - BEAST
- **Structural Design**
Standardized Battery Design

Electrical Design

LIFE

EOL Capacity & Resistance

BEAST

DOD

Battery Configuration

Cell Temperatures

Thermal Dissipation, Battery Configuration

Structural Design

Worst Case Loading

Structural Design

Max Deflection & Stress

Cell Level Vibration

Random Vibration

Max Deflection & Stress

Cell Level Vibration

Natural Frequencies & Mode Shapes

Random Vibration

Modes & Frequencies

Structural Design

BATS

Structural Design

Thermal Design

Time (minutes)

Temperature (°C)

10.0°C

11.0°C

12.0°C

13.0°C

14.0°C

15.0°C

16.0°C

17.0°C

18.0°C

19.0°C

20.0°C

21.0°C

22.0°C

23.0°C

24.0°C

25.0°C

26.0°C

27.0°C

28.0°C

29.0°C

30.0°C

Temperature

Coldest Cell on Failed Block

Warmest Cell on Failed Block

Coldest Cell on Upper Deck

Warmest Cell on Upper Deck

BEAST cell

Coldest Cell on Lower Deck

Average Battery Temperature

Random Vibration

Natural Frequencies & Mode Shapes

Thermal Dissipation, Battery Configuration

DOD

EOL Capacity & Resistance

LIFE

BEAST
Standardized Battery Build

28V Batteries

>100Ah Spacecraft

Primary Batteries

270V LV Batteries
Custom batteries qualified to different levels at customers’ request.

ABSL has pre-qualified “build to print” designs as well, to reduce cost and lead time.
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ABSL’s Next Generation Cells
Contents

- ABSL Space Battery Experience
- The ABSL COTS Approach
- ABSL’s Next Generation COTS Cells
  - Next Gen Summary
  - Cells G & F
  - ABSL 18650LV
Current Next-Gen COTS Cell Status:

- More than 140 COTS cells currently in Phase A (Technology Watch Database)
- Approximately 10 COTS cells currently in Phase B (In-House Testing)
- Multiple COTS cell under investigation via cooperative efforts with NASA/ESA
- One COTS cell starting Phase C (Cell Qualification)
- One COTS cell about to complete Phase C (Cell Qualification)
Next Gen Cells: Phase B

- “Cell G”: Lifetesting

20% DOD LEO

100% DOD

Cell G shows improved percent capacity retention performance relative to the HC at both low and high DOD.
“Cell G”: Additional Completed Characterization
- Consistency & Build Quality Testing
- Capacity at Temperature, -40° C to 60° C
- Rate & Pulse Characterization, up to 3C
- Resistance Characterization, -40° C to 60° C
- Overcharge Testing

ABSL has assessed prototype rather than production cells

Further testing & characterization planned upon initiation of full-scale production
“Cell F”: Lifetesting

20% DOD LEO

100% DOD

Cell F shows improved percent capacity retention performance relative to the HC at low DOD, but not at high DOD.
Next Gen Cells: Phase B

- “Cell F”: Additional Completed Characterization
  - Consistency & Build Quality Testing
  - Capacity at Temperature, -40° C to 60° C
  - Rate & Pulse Characterization, up to 7C
  - Resistance Characterization, -40° C to 60° C
  - Overcharge Testing

- More tests are currently underway

- A full BEAST cell model will be available Dec. 2007
The LV shows very similar percent capacity retention to the HC at both high and low DODs.
Next Gen Cells: Phase C

- ABSL 18650LV: Performance Characterization

**Batch Consistency**

**Rate Characterization**

**EMF vs. SOC**
Next Gen Cells: Phase C

- **ABSL 18650LV: Safety Testing**

**PTC Characterization**

**Overcharge**

**Over Discharge**

TV & Vibration & Safety testing is done – the key risk areas have been mitigated
Currently ABSL has more than 140 COTS cells under investigation in Phase A.

Approximately 10 COTS cells in are presently under going in-house testing in Phase B

“Cell F” is about to graduate from Phase B to C

The ABSL 18650LV has completed key portions of the qualification testing, and is ready for a mission!
Questions?