Directions in Engine-Efficiency and Emissions Research (DEER) Conference

3 October 2011

Dr. Grace M. Bochenek,
Director

U.S. ARMY TANK AUTOMOTIVE RESEARCH, DEVELOPMENT AND ENGINEERING CENTER (TARDEC)

Our Army Ground Community

What We Do

- **A**cquisition: Program Management
- **L**ogistics: Industrial Operations, and Contracting
- **T**echnology: Research, Development, and Life Cycle Engineering

The Magnitude

- Over 60% of the Army's Equipment and Systems (65% BCT's)
- Over 130 Allied Countries Own Our Equipment
- Approximately 3,300 Fielded Product Lines and 38,500 Components

The Product Lines

1. Mine Resistant Ambush Protected (MRAP)
2. Combat Vehicles
3. Armored Security Vehicle
4. Route Clearing Vehicle
5. Howitzers
6. Tactical Vehicles
7. Rifles / Machine Guns
8. Large Caliber Guns
9. Mortars
10. Rapid Fielding Initiative
11. Aircraft Armaments
12. Robotics
13. Soldier Uniforms & Equipment
14. Force Providers
15. Materiel Handling Equipment
16. Chemical Defense Equipment
17. Tactical Bridges
18. Fuel & Water Dist Equipment
19. Trailers
20. Watercraft
21. Rail
22. Construction Equipment
23. Commercial Vehicles
24. Fuel & Lubricant Containers
25. Sets, Kits & Outfits
26. Shop Equipment

We support a diverse set of product lines through their life cycles, from combat and tactical vehicles, armaments, watercraft, fuel and water distribution equipment, to soldier, biological, and chemical equipment.

The DoD Operates the Largest Fleet of Vehicles in the World

Tactical Vehicles

Vehicle	Description	Units
Light Tactical Vehicles (LTV)	HMMWV vehicle variants made up of 1 ¼ ton payload class	163,661
Medium Tactical Vehicles (MTV)	14 variants in 2.5 and 5 ton payload class	43,143
Heavy Tactical Vehicles (HTV)	Heavy-duty trucks, 10 ton and up, used for cargo, moving heavy equipment, tractors, tankers, wreckers, fire fighting trucks, dump trucks and others	55,236
Mine Resistant Ambush Protected (MRAP)	A family of armored fighting vehicles designed to survive IED attacks and ambushes	10,902 (*16238 required)
Total		**272,942**

Non-Tactical Vehicles

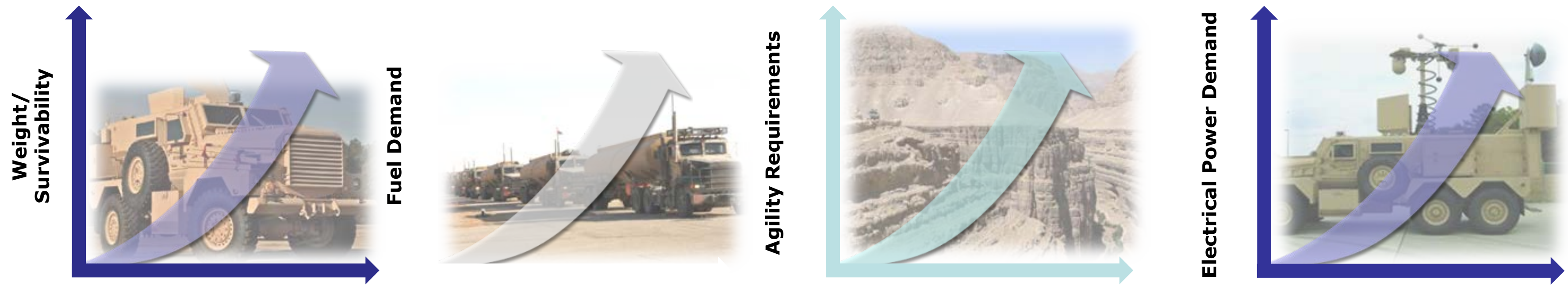
Vehicle	Description	Units
Passenger Vehicles	Sedans, station wagons, passenger vans, SUVs	86,138
Light Trucks	Vans, pickup trucks	42,665
Medium Trucks	Miscellaneous cargo, flatbed, boxvan, others	43,762
Trucks	Heavy-duty trucks	17,598
Other	Ambulances, buses and support vehicles	6,633
Total		**196,796**

- All tactical vehicles are considered medium or heavy-duty by commercial standards (they are above 10,000 GVW, and all use JP8)
- About 30 percent of non-tactical vehicles are also medium or heavy-duty
- In total, about 72% of the total DoD fleet is medium or heavy-duty vehicles

