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Technical Challenges for Vehicle 14V/28V Lithium Ion Battery Replacement

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Agenda

- Goals & Mission
- Introduction
- Power & Energy Requirements
- Army Applications & Approach
- Characteristics of Lithium-Ion & Lead Acid Batteries
- Lithium-Ion Battery Replacements for 14V & 28V
- Battery Voltage Requirements
- Battery Size Considerations
- Lithium Battery Performance at Extreme Conditions
- Battery Management System
- Battery Charging
- Battery Cost & Weight
- Conclusions

Energy Storage Goals and Mission

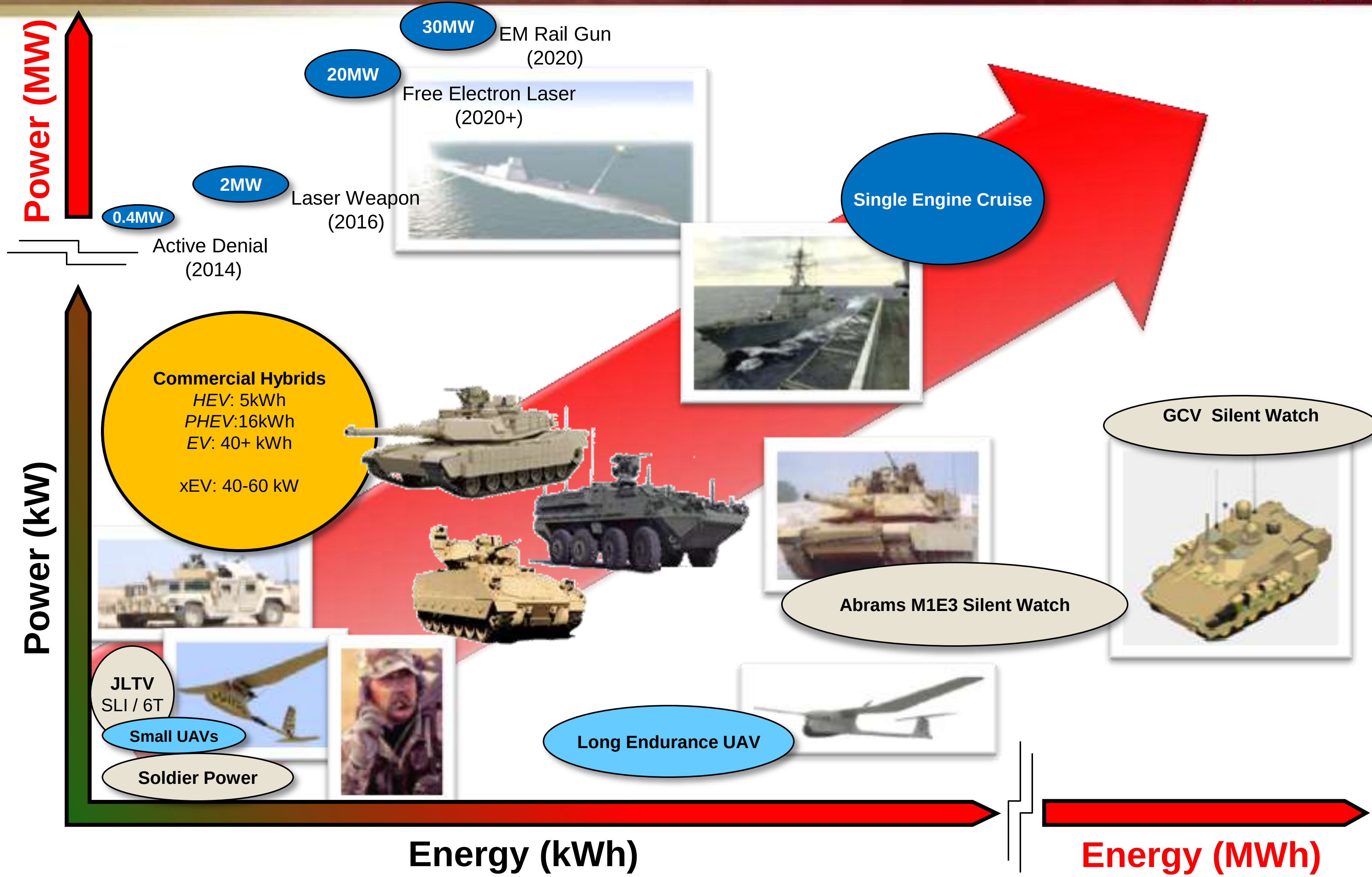
Energy Storage Goals

- 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

Power & Energy Requirements



Army Applications & Approach

- **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

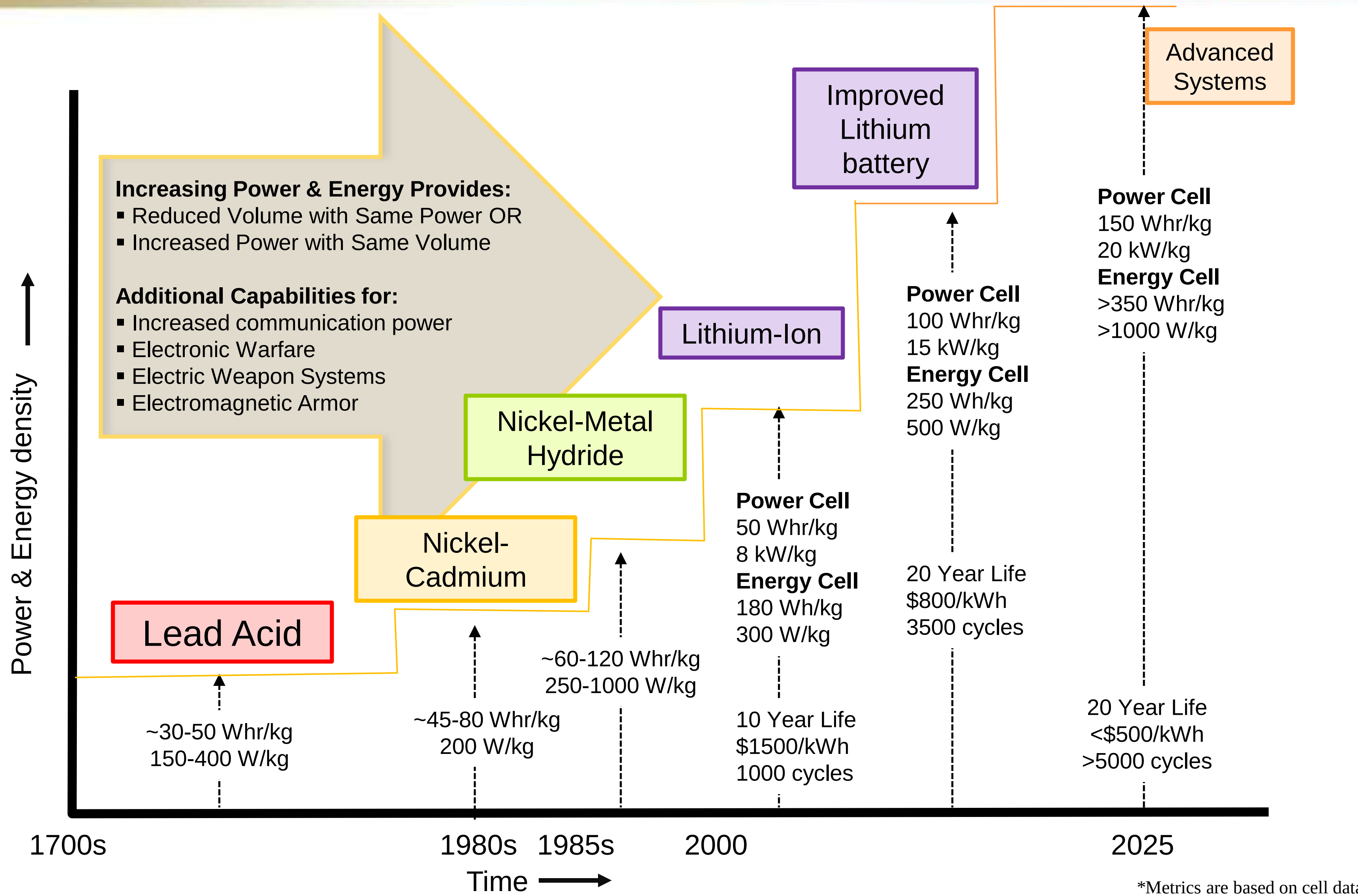
– Approach
  - ➢ Standard Form Factor (6T)
  - ➢ Ultra-capacitor/Battery/Fuel Cell Hybrid Power Sources

