



U.S. Army's Ground Vehicle Energy Storage R&D Programs & Goals



TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

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- **Goals & Mission**
- **Army Applications & Approach**
- **Challenges**
- **Battery Power & Energy**
- **Success Factors**
- **TARDEC Programs**
- **Advanced 6T Roadmap**
- **Failure Mechanism & Thermal Runaway**
- **Ballistic Test Results**
- **SBIR Portfolio & University Portfolio**
- **Battery Logistics Burden**

Energy Storage Goals

- Develop **safe and cost** effective energy storage systems
- Reduce **battery weight & volume burden** (Increase Energy & Power Density)
- Reduce logistics and fuel burdens
- Extend **calendar and cycle life**
- Enhance performance and increase operating time (silent watch, etc)

Energy Storage Mission

- **Develop** and **mature** advanced ES technologies for transfer to vehicle platforms
- Test & evaluate ES technologies for prequalification and to assess their TRL
- Identify **technology barriers** and develop technical solutions
- Provide technical support to customers, other teams and government agencies for all ES requirements
- Provide **cradle-to-grave** support for all Army ES systems

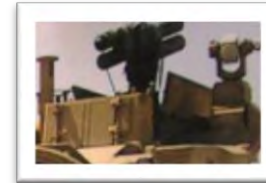


• Army Applications/Drivers:

TARDEC - Ground

– Major Applications

- Robotics
- Survivability
- Weapons Systems
- Electromagnetic Armor (EM Armor)
- Starting, Lighting and Ignition (SLI)
- Hybrid Vehicle Acceleration and Silent Mobility
- Silent Watch



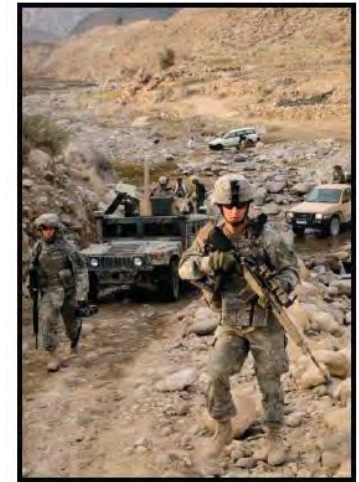
Hit Avoidance



Targeting Systems

– Approach

- Standard Form Factor (6T)
- Ultra-capacitor/Battery/Fuel Cell Hybrid Power Sources



- **Operational issues**

- Wide operation temperature range
- Battery usage & limitations – energy & power density
- Demand for auxiliary power on-board vehicles
- Emphasis on silent (“quiet”) watch
- Unmanned vehicles (air/ground)



