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Energy Storage Requirements & Challenges For Ground Vehicles



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- TARDEC & Energy Storage Team Mission
- Vehicle Requirements for Energy Storage
- Army Ground Vehicle Power & Energy Challenges
- Energy Storage Roadmap
- Technology Readiness Level Assessment



- Provides **full life-cycle engineering** support and is provider-of-first-choice for **all DOD** ground combat and combat support weapons and vehicle systems.
- Develops and integrates **the right technology solutions** to improve Current Force effectiveness and provide superior capabilities for the Future Force.

**Ground Systems Integrator for the
Department of Defense**

Responsible for Research, Development and Engineering Support to **2,800** Army systems and many of the Army's and DOD's Top Joint Warfighter Development Programs

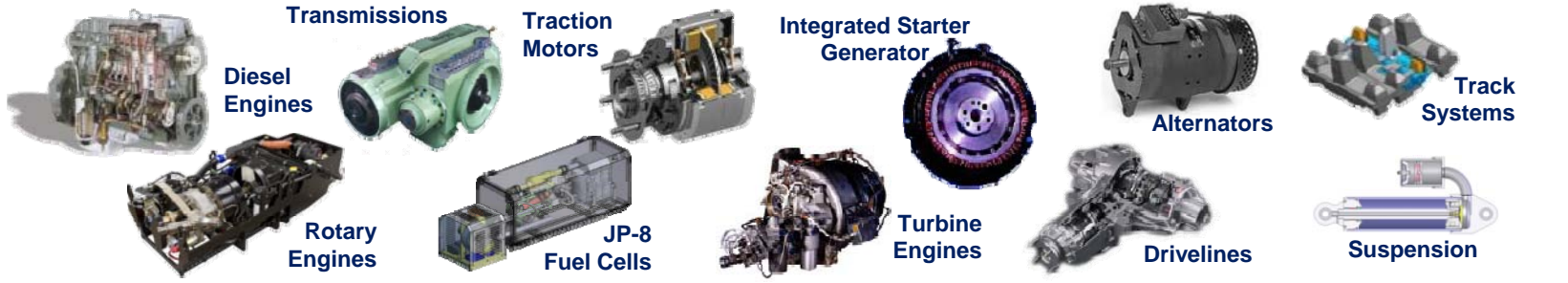


TARDEC invests in targeted Ground Vehicle Energy Solutions



Ground Vehicle Power and Energy Technology

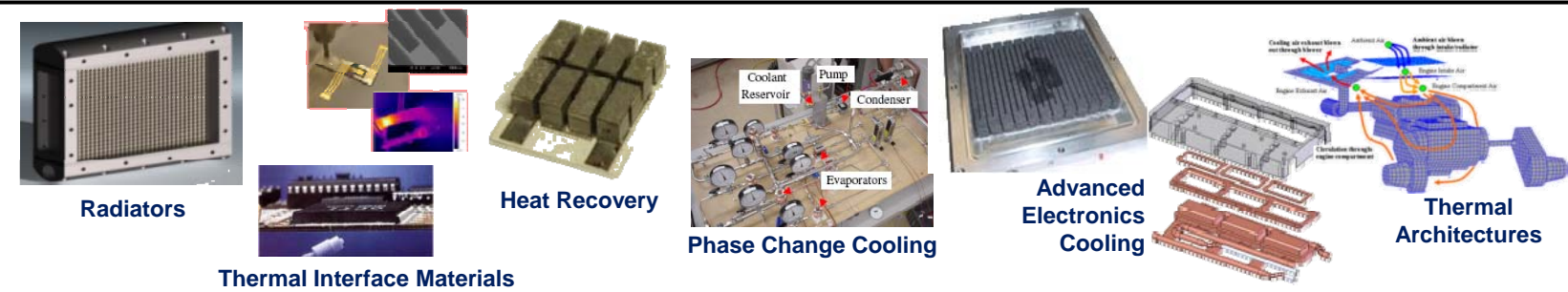
Prime & Non-Primary Power



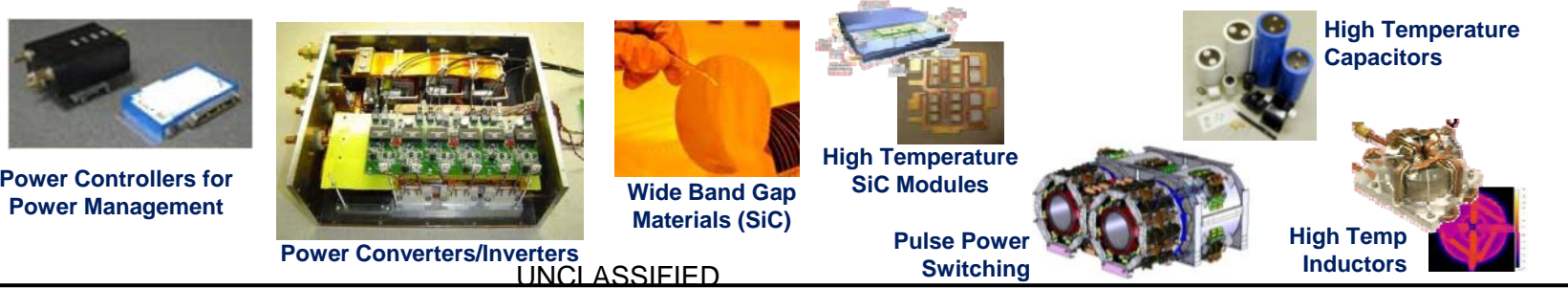
