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

GVSC Planned Combat Vehicle Electrification and Mobility Programs (CVEMP)

Powertrain Electrification and Mobility (PEM): Kevin Boice

Battlefield Hydrogen Technologies (BHT): Jarrod Hoose

All-Electric Combat Powertrain (AECP): Elise Joseph

GVSC GVPM

30 May 2019

Electrification Motivation – Warfighter Capabilities

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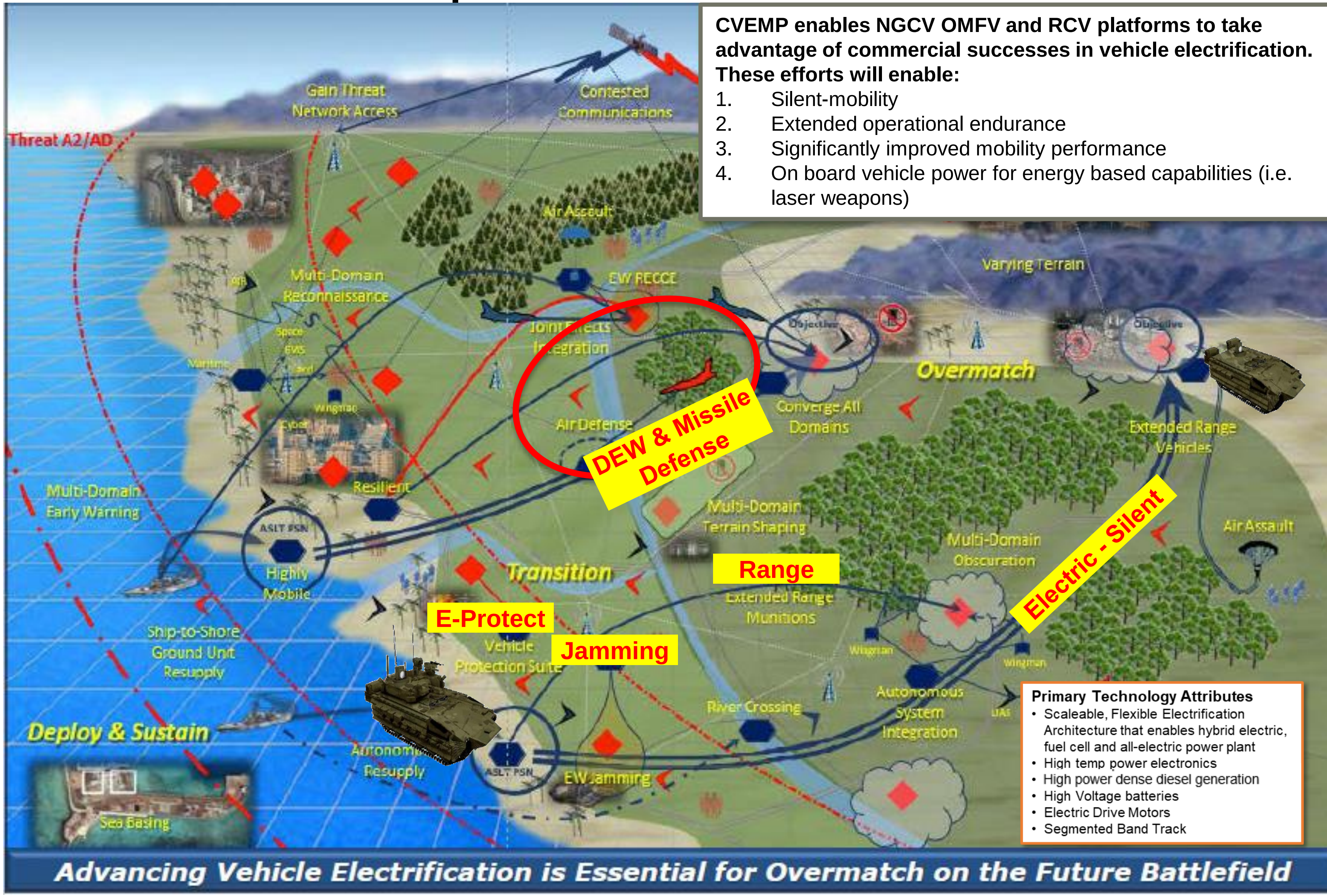
CVEMP enables NGCV OMFV and RCV platforms to take advantage of commercial successes in vehicle electrification. These efforts will enable:

