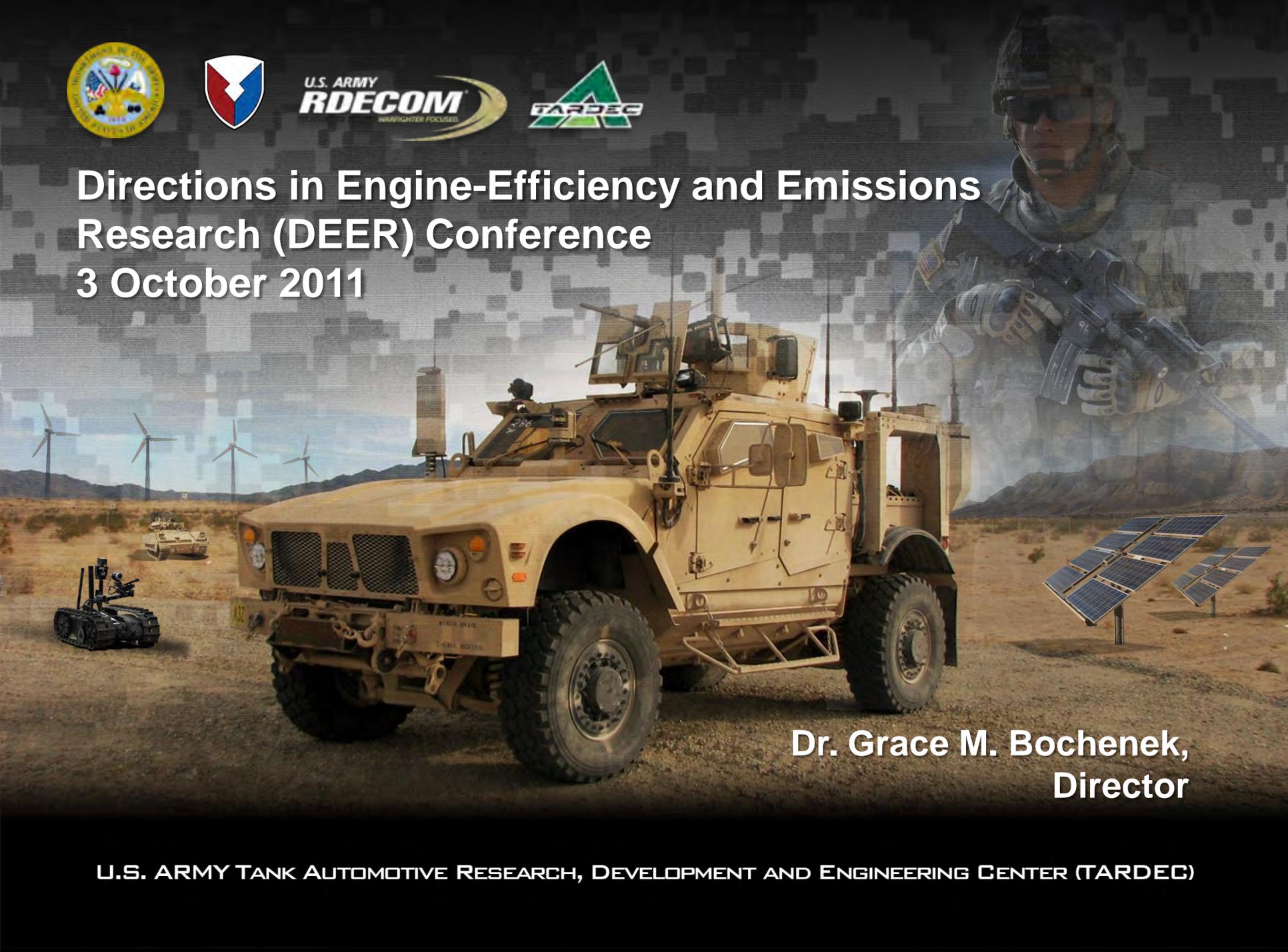




Directions in Engine-Efficiency and Emissions Research (DEER) Conference 3 October 2011



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Director**

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

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

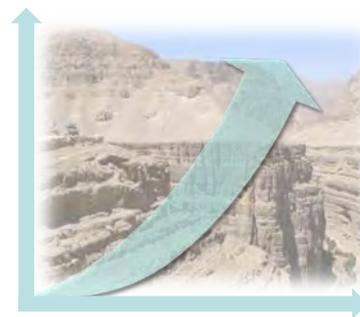
▶ Tactical Vehicles

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



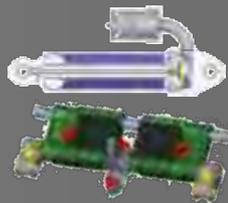
Increasing demands, operational flexibility, and inter-relationships
Requires a Systems Engineering approach and investments in key technology areas