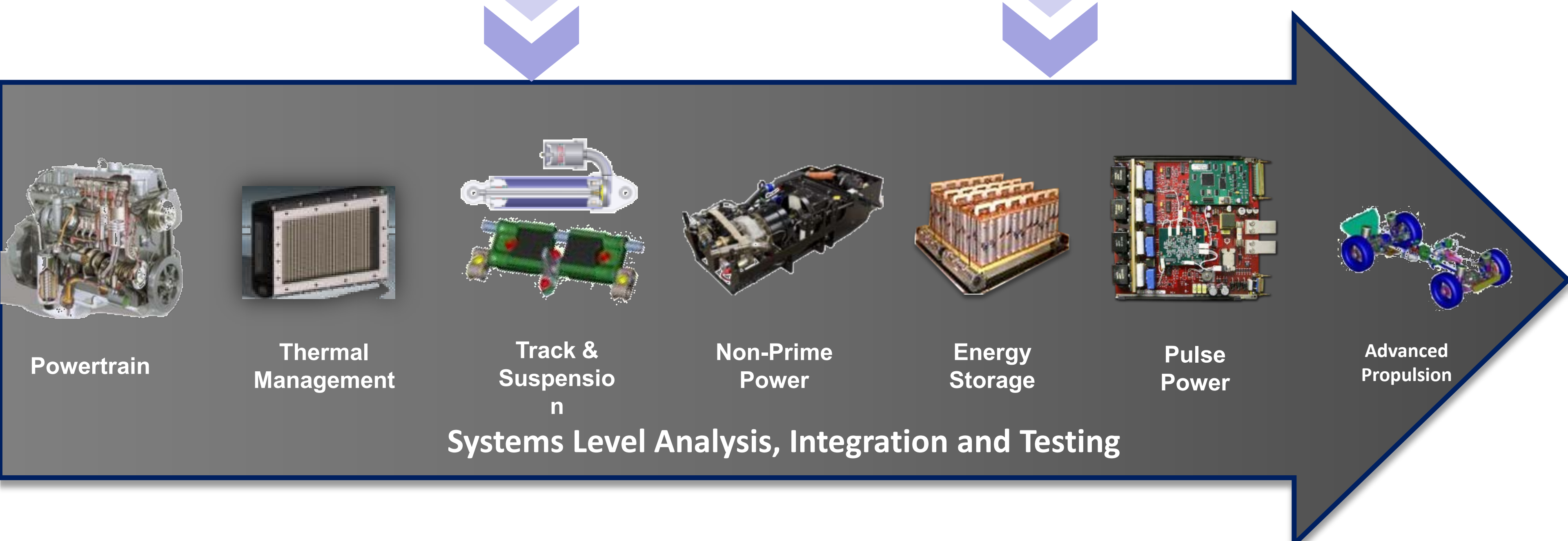
U.S. ARMY RDECOM®

Vehicle Mobility & Energy Efficiency

TARDEC

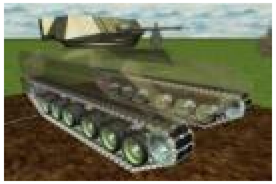


Increasing demands, operational flexibility, and inter-relationships
Requires a Systems Engineering approach and investments in key technology areas



Army Technical Challenge
More Mobile, Fuel Efficient, Safer Vehicles

Power, Energy & Mobility



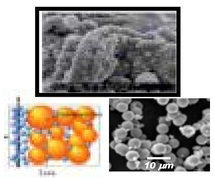
Vehicle Dynamics

Newton-Euler Equations of Motion

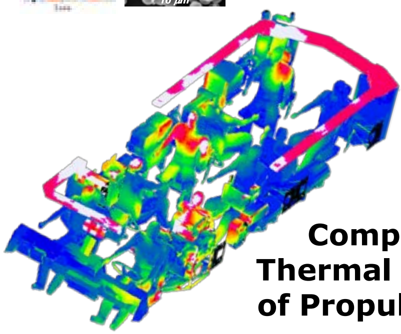
$$\left.\begin{array}{l} \mathbf{M}\ddot{\mathbf{q}} + \mathbf{C}_{\mathbf{q}}^{T}\boldsymbol{\lambda} = \mathbf{Q} \\ \mathbf{C}(\mathbf{q}, t) = \mathbf{0} \end{array}\right\}$$

Solve for vehicle mobility and component loads

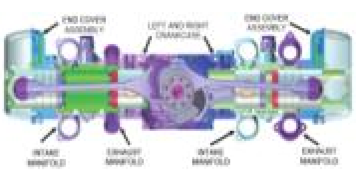
$$\begin{bmatrix} \mathbf{M} & \mathbf{C}_{\mathbf{q}}^{T} \\ \mathbf{C}_{\mathbf{q}} & \mathbf{0} \end{bmatrix} \begin{bmatrix} \ddot{\mathbf{q}} \\ \boldsymbol{\lambda} \end{bmatrix} = \begin{bmatrix} \mathbf{Q}_e + \mathbf{Q}_v \\ \mathbf{Q}_d \end{bmatrix}$$



Hi-Energy, Hi-Density Energy Storage



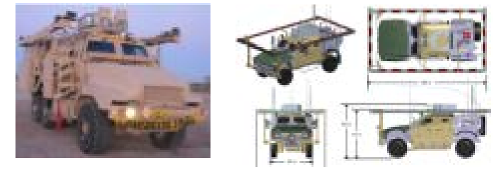
Comprehensive Thermal Management of Propulsion & Cabin



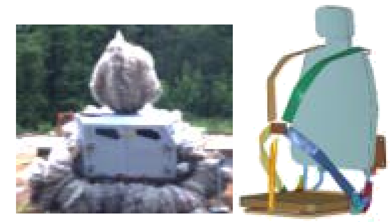
High Power Density, Low Heat Rejection & Fuel Efficient Engines

Multi-Physics Optimization

Soldier & System Survivability



Active Protection Systems



Holistic Occupant Centric Protection

$$\frac{d}{dt}\int_{Vt} f(x,t)\,dV = \int_{Vc\equiv Vt} \frac{\partial f(x,t)}{\partial t}\,dV + \int_{Sc\equiv St} f(x,t) \bullet n\,dS$$

Affordable, Multi-hit Ceramic Armor

$$\frac{dc}{dt} + i\omega(p)c + \Gamma_{+}(p)c - \Gamma_{-}(p)c = f_{\mathrm{n}}(t)$$