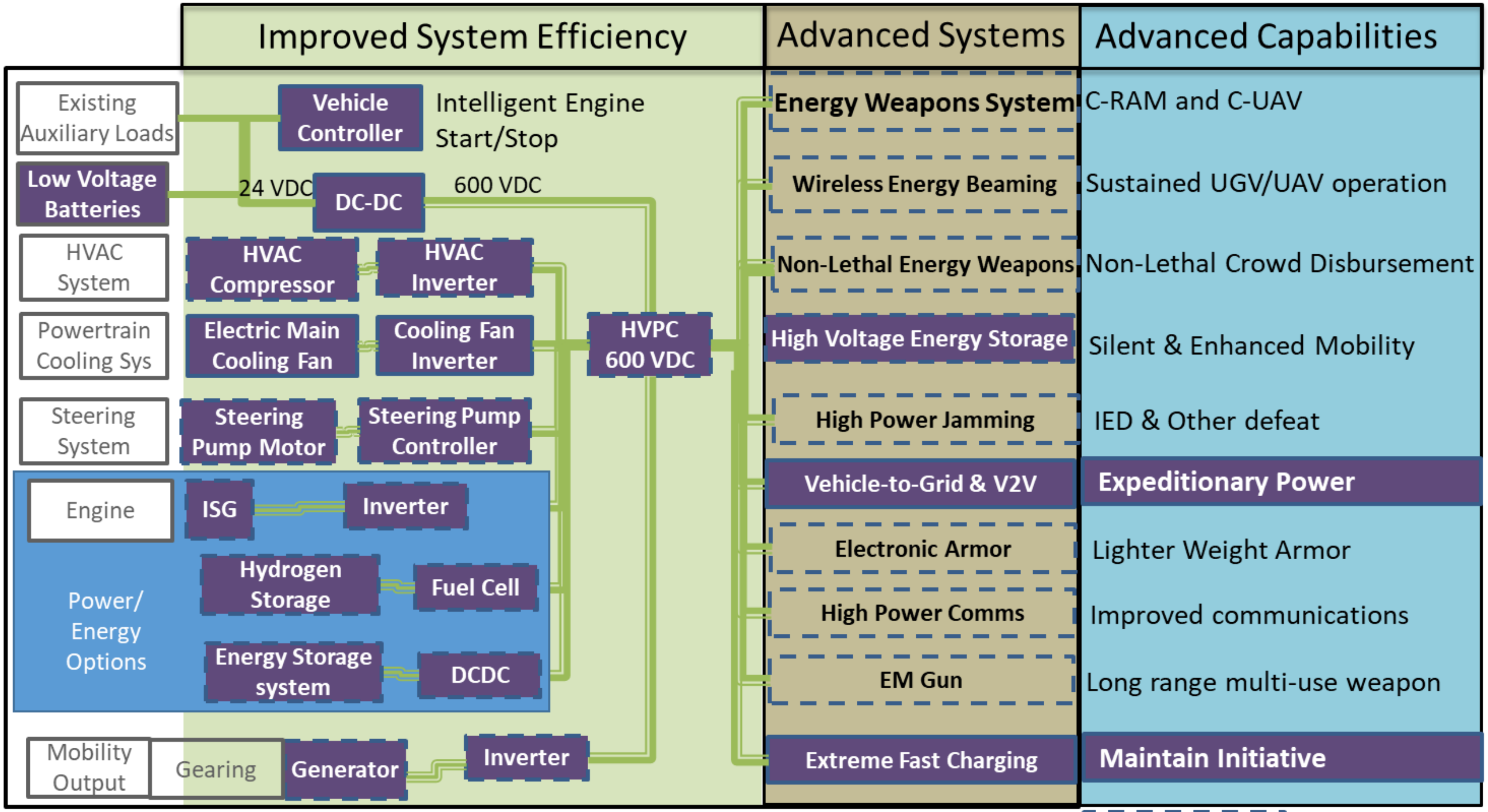
1. Silent-mobility
2. Extended operational endurance
3. Significantly improved mobility performance
4. On board vehicle power for energy based capabilities (i.e. laser weapons)



Primary Technology Attributes

- Scaleable, Flexible Electrification Architecture that enables hybrid electric, fuel cell and all-electric power plant
- High temp power electronics
- High power dense diesel generation
- High Voltage batteries
- Electric Drive Motors
- Segmented Band Track