Powertrain



Thermal
Management



Track &
Suspension



Non-Prime
Power



Energy
Storage



Pulse
Power



Advanced
Propulsion

Systems Level Analysis, Integration and Testing

Power, Energy & Mobility



Newton-Euler Equations of Motion

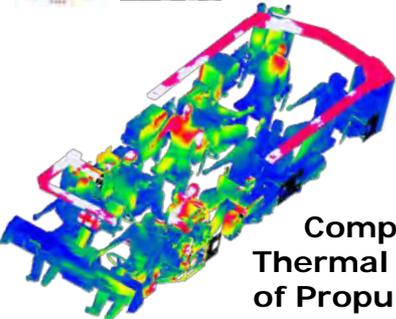
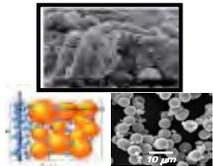
$$\begin{cases} M\ddot{q} + C_q^v \dot{\lambda} = Q \\ C(q, t) = 0 \end{cases}$$

Solve for vehicle mobility and component loads

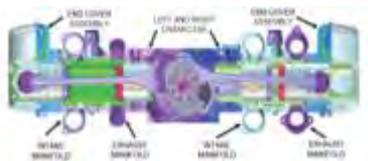
$$\begin{bmatrix} M & C_q^v \\ C_q & 0 \end{bmatrix} \begin{bmatrix} \ddot{q} \\ \dot{\lambda} \end{bmatrix} = \begin{bmatrix} Q_c + Q_v \\ Q_d \end{bmatrix}$$

Vehicle Dynamics

Hi-Energy, Hi-Density Energy Storage



Comprehensive Thermal Management of Propulsion & Cabin



High Power Density, Low Heat Rejection & Fuel Efficient Engines

Soldier & System Survivability



Active Protection Systems



Holistic Occupant Centric Protection

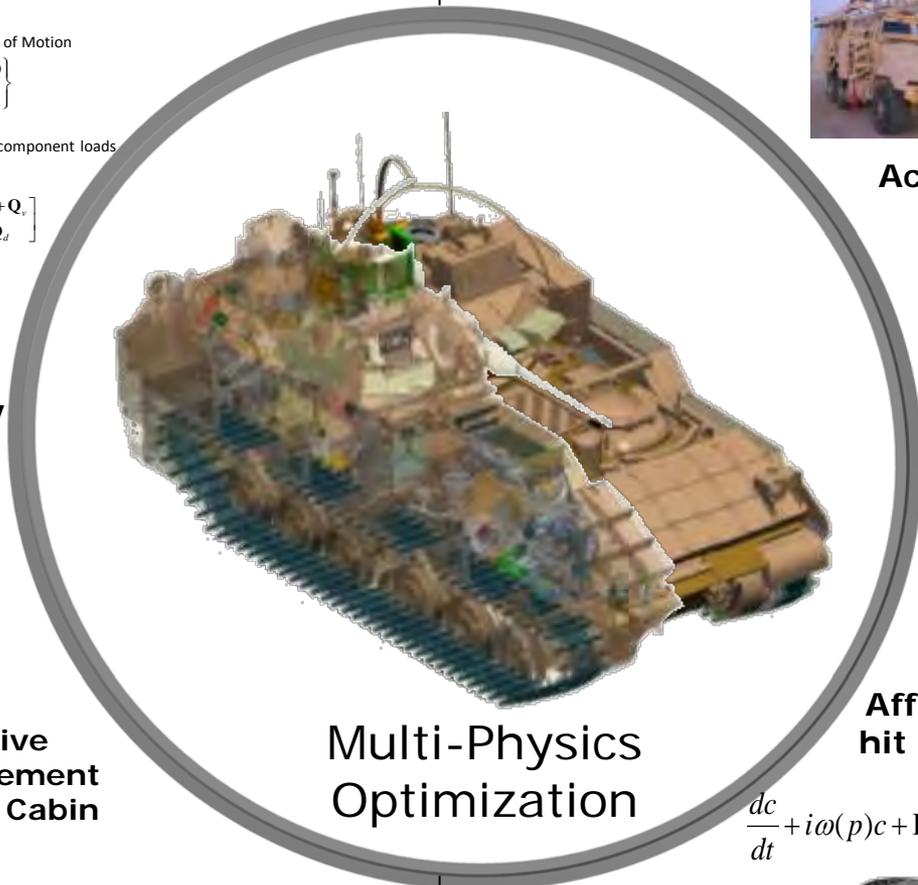
$$\frac{d}{dt} \int_{V_i} f(x, t) dV = \int_{V_i} \frac{\partial f(x, t)}{\partial t} dV + \int_{S_i} f(x, t) \bullet n dS$$