Fire and Toxic Fume Resistant Materials

It's About Balancing Technology, Integration, Mission & Threat

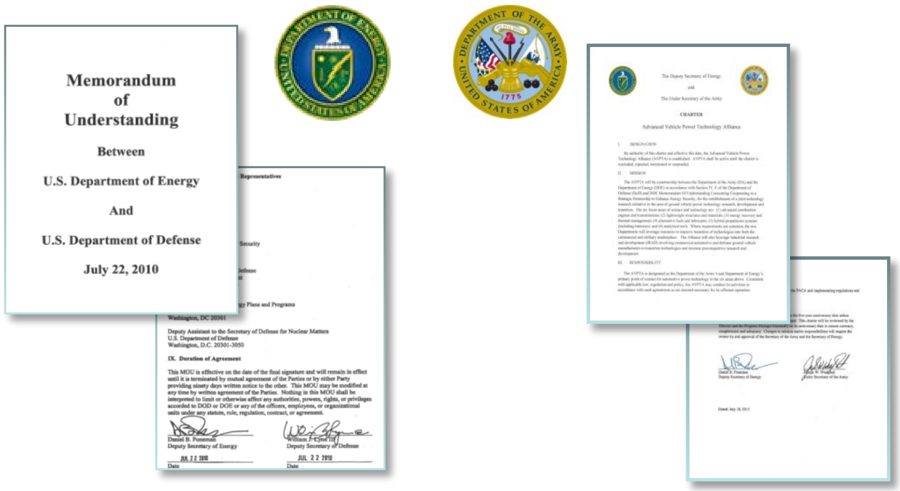
Army/DOE Signs Charter to Achieve Energy Efficiency

AVPTA will move us toward reducing our reliance on fossil fuels.

Combines the intellect of the DA and the DOE to accelerate energy-related R&D initiatives.

Advanced Vehicle Power Technology Alliance (AVPTA)

Breaking New Ground



22 July, 2010

18 July, 2011

- Partnership with true collaboration to enhance national energy security
- Demonstrate federal government leadership
- Provide shared capabilities and access to resources
- Accelerate technology development
- Drive innovation
- Increase the value of research investments
- Address national energy needs

Achieving Common Goals Faster and More Effectively

Advanced Combustion Engines and Transmissions	Lightweight Structures and Materials	Energy Recovery and Thermal Management	Alternative Fuels and Lubricants	Hybrid Power Systems	Analytical Tools
Technical areas for potential joint activity:					
• High density, energy efficient powertrain • Extreme gains in engine efficiency	• Reduce weight to improve performance • Cost reduction for consumer market	• Cost Improved efficiency, manage heat generation • Efficiency gains through waste heat recovery	• Standardization & security • Efficiency gains through advanced oil formulations	• Efficiency improvements	• Assessment/ Design Trades
❖Spray Visualization Project	❖Carbon Fiber Project	❖Thermoelectrics and Enabling Engine Project		❖CAEBAT Project ❖Permanent Magnetic Project	

Driving results through collaboration

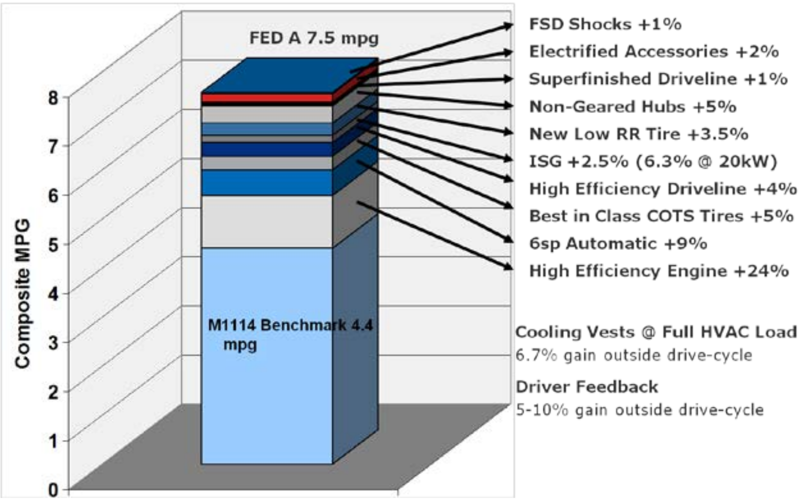
Advancing Platform Energy Efficiency & System Knowledge

FUEL EFFICIENT GROUND VEHICLE DEMONSTRATOR

Designed to validate fuel-efficiency innovations, enhance Soldier safety and reduce Army's energy costs.

System engineering approach. Exceeded the original goal of 30% more fuel efficient than the M1114

Fuel Efficiency Demonstrator (FED)
OSD Sponsored, Army Implemented



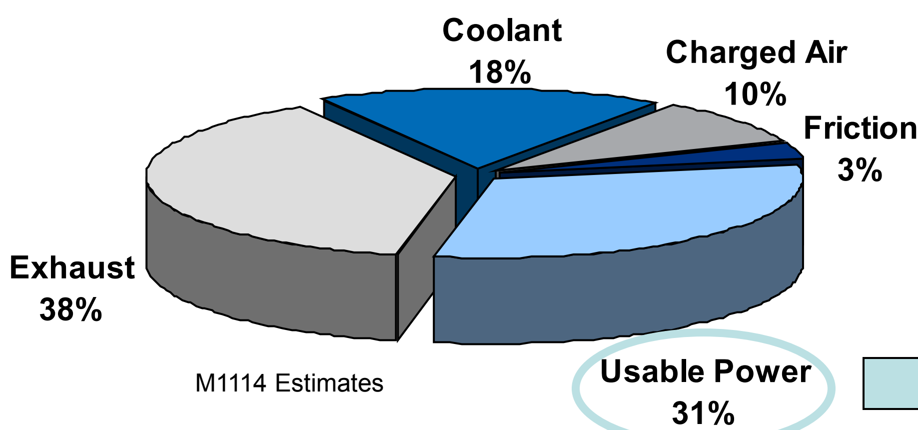
- Identify and assess technologies that support increasing fuel efficiency in a M1114 size vehicle and demonstrate them in a system level demonstrator
  - Alpha – Testing began July 2011
  - Bravo – Nov 2011 delivery
- Developed detailed models & simulations to evaluate energy generation, losses, recovery, etc.
- Engine Energy & Vehicle energy analysis and balancing

Fuel Efficient Demonstrator (FED)