Energy Storage



Thermal Management



Power Management

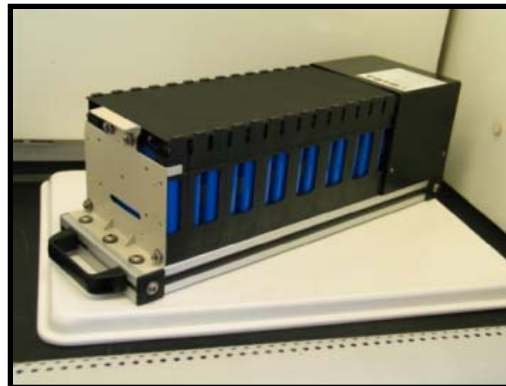


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- Pursue energy storage technology research, development, component test and evaluation for CURRENT and FUTURE ground vehicle fleet
- Identify technology barriers and develop technical solutions
- Provide technical support to customers, other teams and government agencies in all energy storage



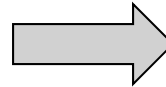
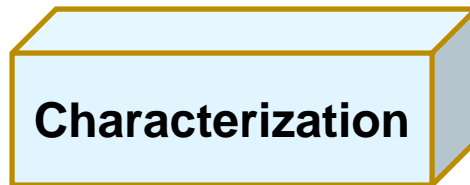
Battery Technology Evaluation Lab



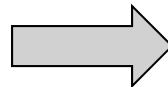
Module Test & Eval



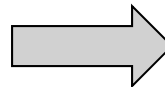
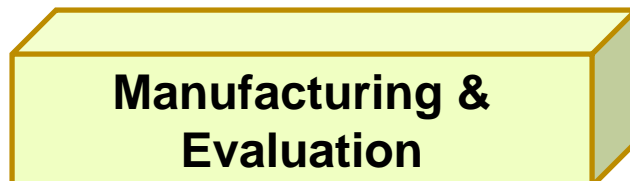
Cell Test & Eval



- Understand aging mechanism
- Safety limits
- Evaluate and/or develop novel materials (cathode, anode, electrolyte) that promise increased power & energy



- Characterize batteries & investigate cell behavior
- Enhanced Battery Management



- Perform battery and capacitor evaluation testing (charge, discharge and service life testing) for cell, module, and full battery systems at different temperatures and rate.