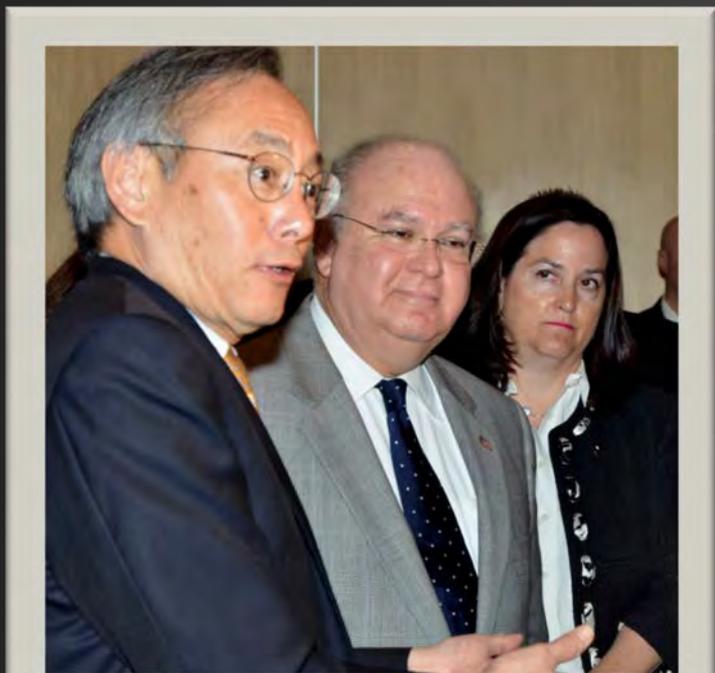
Affordable, Multi-hit Ceramic Armor



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

Fire and Toxic Fume Resistant Materials

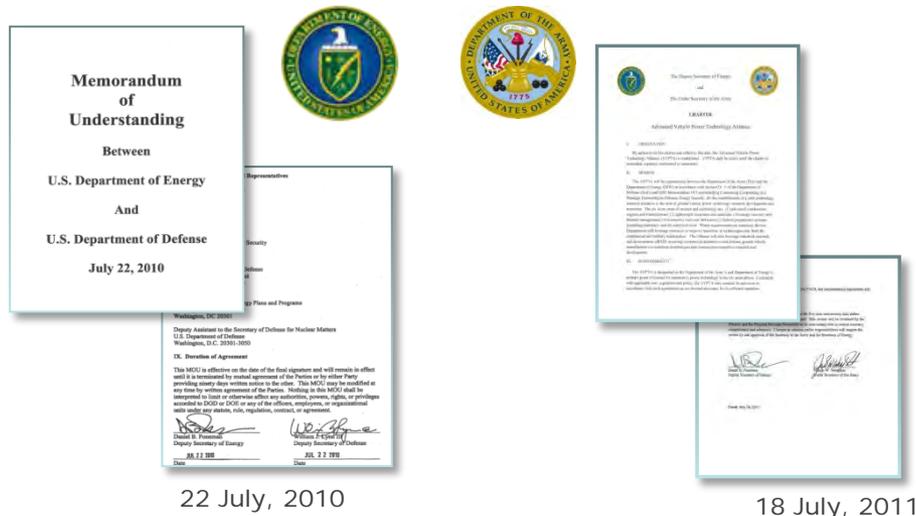




AVPTA will move us toward reducing our reliance on fossil fuels.

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



- 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

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

❖ Spray Visualization Project

- Reduce weight to improve performance
- Cost reduction for consumer market

❖ Carbon Fiber Project

- Cost Improved efficiency, manage heat generation
- Efficiency gains through waste heat recovery

❖ Thermoelectrics and Enabling Engine Project

- Standardization & security
- Efficiency gains through advanced oil formulations