U.S. ARMY RDECOM

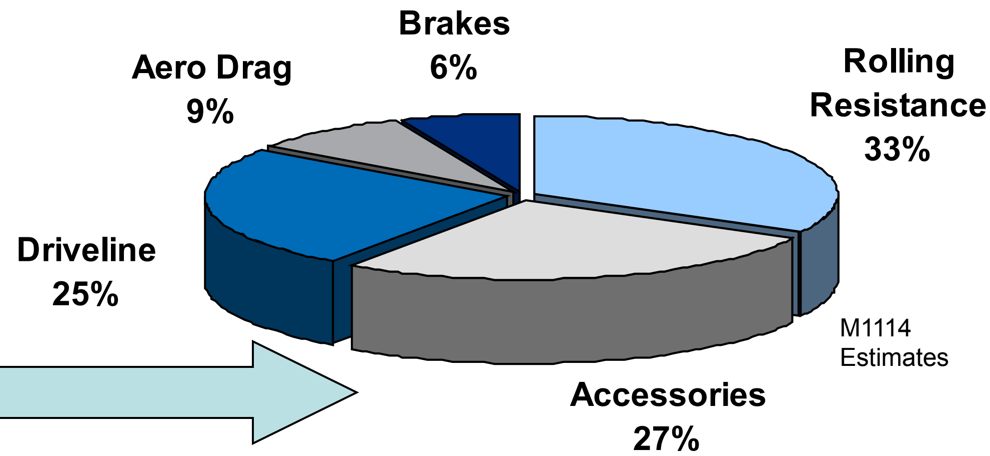
TARDEC

Engine Energy Balance



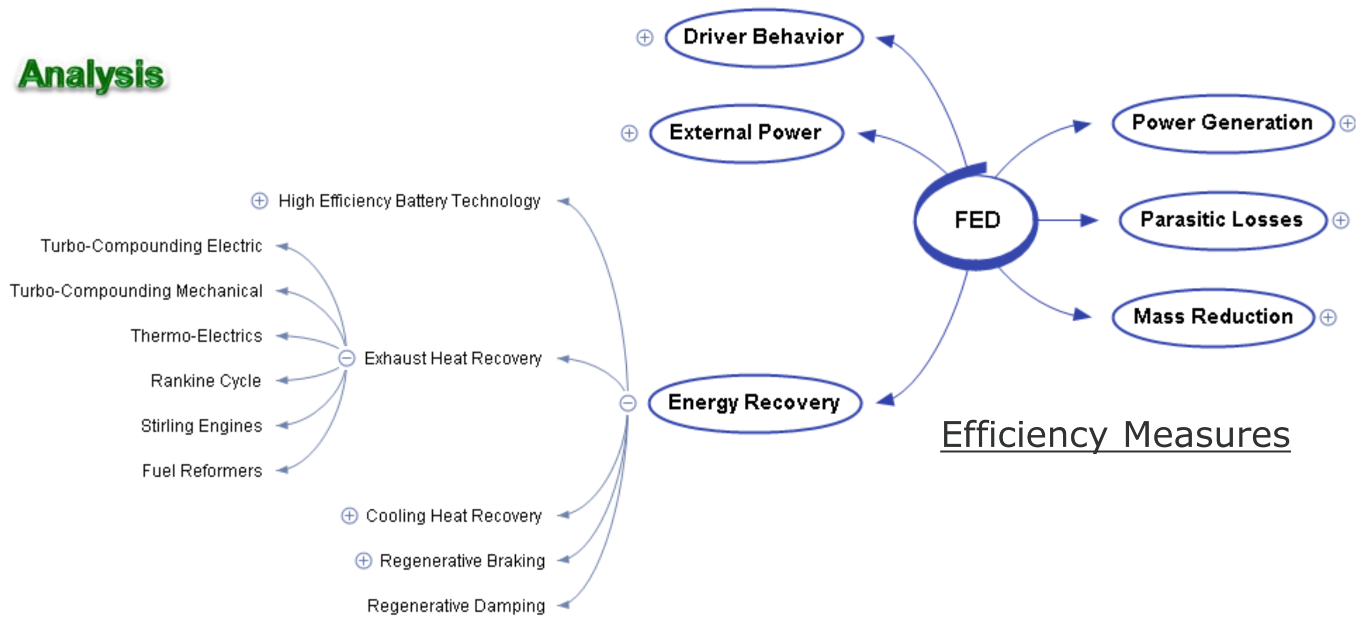
M1114 Estimates

Vehicle Energy Balance



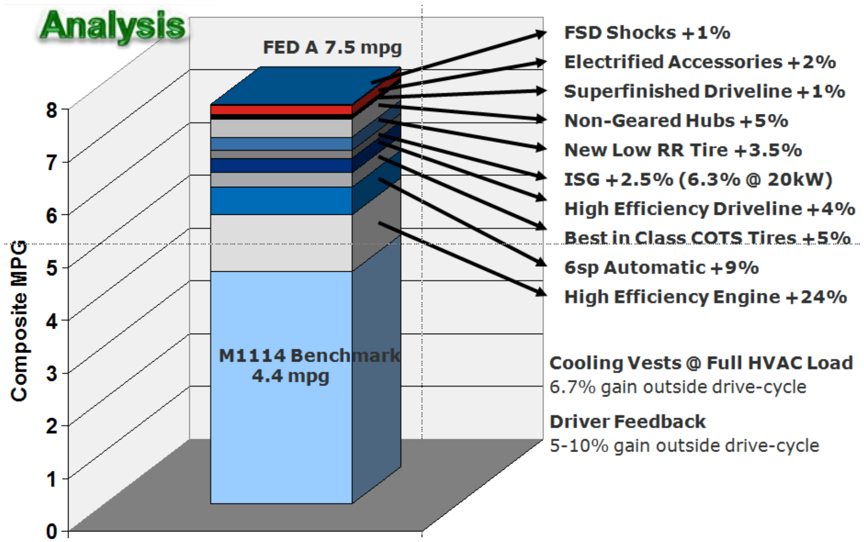
M1114 Estimates

Analysis



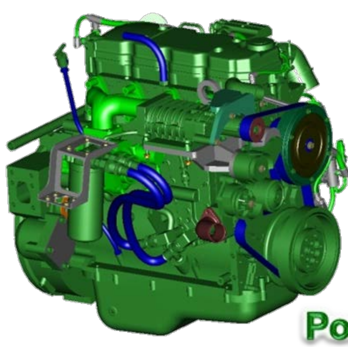
Efficiency Measures

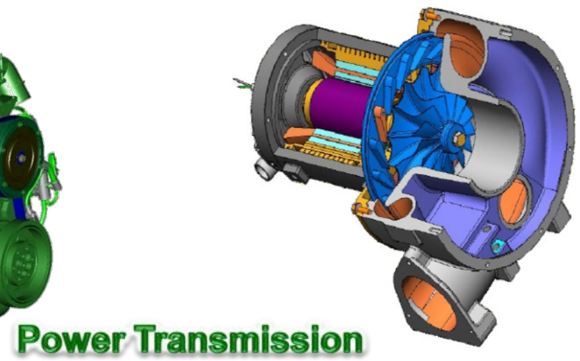
Fuel Efficient Demonstrator (FED)



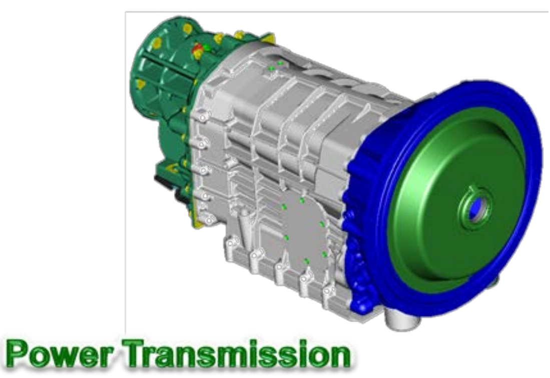
200hp 4.5L I4 diesel; Calibrated for max efficiency.
Right-sized for application

Electric Turbo-Compounding utilizes wasted heat energy.

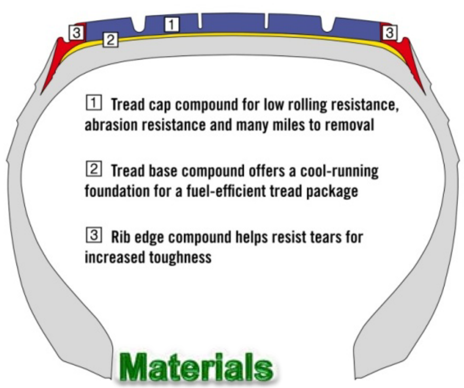




Greatest single contributor to upgrade efficiency is 7-speed dual clutch transmission, best non-hybrid efficiency option.



