Choosing the **Right Lithium Ion Cell** for your Battery Pack

**Carl Gallenson**
VP of Engineering
AGENDA

- Introduction to iTECH
- Criteria Considerations for Cell Selection
  - Safety
  - Electrical
  - Mechanical
  - Regulatory
  - Environmental
  - Cost, Manufacturer’s support & Cell Roadmap
- Examples
iTECH specializes in the **design and manufacture** of custom battery packs and battery chargers.

Providing **engineered application-specific product solutions**.

- **Location:** San Diego, CA
- **Founded:** 1997
- **Design & Manufacturing:** San Diego
- **Design:**
  - Electrical
  - Software / Firmware
  - Electromechanical Packaging / ID
  - Systems Design
  - DVT - Authentication
  - Environmental Testing
  - Test Development

- **In-House capabilities:**
  - SMT / PCA
  - Resistive Welding
  - Soldering
  - Electro-Mechanical Assembly
  - Ultrasonic sealing
  - Shrink wrap packaging
  - Potting

- ISO 9001:2008 & ISO 13485 Certified
- ITAR registered & FDA licensed
Introduction to iTech

Application Focus...

- **Portable Power** → **Batteries, Charging** and **Docking Systems** supporting a **Host Device**

- Where **health, safety**, or **significant revenue** count on predictable battery & product operation.

Markets Served...

- Handheld Instruments
- Medical
- Industrial
- Safety & Security
- Military / Homeland Security
- Communications
Cell Selection: Requirements Overview

**Cell Safety**
- CID
- Venting
- PTC
- Separator Design
- Thermal Fuse

**Mechanical**
- Form factor
  - Cylindrical
  - Prismatic
  - Polymer Pouch

**Electrical**
- Capacity
- Current Peaks
- Operating Voltage Range
- Discharge Profile
- Cycle/calendar Life

**Regulatory**
- UN/DOT
  - UL2054
- IEC 62133
- PSE
- BAJ
- CTIA
- CE
- CCC

**Environmental**
- Storage Temperature
- Operating Temp Extremes
- IP Rating
  - Intrinsically Safe
- Shock & Vibration
  - drop Test

**Cost**
- Application Support
- Product Roadmap
Cell Safety

• Verification of Cell Safety Devices
  – CID
  – PTC
  – TCO / Thermal fuse
  – Separator Design
  – Venting
Cell Safety

- Verification of Cell Safety Devices
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### Mechanical Form Factor

<table>
<thead>
<tr>
<th>Features</th>
<th>Cylindrical</th>
<th>Prismatic</th>
<th>Pouch</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy density</td>
<td>★★</td>
<td>★☆</td>
<td>☆☆</td>
</tr>
<tr>
<td>Standard sizes</td>
<td>★★</td>
<td>★☆</td>
<td>☆☆</td>
</tr>
<tr>
<td>Cost/Wh</td>
<td>★★</td>
<td>★☆</td>
<td>☆☆</td>
</tr>
<tr>
<td>Thin profile</td>
<td>★☆</td>
<td>★☆</td>
<td>★☆</td>
</tr>
<tr>
<td>Low weight</td>
<td>★☆</td>
<td>★☆</td>
<td>★☆</td>
</tr>
<tr>
<td>Volumetric packing efficiency</td>
<td>☆☆</td>
<td>★☆</td>
<td>★☆</td>
</tr>
<tr>
<td>Low swelling</td>
<td>★★</td>
<td>★☆</td>
<td>☆☆</td>
</tr>
</tbody>
</table>

- ★★: Best
- ★☆: Better
- ☆☆: Average
- ☆☆: Poor
- ★: Worse

*Battery Power 2013*
Electrical

• Cell Voltage
  – Operational Range
  – Depth of Discharge
    • Cycle Life
  – Cathode Material
• Capacity
  – Usable vs. Nominal
• Power
  – Discharge rate
  – Impedance
  – Pulse Loads
• Charging
  – Charge Rate
  – Charge Voltage
  – Electrolyte dependent
Electrical

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<table>
<thead>
<tr>
<th>Depth of discharge</th>
<th>Discharge cycles</th>
</tr>
</thead>
<tbody>
<tr>
<td>100% DoD</td>
<td>300 – 500</td>
</tr>
<tr>
<td>50% DoD</td>
<td>1,200 – 1,500</td>
</tr>
<tr>
<td>25% DoD</td>
<td>2,000 – 2,500</td>
</tr>
<tr>
<td>10% DoD</td>
<td>3,750 – 4,700</td>
</tr>
</tbody>
</table>

Table 2: Cycle life as a function of depth of discharge

A partial discharge reduces stress and prolongs battery life. Elevated temperature and high currents also affect cycle life.