- Efficiency improvements

❖ CAEBAT Project
❖ Permanent Magnetic Project

- Assessment/ Design Trades



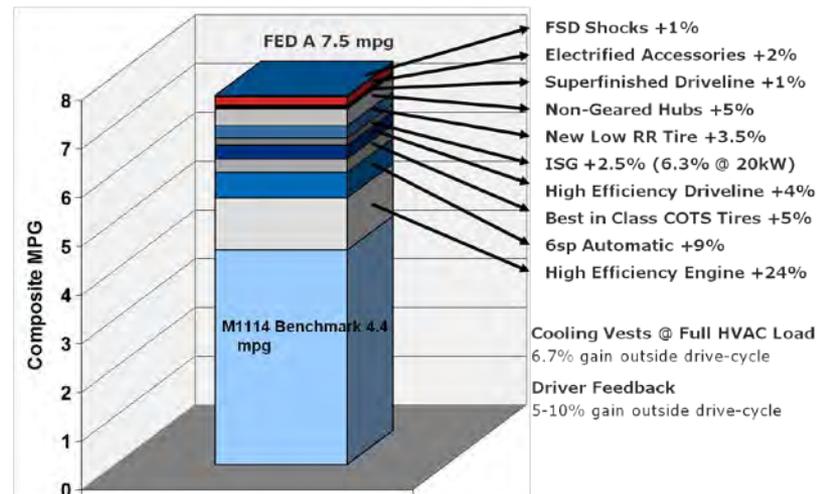
Driving results through collaboration

Fuel Efficiency Demonstrator (FED) OSD Sponsored, Army Implemented



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

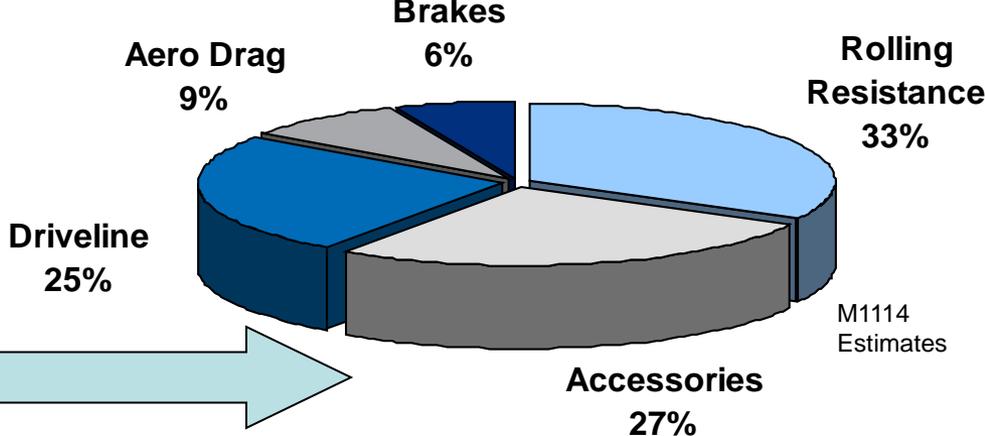
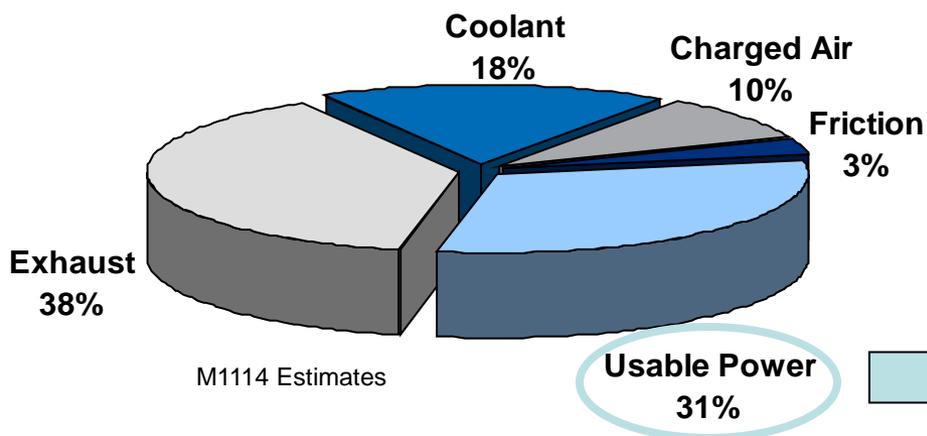
System engineering approach.
Exceeded the original goal of 30% more fuel efficient than the M1114