35% rolling resistance improvement (pavement) using 22.5" commercial wheel w/ custom tread & tire compound.

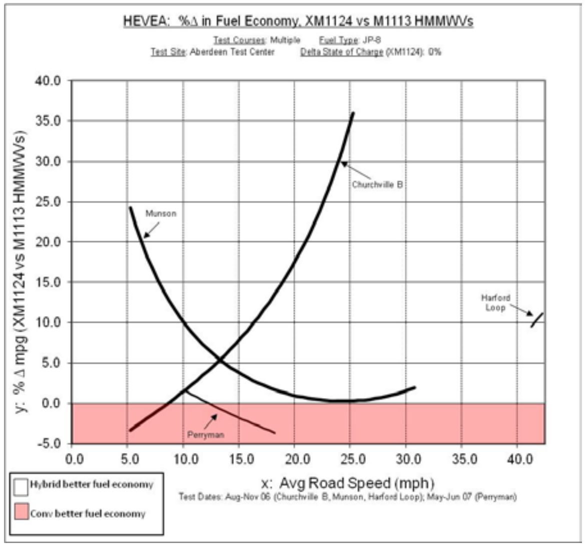


Hybrids and Vehicle Electrification

HEVEA - In 4 years, the Army developed physical & analytical methods for evaluating conventional and hybrid vehicles which have been accepted by the acquisition and industry communities, including SAE.

Hybrid Electric Vehicle Experimentation and Assessment (HEVEA)

20 Vehicles (10 Conventional/10 Hybrid)

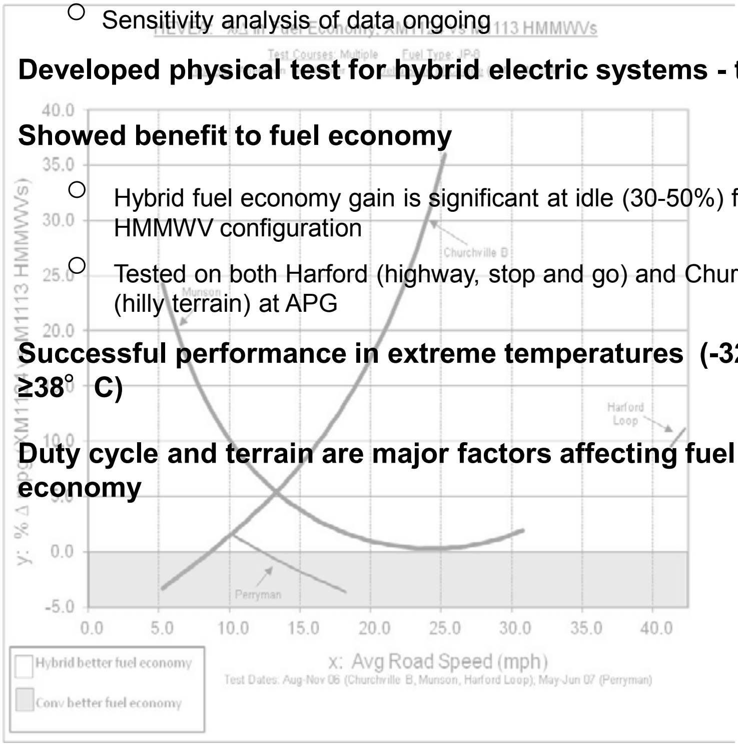


- Developed a standard testing procedure & methodology for testing HEV's
- Developed analytical tools for both assessment and evaluation
- Established credible/quantifiable data of HEV vice conventional vehicles (fuel economy, reliability,
- Developed M&S methods