Ultra-Fast Battery Charging Isador Buchmann ECN Magazine June 2012
Electrical

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CATHODE MATERIALS - Types of Lithium-Ion Batteries

<table>
<thead>
<tr>
<th>Chemistry</th>
<th>Nominal V</th>
<th>Charge V limit</th>
<th>Charge &amp; Discharge C-rates</th>
<th>Energy Density Wh/kg</th>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cobalt</td>
<td>3.60V</td>
<td>4.20V</td>
<td>1C limit</td>
<td>110-190</td>
<td>Cell phone, cameras, laptops</td>
</tr>
<tr>
<td>Manganese (spinel)</td>
<td>3.7-3.80V</td>
<td>4.20V</td>
<td>10C cont. 40C pulse</td>
<td>110-120</td>
<td>Power tools, medical equipment</td>
</tr>
<tr>
<td>NCM (nickel-cobalt manganese)</td>
<td>3.70V</td>
<td>4.10V*</td>
<td>~5C cont. 30C pulse</td>
<td>95-130</td>
<td>Power tools, medical equipment</td>
</tr>
<tr>
<td>Phosphate</td>
<td>3.2-3.30V</td>
<td>3.60V*</td>
<td>35C cont.</td>
<td>95-140</td>
<td>Power tools, medical equipment</td>
</tr>
</tbody>
</table>

http://www.targray.com/li-ion-battery/cathode-materials/

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How to prolong Lithium-based Batteries Isador Buchmann Battery University
Electrical

- **Cell Voltage**
  - Operational Range
  - Depth of Discharge
    - Cycle Life
  - Cathode Material
- **Capacity**
  - Usable vs. Nominal
- **Power**
  - Discharge rate
  - Impedance
  - Pulse Loads
- **Charging**
  - Charge Rate
  - Charge Voltage
  - Electrolyte dependent
Regulatory

• Transport
  – UN/DOT 38.3 Certification
    • United Nations Recommendation on the Transport of Dangerous Goods – Manual of Tests and Criteria section 38.3 Lithium metal and lithium ion batteries
    • Required for transport ICAO/IATA/PHMSA
  – ISO 9001 / Quality Management Systems
  – Transport of prototype batteries by air requires Competent Authority Approval

• Safety
  – UL 1642
    • Required for UL 2054 on pack & IEC 60601 on system
  – IEC 62133
    • Required on cell for IEC 62133 on pack
BEGIN A BASIC SEARCH

To begin a search, please enter one or more search criteria in the parameters below.

- **Company Name** (options)
- **City**
- **US State**
- **US Zip Code**
- **Country**
- **Region**
- **Postal Code** (non-US)
- **UL Category Code** (options)
- **UL File Number** (help)
- **Keyword**

[SEARCH]  [CLEAR]

TIPS FOR EFFECTIVE SEARCHES

Select a search method:
- Match all words - type AND between words (i.e., display and warn)
- Match any word - type OR between words (i.e., hair dryer or blow dryer)

ABOUT THE ONLINE CERTIFICATIONS DIRECTORY

You can use the UL Online Certification Directory to:
- Verify a UL Listing, Classification, or Recognition
- Verify a UL Listed product use
- Verify a UL Recognized component use
- Verify a product safety standard

Learn more with the [Quick Guide to the Online Certifications Directory](#)

SPECIFIC SEARCHES
(New! UL Evaluation Reports)

Select a specific search:

FEATURED LINKS

- UL Alarm Services Search
- UL Code Correlation Database

LINKS OF INTEREST

UL Anytime: We are ready to assist you at any time!
• Temperature range
  – Operational
    • Voltage depression at cold temp
    • Limited peak current at high temp
  – Storage
  – Manufacturing

• Packs IP rating

• Vibration & Shock/Drop

Environmental

Prior to drop

After drop

X-ray image of bottom of 18650 cell

Jelly-roll shifted
Cost / Application Support

• **Cost**
  - Higher capacity cells in a given size ⇒ cost premium
  - Know the Manufacturing volume.
    • Leverage volume of ancillary markets when possible.
    • Ex. 2200mAh / 18650 cells
  - Varies by cell Manufacturer.

