



U.S. ARMY COMBAT CAPABILITIES DEVELOPMENT COMMAND – GROUND VEHICLE SYSTEMS CENTER

Combat Vehicle Energy Storage

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CCDC GVSC

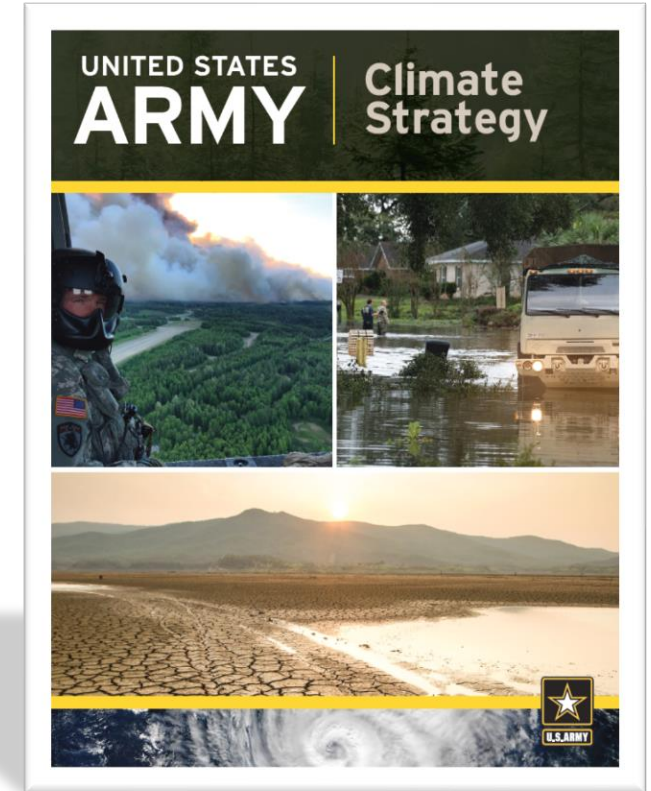
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Vehicle Electrification Benefits/Drivers



1. Onboard power for energy-based capabilities, such as directed energy weapons, jammers, electrified armor, etc.
2. Silent Mobility/Silent Watch
3. Extended Operations between resupply due to anti-idling.
4. Improved Mobility (and Survivability) due to improved acceleration and burst speed.
5. Ability to leverage vehicle to grid to support base camps for expeditionary operations
6. Ability to leverage host nation power grid to reduce logistics.
7. Reduced maintenance/sustainment costs



Calls for the Army will field purpose-built hybrid-drive tactical vehicles by **2035** and fully electric tactical vehicles by **2050**



Challenges: All Electric Tank Feasibility (Hybrid vs. full e-Tank)



Tesla Model S

Car: ~4500 lbs

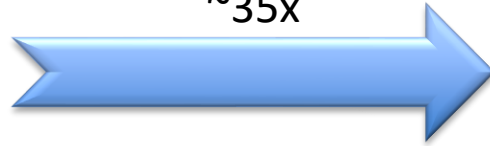
Range: 315 miles

100kWhr battery (~300Whr/mile)

Battery Weight: ~1,700 lbs

(~35-40% of vehicle weight)

~35x



All Electric Tank (with Today's Technology)

~100,000 lbs (50 ton)

Range: 300 miles

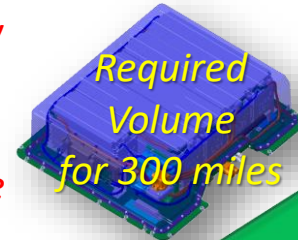
11.5kWh/mile (3.4MWhr battery)

Battery Est. Weight: 60,100 lbs

Battery Est. Vol: 605 ft³

Recharge: 3.4MW (1hr), 6.8MW (30min) or 13.6MW (15min)

*300 mile All Battery
Powertrain
Volume = ~650ft³
(for all electric drive
components)*



X ~35



X ~10



*Available volume in the concept = 225ft³
(Results in estimated range of ~100 miles
in a military battery)*