Hybrid Electric Vehicle Experimentation Assessment (HEVEA)

Accomplishments

- **Developed analytical tools for both assessment and evaluation**
  - Implemented as a design tool for the JLTV effort
  - Used on FED program
  - Sensitivity analysis of data ongoing
- **Developed physical test for hybrid electric systems - the TOP**
- **Showed benefit to fuel economy**
  - Hybrid fuel economy gain is significant at idle (30-50%) for test HMMWV configuration
  - Tested on both Harford (highway, stop and go) and Churchville (hilly terrain) at APG
- **Successful performance in extreme temperatures (-32° to ≥38° C)**
- **Duty cycle and terrain are major factors affecting fuel economy**



Hybrid-Electric Work to do

- <u>**Reliability**</u> **–** Evaluate the reliability of technology in military environment
- <u>**Operational Analysis**</u> **–** Assess technology value in operational scenarios
- <u>**Cost Analysis**</u> – Conduct cost analysis of fuel savings versus cost incurred for a specific platform in an operational mode
- <u>**Life Cycle Cost Analysis**</u> - Evaluate life cycle costs

Hybrid Electric Advantages

- **Hybrid electric provides additional mission capabilities:**
  - **Power Generation – (On-board vehicle power)**
  - **Auxiliary Engine Support**
  - **Export Power**
  - **Silent operations**

Army Efforts…Integral to Installation and Operational Energy Security

Hawaii's Energy from Oil	90%
HI Imports 51 million barrels of Oil Annually	$7B
Hawaii's Supply of Oil (at any given time)	14-21 Days

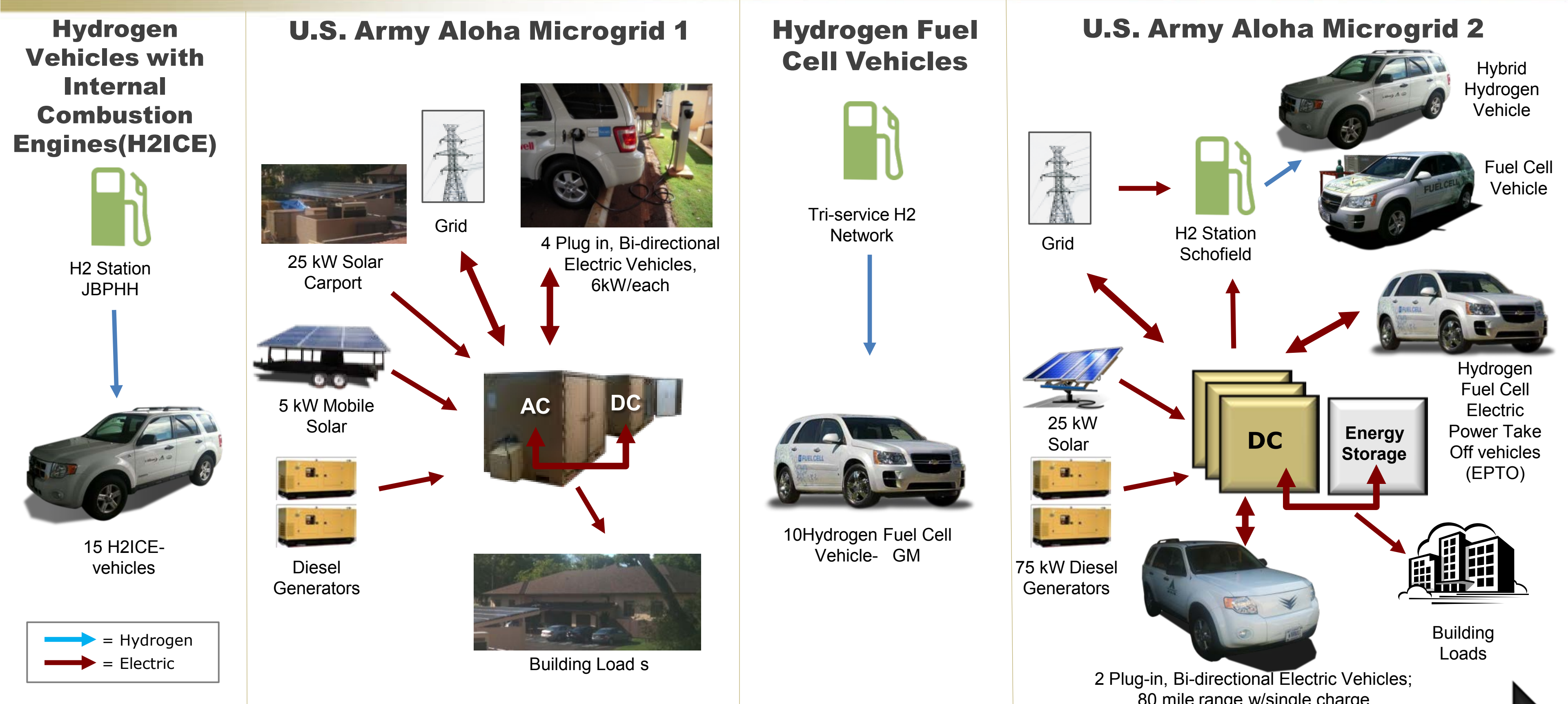
Partnerships

- Hawaii Tri-Service Advanced Vehicle Working Group
- DOD-DOE Advanced Vehicle Power Technology Alliance
- PACOM/NORTHCOM SPIDERS JCTD
- State of Hawaii
- University of Hawaii-HNEI
- Hawaii Tri-Service Military Installations