- **Safety**

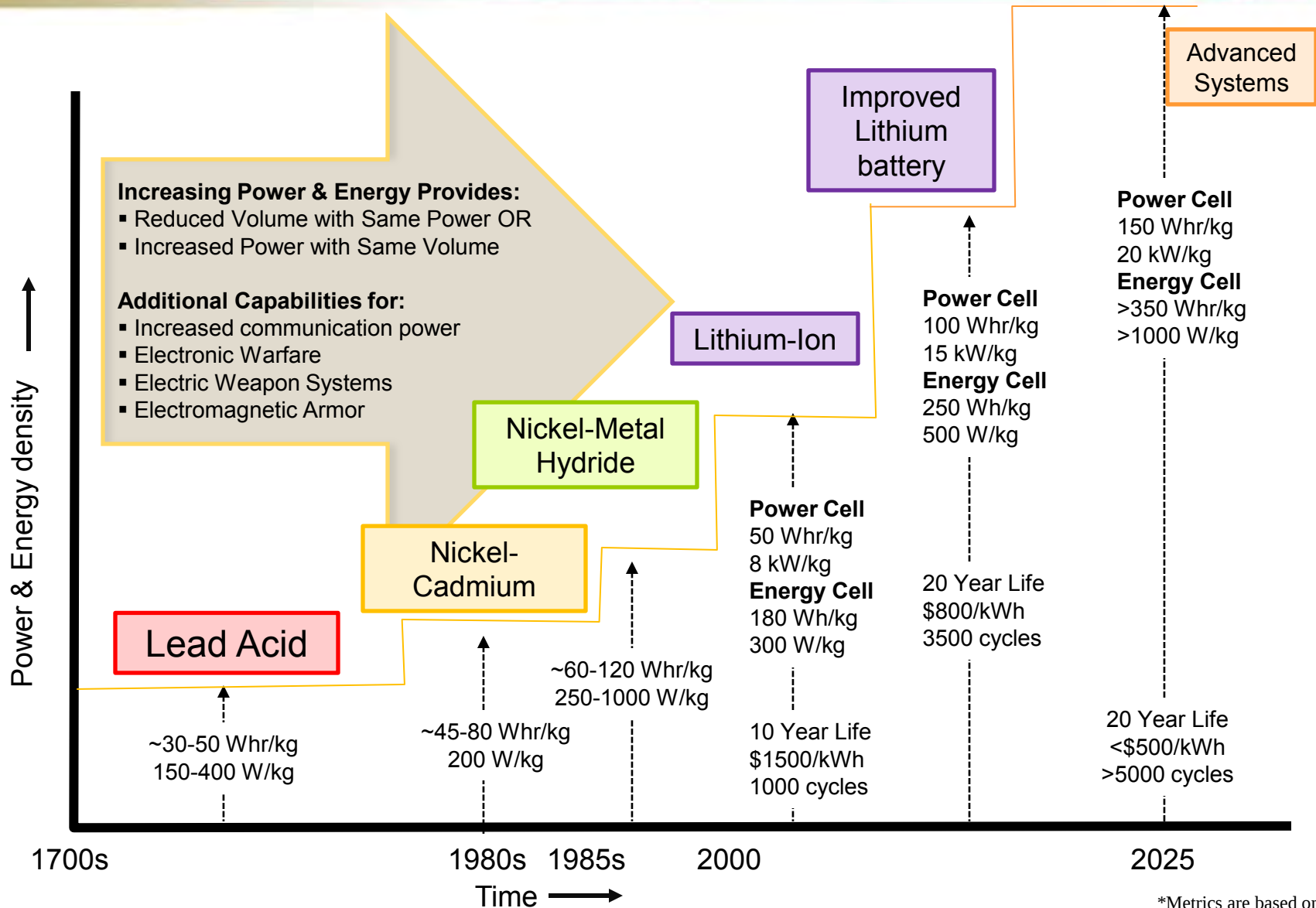
- Thermal runaway

- **Cost**

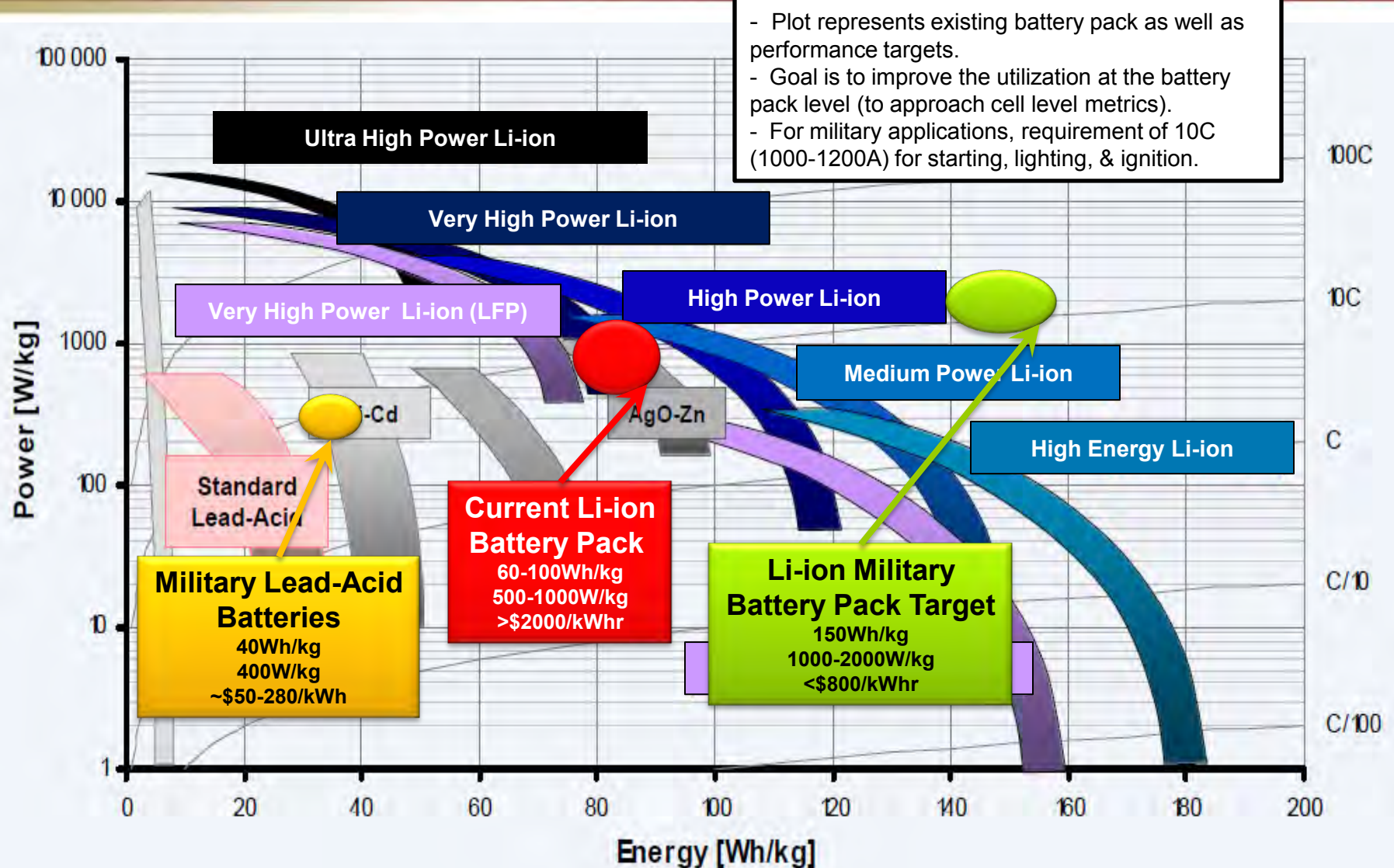
- Limited service life
- High cost
- Increased emphasis on system power metrics (KPPs, low consumption components)



