Battery Technologies for Munitions

The Future of Munitions Batteries Workshop

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EaglePicher Technologies Profile

Leader in Batteries, Battery Chargers & Energetic Devices for Defense, Aerospace, Commercial, and Medical Applications

- EPT is headquartered in St. Louis, MO with 10 plants in:
  - Joplin, MO
  - Seneca, MO
  - Pittsburg, KS
  - Vancouver, B.C.
  - East Greenwich, RI
  - Rothenbach, Germany (JV)
- Expertise in >30 Chemistries
- Millions of specialty batteries delivered from thousands of designs

Headquarters – St. Louis, Missouri

Dual certification to ISO 9001:2008 and AS9100C

Trusted Power ♦ Reliable Power ♦ Innovative Power
EaglePicher Heritage

1843  The Eagle-White Lead Company Formed in Cincinnati, OH
1874  The Picher Lead Company begins mining in Joplin, MO
1922  EaglePicher Initiates research into storage battery technology
1944  First special purpose battery contract awarded to EaglePicher
1970  Apollo 13 safely returned to Earth on EaglePicher batteries
1981  Space Shuttle Colombia launches with EP powered memory backup
1990  Patriot Anti-Missile System and Tomahawk Cruise Missiles powered by EP
2003  USS Virginia (SSN-774) launches with EP battery power system onboard
2004  Mars Exploration Rovers land on Mars supported by EP batteries
2006  EP delivers first Lithium Ion emergency batteries for commercial aircraft
2007  New state-of-the-art battery facilities in Pittsburg, KS and Joplin, MO
2008  SES Americom’s AMC-21 is launched with EP assembled Lithium Ion battery
2009  Original EaglePicher Nickel-Hydrogen batteries and electronics on Hubble Space Telescope removed from service after 19 successful years
2010  EaglePicher becomes a wholly owned subsidiary of OM Group
2010  EaglePicher wins first commercial aircraft lithium ion main battery program
2011  Mars Science Laboratory supported by EP batteries
2014  Received Title III Phase II Lithium Ion for Military Applications contract
2014  Yardney Acquisition
2015  OM Group purchased by Apollo Affiliated Funds and emerges as VECTRA
EaglePicher Market Segments

Missiles:
- Batteries
  - Thermal
  - Silver Zinc
  - Lithium Oxyhalide
  - Custom Packaging
  - Energetic Devices

Launchers:
- Batteries
  - Silver Zinc
  - Lithium Ion

Unmanned Vehicles:
- Batteries
  - Lithium Ion
  - Lead Acid
  - Nickel Cadmium
- Battery Assemblies
- BMS

Aircraft:
- Batteries
  - Lithium Ion
  - Nickel Cadmium
  - Nickel Metal Hydride
  - Primary Lithium
- Electronics
- BMS

Portable Power:
- Batteries
  - Lithium Sulfur Dioxide
  - Lithium Carbon Monofluoride
  - Lithium Manganese Dioxide
  - Lithium Thionyl Chloride

Special Applications:
- Chargers & Charger/Analyzers
- Battery Systems
- Custom Cells & Batteries

Space:
- Batteries
  - Nickel Hydrogen
  - Lithium Ion
- Electronics
- Electronics & BMS

Distributed/Commercial Power:
- Batteries
  - Sealed Lead Acid
  - Lithium Thionyl Chloride

Alternative Energy:
- Hybrid Power
- Storage Systems
- HEV Systems

Oil & Gas Solutions:
- Well-Head Tree Power
- Thermal Flow
- Undersea

Medical Power:
- Batteries
  - Lithium Ion
  - Lithium Manganese Dioxide
  - Lithium Carbon Monofluoride
  - Lithium Thionyl Chloride
  - Microcell
  - Nickel Cadmium
## Primary Battery Chemistries

<table>
<thead>
<tr>
<th>System</th>
<th>Thermal</th>
<th>Li/OCl</th>
<th>SOZ</th>
<th>Li-CF&lt;sub&gt;x&lt;/sub&gt;/MnO&lt;sub&gt;2&lt;/sub&gt; Hybrid</th>
<th>High Temperature CF&lt;sub&gt;x&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Configuration</td>
<td>Reserve</td>
<td>Reserve</td>
<td>Reserve</td>
<td>Active</td>
<td>Active</td>
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<tr>
<td>Cathode</td>
<td>FeS&lt;sub&gt;2&lt;/sub&gt;</td>
<td>SOCl&lt;sub&gt;2&lt;/sub&gt;-SO&lt;sub&gt;2&lt;/sub&gt;Cl&lt;sub&gt;2&lt;/sub&gt;</td>
<td>Zn</td>
<td>CF&lt;sub&gt;x&lt;/sub&gt;/MnO&lt;sub&gt;2&lt;/sub&gt;</td>
<td>CF&lt;sub&gt;x&lt;/sub&gt;</td>
</tr>
<tr>
<td>Anode</td>
<td>Li alloy</td>
<td>Li metal</td>
<td>AgO</td>
<td>Li metal</td>
<td>Li metal</td>
</tr>
<tr>
<td>Open Circuit Voltage (Vdc)</td>
<td>2.05</td>
<td>3.68</td>
<td>1.58 to 1.86</td>
<td>3.30 to 3.50</td>
<td>3.30 to 3.50</td>
</tr>
<tr>
<td>Nominal Voltage (Vdc)</td>
<td>1.95</td>
<td>3.40</td>
<td>1.50</td>
<td>2.40 to 2.90</td>
<td>2.95</td>
</tr>
<tr>
<td>Operating Temp. (°C)</td>
<td>-60 to +100</td>
<td>-40 to +65</td>
<td>-55 to +55</td>
<td>-40 to +90</td>
<td>-20 to +160</td>
</tr>
<tr>
<td>Specific Energy (Wh/kg)</td>
<td>Up to 100</td>
<td>250</td>
<td>Up to 220</td>
<td>Up to 700</td>
<td>520</td>
</tr>
<tr>
<td>Energy Density (Wh/L)</td>
<td>40-120</td>
<td>500</td>
<td>Up to 450</td>
<td>800-900</td>
<td>890-1000</td>
</tr>
<tr>
<td>Specific Power (W/kg)</td>
<td>500-10,000</td>
<td>50-300</td>
<td>Up to 1,400</td>
<td>50-300</td>
<td>10-100</td>
</tr>
<tr>
<td>Expected Life (Years)</td>
<td>20+</td>
<td>Up to 20</td>
<td>7+</td>
<td>10+</td>
<td>10+</td>
</tr>
<tr>
<td>Comments</td>
<td>Press pellet or Thin film</td>
<td>Cold temperature operation with heater</td>
<td>&lt; 1% self discharge/yr. at room temp</td>
<td>&lt; 1% self discharge/yr. at room temp</td>
<td></td>
</tr>
</tbody>
</table>
Thermal Batteries