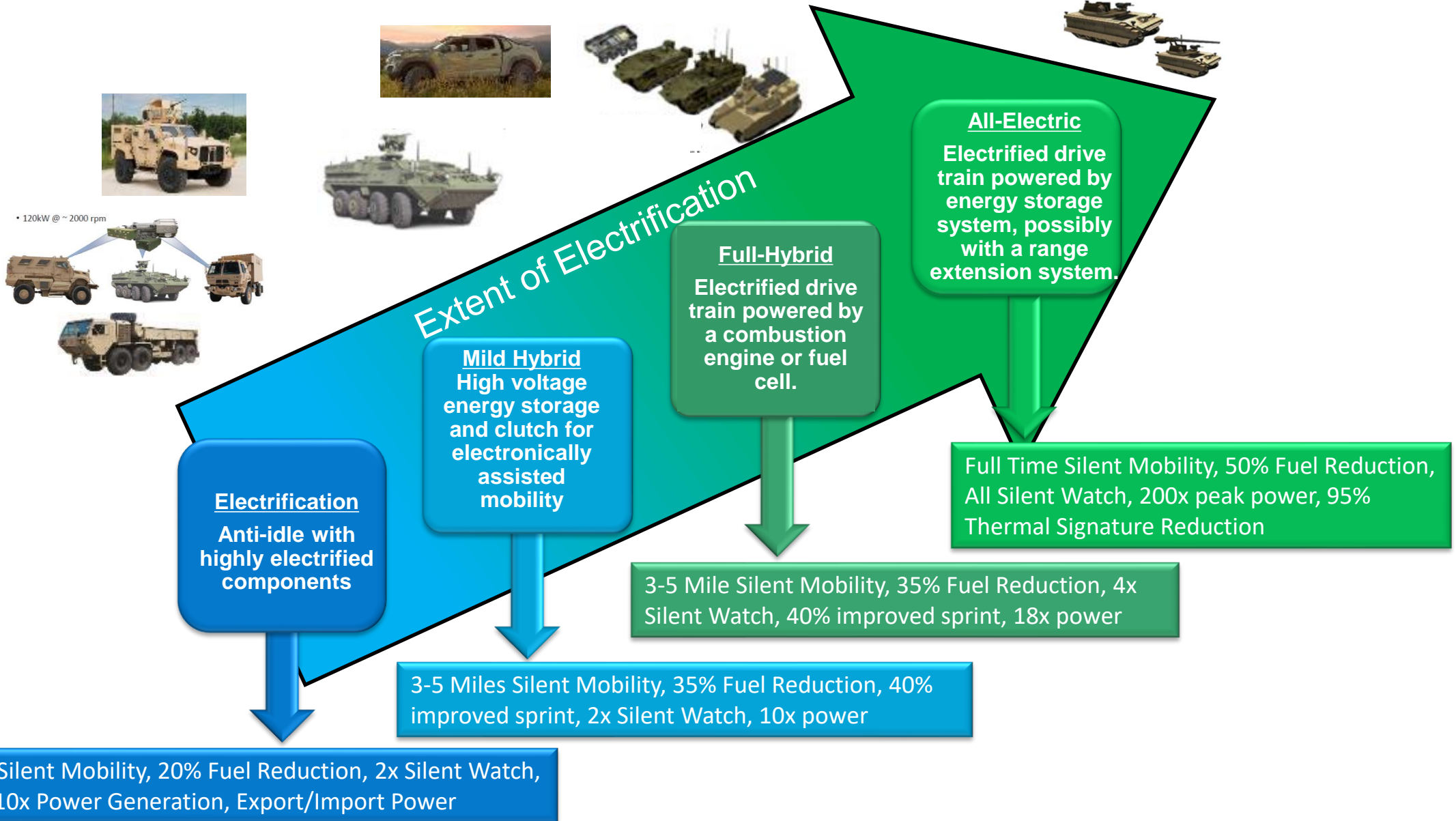
Hybrid

Powertrain Volume = 225ft³





GVSC/Army Approach to Electrified Platforms

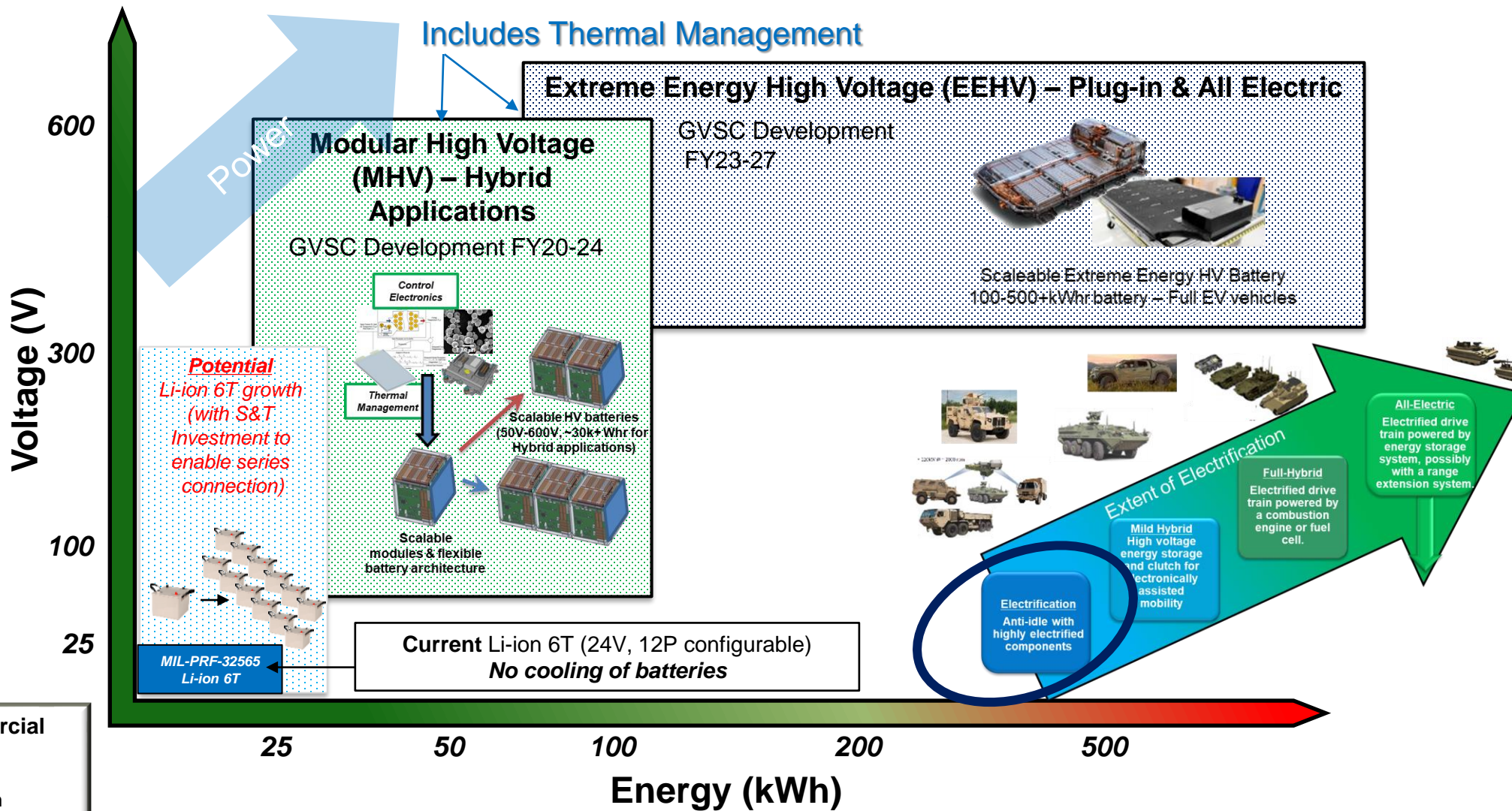




GVSC Energy Storage Roadmap



To meet unique military requirements including Navy Safety certification, standardized/scalable military batteries are needed



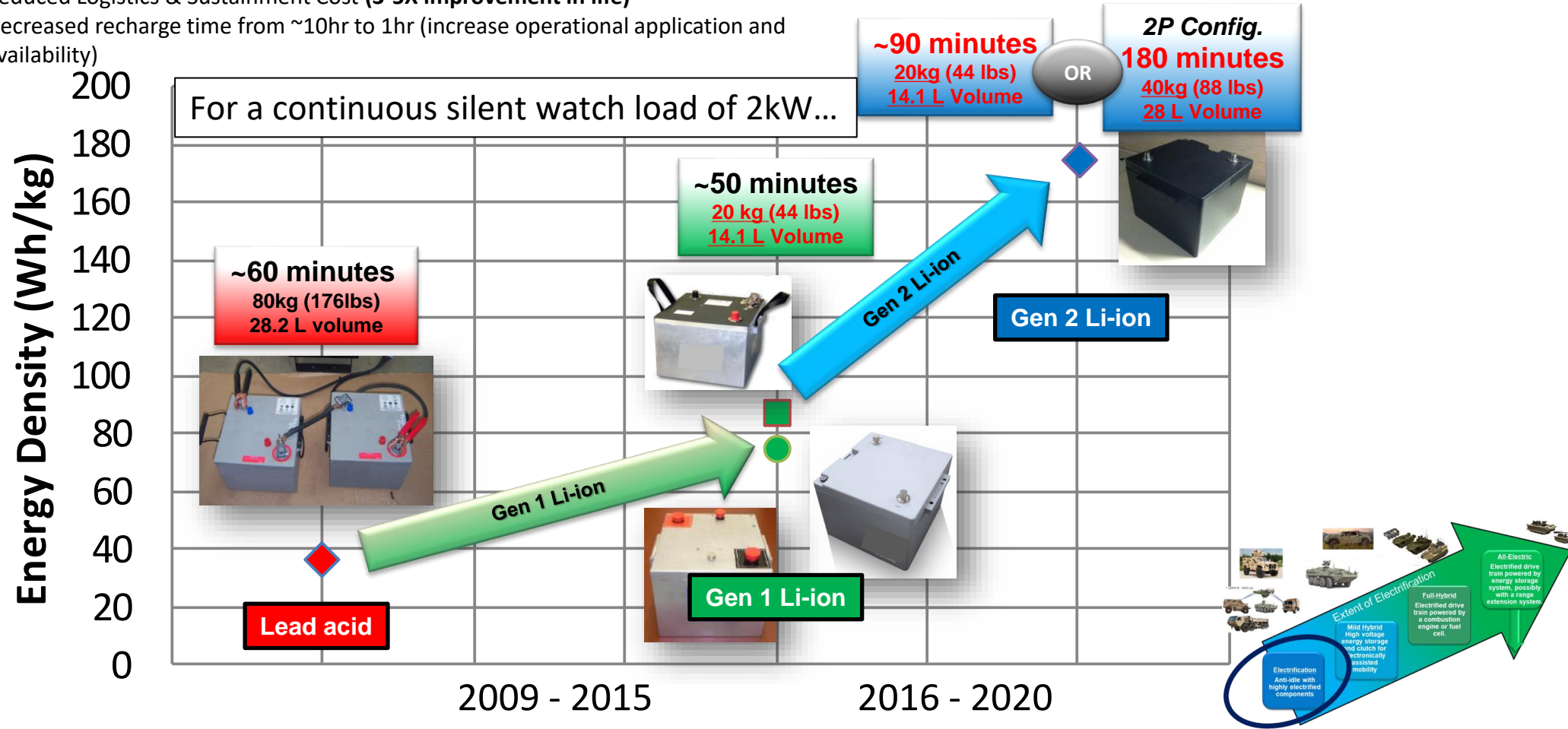


6T Battery Development (Modular Example)