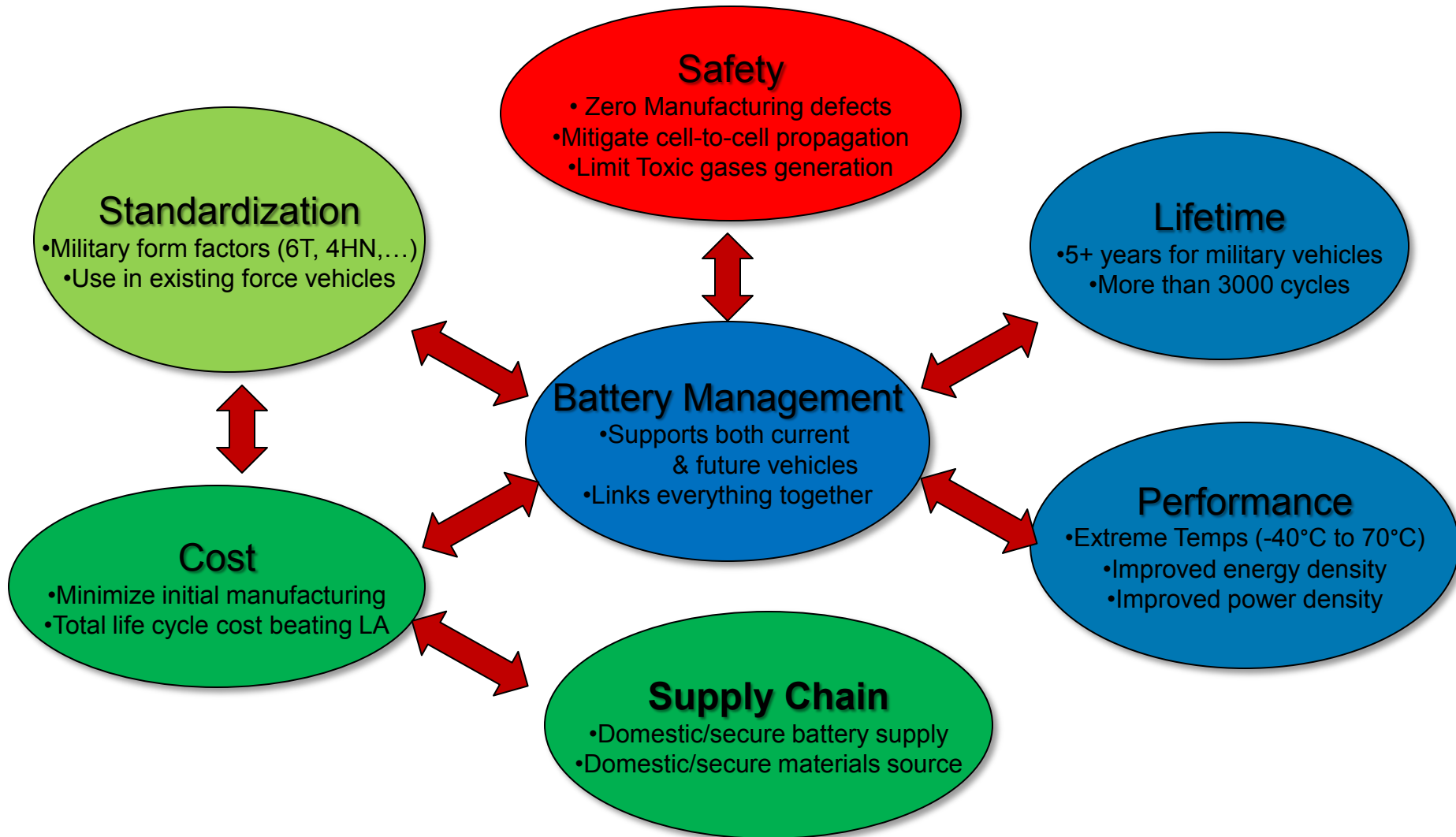
Battery Power & Energy Versus Time (Technology Roadmap)



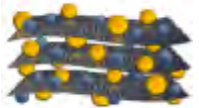
*Metrics are based on cell data
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Successful introduction of Li-ion Batteries depends on a number of factors:



Energy Storage Functional Breakdown



Basic Research

- Lithium plating phenomenon in Li-ion batteries
- **Study on the mechanism of thermal runaway in VRLA Batteries and Methods of Suppression**
- Study of electrode/current collector interface & safe separator for Li-ion batteries
- Development of high energy density anode materials for improved Li-ion batteries
- Alternative electrolyte for use in lithium-ion batteries (higher voltage, improved performance)

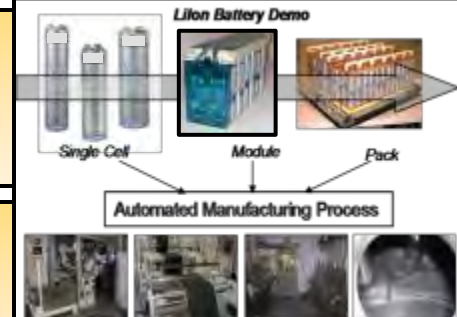
Applied / Applications Research

- Electromagnetic Armor Power Maturation
- Nickel-Zinc 6T Battery Development
- **Development of 6T battery for SLI and silent watch using Li-ion chemistries**
- Absorbed Glass Matt lead acid battery for 24V military 4HN battery



Manufacturing

- High Power, High Energy Density Li-Ion Battery Manufacturing Program
- **Lithium-Ion Cell/Battery Pack Manufacturing**
- Advanced battery material scale-up facility



Battery Management / Safety

- **In-House BMS evaluation for PM HBCT & new laboratory**
- Universal BMS using novel algorithms for battery health
- Ballistic and abuse tolerance studies on cells, module and packs
- Development of advanced diagnostic tools for cycled cells