Ongoing R&D:

- Focused investigations on novel materials (cathode, anode, electrolyte) for increased power and energy & reduced cost
- Develop advanced diagnostic tools and battery management system.
- Develop and apply advanced models for batteries and components
- Advanced battery design techniques
- Advanced battery manufacturing techniques



Pacing Vehicle Requirements for Energy Storage



There are three distinct requirements for Military Energy Storage:

- ***Starting, Lighting and Ignition***

Batteries provide electric power to start the vehicle power generation (Engines / APUs)

- ***Hybrid Vehicle Boost Acceleration and Regenerative Braking Energy Capture***

In hybrid vehicle powertrains, batteries have the ability to supplement main engine power for burst accelerations.

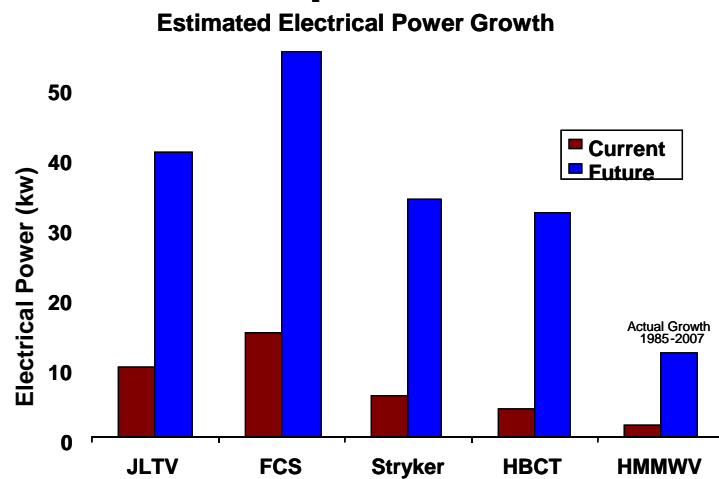
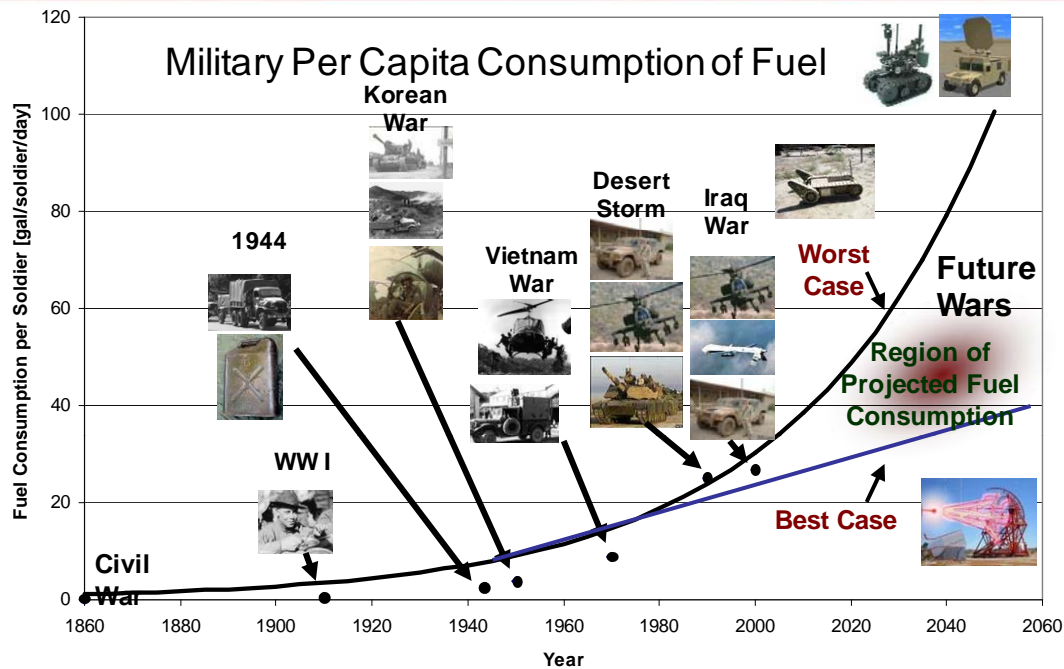
In addition, batteries can be used to recover wasted energy in vehicle braking