Hit Avoidance

Targeting Systems

- **Key Energy Storage Challenges:**
  - ➢ Battery safety & reliability
  - ➢ Higher energy / higher power designs & chemistries
  - ➢ Manufacturing process development and cost control
  - ➢ Thermal runaway process and its control
  - ➢ Standardization of cells, modules and pack

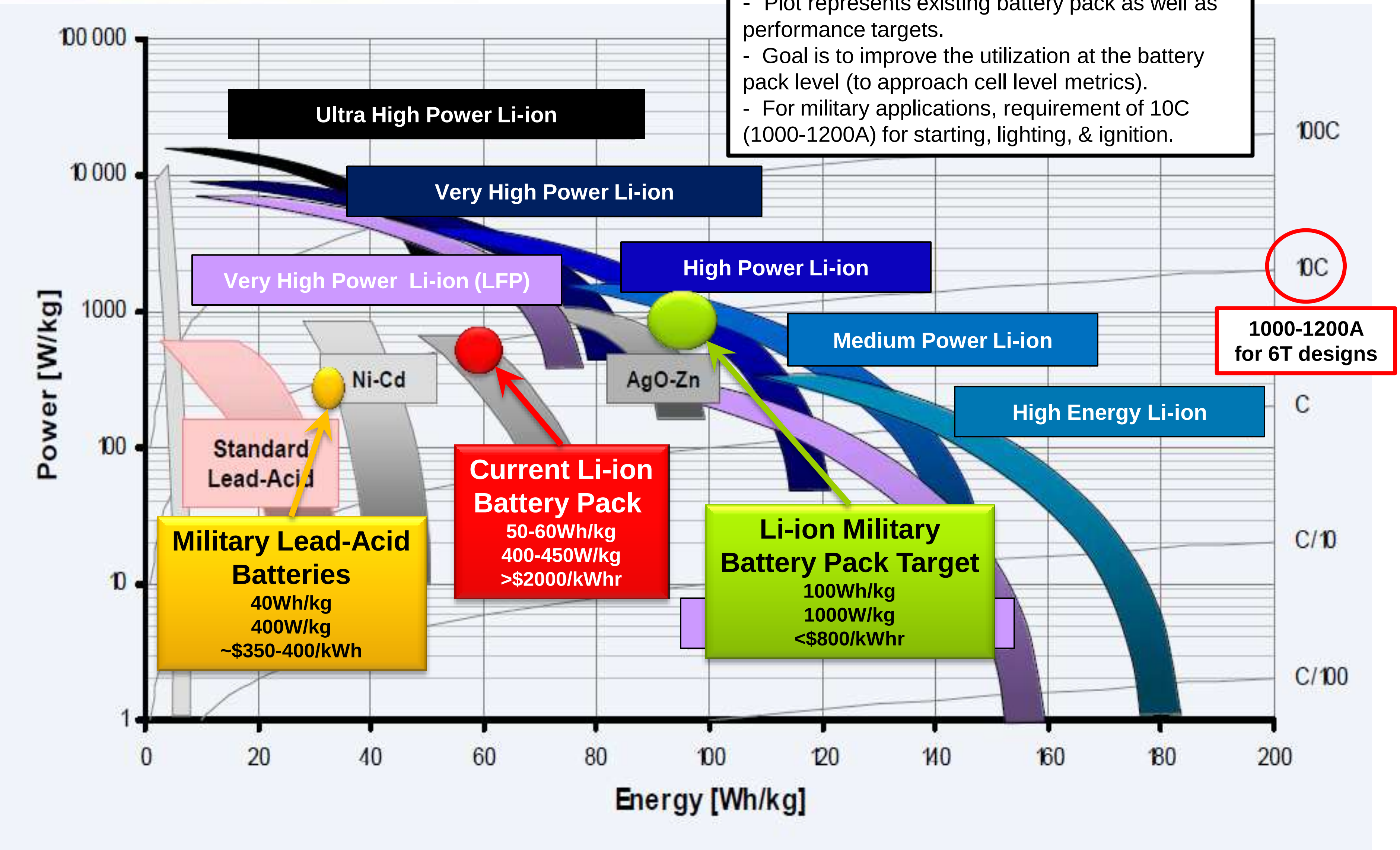
Battery Power & Energy Versus Time (Technology Roadmap)