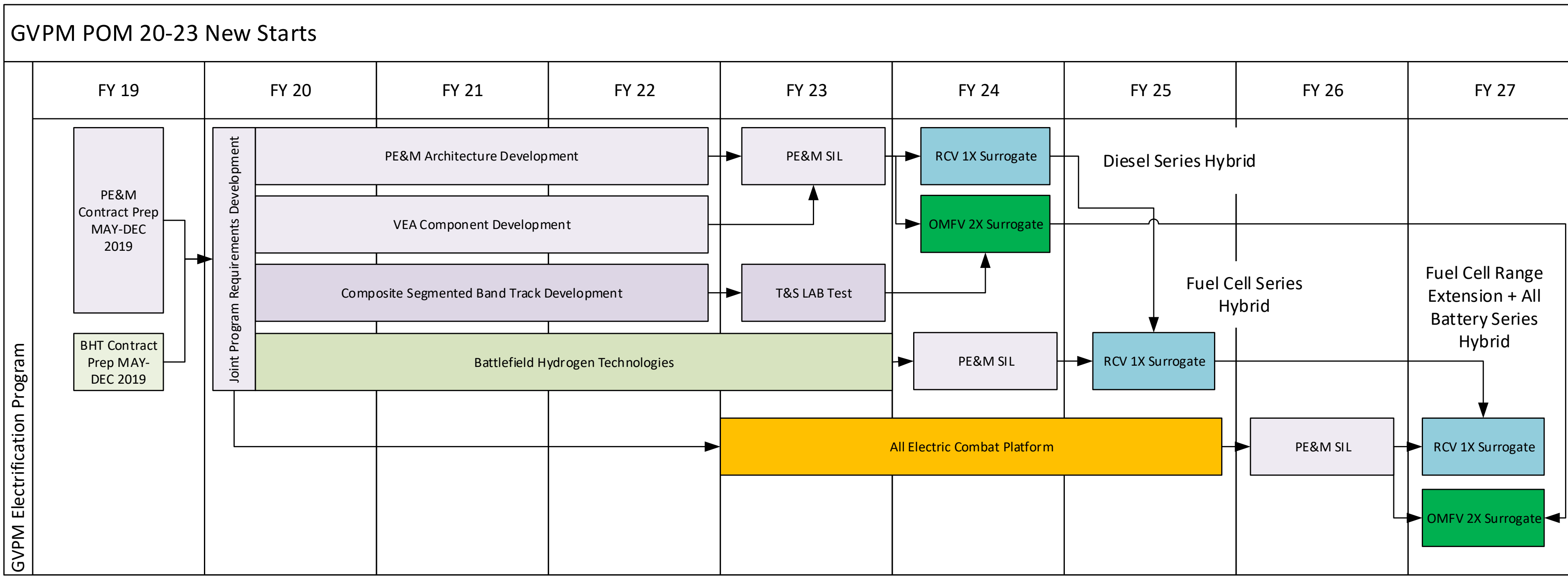
Vehicle Electrification Enabling / Advanced Capabilities



Legend: Existing Architecture | 28VDC | 600VDC | Mechanical | 200 - 600VAC | Planned/Future Development

AC and VAC = Alternating Current
C-RAM = Counter Rocket, Artillery and Mortar
C-UAV = Counter Unmanned Arial Vehicle
DC = Direct Current
DC-DC = HV/LV DC Power Conversion
HV = High Voltage
HVAC = Heating Ventilation and Cooling
HVPC = High Voltage Power Control
ISG = Integrated Starter Generator
LV = Low Voltage (24 VDC)
UAV = Unmanned Arial Vehicle
UGV = Unmanned Ground Vehicle
VDC = Volts Direct Current
V2G = Vehicle to Grid
V2V = Vehicle to Vehicle

GVPM Combat Vehicle Electrification and Mobility Program (CVEMP)

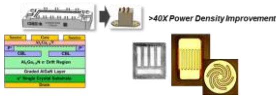


GVSC Program Leads:

- Powertrain Electrification and Mobility (PEM): Kevin Boice (GVPM) /Tessa Hufstedler (VEA)
- Battlefield Hydrogen Technologies (BHT): Jarrod Hoose (GVPM)
- All-Electric Combat Powertrain (AECP): Elise Joseph (GVPM)

Platform Electrification and Mobility

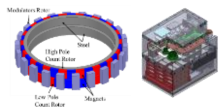
PROGRAM OVERVIEW



Power Electronics Components Maturation

High Density Diesel Electric powerpack

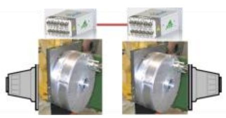
SIL Integration, Maturation and Risk Burn Down



Advanced Distributed Power for Autonomous Systems

Scalable HV batteries (50V-600V, ~20kWhr for Hybrid applications)

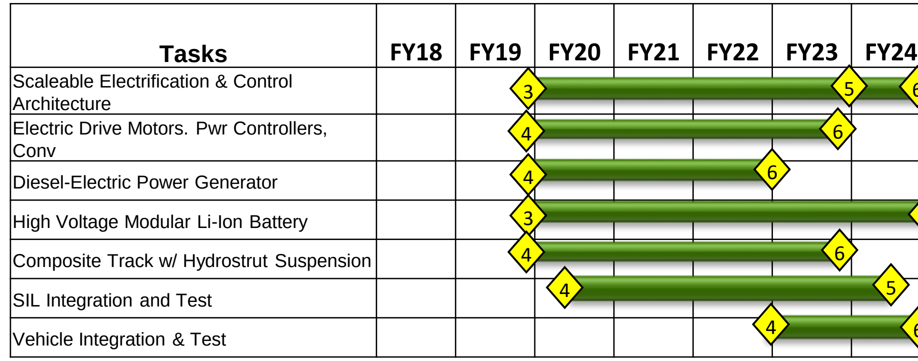
Integration and Demo OMFV or RCV Role 1 & 2 Demonstrators