- ***Silent Watch***

Batteries can provide the energy storage capability to power mission equipment with main engine off while the vehicle is stationary

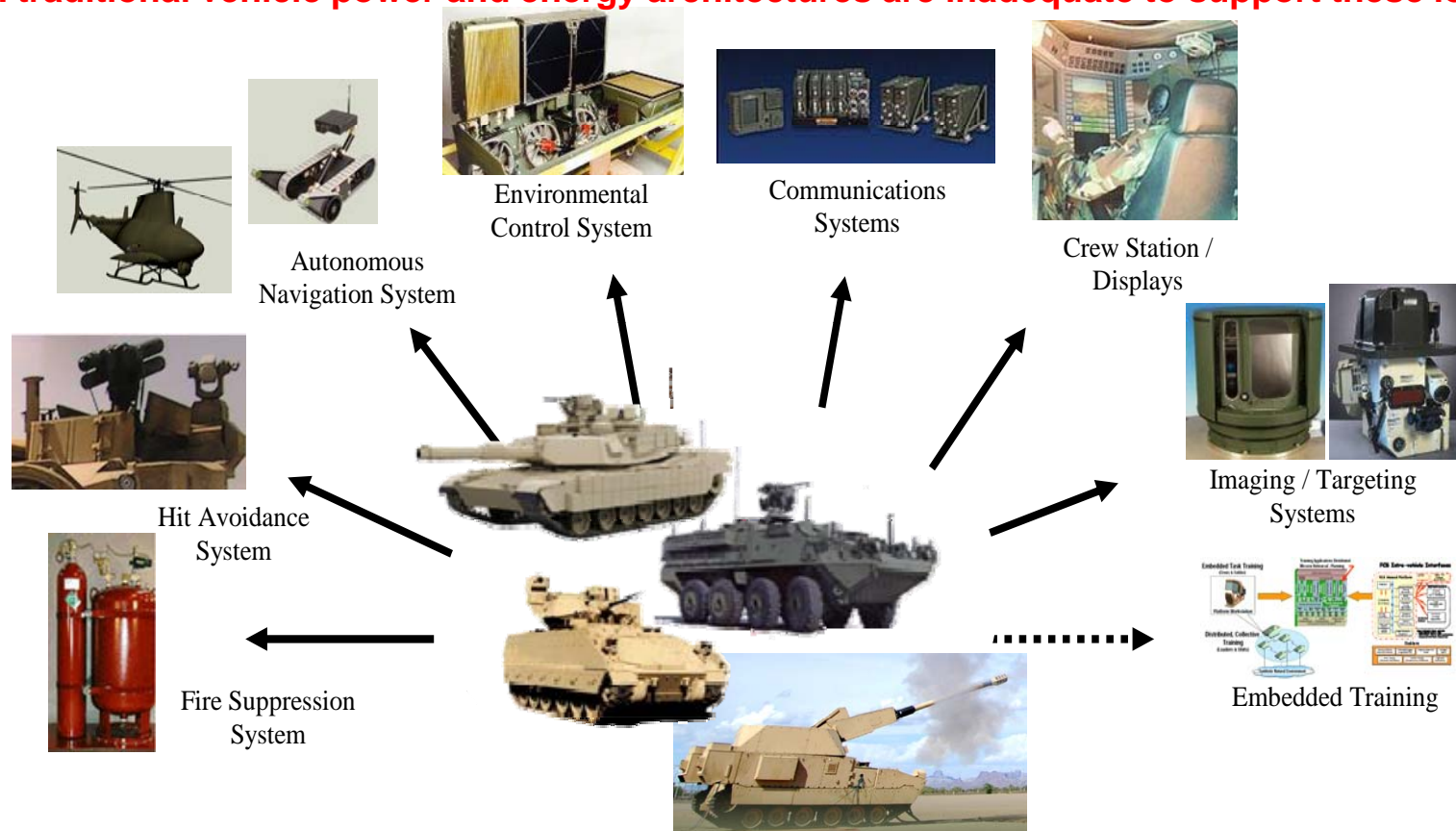
Power & Energy Challenges

- **Battlefield consumption of energy increasing**
 - New C4ISR technologies
 - IED Defeat Systems
 - New weapons (EM guns, lasers)
- **Energy security problematic**
 - Cost of fuel skyrocketing
 - Alternative sources sought – wind, solar, bio-mass, waste to energy
- **Operational issues**
 - Battery usage & limitations – energy & power density
 - Demand for auxiliary power on-board vehicles
 - Emphasis on silent (“quiet”) watch
 - Unmanned vehicles (air/ground)
 - Unattended sensors
 - Inefficient management/ distribution of power
 - Demand for Soldier-wearable power
- **Increased emphasis on system power metrics and energy efficiency** (KPPs, low consumption components)



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Advanced survivability, weapons and C4ISR equipment are driving vehicle power demands dramatically higher... traditional vehicle power and energy architectures are inadequate to support these loads.



The current force is modernizing with it the tremendous power and thermal burdens associated with the advanced technology

As the Army transforms the Current to the Future Force, significant technical challenges in power and energy must be overcome to enable the Warfighter with its superior capability

REQUIREMENTS DRIVERS FOR SILENT WATCH POWER GROWTH ON MILITARY GROUND VEHICLES:

NET-CENTRIC WARFARE

Continuous Power for C4ISR

Node on Network, High Bandwidth

Low-Grade Heat

Silicon based Power Electronics

SURVIVABILITY

Power for APS, Countermeasures, 360° SA

ENVIRONMENTAL CONTROL

Power for Air Conditioning

Compressor, Fan

Air Conditioning Thermal

Condenser Heat Load

- Future ground vehicle will demand more electric power