*Metrics are based on cell data

Energy Storage Technology: Ragone Plot (with Military Pack Targets)

- Plot represents existing battery pack as well as performance targets.
- Goal is to improve the utilization at the battery pack level (to approach cell level metrics).
- For military applications, requirement of 10C (1000-1200A) for starting, lighting, & ignition.



Battery Logistic Burden

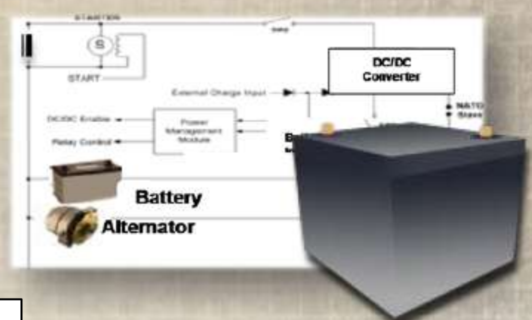
AGM Battery Failures 2002-2008	~5%
Incorrect Voltage Output	50%
Damaged - Transport Issues	30%
Improper Electrical Performance	20%

Approximately 80% of incorrect voltage failures were serviceable

Improved charging techniques can lead to 2X life improvement

Field Battery Maintenance & Training

Improved Charging



Battery Management

* AGM = Absorbed Glass Mat.: “maintenance free”

It’s All About The Warfighter

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Key Success Factors For Li-ion Battery Replacement

Successful introduction of Li-ion Batteries depends on a number of factors:

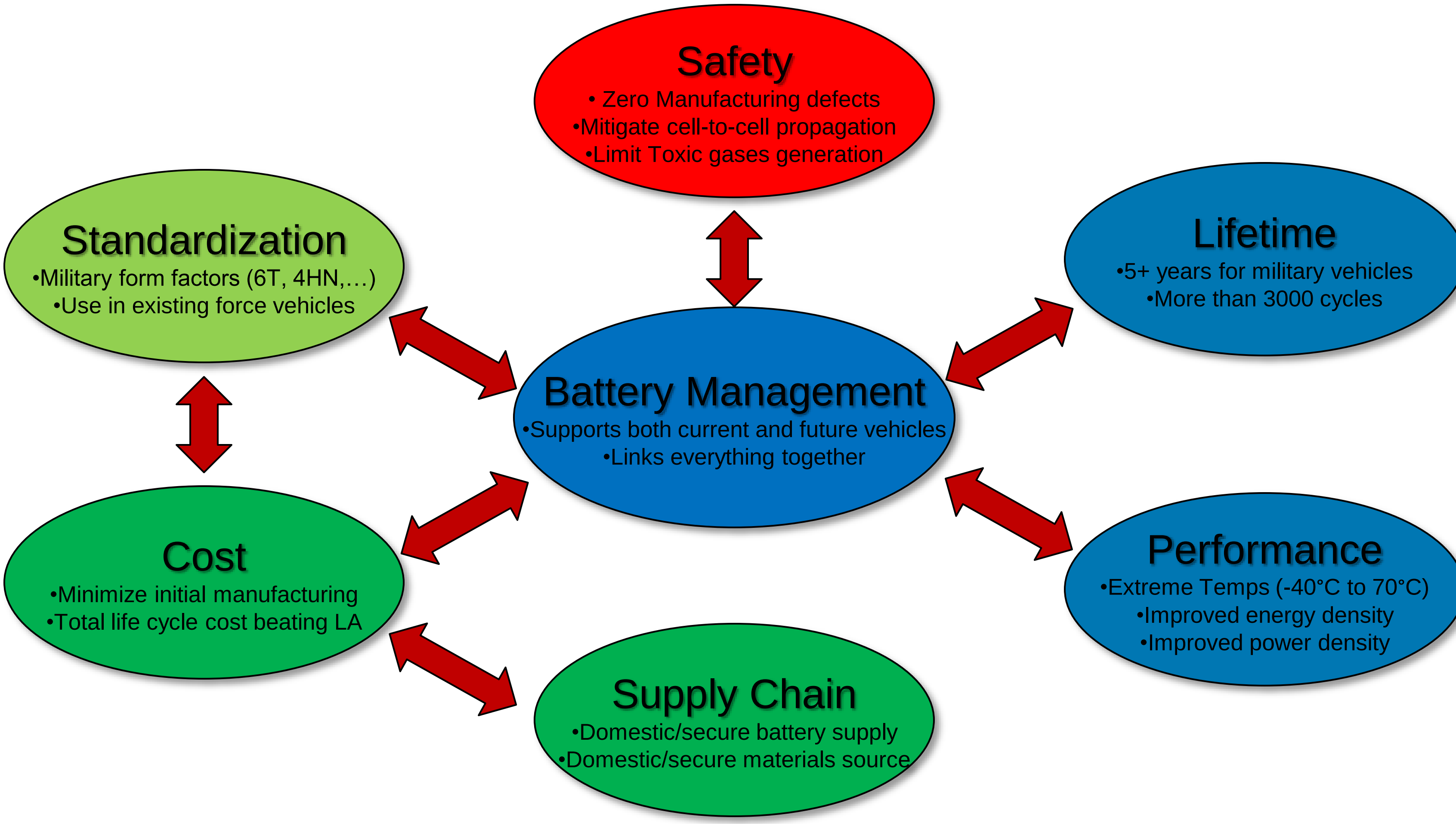
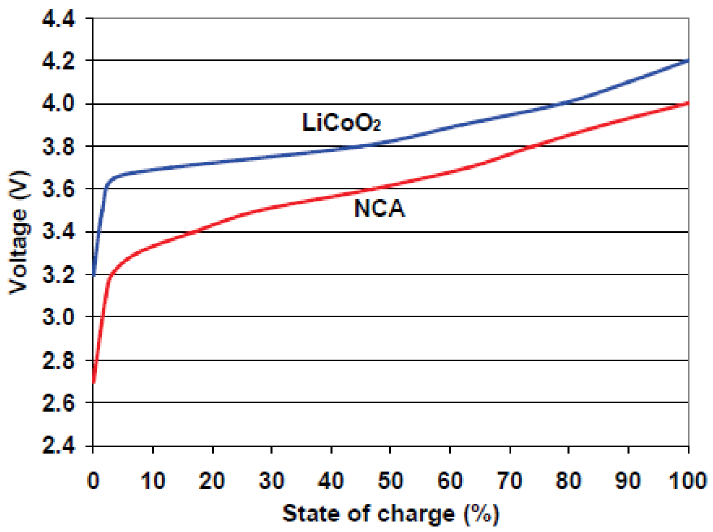
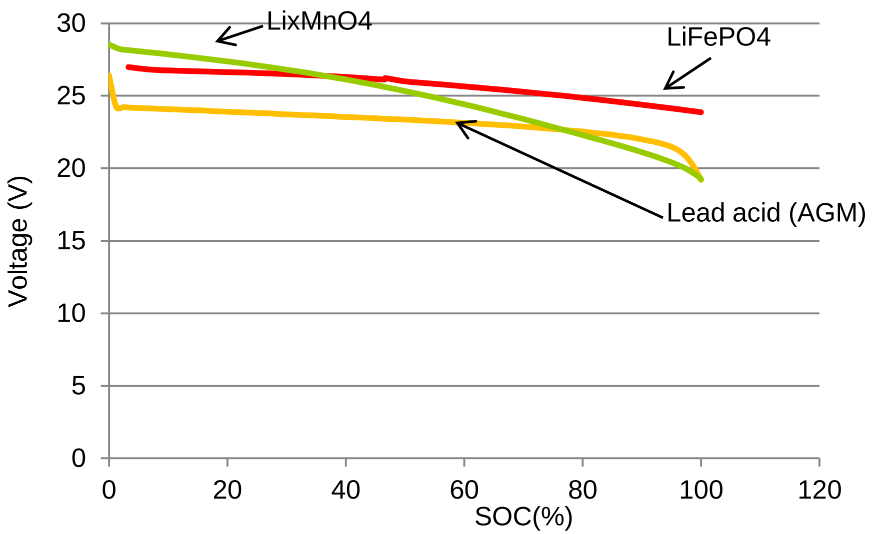