Alternative Systems

- Hybrid Power Module
- Lithium-Titanate Hybrid Vehicle Pack Integration
- **Characterization of ultra-capacitors for SLI and high power applications**





Military Lead-Acid 6T Batteries

40Wh/kg
400W/kg
~\$100-280/kWh

Baseline



Advanced (Li-ion) 12V 6T Battery

400-450W/kg
>\$2000/kWhr

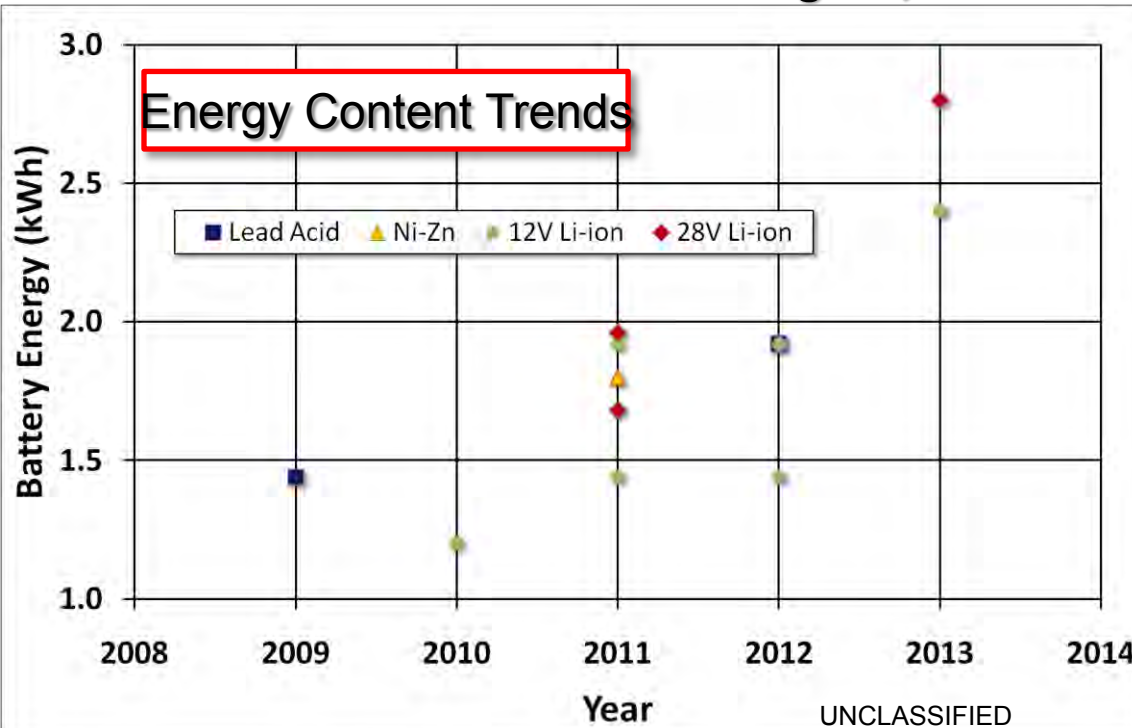
Lighter, 33% More Energy



Li-ion Military Battery Pack Target

>90Wh/kg
>920W/kg
<\$500/kWhr

**2-for-1 Drop-in
Replacement
½ Volume**



Advanced Battery Technologies Price Targets

Battery Technology	Near-Term	Mid-Term Production	Long-Term High Volume
Lead Acid (12V)	\$280/kWh	\$250/kWh	\$200/kWh
Ni-Zn (12V)	\$500/kWh	\$350/kWh	\$200/kWh
Li-ion (12V or 28V)	\$2,000/kWh	\$1,000/kWh	\$500/kWh

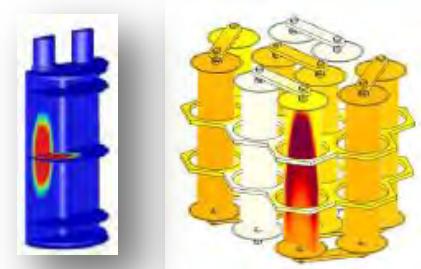
• Field Failures:

- Unpredictable and Potentially Catastrophic
- Typically Caused by Manufacturing Defects
 - Metallic particles/debris
 - Separator defect/damage
 - Other manufacturing issues
 - ❖ Electrode misalignment
 - ❖ Poor internal welds
 - ❖ Loose internal connections

• Abuse Failures:

- Electrical
 - Overcharge / Overdischarge
 - External Short Circuit
- Mechanical
 - Ballistic penetration
 - Crush, Nail penetration
- Thermal
 - Overheating

Internal Short Circuit



Thermal Runaway



- **Pack level testing carried out on Prototype Li-ion Packs (not designed to withstand ballistic impacts)**
 - Purpose: characterize worst case scenario during ballistic impact
- **The pack level ballistic testing indicate that battery designs must be developed to:**
 - Limit cell to cell and module to module thermal propagation during ballistic threats
 - Control/mitigate the release of toxic gases during ballistic threats
 - Balance the energy content and performance/safety requirements with Li-ion chemistry selection.
- **Additional areas of research:**
 - Development of new materials and technologies to optimize safety and performance during abuse conditions.
 - Improved cell/pack designs to improve safety during abuse testing.

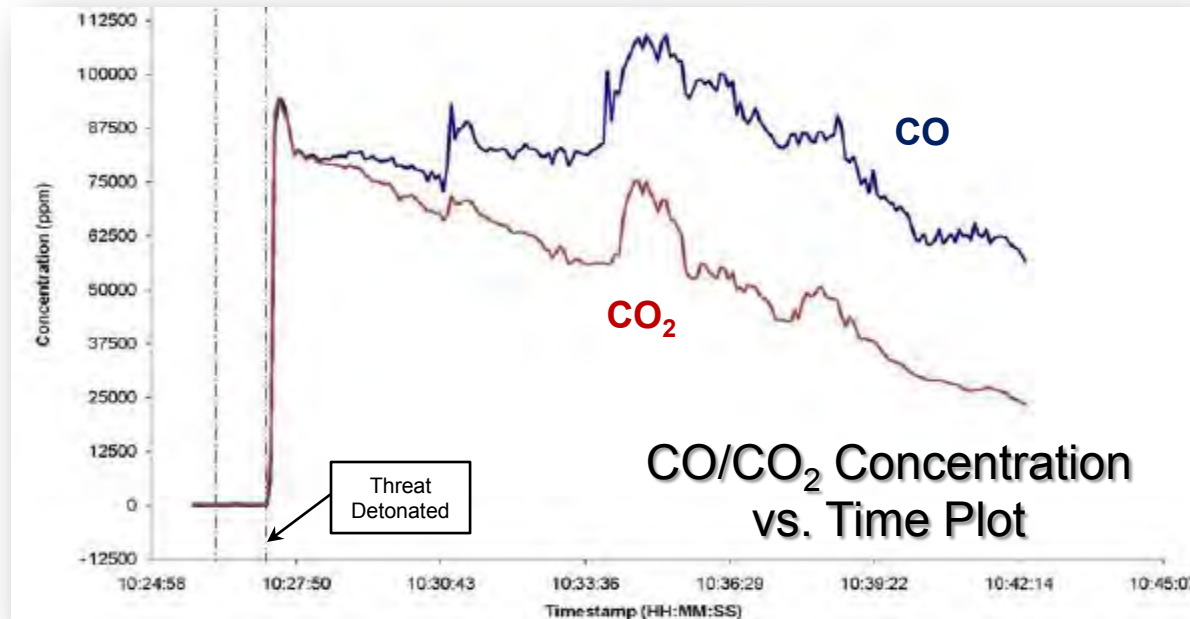
Ballistic Test Results

Li-ion Pack Testing (NCA)

- NCA Cell Chemistry
- 173V, 6.4kWhr Pack
- Prototype pack design
(to determine worst case scenario)
- 125 ft³ volume chamber