Power Dense Motors Controllers

Advanced Suspension and Segmented Band Track

Timeline



Overall Project Design

- Leverage recent successes in Silicon Carbide (SiC) for power electronics (15 kW/L and 105C capable), and modularizing energy storage, we will create a scalable electronics architecture meeting NGCV power density requirements
- Improvements in final drive, track segmentation, and high speed power generation will improve mobility performance and survivability
- An extensible advanced and flexible power and mobility system provides BGCV power and energy required for directed energy weapons, sensors, missile and active protection systems, communications, jamming, and fast-forming power grids.
- System will improve sprint 30% = 60% fewer hits and ~30x more electrical power for emerging capabilities, 40% increased range.
- Modular approach = highly re-usable power architecture for systems ranging from 15 to 40 tons.
- Foundation for future electrified platforms, enables transition to fuel cell and all-electric for full-time silent mobility, fewer hits, ~30x electrical power .

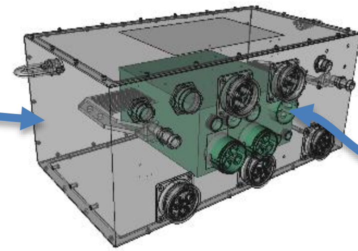
Platform Electrification and Mobility Combat Powertrain

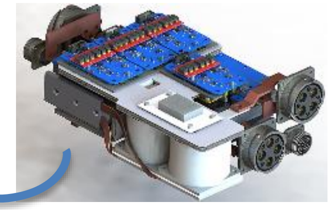
Current Operational State	Future Operational State

Bump-out for electronics

Current Inverters

Package Comparison



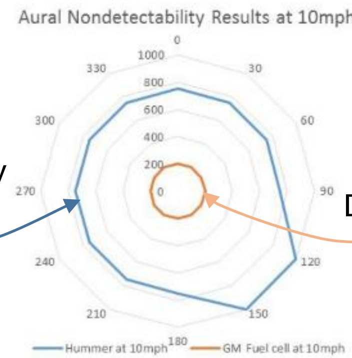


5x> Density & higher temp

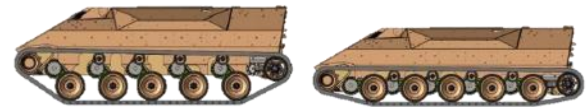
No bump-out for electronics

Band track difficult field repair

Today's Acoustic Detectability



Future Acoustic Detectability



Ride and height adjustable

DEW Capable

Segmented Composite Track

Current Tracked Platforms:

1. No silent-mode capability
2. Low electrical power capability
3. Degraded range due to incremental weight gain
4. Degraded acceleration
5. Not readily capable of conversion to fuel cell or all-electric

Current Commercial Systems

1. Electronics - Operating temperature too low
2. Electronics – Power density restricts integration
3. Current OBVP (15kW) does not support future needs
4. Track – Band track not fieldable
5. Segmented track not durable or logistically feasible
6. Suspension is not ride-height adjustable

Future Tracked Platforms:

1. Silent-mode capable
2. High electrical power capability
3. Significantly improved range
4. Significantly improved acceleration
5. Conversion-ready powertrain for fuel cell or all-electric

Future MCOTS Systems

1. Electronics - Operating temp = engine coolant temp (105C)
2. Electronics – 5x to 7x more power density
3. Electrical power available 25x to 40x increase in OBVP
4. Segmented track fieldable and durable
5. Segmented track reduces maintenance and logistics burden
6. Suspension ride height adjustable for terrain and threat

PEM Community Context

Key Characteristics	Hybrid (Power Electronics)	
	Power Density	Temperature Threshold
Current / Army or Industry	3kW/L	85C Coolant
Future Army Requirement	12kW/L	105C Coolant Engine coolant
Improvement Required	4x *	24% *
Industry Gaps	High power density / high temperature power electronics is a military unique requirement not being developed by industry.	

* Silicon Carbide power electronics is the emerging capability that is closing the gap.