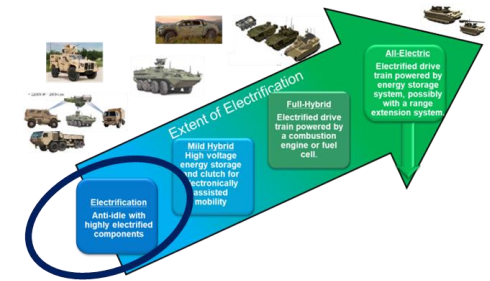
- Reduced Volume (single Li-ion battery replaced two PbA batteries)
- Weight Savings (vs lead acid) (132lbs/pair of PbA replaced)
- Maximization of power and energy density (up to 3X increase in silent watch duration)
- Reduced Logistics & Sustainment Cost (3-5X improvement in life)
- Decreased recharge time from ~10hr to 1hr (increase operational application and availability)

Number of 6T	PbA (lbs)	Li-ion (lbs)	Weight Savings
2- 6T	176	44	132lbs
4- 6T	352	88	264lbs
6- 6T	528	132	396lbs
12- 6T	1056	264	792lbs





Li-ion 6T Specification – Update



Characteristics	Type 1 minimum values (at normal conditions unless specified)			
	Class A		Class B	
Classification:	Class A		Class B	
Sub-Classification:	1-A55	1-A75	1-B55	1-B90
Color:	SAE AMS-STD-595 color 33446	SAE AMS-STD-595 color 33446	SAE AMS-STD-595 color 33446	SAE AMS-STD-595 color 33446
Weight (max):	30 kg	30 kg	30 kg	30 kg
Nominal voltage:	24 V	24 V	24 V	24 V
Full charge capacity:	55 Ah (at 22 °C)	75 Ah (at 22 °C)	55 Ah (at 22 °C)	90 Ah (at 22 °C)
Cranking amps (no pre-heating):	1100 A for 30 sec at 55 °C	1100 A for 30 sec at 55 °C	1100 A for 30 sec at 55 °C	1100 A for 30 sec at 55 °C
	600 A for 30 sec at -18 °C	600 A for 30 sec at -18 °C	1100 A for 30 sec at -18 °C	1100 A for 30 sec at -18 °C
	300 A for 30 sec at -32 °C	300 A for 30 sec at -32 °C	600 A for 30 sec at -32 °C	600 A for 30 sec at -32 °C
	200 A for 30 sec at -40 °C	200 A for 30 sec at -40 °C	400 A for 30 sec at -40 °C	400 A for 30 sec at -40 °C
	1100 A for 30 sec within 15 minutes	1100 A for 30 sec within 15 minutes	1100 A for 30 sec within 10 minutes	1100 A for 30 sec within 10 minutes
Cranking amps (pre-heating at -18 °C):	600 A for 30 sec within 30 minutes	600 A for 30 sec within 30 minutes	1100 A for 30 sec within 30 minutes	1100 A for 30 sec within 30 minutes
Cranking amps (pre-heating at -48 °C):	600 A for 30 sec within 30 minutes	600 A for 30 sec within 30 minutes	1100 A for 30 sec within 30 minutes	1100 A for 30 sec within 30 minutes
Deep cycle life:	1000 cycles at 38 °C 500 cycles at 50 °C	1000 cycles at 38 °C 500 cycles at 50 °C	1000 cycles at 38 °C 500 cycles at 50 °C	1000 cycles at 38 °C 500 cycles at 50 °C
Battery service life:	5 years	5 years	5 years	5 years
Continuous cycling current discharge rating:	120 A	150 A	120 A	180 A
Continuous cycling current charge rating:	60 A	75 A	60 A	90 A
Pulse load rating:	600 A (at 30 seconds)	600 A (at 30 seconds)	1100 A (at 30 seconds)	1100 A (at 30 seconds)
Rapid charging time:	20 minutes	25 minutes	20 minutes	30 minutes
Operating temperature range:	-46 to 71 °C	-46 to 71 °C	-46 to 71 °C	-46 to 71 °C
Storage temperature range:	-54 to 88 °C	-54 to 88 °C	-54 to 88 °C	-54 to 88 °C
Minimum cranking voltage (below 0 °C)	14.4 V	14.4 V	14.4 V	14.4 V
Number of batteries capable of being connected in series	1	1	1	1
Number of batteries capable of being connected in parallel	12	12	12	12
SAE J2464 Hazard Severity Level (battery nail penetration, crush, and overcharge abuse only)	≤ 4	≤ 4	≤ 4	≤ 4
SAE J2464 Hazard Severity Level (battery projectile penetration only)	≤ 6	≤ 6	≤ 6	≤ 6

Characteristics	Type 2 minimum values (at normal conditions unless specified)		
	Class A	Class B	Class B
Classification:	Class A		
Sub-Classification:	2-A55	2-A75	2-B90
Color:	SAE AMS-STD-595 color 33446	SAE AMS-STD-595 color 33446	SAE AMS-STD-595 color 33446
Weight (max):	30 kg	30 kg	30 kg
Nominal voltage:	24 V	24 V	24 V
Full charge capacity:	55 Ah (at 22 °C)	75 Ah (at 22 °C)	90 Ah (at 22 °C)
Cranking amps (no pre-heating):	1100 A for 30 sec at 55 °C	1100 A for 30 sec at 55 °C	1100 A for 30 sec at 55 °C
	600 A for 30 sec at -18 °C	600 A for 30 sec at -18 °C	1100 A for 30 sec at -18 °C
	300 A for 30 sec at -32 °C	300 A for 30 sec at -32 °C	600 A for 30 sec at -32 °C
	200 A for 30 sec at -40 °C	200 A for 30 sec at -40 °C	400 A for 30 sec at -40 °C
	1100 A for 30 sec within 15 minutes	1100 A for 30 sec within 15 minutes	1100 A for 30 sec within 10 minutes
Cranking amps (pre-heating at -18 °C):	600 A for 30 sec within 30 minutes	600 A for 30 sec within 30 minutes	1100 A for 30 sec within 30 minutes
Cranking amps (pre-heating at -48 °C):	600 A for 30 sec within 30 minutes	600 A for 30 sec within 30 minutes	1100 A for 30 sec within 30 minutes
Deep cycle life:	1000 cycles at 38 °C 500 cycles at 50 °C	1000 cycles at 38 °C 500 cycles at 50 °C	1000 cycles at 38 °C 500 cycles at 50 °C
Battery service life:	5 years	5 years	5 years
Continuous cycling current discharge rating:	120 A	150 A	180 A
Continuous cycling current charge rating:	60 A	75 A	90 A
Pulse load rating:	600 A (at 30 seconds)	600 A (at 30 seconds)	1100 A (at 30 seconds)
Rapid charging time:	20 minutes	25 minutes	30 minutes
Operating temperature range:	-46 to 71 °C	-46 to 71 °C	-46 to 71 °C
Storage temperature range:	-54 to 88 °C	-54 to 88 °C	-54 to 88 °C
Minimum cranking voltage (below 0 °C)	14.4 V	14.4 V	14.4 V
Number of batteries capable of being connected in series	1	1	1
Number of batteries capable of being connected in parallel	12	12	12
SAE J2464 Hazard Severity Level (battery nail penetration, crush, and overcharge abuse only)	≤ 6	≤ 6	≤ 6
SAE J2464 Hazard Severity Level (battery projectile penetration only)	≤ 6	≤ 6	≤ 6

Type 1 Or Type 2 (Smoke vs. Fire on Abuse)

Class A or Class B (Full vs Half 6TAGM CCA)

Subclass 55, 75, or 90 Ah minimum capacity

Varieties: 1-A55, 1-A75, 1-B55, 1-B90, 2-A55, 2-A75, 2-B90



MIL-PRF-32565 Safety and Abuse Tests



- Integrated battery management system provides protections against battery abuse:
 - Overcharge
 - Over-discharge
 - Over-current/short-circuit
 - Over-temperature
- Verification tests based on standard abuse tests from SAE J2464 and U.S. Navy S9310-AQ-SAF-010 Lithium Battery Safety Program. Test outcomes characterized according to SAE J2464 hazard severity level criteria (see table). Batteries tested with protections active and protections bypassed.