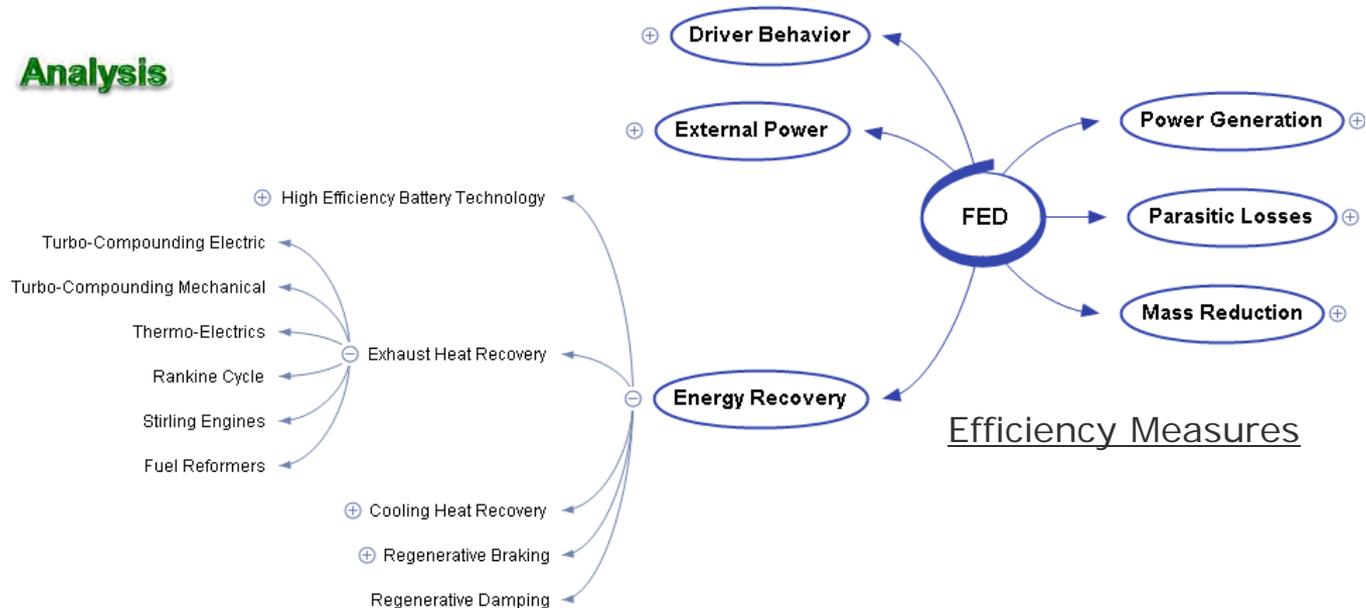
- Identify and assess technologies that support increasing fuel efficiency in a M1114 size vehicle and demonstrate them in a system level demonstrator
 - Alpha – Testing began July 2011
 - Bravo – Nov 2011 delivery
- Developed detailed models & simulations to evaluate energy generation, losses, recovery,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

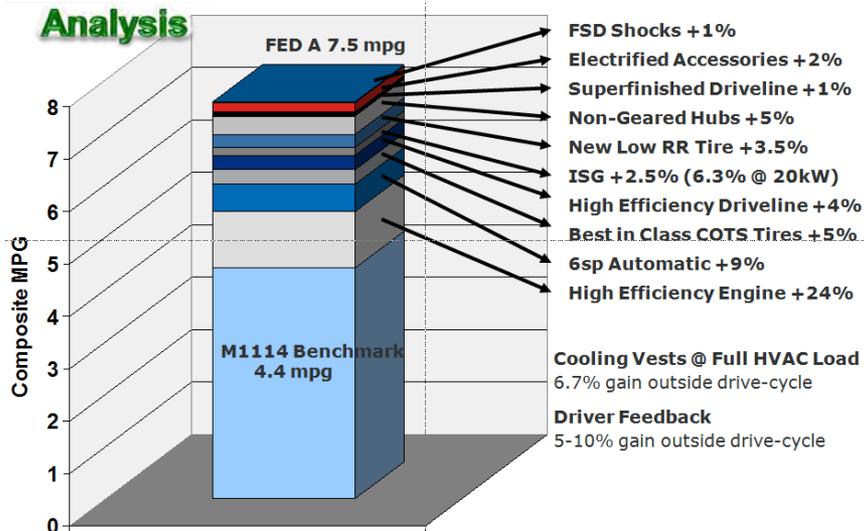
Engine Energy Balance

Vehicle Energy Balance



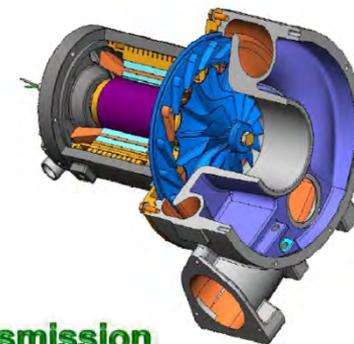
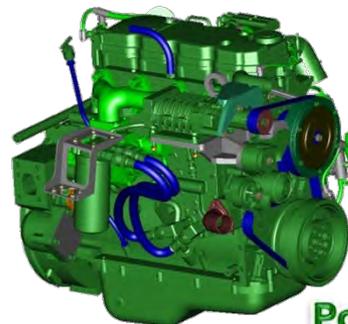
Analysis





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

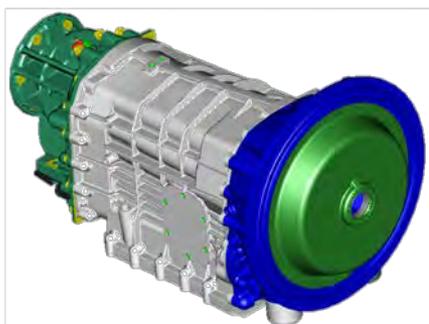
Electric Turbo-Compounding utilizes wasted heat energy.



Power Transmission

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.