- Leading supplier to U.S. DOD over 40 years
- 1st to produce LiSi/FeS$_2$ thermal batteries
- Delivered millions of batteries; over 375 unique designs
- Supports most missile applications
- Li-Al/FeS$_2$, LiSi/FeS$_2$, LiSi/CoS$_2$, and Thin Film technologies
  - High-volume production capacity
  - Cost-effective
  - Automated production
  - Long storage life (20 years or more)
  - No maintenance required
  - Full range of temperatures, climates, and dynamic environments

**Typical Size**
- Diameter 0.5” to 6”
- Length up to 15”
- Typ. Density of 0.1 lb/in$^3$

**Case Material**
- Stainless Steel
- Titanium
FeS$_2$ Cathode plus Additive

- Standard cathode material is FeS$_2$
  - Readily available
  - Impurities and particle size/morphology affect performance
  - Dissociation limits operational temperature

- Alternate cathode formulations
  - Higher operating temperature
    → Lower resistance, longer life
  - Higher voltage
    → Fewer cells, lighter battery
  - Higher density
    → Thinner/stronger pellets
  - Lower impedance
    → Better voltage regulation
  - Higher capacity
    → Longer life
Thermal Battery Anodes

Reduced Impedance
- Lower impedance under same conditions
- Tighter voltage regulation when combined with improved cathode

Improved Discharge
- Higher voltage during discharge under the same conditions
- Longer operating life and/or higher power output
Thin Film Thermal Battery

- Demonstrated components made with production-scale equipment in non-circular design.
- All components except heat pellets were tape-cast.
High-Voltage Cathode

- EPT has developed and demonstrated a higher-voltage cathode material for thermal batteries
- 2.5 volts vs. 2.0 volts (FeS$_2$)
- Demonstrated in 10 cell test batteries
Thermal Battery Insulation

- New coupled thermal/electrochemical model allows for quick optimization of cell size and insulation type/thickness for new and existing batteries

- Thermal battery stacks are wrapped with a fibrous insulation blanket

- Enhanced insulation materials offer improved insulation capability
  - Same performance with thinner insulation
  - Greater performance with same thickness of insulation
Silver-Zinc Batteries

- Manually and remotely-activated battery systems
  - High energy density
  - Flexible configurations
  - Numerous qualified designs
  - Long shelf life and activated life
  - Excellent voltage regulation
  - Proven safety and reliability

- Experienced engineering capability for battery design and production

- Domestic and international repeat customers
Lithium Oxyhalide Batteries

- World’s most advanced thin film electrode technology
- High energy density
- High power capability
- High cell voltage
  - Nominal: 3.6V to 3.9V
- Low impedance for good pulse capability
- Low external surface temperature
- Long operational life
- Long storage life (20 years or more)
- No maintenance

Anti-Ballistic Missiles
Guidance Power
Actuator Power
Initiation Power
Flight Termination
Data Hold (Memory Power)
Torpedo Power
Small Reserve Oxyhalide

- Glass ampoule as electrolyte reservoir
  - Pyrotechnic shock activation
  - Ampoule shatters releasing the electrolyte activating the battery
- Glass membrane reservoir barrier for the electrolyte.
  - A mechanical or pyrotechnic force is exerted on the exterior of the battery.
  - Glass membrane shatters, releasing the electrolyte activating the battery
Energetic Devices

- Supports major U.S. ordnance programs
- Can be customized for specific applications
- Facilities:
  - ATF-licensed explosives manufacturer
  - Site Plan certified for Class 1.1 & 1.3 materials by DOD
- Products:
  - Actuators/Motors
  - Cutters
  - Gas Generators
  - Igniters (Squibs)
  - Pyrotechnic Switches
  - Detonators
  - Explosive Leads

- Markets:
  - Missiles
  - Munitions
  - Fuzing
  - Safety Devices
Summary – EaglePicher

• Well-established company with a rich heritage and a bright future
• Multiple primary reserve battery solutions for munition batteries, including thermal, oxyhalide, and silver-zinc
• Qualification of hundreds of unique primary reserve battery designs
• Largest supplier of thermal batteries to the US government and prime contractors
• Custom designs to meet customers’ specific energy and power requirements