PEM Expected Performance/Trade-offs

Goals:

- Modular and Scalable Electrification Architecture supporting RCV and OMFV
- Power dense electrified drive and transmission capable of high temperature operation & silent mobility
- Power dense and low heat rejection diesel electric power generator
- Modular energy storage system capable meeting silent mobility range and providing electric magazine for DEW
- Segmented Composite Track with >30% less weight, low noise/vibration and favorable RAM characteristics
- Hydrostrut Suspension providing ride height management and semi-active damping

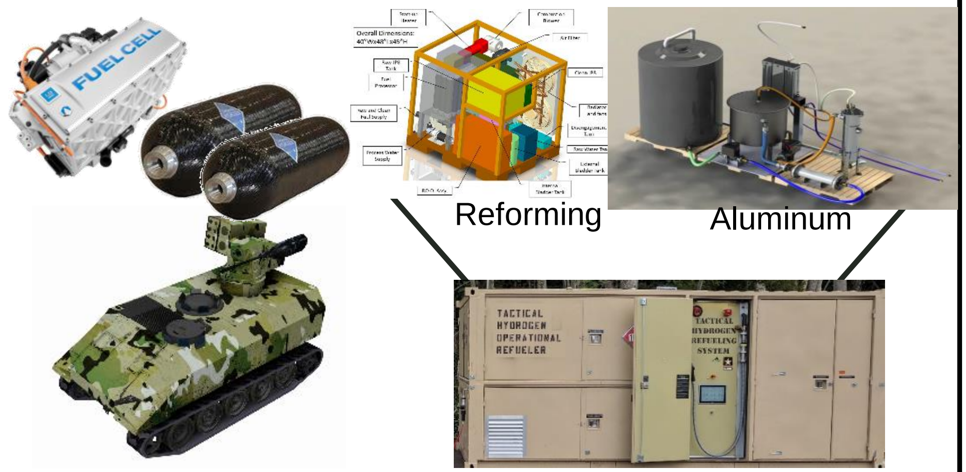
Expected Outcomes

- Mobility Improvements : 30% acceleration, 15% speed on grade, 25% off-road speed
- Available Electrical Power: 100% of prime power (~400 kW continuous)
- Silent Mobility: 3 kilometers (T) and 6 kilometers (O) @ 15 kph (4:1 (T) and 5:1 (O) reduction in detection distance)
- Range improvement – 25% (T) and 50% (O) reduced fuel usage
- SIL for early identification, maturation and risk burn down of UMT critical technologies and interfaces
- System Integration Lab demonstration of mobility and on-the-move available electrical power
- Vehicle integration/demonstration in a vehicle test lab evaluating the system against the high level vehicle performance requirements

Significantly improved mobility, range, electrical power available, and silent mobility

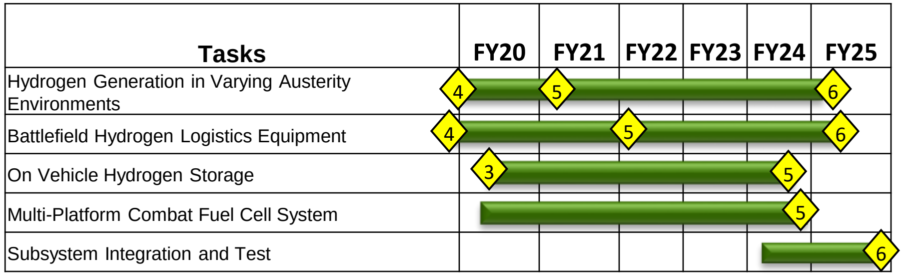
Battlefield Hydrogen Technologies

PROGRAM OVERVIEW



Develop and demonstrate battlefield hydrogen generation capability to enable increased survivability and lethality for platforms.

Timeline



Overall Project Design.

- Hydrogen production, storage, and distribution technologies will be matured and adapted for military use enabling electrified combat vehicles with efficient and quiet fuel cell power generation. Hydrogen is usually attached to oxygen (water) or carbon (hydrocarbon fuels), and the challenge is to efficiently extract hydrogen on the battlefield.
- In current practice, hydrogen is produced as a by-product of industrial processes, electrolysis, or natural gas reformation at large fixed sites. Current liquid hydrogen generation processes are insufficient to meet the volumes of hydrogen needed for broad application for tactical and combat systems.
- The program will leverage commercial and Department of Energy investment in hydrogen production and distribution making it transportable. Advance the state of the art in solid and cryo-compressed hydrogen storage technologies on a vehicle with innovative research and partnerships to ease hydrogen logistics.
- Success enables H2 fuel cell electrified vehicles to meet mission requirements