• **Know Cell Manufacturer’s Support**
  - Medical: Class I, II or III
  - Military
  - Intrinsically Safe
Product Roadmap

- **Product Life Cycle / Roadmap**
  - Cell Manufacturer’s projected Product Life?
  - In wide use or driven by one customer?
  - Annual Volume?
  - Policy regarding EOL?
Example #1

- **Application:** Industrial Hand Held Data Terminal or Computer.
- **Requirements:**
  - Operating range: 3.2 – 4.2Vdc
  - 36 hour run time, 3 year life
  - 70mA avg current (97%), 1.0A peak (3%)
  - Charge in 4 hours or less
  - Maximum envelope for pack 2.75”L x 1.75”W x 1.0”H
  - Operating temperature -20C to +50C
  - Pack will need UL2054, IEC62133, UN/DOT
Example #1

- Voltage range allows for a 1S Lithium Ion pack
- Form factor could allow any of the 3 types

<table>
<thead>
<tr>
<th>Cell Dimensions</th>
<th>Diameter</th>
<th>Height</th>
<th>Length</th>
<th>Width</th>
<th>No. of Cells Fit In Allowed Envelope</th>
</tr>
</thead>
<tbody>
<tr>
<td>18650 Cylindrical</td>
<td>18.6 mm</td>
<td>65.2 mm</td>
<td>N/A</td>
<td>N/A</td>
<td>2</td>
</tr>
<tr>
<td>103450 Prismatic</td>
<td>N/A</td>
<td>10.5 mm</td>
<td>50 mm</td>
<td>34 mm</td>
<td>2</td>
</tr>
</tbody>
</table>
### Example #1

- Long run time & low current calls for Energy Cell

<table>
<thead>
<tr>
<th>CURRENT</th>
<th>RUN TIME</th>
<th>Duty Cycle</th>
<th>SubTotal</th>
</tr>
</thead>
<tbody>
<tr>
<td>AVG</td>
<td>70mA</td>
<td>36 Hours</td>
<td>2444mAh</td>
</tr>
<tr>
<td>PEAK</td>
<td>1000mA</td>
<td>36 Hours</td>
<td>1080 mAh</td>
</tr>
</tbody>
</table>

Unusable capacity under 3.2V: 528mAh
Adder for aging over 365 cycles: 1013mAh

**Total:** 5065 mAh

- Could use 1S2P 2600mAh 18650 or 5.2Ah prismatic (Polymer OK if a 5.2Ah cell in correct envelope available)
Example #1

• With cell choice narrowed down, choose cells with best performance over temperature range

Cell discharge time comparison at -20°C
Example #1

• Cells “D”, “E”, and “F” performed well at -20°C
• Check for UL1642 certifications
• Check cells can be charged in under 4 hours
• Check relative costs of final candidates to make the final choice
Example #2

- **Application:** 12V power tool
- **Requirements:**
  - Operating range: 10 – 14 Vdc
  - Peak current 15A for 10 second usage
  - 50 uses per charge
  - Minimum 500 cycles, more if possible
  - Maximum envelope is 3.25”L x 3.25”W x 1.25”H
  - Operating temperature -10 to +40°C
Example #2

- Power cell needed to supply the 15A
- Power cells available in cylindrical or polymer
- Capacity is \(15 \times 10/3600 \times 50 = 2083\text{mAh}\)
- Required voltage suggests cylindrical or polymer
  - 3S2P Li-Ion 18650 (3.7 \times 3 = 11.1V)
  - 4S2P LiFePO4 18650 (3.2 \times 4 = 12.8V)
  - 3S1P Li-Ion 26650 or 26700
  - 4S1P LiFePO4 26650 or 26700
  - High output polymer
Example #2

• Required envelope of 3.25”L x 3.25”W x 1.25”H eliminates most configurations
• 3S1P with 26650 or 26700 cells fits the envelope
• Cells available with 2.8Ah capacity and more than enough power and cycle lifetime.
Quality and reliability of the pack design starts with proper cell selection.

There are many criteria that affect cell selection.

Selection criteria should be based on needs of the application.

Account for unusable capacity and cell aging when calculating capacity.

Application Support by Cell Manufacturer and the Product Roadmap are important factors to know.

There may be several cells that meet basic requirements, finding the best candidate may require additional testing – e.g. temperature profiling with anticipated load.
Thank you!

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