TARDEC Involvement Achieves Goals

- Supports the increase in renewable energy
- Military as an early adopter
- Develop a competitive & sustaining industry
- **Army Hydrogen based Vehicles & Refueling**
- **Army Microgrid 1-**
  - 250kW sufficient to power a building
- **Army Microgrid 2-**
  - 450kW capable of powering 500-Soldier/Forward Operating Base

TARDEC – Addressing Microgrid to Vehicle Advancements



2004
Created the H2ICE network and tested

2008
Existing CONUS vehicles arrive in Hawaii

2009
Hybrid Hydrogen Vehicles; In operation in Hawaii since February 2009

First Hawaii Advanced Vehicle Working Group Meeting Held

2010
Microgrid Planning Begins at Wheeler Army Airfield/Schofield Barracks

U.S. Army Aloha Microgrid 1; In operation in November

2011
FCV deployed to Hawaii

General Motors Fuel Cell Vehicles; In Operation Starting August 2011

EPTO used by Marines in August 2011

2012
SPIDERS JCTD

TARDEC Hydrogen Station; Planned operational for March 2012

U.S. Army Aloha Microgrid 2; Planned operational for January 2012

It's All About the Warfighter

Unclassified FOUO

Lead. Innovate. Integrate. Deliver.

Back-up

Non Tactical Vehicle to Grid Technologies

Transfer Layer Technologies

Vehicle to Grid

Demo bi-directional power for grid services (HI)

Interface standards
Physical, communication, cyber-security
(SPIDERS – Ft. Carson)

Export power system development and demonstration

Microgrids

Modular mobile microgrid product development

Enduring microgrid product development and demonstration (NetZero JCTD - Ft Irwin, others)

Tactical load control product development

Integrated microgrid testbed demonstration (HI)

Hydrogen fuelled propulsion

Hydrogen ICE fleet demonstration (HI)

Demonstration of fuel cells in non-tactical fleet (past Ft. Belvoir, current HI)

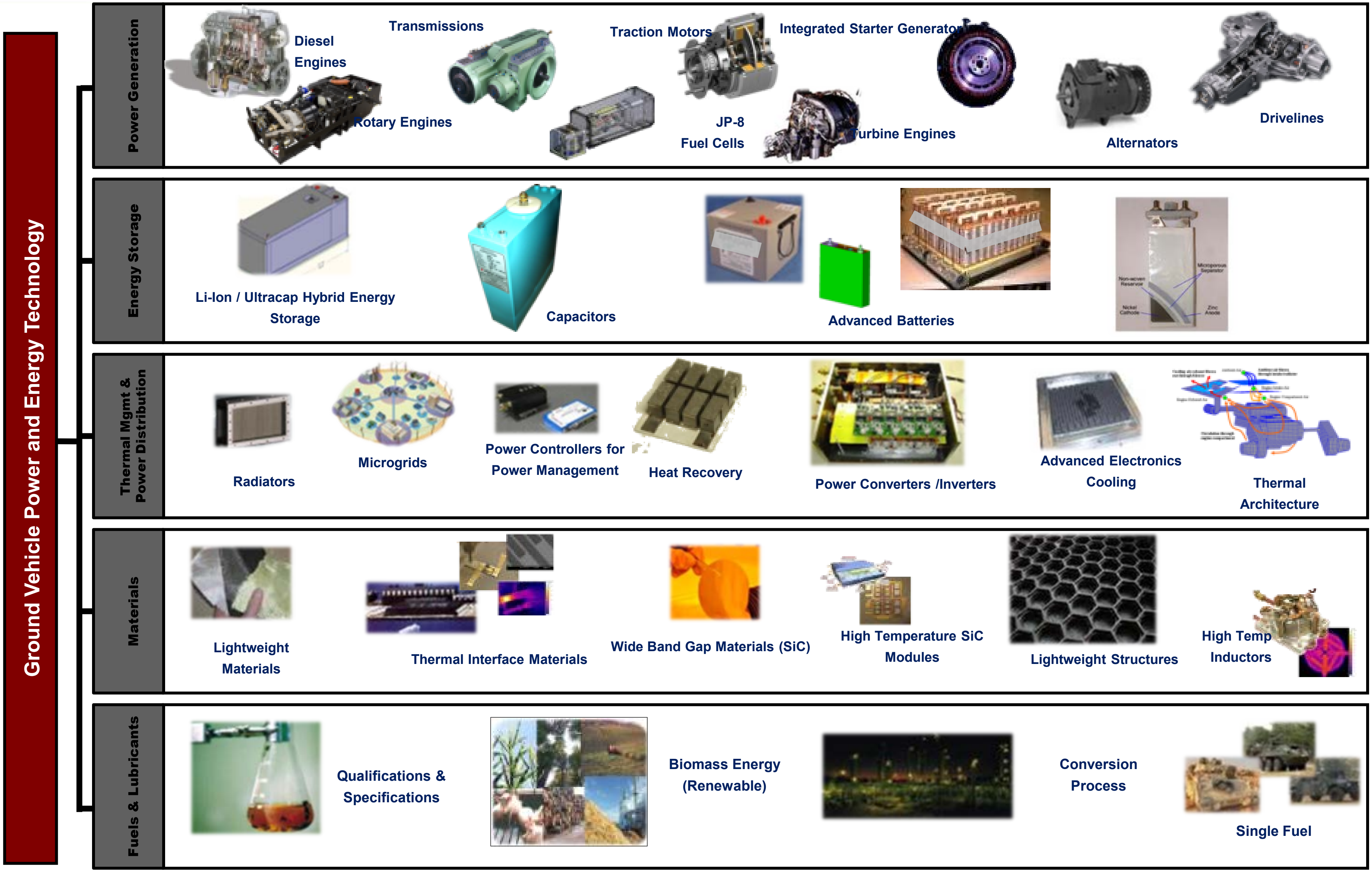
Fuel cell propulsion concept development