Battlefield Hydrogen Technologies

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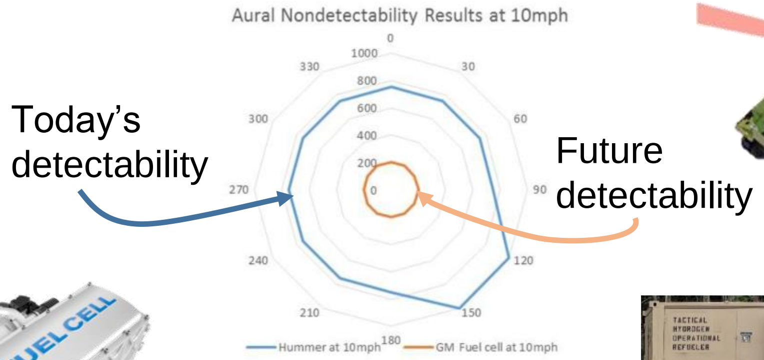
Current Operational State	Future Operational State



RCV Surrogate

- 300 mile silent range
- Support directed energy weapons
- Fuel Cell range extension

Battlefield H2 Refueling

- 1-6+ MW
- 15-30 min recharge

Current Military Platforms:

1. No silent mobility capability
2. Limited electrical power export capability
3. Degraded range due to incremental weight gain
4. Degraded acceleration
5. Not readily capable of conversion to fuel cell
6. Not able to be refueled by H2 logistics

Current Commercial Systems:

1. Components have limited environmental requirements (temperature, shock/vib, sand/dust) – designed for on-road applications
2. Components power density restricts integration (limited range and operational capability)
3. Commercial auto and heavy duty trucking investments in H2 fuel cell
4. Commercial H2 generation at large sites, commercial refueling growing.

Future Fuel Cell Electric Military Platforms:

1. Continuous silent mobility unlimited range
2. High electrical power export capability
3. Significantly improved range with improved acceleration.
4. Enabler of new electrified weapon of defensive systems.
5. Scale-able architecture to enable new class of combat platforms that are capable of battery only or fuel cell/battery operation.
6. Able to refuel from H2 logistics system. Significant reduction in battlefield fuel consumption.

Focus of Army Investment (leverage commercial systems):

1. Develop militarized electrification components
2. Increase power density 5x to 7x more power dense to enable packaging in combat platforms
3. Develop modular fuel cell architecture to permit future fuel cell options for various platform applications
4. Develop H2 logistical refueling capability

Result – Improve lethality by increasing platform capability

BHT Community Context

Battlefield Hydrogen Technologies leverages past, present and future TARDEC, OGA, Industry, Academia, and other R&D technologies in this tech space that includes:

Industry & Academia

- Commercial automotive industry, such as General Motors, has invested billions of dollars in fuel cell technology development that use hydrogen as a fuel. Toyota, Honda and Hyundai all have fuel cell passenger vehicles for sale in California.
- Heavy duty trucking (Nikola, Toyota-Kenworth) has started to invest in fuel cell based Class 8 trucks. This pushes power levels and hydrogen storage requirements closer to military requirements.
- Shell, Air Products, Air Liquide, and Linde are all hydrogen suppliers addressing economics of hydrogen
- Several universities are developing hydrogen generation technologies that can be leveraged as they mature for military use.
    - Gap to leverage: Cost, reliability, availability

Other DoD

- Army Research Lab, Naval Undersea Warfare Center, Navy Research Lab, Air Force Research Lab and CERDEC are all investing in hydrogen generation or storage.

Other Government Agency

- NASA has experience shipping and using liquid hydrogen as well as other vehicle hydrogen storage technologies.
- Department of Energy has multiple programs addressing hydrogen: H2@Scale, H2@Rail, H2@Port, and several specific consortiums addressing technical challenges at material levels

Commercial Hydrogen Generation

Commercial Heavy Duty Trucking Market

Commercial Hydrogen Filling

Exploits Emerging Electrification and Mobility Technologies for Urban Warfare Platform Application

BHT Expected Performance/Trade-offs

- Up to a 50% reduction in energy consumption, meeting strict diesel emission standards when operating in NATO countries without fines or restrictions, the ability to produce water at the point of need for Soldiers, increased vehicle silent range, extended silent watch capabilities and long duration subterranean operations without special filters or equipment to filter emissions.
- Midterm assessments will be focused on hydrogen generation and support equipment to demonstrate vehicles can be supported at a small scale in austere environments.
- Final demonstration of a robotic combat vehicle with adequate hydrogen storage potential and a generation capability to support multiple combat platforms.
- Progress will be measured through demonstrated performance of both hydrogen generation equipment and application of fuel cells on existing surrogate vehicles. Benefits to logistics and maintenance will be analyzed.