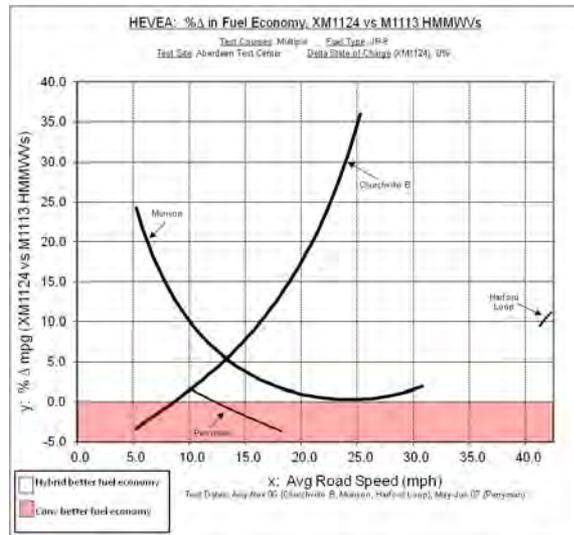
Power Transmission



Materials

Hybrid Electric Vehicle Experimentation and Assessment (HEVEA)

20 Vehicles (10 Conventional/10 Hybrid)

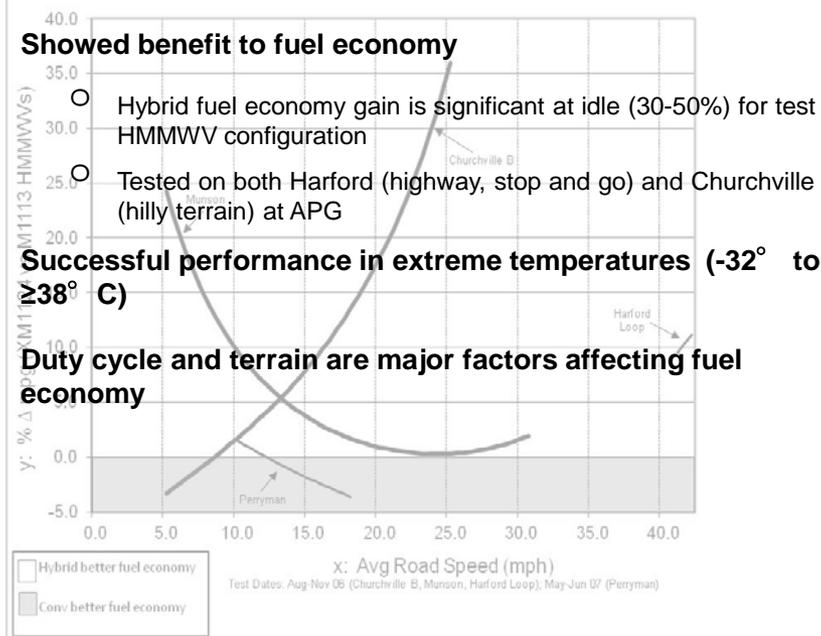


HEVEA - In 4 years, the Army developed physical & analytical methods for evaluating conventional and hybrid vehicles which have been accepted by the acquisition and industry communities, including SAE.