- Cooling requirements of high power systems compound power growth
- Efficiency critical to reducing system power demands



Abrams & Bradley

Current: ~2kW

Future: 27kW (T), 50kW (O)

Ground Combat Vehicle

Current Estimate: 45kW

LEGEND:

- █ Thermal Burden
- █ Electrical Burden

Increasing power demand for new mission equipment and heat rejection parasitic loads have dramatically increased the silent watch loads for future combat vehicles

	Battery Design Specifications
Commercial Vehicles	Hybrid Electric Vehicles 5 kW-hrs Plug-In Hybrids 16 kW-hrs Electric Vehicles 40 kW-hrs
Joint Light Tactical Vehicles (JLTV)	4 – 12 kW-hrs (2kW over 2 - 6 hours)
Stryker Modernization (SMOD)	8 kW-hrs (2kW over 4 hours)
Abrams M1E3	336 - 672 kW-hrs (28kW over 12 - 24 hours)
Future Combat System – Manned Ground Vehicle	100 – 560 kW-hrs (50-70kW over 2 - 8 hours) AND 180kW over 20 seconds
Ground Combat Vehicle	270 – 3240 kW-hrs (~45kW over 6 - 72 hours)

Military vehicle silent watch requirements are driving battery designs that are optimized for high energy



Integrated Solutions for Silent Watch Requirements



2010

2011

2012

2013

2014

2015

2016

2017

Non-primary Power System ATO-D

Current Force Silent Watch Solutions (8 – 10 kW)



Challenges:

- Reduce APU Signature
- Integration of Batteries & APU
- Power Management

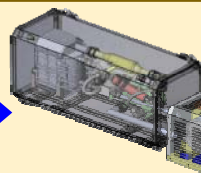
Extended True Silent Watch with Efficient APU to Enable Long Duration Engine-off Missions

Engine Generator APUs Hybridized with Advanced Chemistry Batteries

JP-8 Fuel Cell APU System ATO-R

JP-8 Fuel Cell APU System ATO-D

Joint DOD Program with:



TRL 6



Challenges:

- Reformer/Fuel Cell Integration
- Improve System Power Density
- Thermal and Water Management

Efficient, Long Duration Engine-off Mission Enable True Silent Watch

JP-8 Reformed Fuel Cell System APU with Advanced Batteries

Non-primary Power System ATO-D

Future Force Silent Watch Solutions (30 – 70 kW)