- Short-circuit
- Overcharge
- Nail Penetration
- Projectile Penetration
- Crush
- Drop (30 cm / 2m)

SAE J2464 Hazard Severity Level	Criteria
0	No effect or loss of functionality
1	No damage, passive protection activation, reversible loss of function
2	Damage, irreversible loss of function
3	Minor leakage/venting (<50% of electrolyte weight).
4	Major leakage/venting (>50% of electrolyte weight).
5	Rupture
6	Fire or Flame
7	Explosion

Type 1* →

Type 2 →

*Except Projectile Penetration (API)

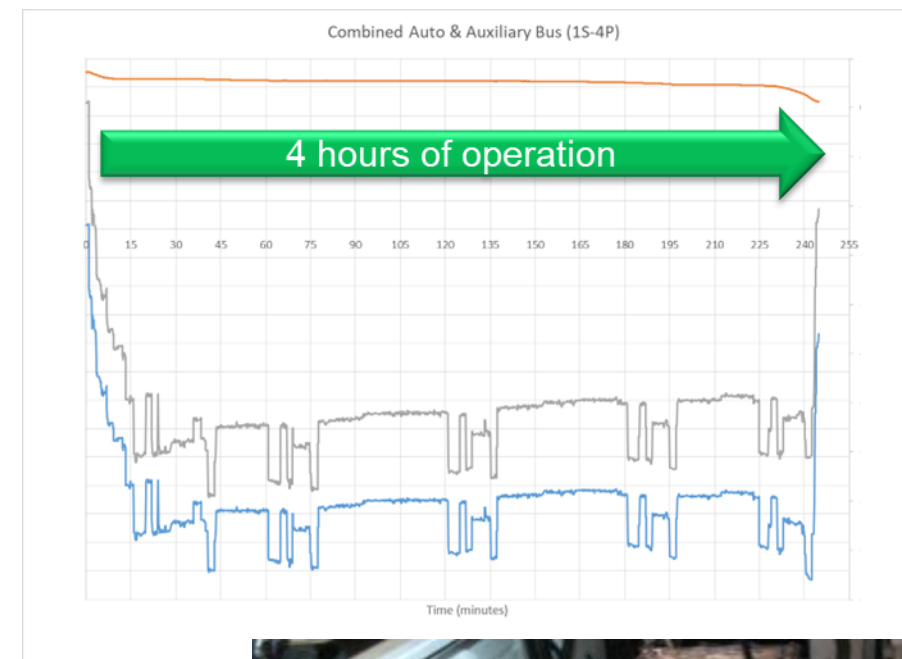
From SAE J2464 Table 3.



Stryker Demos



- **Li-ion 6T battery demo at US Army Electronic Proving Grounds in Fort Huachuca, AZ from August 26-30, 2019.**
 - Event was highly successful as the Li-ion 6T batteries met the 4-hour silent watch requirement significantly surpassing what can be done with the existing lead acid battery (which lasts ~20-30 minutes).
- **Li-ion 6T battery demo at Fort Wainwright, Alaska February 2-14, 2020.**
 - Evaluated Li-ion 6T batteries in severe cold environments: conducting engine cold start, engine cold start without PECCH (abusive, 10 attempts), and mobility (~5 miles). Ambient temperatures of -35 to -2 degrees F reported during evaluation.
 - Batteries were capable of starting the engine with no safety concerns.
 - Demonstrated new smart alternator voltage regulator and algorithm capable of recharging Li-ion 6T batteries safely in cold environments.
 - Observed and gather information on cold weather performance and maintenance challenges encountered at the unit level with 6T AGM and 6T maintenance-free lead-acid batteries.





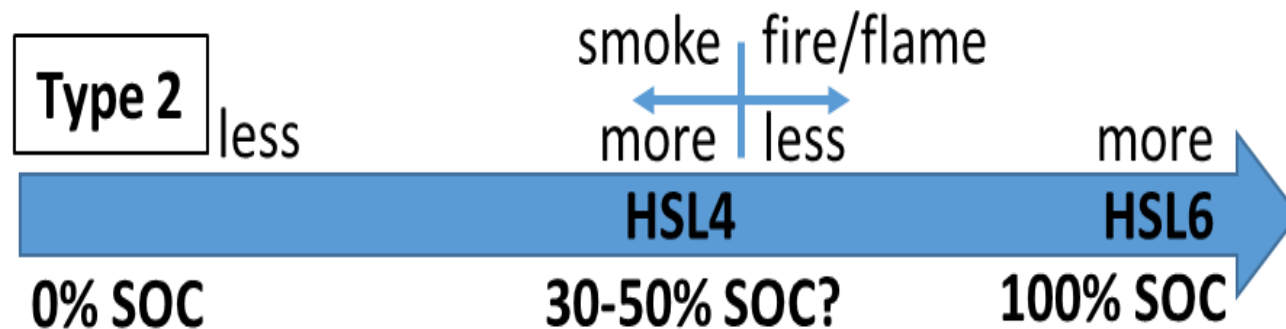
Type 2-90B Projectile Test Results Overview



40% SOC 50% SOC 100% SOC 100% SOC



20% SOC 30% SOC

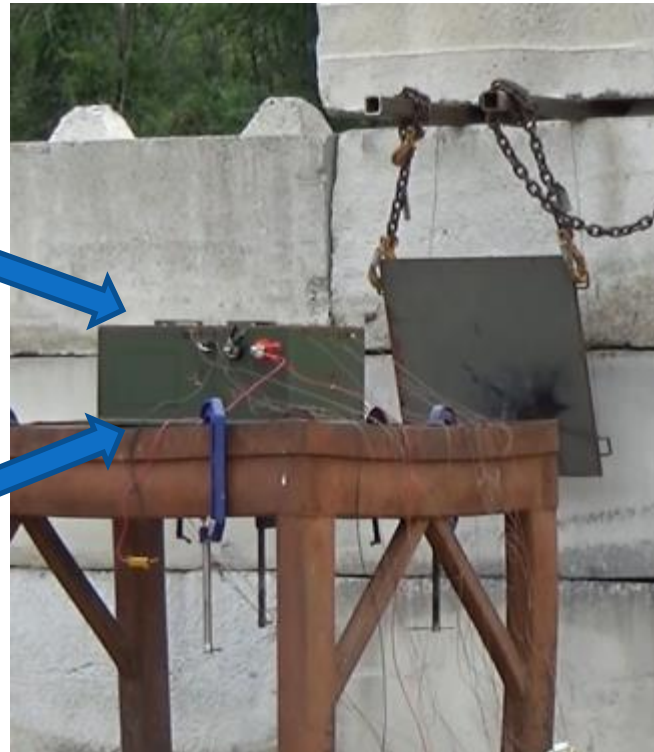
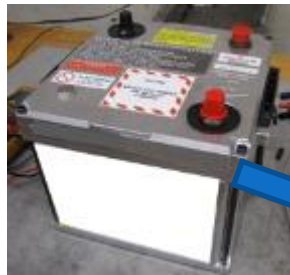




HMMWV Battery Box Projectile Penetration Test



- HMMWV Prototype Battery Box was subjected to Projectile Penetration Testing with two installed Type 2A Li-ion 6T Batteries (HSL 6 Fire/Flame under abuse)
- Event was mitigated to a HSL 4 (Smoke only)

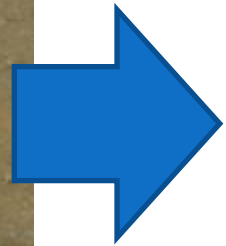




Battery Projectile Penetration Testing Results



Type 2B (>90Ahr) Batteries in Commercial Li-ion 6T Transport/Storage Container)



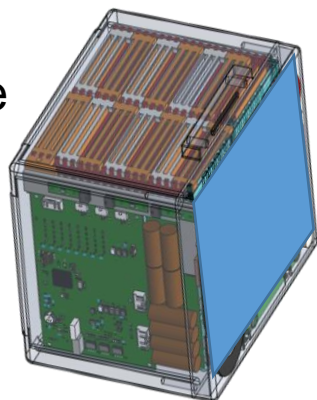
Bottom line: Enclosure successfully contained response from 2 fully charged Type 2A Li-ion 6T batteries shot with API round