Table 2 – Battery voltage

Lithium Ion Batteries and Lead Acid Batteries

Battery Chemistry	Specific energy (Wh/kg)	Specific power (W/kg)	Energy Density (Wh/l)	Cycle life	Working tem range
Li-ion	120~200	200~3000	300~600	>1000	-30°C-60°C
Lead Acid	~40	300~650	80~120	100~300	-30°C-70°C





The charge-discharge characteristics of Li-ion and lead acid batteries

Table 2 – Battery voltage

Battery Standardization - Design

- Li-ion battery has to work with existing vehicle electrical system

- Li-ion battery is sensitive to the battery overcharge

- Li-ion battery is sensitive to the battery overdischarge

# of Cells	1	3	4	6	7	8	n
Nominal Voltage(V)	3.7	11.1	14.8	22.2	25.9	29.6	n x 3.7
Voltage range (V) (NCA, NCM)	2.5-4.1	7.5-12.3	10-16.4	15-24.6	17.5-28.7	20-32.8	
Nominal Voltage(V) ($LiFePO_4$)	3.3	9.9	13.2	19.8	23.1	26.4	n x 3.3
Voltage range (V) ($LiFePO_4$)	2.0-3.7	6-11.1	8-14.8	12-22.2	14-25.9	16-29.6	

Battery Standardization - Size

- **ARMY's focus is to develop Li-ion batteries in existing lead acid standardized form factors (such as 6T, 4HN, Group 31 and Group 34)**
  - Development of a set of standardized battery packs would allow for standardization of components – provide significant cost benefits.
- **Implementing a 6T size battery form factor (10.5in. X 10 in. x 8.5 in.) would provide the following for a Military vehicle battery:**
  - Allow of the use in both current force vehicles (as replacement for existing lead acid batteries) as well as next generation vehicles that are designed to utilize Li-ion batteries.
    - ➢ Increased flexibility in field – can use either Lead acid or Li-ion batteries depending on availability.
  - To reduce logistic burden – support limited number of battery sizes in field.
  - Cost benefits (leverage volume).