Challenges:

- APU Fuel Efficiency
- Improve APU Power Density
- Reduce APU Signature

- Both Technology Paths Provide Extended Duration, High Power Engine-off Missions
- System Specific Trade-offs due to Vehicle SWAP and Power Requirement

High Power Engine Generator APUs with Advanced Batteries

Efficient Powertrain Technologies ATO-R

Efficient Powertrain Systems ATO-D



Challenges:

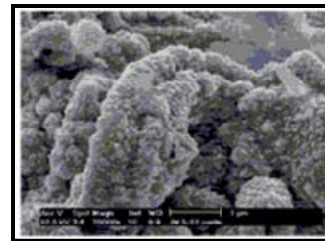
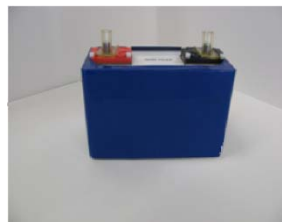
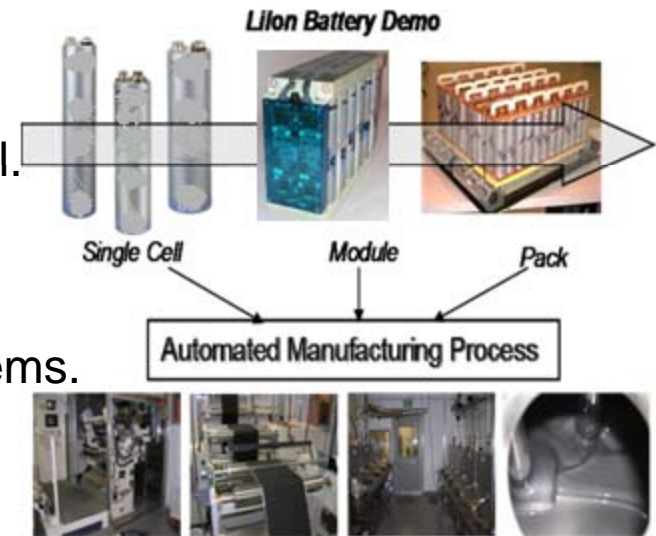
- Integration of Adv. Powertrain
- Reduce Idle Fuel Consumption
- Reduce Powertrain Signature

Efficient Powertrain w/ Integrated Starter Generator & Advanced Batteries

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Energy Storage

- Power vs. Energy trade-off design optimization.
- Manufacturing process development and cost control.
- Thermal management.
- Cell & system safety & reliability.
- System control & cell and battery management systems.
- Alternative electrochemical improvements.
- Thermal runaway process and its control.



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TARDEC Path Forward To Address Power & Energy Challenges