Focus on Increasing Hydrogen Production Scale and Efficiency

All-Electric Combat Overview

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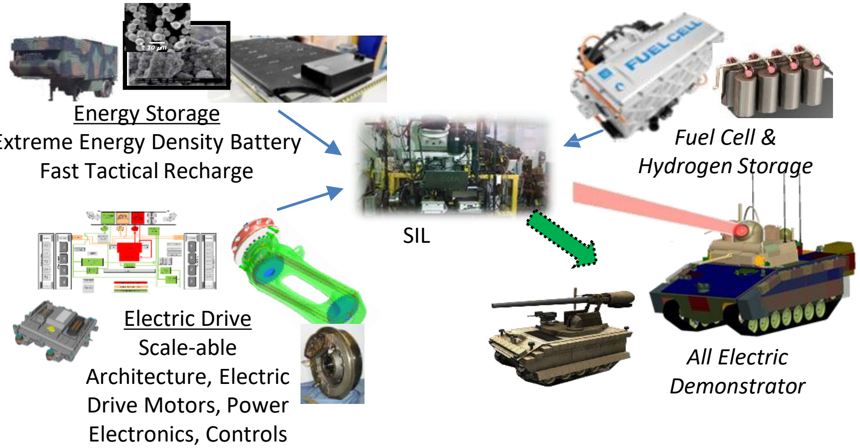
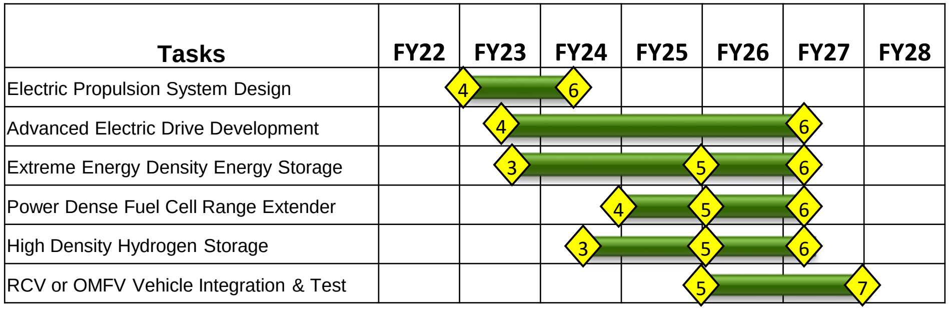
PROGRAM OVERVIEW



This project develops, integrates, and tests essential electrification technologies necessary to convert the series hybrid Next Generation Combat Vehicle (NGCV) platforms to All-Electric vehicles for soldier experimentation.

Timeline



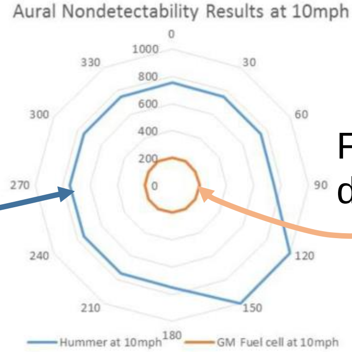
Overall Project Design.

- This effort will provide full time silent mobility, reduced acoustic and thermal signature (survivability), increased acceleration and mobility, enables of new electric weapons (high energy laser systems) or defensive capabilities, extension of operational range, and reduction in battlefield fuel consumption. Current commercial technologies must be improved by a factor of at least 4x and adapted to the military environment in order to enable all-electric combat platforms given volume and range needs.
- Currently there are no viable military all-electric combat platforms today and commercial technologies will not meet packaging and range needs.
- This approach will start with commercial components and focus on addressing deficiencies at meeting military requirements. The approach will result in scalable power architectures that will be adaptable to various military platforms which to reduce development time for future implantation.
- Success with this effort will result in a set of technologies that will enable an entire class of military combat vehicles that are capable of full time silent mobility and can support electrified weapons.

All Electric Combat Powertrain

Current Operational State

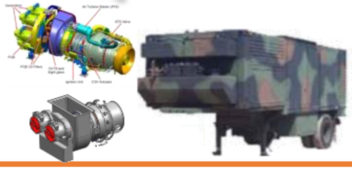
Today's detectability



Future detectability

Future Operational State

OMFV/RCV Surrogates
- 300 mile silent range
- Support directed energy weapons
- Fuel Cell range extension



Battlefield Tactical Recharge
- 1-6+ MW
- 15-30 min recharge

Current Military Platforms:
1. No silent mobility capability
2. Limited electrical power export capability
3. Degraded range due to incremental weight gain
4. Degraded acceleration
5. Not readily capable of conversion to fuel cell or all-electric
6. Not able to be powered from host national grid

Current Commercial Systems:
1. Components have limited environmental requirements (temperature, shock/vib, sand/dust) – designed for on-road applications
2. Components power density restricts integration (limited range and operational capability)
3. Lack of common electrification components (customized for each platform)
4. No mobile electrical recharge capability exists to enable 30 min recharge.