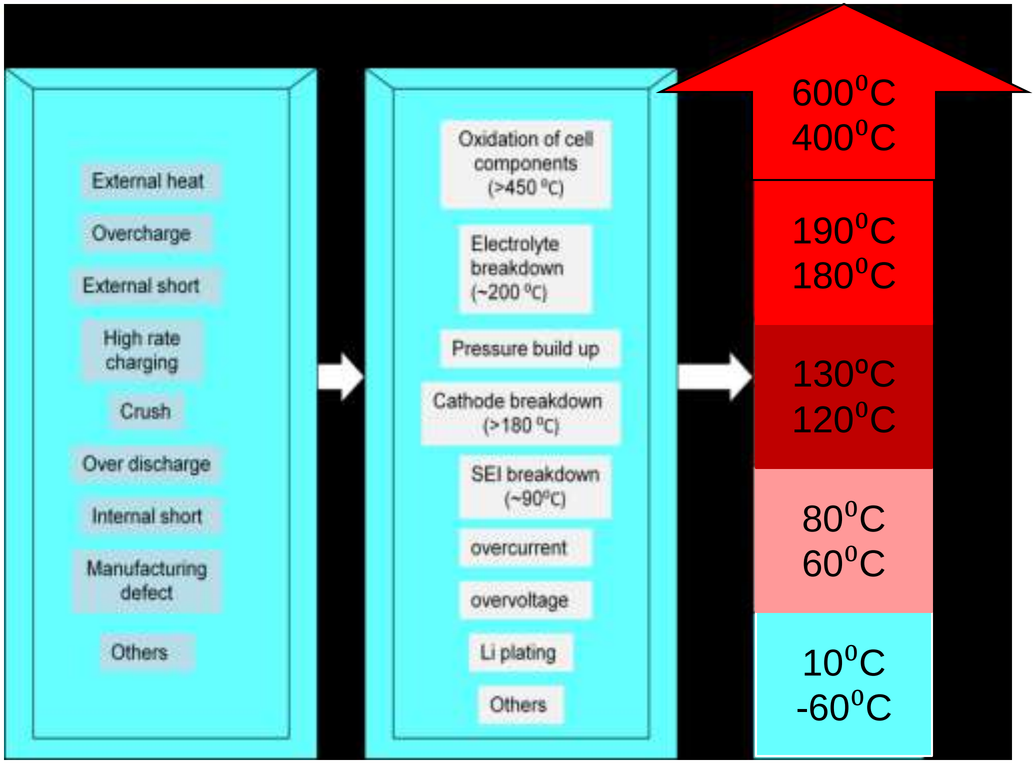
Li- Ion Battery Performance at Extreme Conditions

- **Low temperature operation (-40°C)**
  - Difficulty meeting startup requirements
    - Reduced power from increased impedance
  - Reduced discharge current and capacitance
  - Reduced charge acceptance/ Li Plating
  - ✓ Battery heater can be added
  - ✓ New electrolytes and additives are being developed

- **High temperatures operation (70°C)**
  - ✓ Improves battery performance
    - Increased electrochemical reactions
  - Reduced lifetime
    - Increased corrosion
  - Increased safety hazard

- **Optimization**
  - ✓ Operating temp between 0-50°C
  - ✓ Uniformity within and between modules