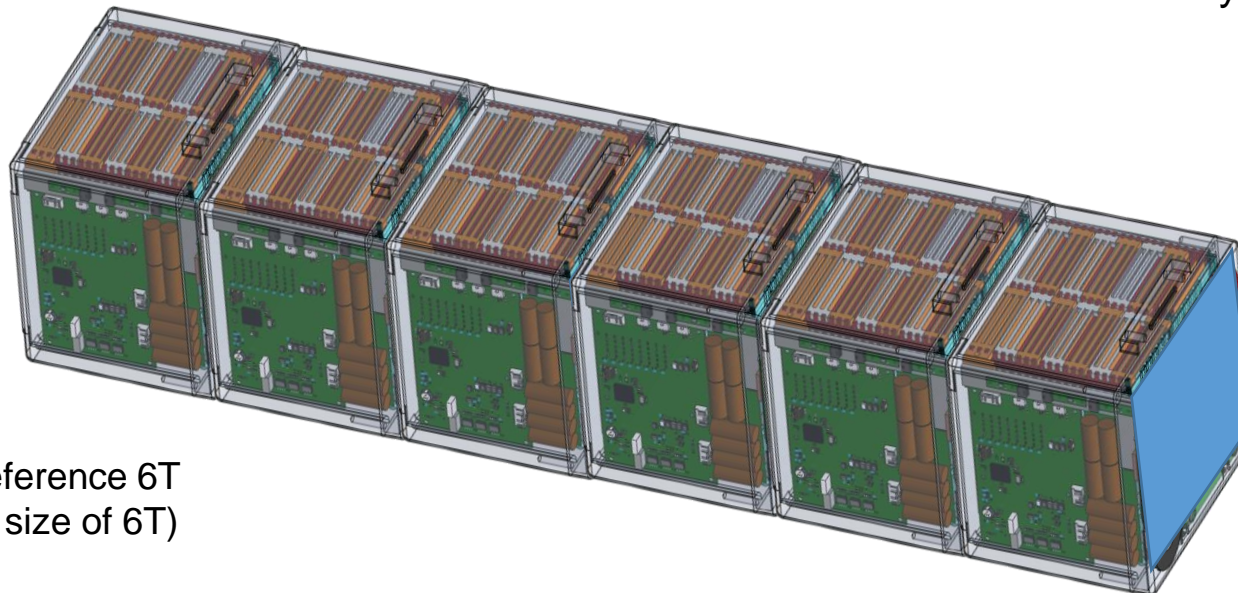
Concept for Standardized High Voltage Batteries



50V Module



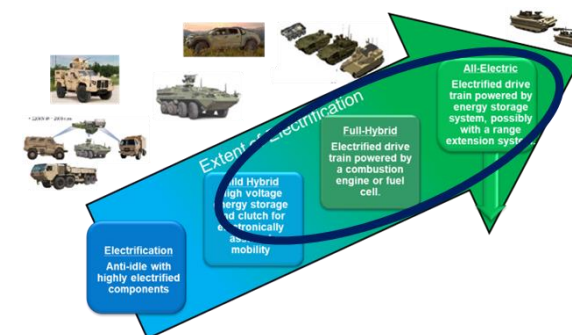
Each section likely consist of 6 modules – configurable to 300V or dual 150V. Section would serve also serve as base militarized 300V battery



Li-ion 6T battery

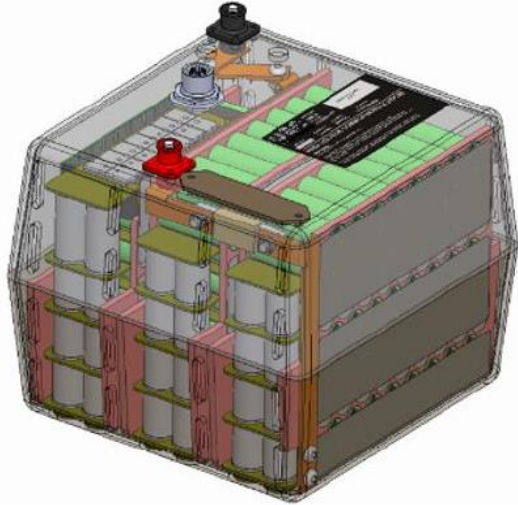
Pack estimated size vs reference 6T (module is approximately size of 6T)

Chemistry	Li-ion (NMC)	Cells in series	Module Voltage (V)	Module Energy (kWhr)
Charge voltage	4.2	14	58.8	2.6
Discharge Voltage	2.5	14	35	
Nominal Voltage	3.7	14	51.8	

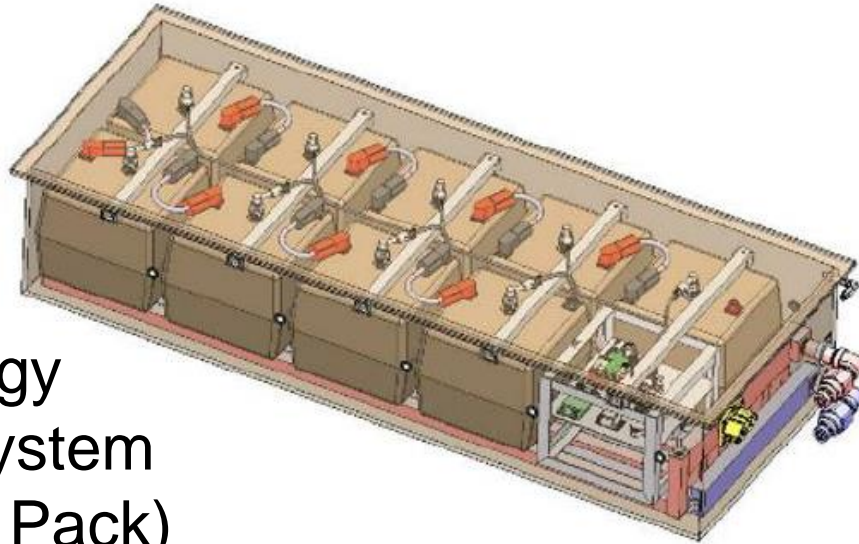




Modular High Voltage (MHV) Overview



High-Voltage
Common
Module
(HVCM)