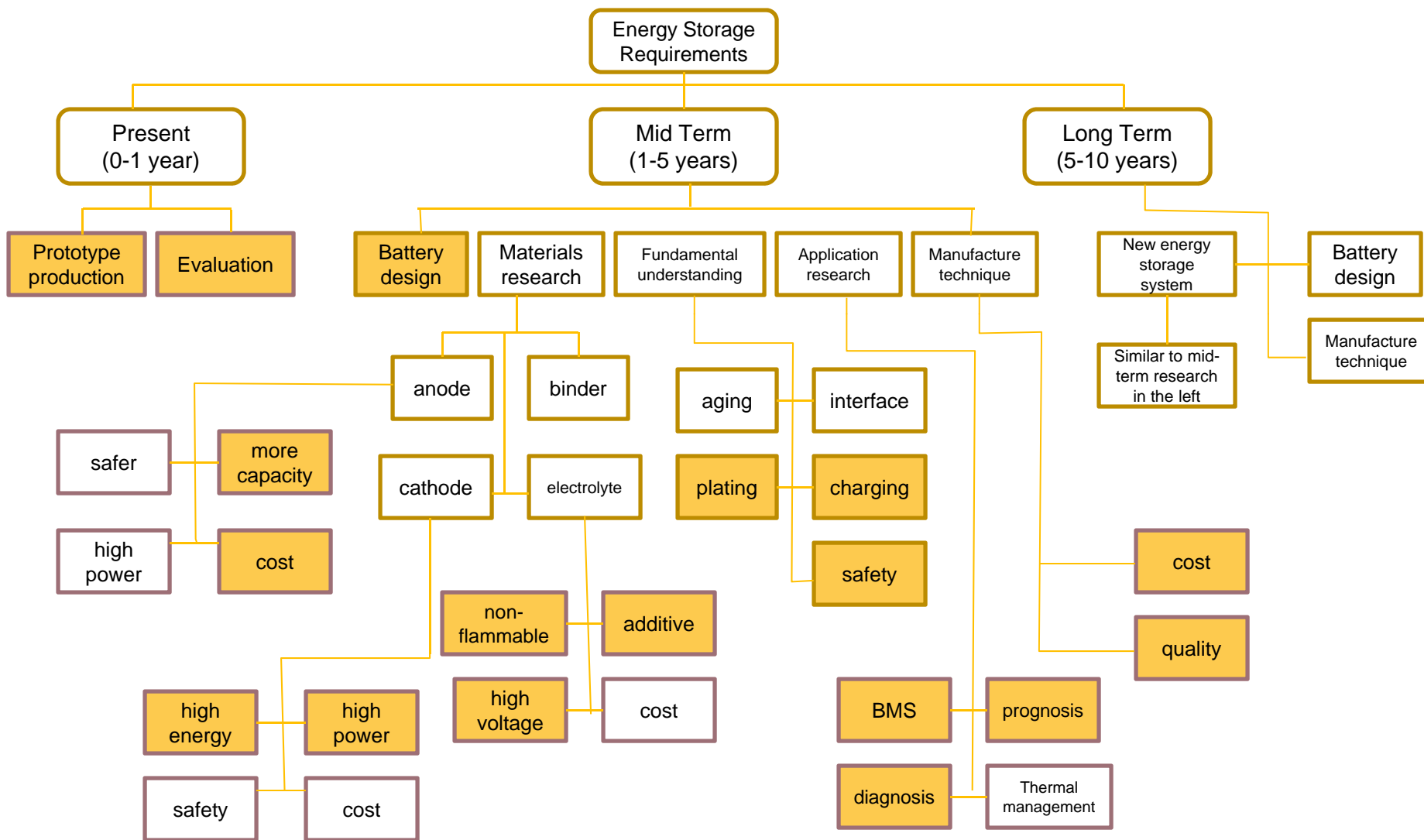


- **Development of Advanced Power and Energy Batteries:**
 - Ultra High Power Batteries for Burst Power Applications
 - New Chemistries to provide Increased Energy for Silent Watch
- **Hybridized Devices with Both Power and Energy Capabilities:**
 - Battery (energy) / Capacitor (power) Combination Device
 - Combination Power and Energy Battery
- **Development of Advanced Battery Manufacturing Capability**
- **Development of Advanced Power Management Capabilities**
- **Development of Advanced Thermal Management Technologies**
- **High Temperature Power Electronics for Reduced Thermal Loads**

TARDEC will Utilize a Multi Faceted & Integrated Technology Approach to Address Power and Energy Challenges