Hydrogen Infrastructure

Infrastructure component development

Hydrogen refuelling demonstration (past Selfridge, MI; future HI)

Ground Vehicle Power and Energy Technology Taxonomy



Electronic Power Conditioning & Control Distributed Generation

Vehicle Inputs

Plug-in Hybrid Electric Vehicles (PHEV)

Electric Power Control and Conditioning (EPCC)

Renewable Inputs

Mobile Encampment Waste to Electrical Power (MEWEPS)

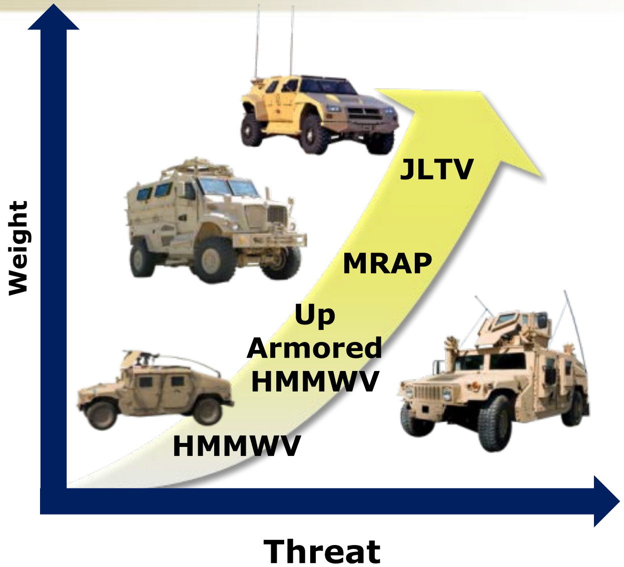
Supply – Infrastructure - Demand

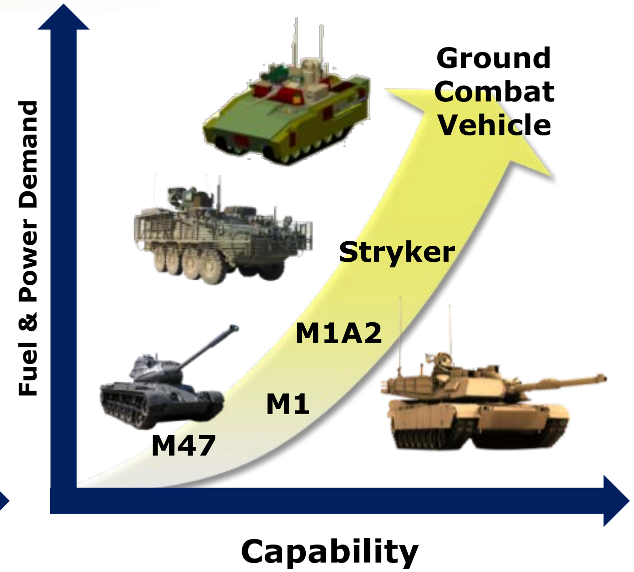
Generator Inputs

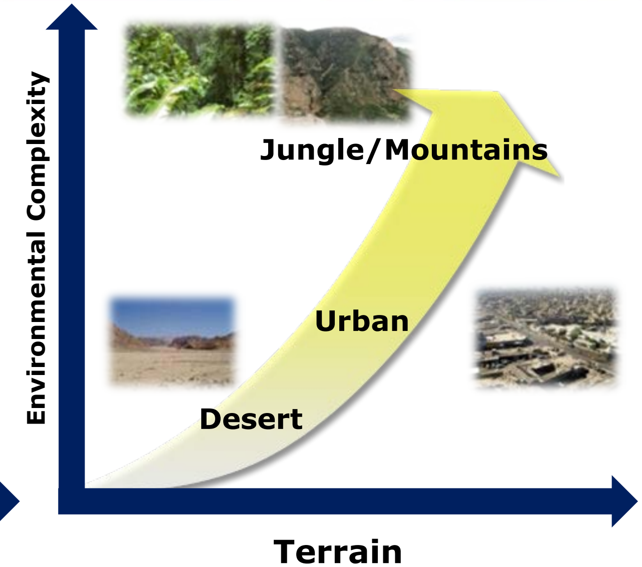
Solar

Tactical Quiet Generator (TQG)

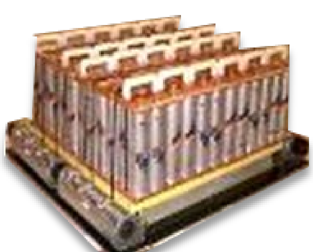
Excellence in Vehicle Mobility & Energy Efficiency





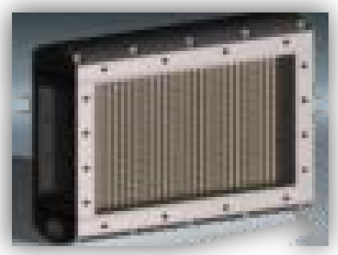


Increasing Demands and Operational Flexibility Require Strategic Investments in Key Areas

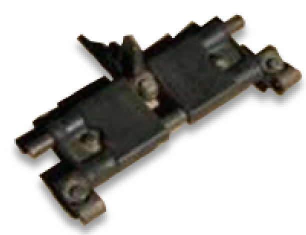


Energy Storage

Power Generation & Control



Thermal Management



Track & Suspension

Technology & Energy Efficiency Drive Excellence