- 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

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**

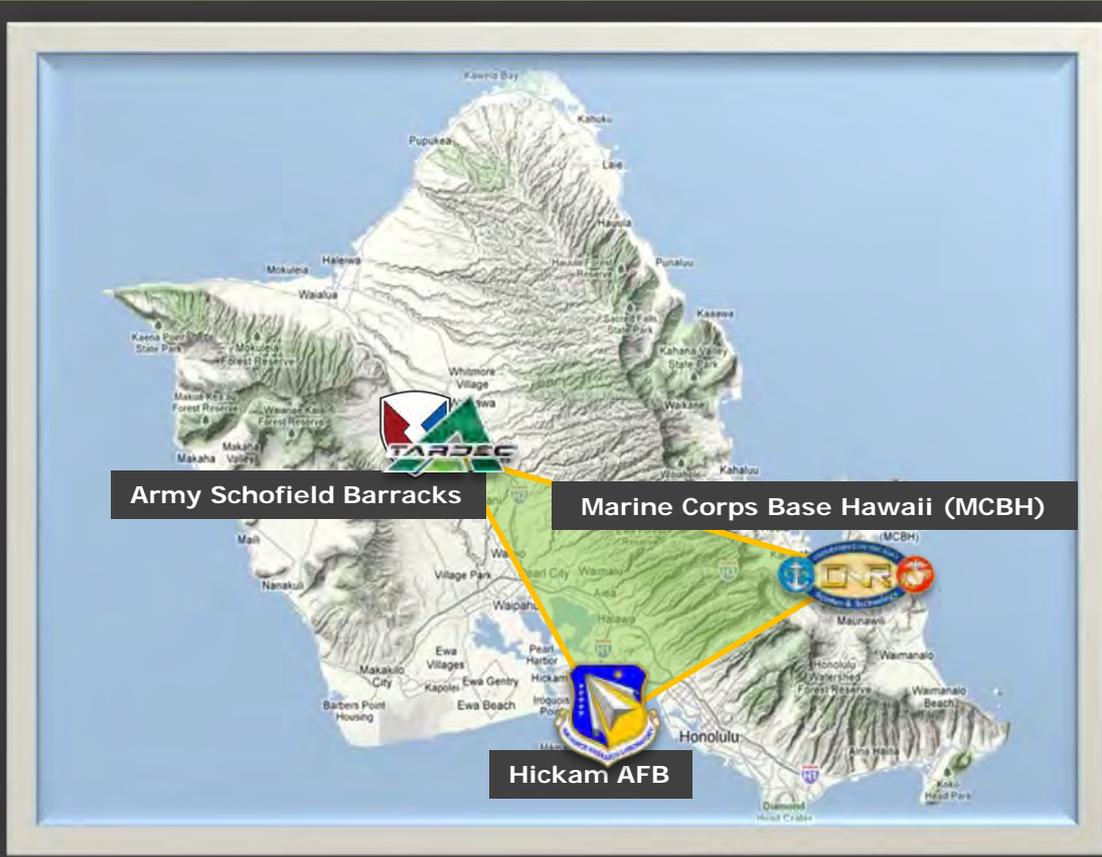


Hybrid-Electric Work to do

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



Partnerships

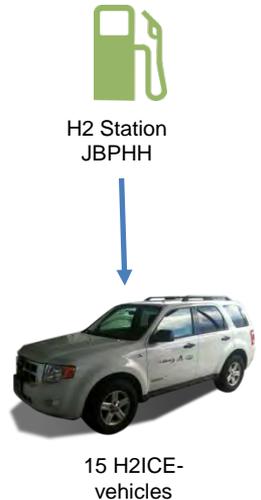
- Hawaii Tri-Service Advanced Vehicle Working Group
- DOD-DOE Advanced Vehicle Power Technology Alliance
- PACOM/NORTHCOM SPIDERS JCTD
- State of Hawaii
- University of Hawaii-HNEI
- Hawaii Tri-Service Military Installations

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

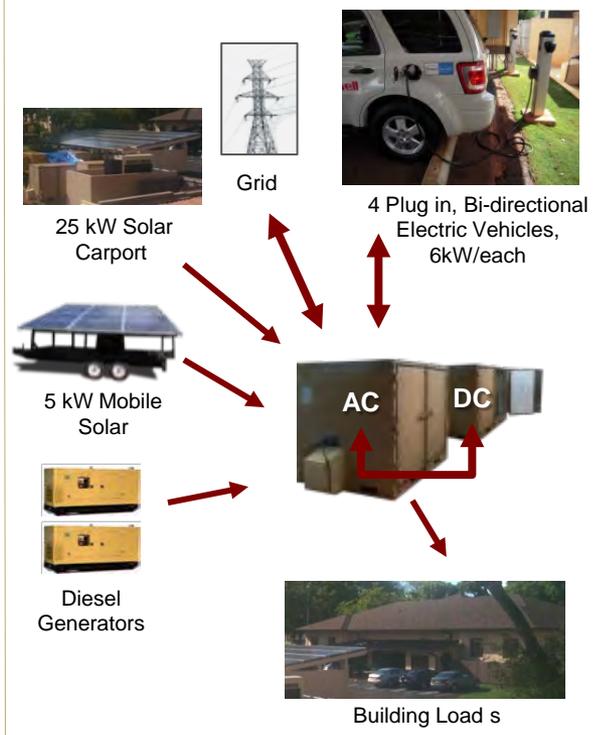
Hawaii's Energy from Oil	90%
HI Imports 51 million barrels of Oil Annually	\$7B
Hawaii's Supply of Oil (at any given time)	14-21 Days

Hydrogen Vehicles with Internal Combustion Engines (H2ICE)