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Roadmaps



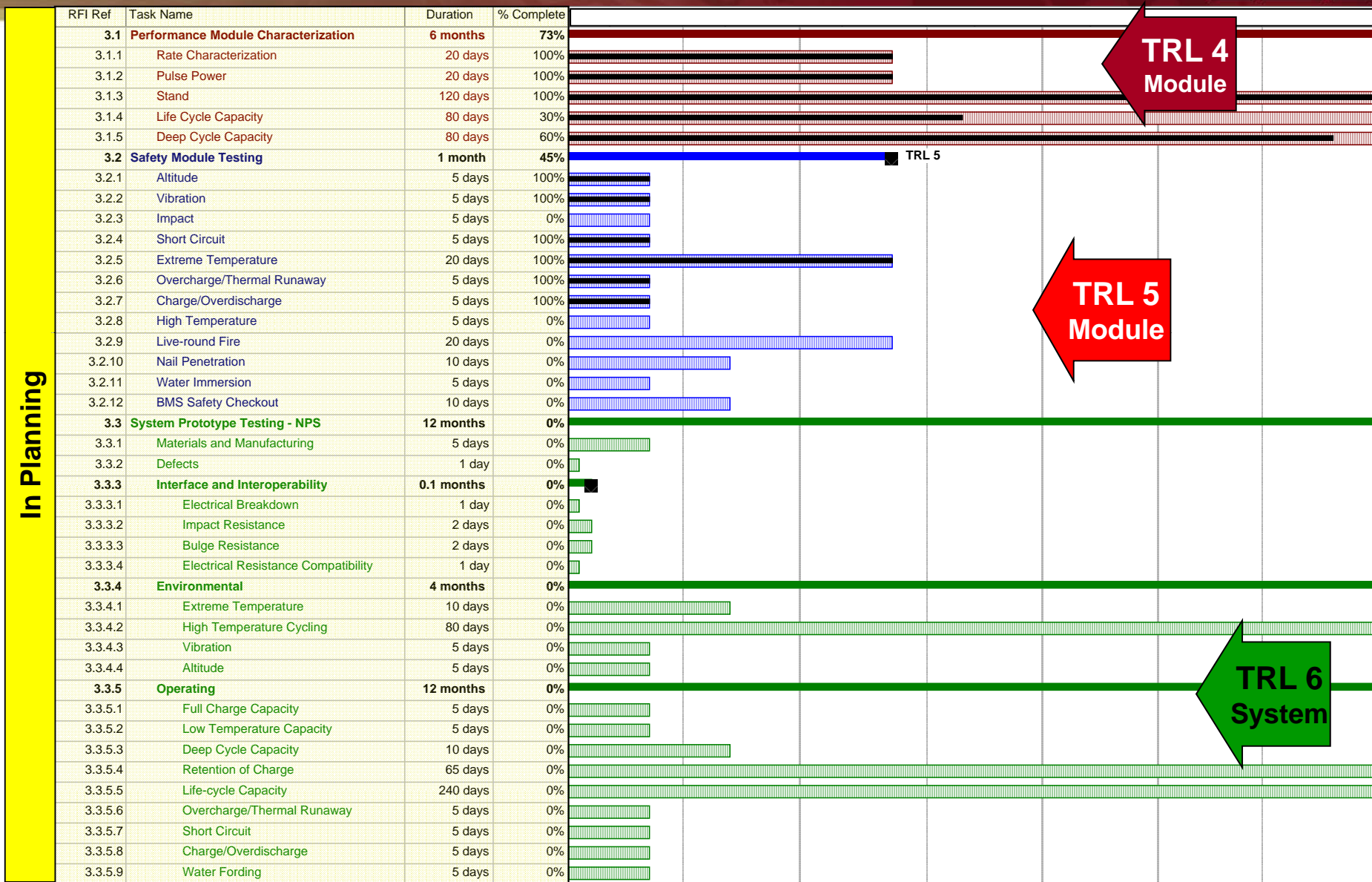
Over 56 Projects & Programs

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TARDEC TRL Assessment for Batteries



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“Power and energy is not only the greatest enabler of the Warfighter, it is also the most significant limitation.”

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High Energy Battery Roadmap



Criterion	Units	Current	Mid-term	Long-term
Specific power	kW/kg	0.3	0.5	1
Specific energy	Wh/kg	160	250	350
Calendar Life	Years	5-10	12	15
Cycle life	Cycles	500-1,000	2,000	>4,500
Sale price	\$/kWh	1000	500	<150

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High Power Battery Roadmap



Criterion	Units	Current	Mid-term	Long-term
Power density	kW/l	16	30	40
Specific power	kW/kg	8	15	20
Energy density	Wh/l	100	140	200
Specific energy	Wh/kg	40	70	100
Calendar Life	Years	10	15	20
Cycle life	Cycles	1000	3000	5000
Sale price	\$/kWh	1000	500	300

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