Analyte	Peak Concentration (ppm)	15 min Average Concentration (ppm)
Carbon Monoxide (CO)	108939	81588
Carbon Dioxide (CO ₂)	94089	55651
Methane (CH ₄)	16971	11445
Ethylene (C ₂ H ₄)	3670	2497
Formaldehyde (HC(O)H)	8602	5347
Methanol (CH ₃ OH)	3771	2787
Dimethyl Carbonate (DMC)	21734	14307
Methyl Butyrate (MB)	47198	33368

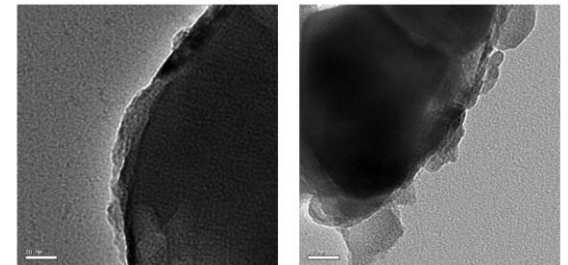
Gas analysis via FTIR



Max cell temperature:
>750°C

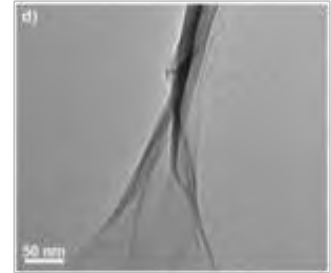
History of Topics from 2009 to 2011:

- A093-175 – Development of Silicon Based Li-ion Battery Technology
- A093-178 – Development of High Power Rechargeable Li Batteries
- A093-200 – Advanced Battery Management System Development (including advanced prognostic and diagnostic capability)
- O092-EP7 – Enhancing the Utilization Efficiency of Cathode Materials in the Li ion Battery
- A102-124 – Lithium Ion Batteries with Wide Operating Temperature Range
- A102-138 – Development of Super-Capacitor with Improved Energy Density
- A102-139 – Lithium Air Rechargeable Battery
- A111-065 – Lithium Ion Battery Separator Development
- A112-116 – High Energy Cathode



University 1

- Neutron Imaging of Lithium concentrations in Battery Cells
- Thermal modeling of Lithium ion batteries



University 2

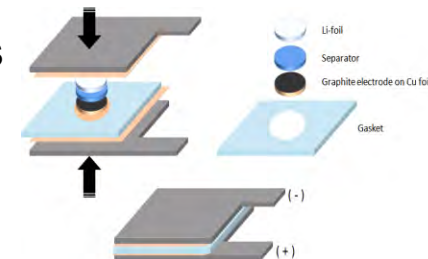
- Research study on novel carbonaceous anode materials (Graphene Nano-ribbons)
- First principals modeling of materials identified graphene edges as favorable for lithium intercalation

University 3

- Six research projects on: Ionic Liquid Electrolytes, Li-Air Catalysts, Graphene Electrodes, In-Situ observation of battery Cycling, Polymer Electrolytes, and Solid State Electrolytes

University 4

- Study of Lithium ion battery anodes to eliminate the formation of dendrites
- Development of ceramic electrolytes for safer lithium ion battery operation



University 5

- Study of the mechanisms of thermal runaway in lead acid VRLA batteries
- Research into methods for suppressing thermal runaway

Lead acid Battery

Incorrect Voltage Output	50%
Damaged - Transport Issues	30%
Improper Electrical Performance	20%

Approximately 80% of incorrect voltage failures were serviceable

Improved charging techniques can lead to 2X life improvement

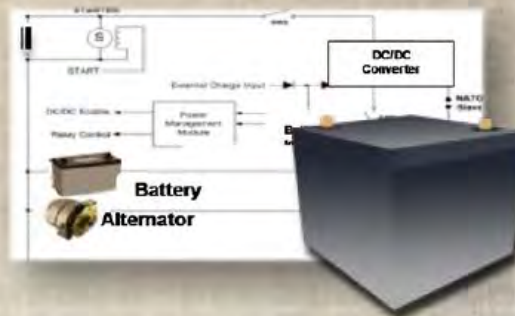


Field Battery Maintenance & Training



Battery represents one of the top 10 on-going maintenance cost in the theater

Improved Charging



Battery Management





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