MHV Energy
Storage System
(MHVESS Pack)
450V, 30kWhr

Key Features: Flexible architecture to accelerate vehicle hybridization

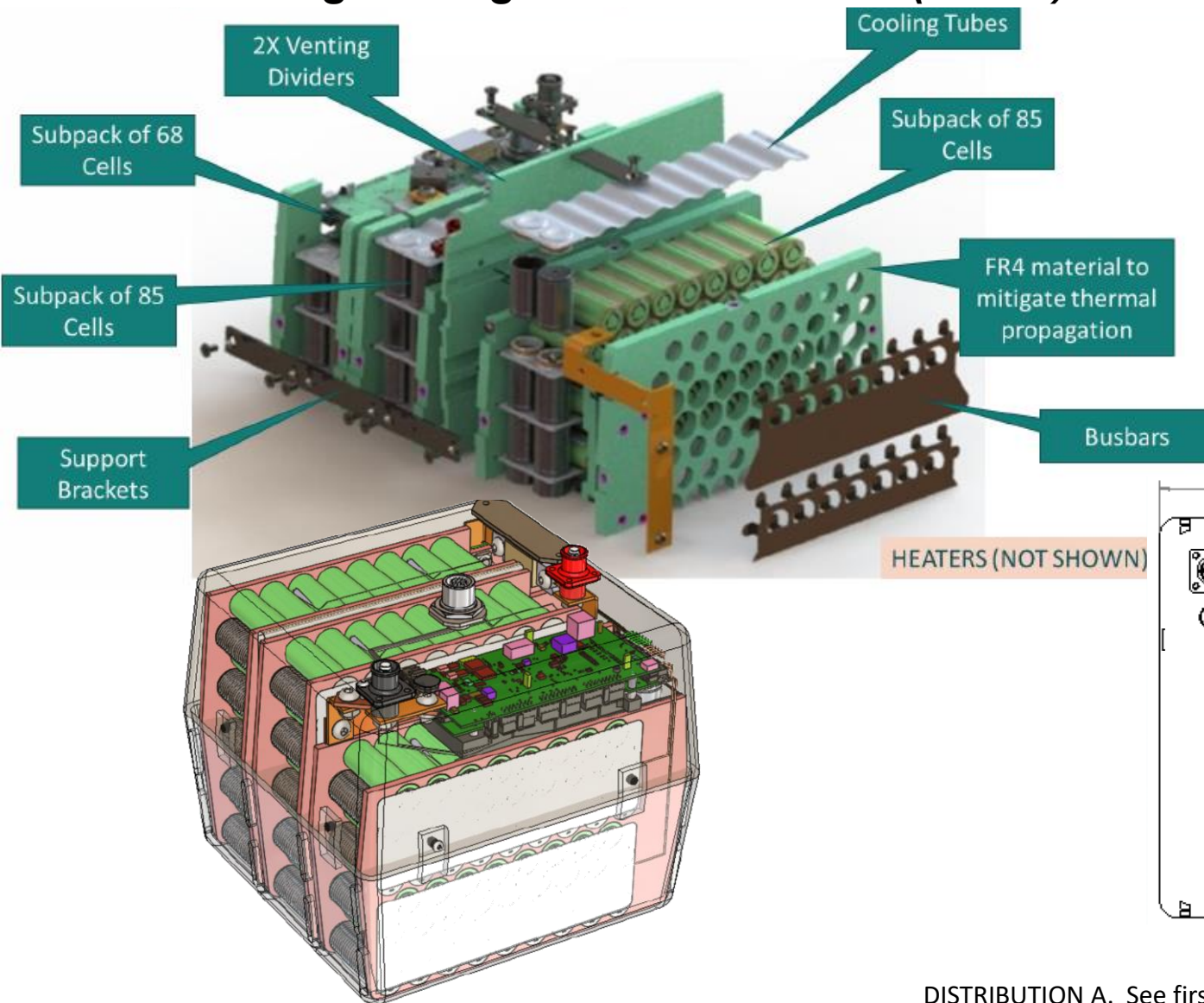
- Voltage: 50 – 600+V
- Energy: 3 – 100 kWh
- Scalable modules (~50V) connected in series/parallel for various applications.
- Qualification to occur at the module level.
- Some consideration for backward compatibility of current force vehicles
- Full operational capabilities between -30°C to 60°C WITH thermal management. Reduced operation down to -46°C or up to 71°C or WITHOUT thermal management.
- Module BMS: provides status and monitoring information for safe operation of pack, built-in tests, diagnostics and cell balancing.
- *Pack BMS (NextBMU Mini)*. Reports pack status and monitoring info to vehicle digital com buses. Controls of battery thermal management, battery protection and pre-charge/main contactors.



MHV Program Breakdown

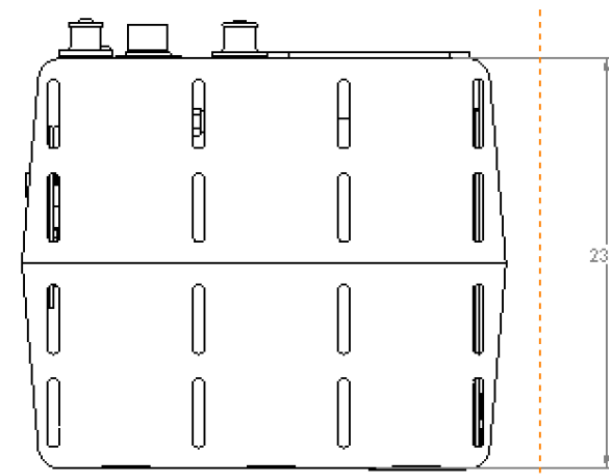
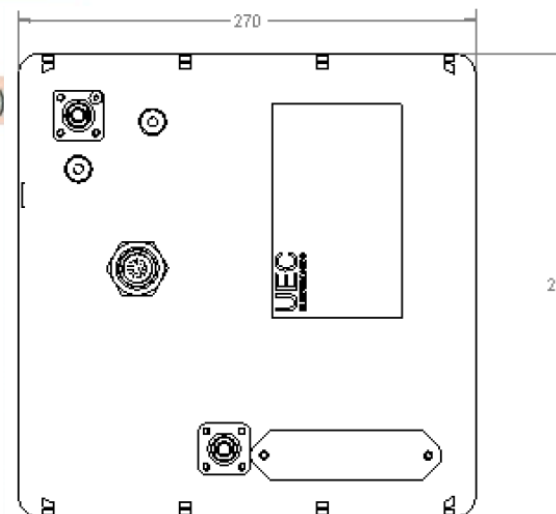


• UEC High Voltage Common Module (HVCM):



Each High Voltage Common Module (HVCM) is comprised of three subpacks, two arranged in a 5S17P (85 cells) configuration and one in a 4S17P (68 cells) configuration. The cells are connected via busbars on top and bottom. These three packs are connected in series with busbars.

Total configuration: 14S17P (3.7V, 4.2Ahr cells) - BSF = 238
 Nominal electrical characteristics: 50.4V, 3.4kWhr
 Anticipated peak 10s power: 26kW (Beginning of Life (BOL))