Future All-Electric Military Platforms:
1. Silent mobility range up to 300 miles
2. High electrical power export capability
3. Significantly improved range with improved acceleration.
4. Enabler of new electrified weapon of defensive systems.
5. Scale-able architecture to enable new class of combat platforms that are capable of battery only or fuel cell/battery operation.
6. Able to recharge from host electrical grid for extended operation. Significant reduction in battlefield fuel consumption.

Focus of Army Investment (leverage commercial systems):
1. Develop militarized electrification components
2. Increase power density 5x to 7x more power dense to enable packaging in combat platforms
3. Develop scalable power architecture to permit future all-electric options for various platform applications
4. Develop mobile recharge capability

Result – Improve lethality by increasing platform capability

AECP Community Context

Key Characteristics	All-Electric (Energy Storage)		Fuel Cell
	Capacity (300 mile range)	Charge Rate	Hydrogen Storage
Current / Army or Industry	~0.15kW/L (best Li Ion)	100 kW	3.4MJ/L
Future Army Requirement	0.60 kW/L	6 MW	13.6MJ/L
Improvement Required	4x **	60x ***	4x ****
Industry Gaps	High power / high energy / temperature a military unique requirement not being developed by industry.	Industry also desires fast charging. DOE leading effort to satisfy future military requirement.	Industry not investing in leap ahead military requirement.

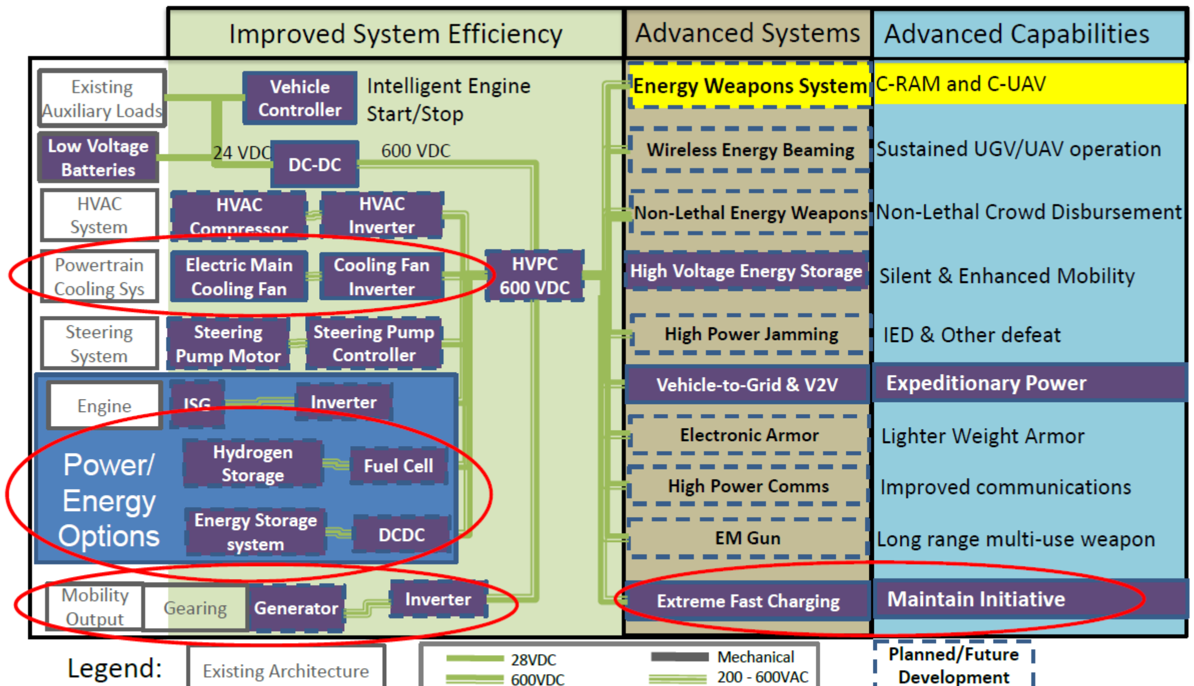
** Beyond Lithium Ion energy storage is required.
*** 6 MW = ½ hour fill rate. Desired fill rate is ¼ hour = 12 MW.
**** Aluminum powder is most promising future technology.

Current commercial technologies need 4x to 60x improvement to facilitate All-Electric Combat Powertrains.

AECP Expected Performance/Trade-offs

- Full time silent mobility, increased silent watch duration, reduced acoustic and thermal signature enabling survivability, increased range, acceleration and mobility, and the ability to integrate advanced lethality and protection systems on future combat vehicles with a reduction in fuel consumption.
- Demonstration of an all-electric combat vehicle.

Vehicle Electrification Enabling - Advanced Capabilities



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V2G = Vehicle to Grid
V2V = Vehicle to Vehicle

Effort focused on paradigm shifting capability improvements such as extended silent mobility and advanced warfighting capabilities