Engineering Challenge - Safety



Field failure caused by usage, control, etc

Transportation may trigger safety hazard

Battery thermal runaway

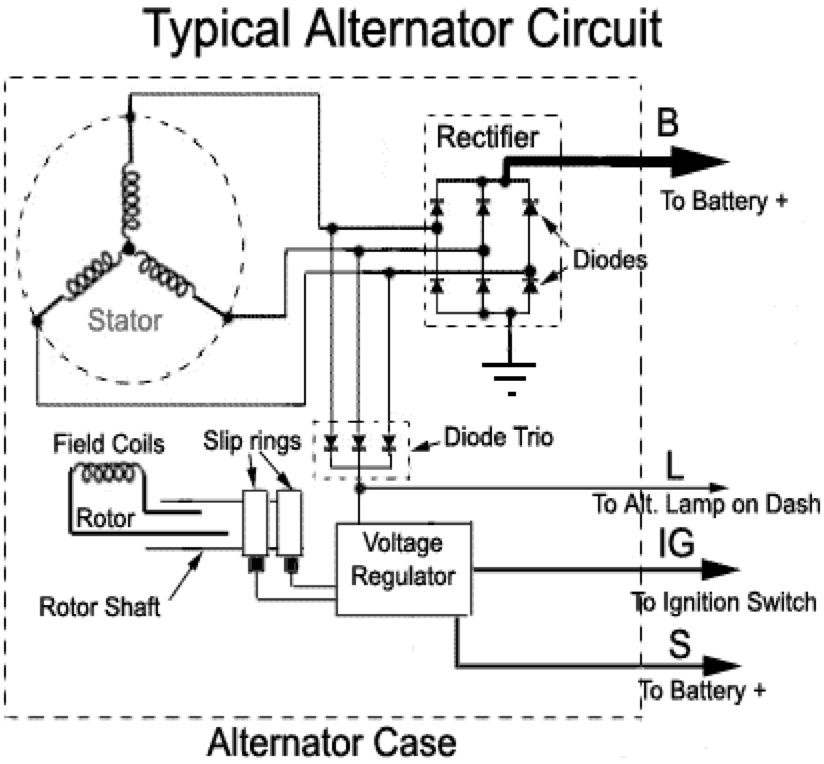
Battery Management System

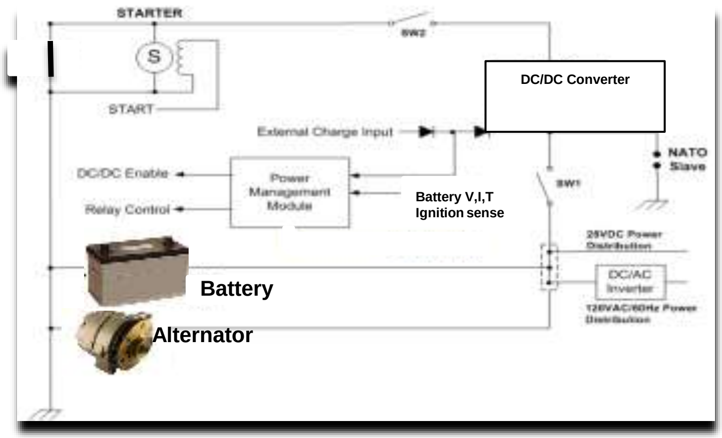
- **Needed to reduce safety hazard**
- **Required to increase battery life**
- **Monitors and reports**
  - State of Charge (SOC)
  - State of Health (SOH)
  - Voltage
  - Current
  - Temperature

- **Design challenges**
  - Handling transient spikes
    - Over-charge
    - Over-discharge
    - Over-current
  - Affordability
  - Varied charge/discharge methods
  - Communication interface
  - Battery self-discharge

Battery Charging

• The charge control for lithium ion battery chemistries is different from those of flooded and sealed lead acid batteries.
• The discharge control for lithium ion battery chemistries is different from those of flooded and sealed lead acid batteries.
• Battery charging voltage changes with the temperature





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Challenge - Cost

- Current Lead acid battery: $50-$280/kWh
- Current Lithium ion battery: $800-$2000/kWh
- Long term target price for Li-ion battery is $500/kWh

Batteries represent one of the top ten ongoing maintenance costs in theater.

Conclusions

- The Li-ion battery replacement offers advantages due to the winning combination of energy and power density.
- Engineering challenges for Li-ion battery Replacement:
  - Control
  - Safety
  - Cost
  - Dual Applications