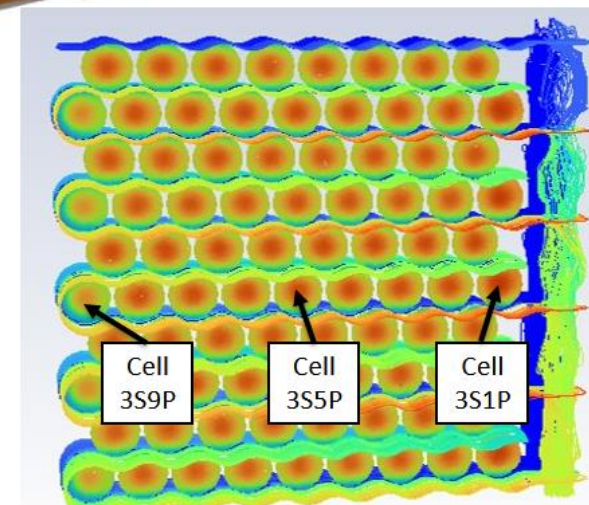
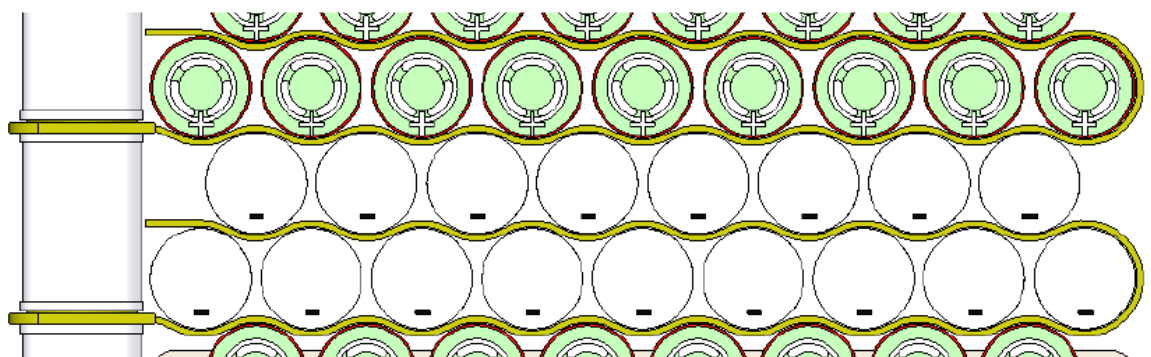
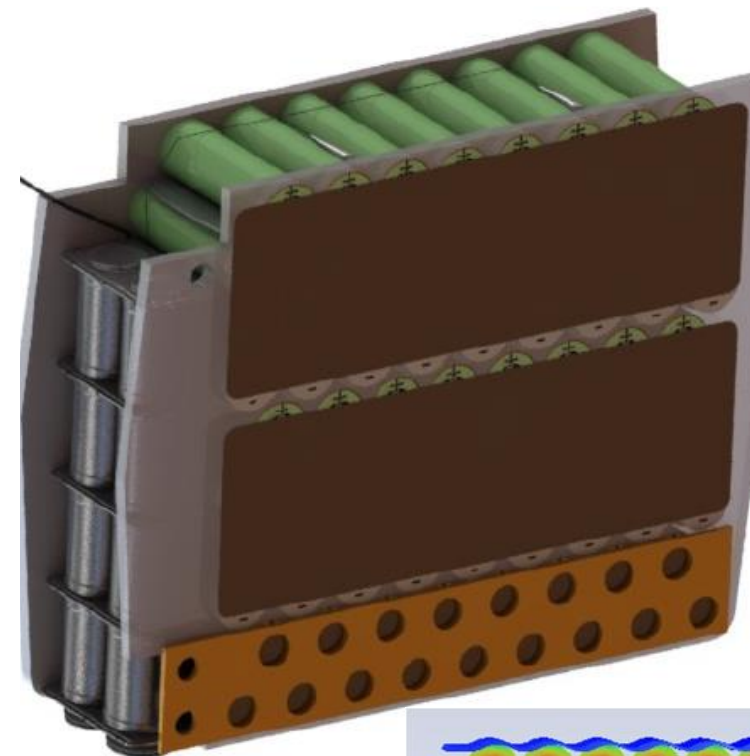
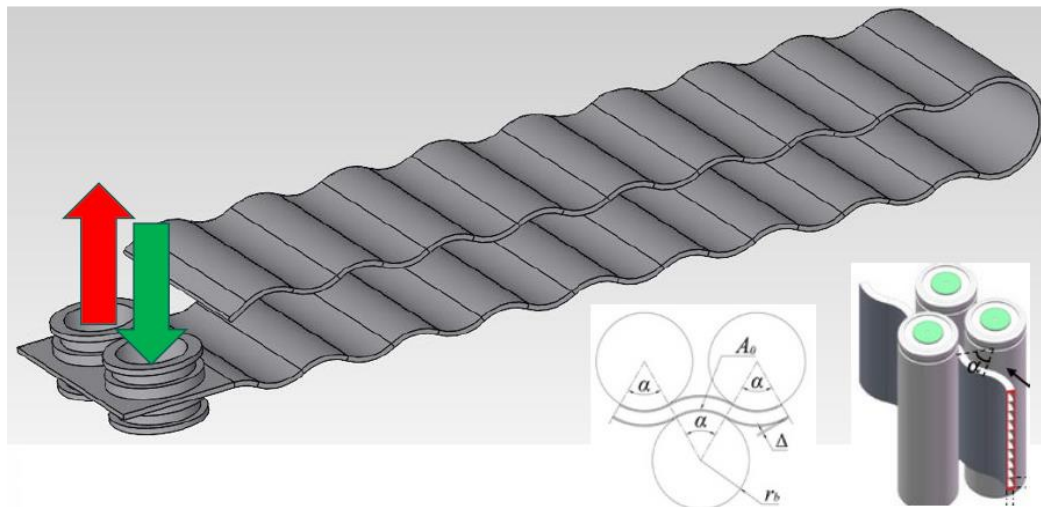




MHV Program Breakdown



- UEC project update – Thermal Management:





JumpSTART for Advanced Battery Standardization (JABS)



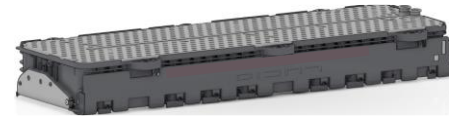
- OSD Section 8132 funding \$10M to DIU (plus funding to DoD labs for support) to leverage commercial EV battery investment to develop common battery modules for deployment into DoD platforms.
- Starts the development of a DoD battery performance standard to incorporate commercial EV batteries into medium and low weight ground platforms, defines form/fit/function/interface requirements
 - Funds joint standardization development within defense ground vehicles coordinated with industry OEMs
 - Resources industry engagement on standard development, prototype development, prototype evaluation
 - Provides DoD access to proven (and fielded) automotive technologies!

Status: (TAD – 8/31/2022) – we had 20 companies submit.

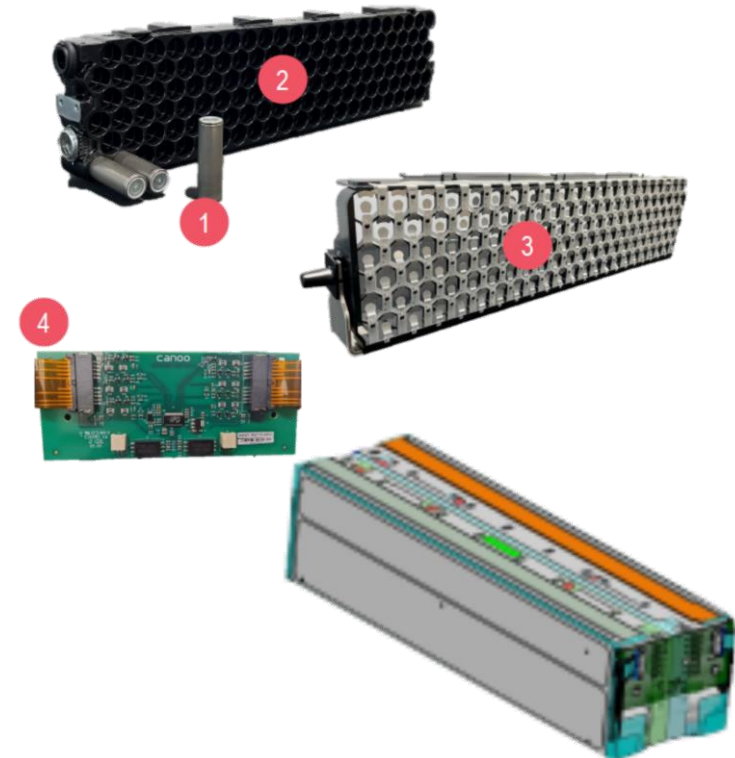
- 3 companies have been selected to initiate request for prototype proposal
- Up to 2 additional companies will also be selected for RPP
- Modules and ~60kWhr batteries will be acquired from efforts
- Looking to support demonstration Army and/or AF platforms.

Three Major Subsystems:

1. 21700 Battery Cell (Highly durable Panasonic cells)
2. Cold Plate
3. Interconnect Board (ICB)
4. Cell Sensing Board (CSB)



VDA590

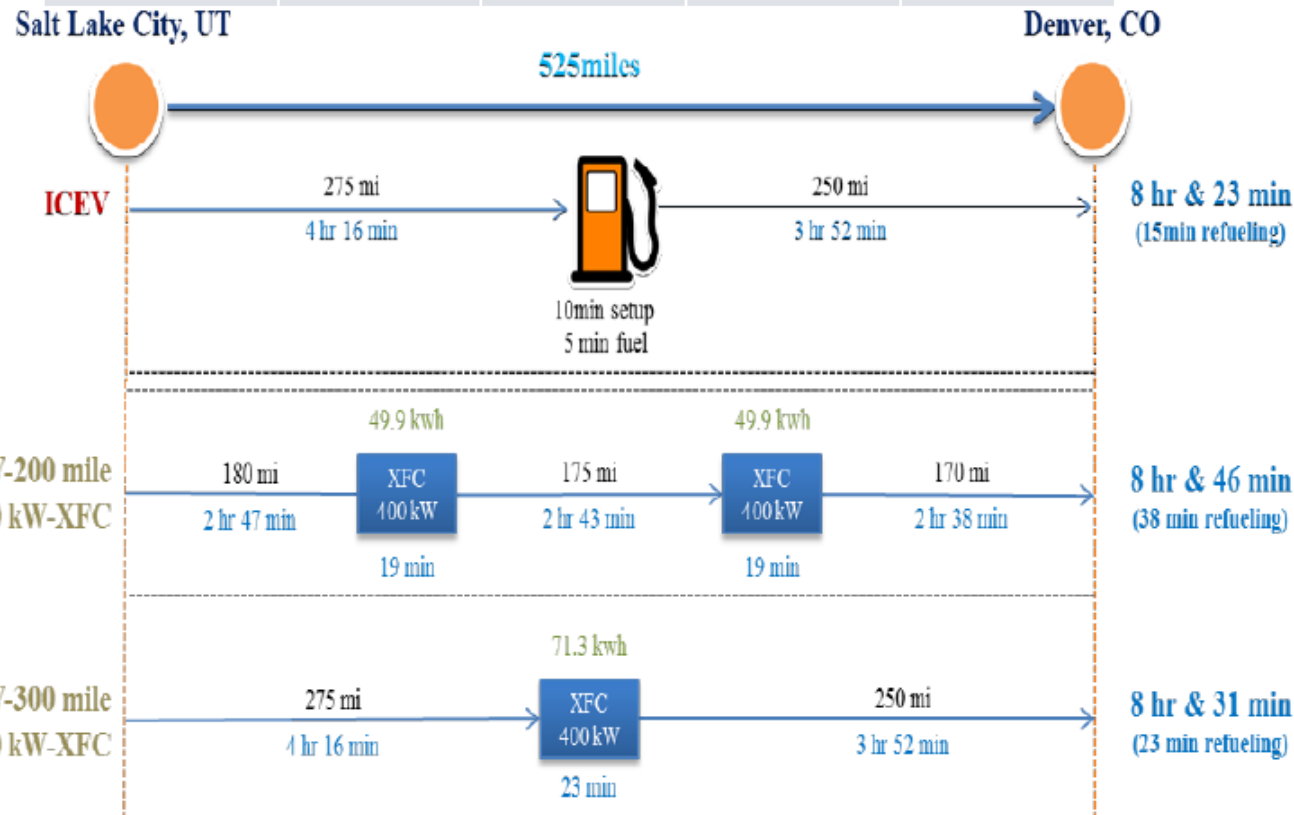




Key Challenge Area: Fast Recharge/Mobile Charging



Type of Charging Station	Level 2 220V (~7.2kW)	DC Fast Charger (50kW)	Tesla Super Charger (140 kW)	Extreme Fast-Charging (400kW)
Time to charge (for 200 miles)	8 hours	2 hours	25 mins	10-15 mins



Sources: Enabling Fast Charging, A Technical Gap Assessment, U.S. Department of Energy, Energy Efficiency and Renewable Energy, October 2017

DOE Efforts in Extreme Fast Charging

Fast Recharge Capability is a result of combination of fast charge batteries and availability of high capacity chargers.

- Leverage the work being done at DOE on fast charge batteries – This will be done with GVSC future high voltage battery development programs.
- *Challenge:* Commercial focus remains on stationary rechargers - need to focus resources on deployable recharge stations – limited commercial focus on this (no commercial pull). Commercial focus is limited to ~400kW, therefore may have limited ability to support larger military EVs.
- Other alternative is on-board APU based range extension.

Commercial focus on fast recharge is limited to stationary chargers and limited to 400kW



Tactical Battlefield Recharger (TBR)/Charging Ecosystem



Goals for the Tactical Battlefield Recharger (TBR):

Recharge capability for wide class of electrified platforms that can be rapidly deployed to austere battlefield environment.

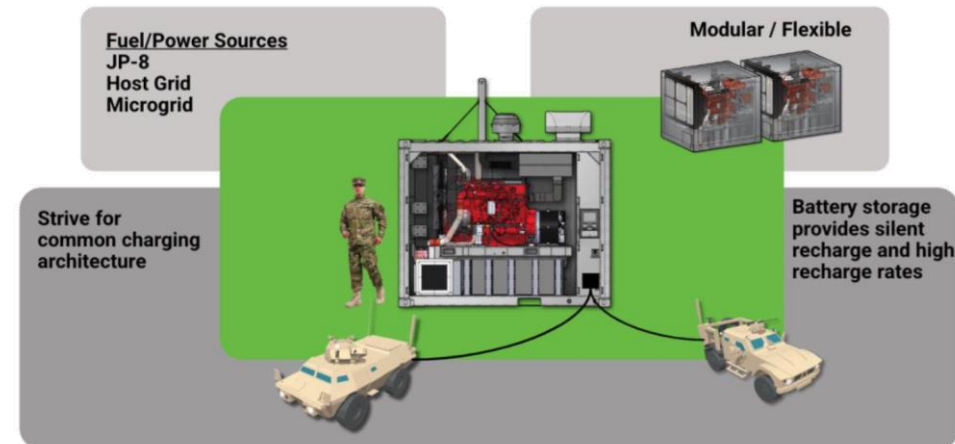
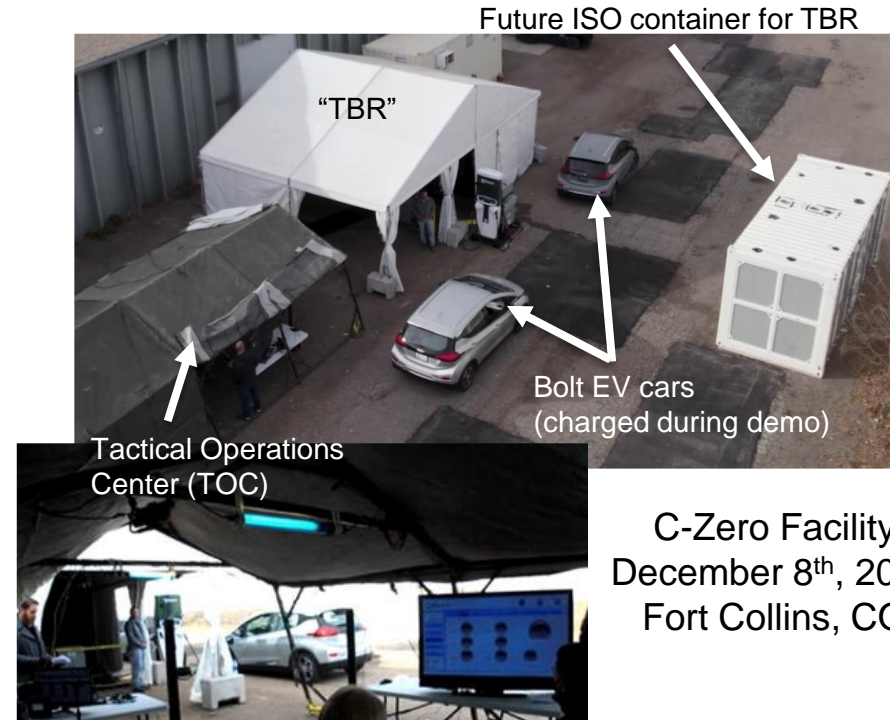
Army Applications Lab (AAL) C-Zero TBR Demonstration (Dec. 8, 2021):

- Demo attended by 18 stakeholders with 12 additional participants via live stream.
- Hybridized-asynchronous generator (66kWhr Li-ion battery and 420kW generator) plus 50kW charger. [Full system: 500kW generator with 160kWh battery – ~1MW for 20 minutes]
- TBR powered EV charger and Tactical Operations Center (TOC) – a Chevy Bolt EV (simulating military vehicle) was charged
- Several operational modes demonstrated including a silent mode (power for TOC/charger from battery only), quiet mode (generator runs at low RPM with support of battery to minimize heat/acoustic signature) and burst mode (generator is run at peak to charge battery and vehicle)

Requirements for Follow-on SBIR Effort (approved for \$1.7M direct to Ph2 award):

- Self-contained in 20' ISO container that is tactical vehicle transportable (HEMTT 10T, PLS 16.5T).
- JP8 compatible and host electrical power/microgrid
- Scalable output electrical power 1MW (O) – demonstrate scale-ability to 6MW
- Operating temperature range: -46°C to +71°C
- 2- 50kW chargers OR 1- 350kW charger

Future investment (\$9.75M from FY23-27) will also focus on MOBILE charger – bringing “electrons” to the vehicle. Focus will generation/distribution on mobile platform coupled with wireless power transfer (~1MW) for “autonomous recharge”.





THANK YOU



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