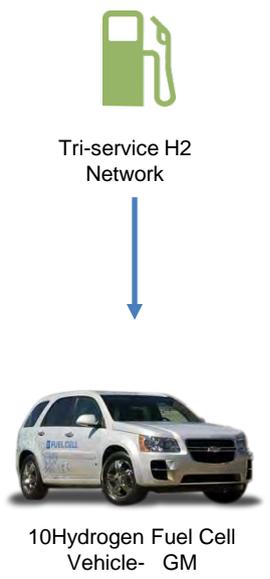


→ = Hydrogen
→ = Electric

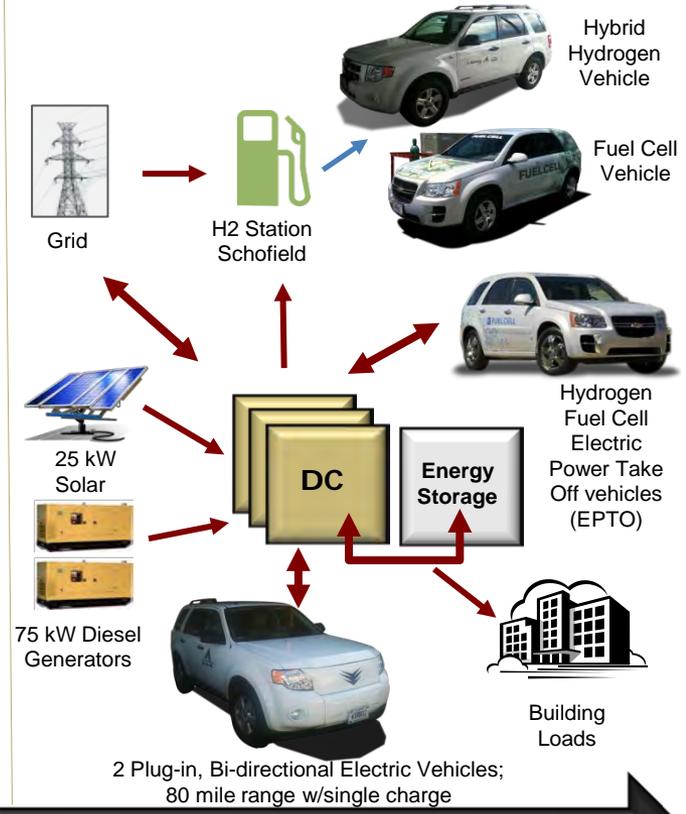
U.S. Army Aloha Microgrid 1



Hydrogen Fuel Cell Vehicles



U.S. Army Aloha Microgrid 2



Year	Event
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
2009	First Hawaii Advanced Vehicle Working Group Meeting Held
2010	Microgrid Planning Begins at Wheeler Army Airfield/Schofield Barracks
2010	U.S. Army Aloha Microgrid 1; In operation in November
2011	FCV deployed to Hawaii
2011	General Motors Fuel Cell Vehicles; In Operation Starting August 2011
2011	EPTO used by Marines in August 2011
2012	SPIDERS JCTD
2012	TARDEC Hydrogen Station; Planned operational for March 2012
2012	U.S. Army Aloha Microgrid 2; Planned operational for January 2012

Unclassified FOUO



Lead. Innovate. Integrate. Deliver.



Back-up

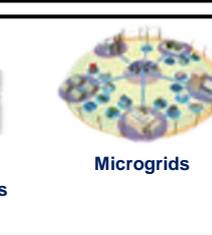
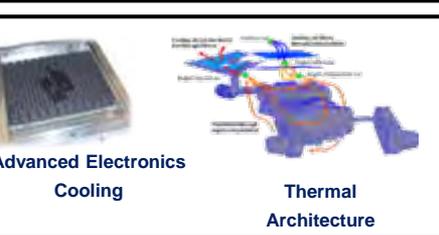
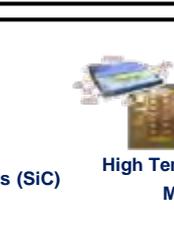
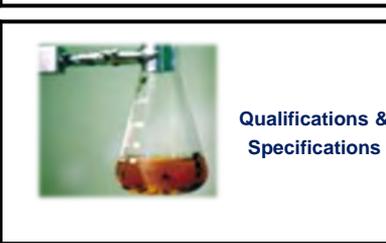


Transfer Layer Technologies

<p>Vehicle to Grid</p>	 <p>Demo bi-directional power for grid services (HI)</p>		<p>Interface standards Physical, communication, cyber-security (SPIDERS – Ft. Carson)</p>		 <p>Export power system development and demonstration</p>
<p>Microgrids</p>	 <p>Modular mobile microgrid product development</p>		<p>Enduring microgrid product development and demonstration (NetZero JCTD - Ft Irwin, others)</p>	 <p>Tactical load control product development</p>	 <p>Integrated microgrid testbed demonstration (HI)</p>
<p>Hydrogen fuelled propulsion</p>	 <p>Hydrogen ICE fleet demonstration (HI)</p>	 <p>Demonstration of fuel cells in non-tactical fleet (past Ft. Belvoir, current HI)</p>			 <p>Fuel cell propulsion concept development</p>
<p>Hydrogen Infrastructure</p>	 <p>Infrastructure component development</p>		<p>Hydrogen refuelling demonstration (past Selfridge, MI; future HI)</p>		



Ground Vehicle Power and Energy Technology

Power Generation	 Diesel Engines	 Transmissions	 Traction Motors	 Integrated Starter Generator	 JP-8 Fuel Cells	 Turbine Engines	 Alternators	 Drivelines
Energy Storage	 Li-Ion / Ultracap Hybrid Energy Storage	 Capacitors	 Advanced Batteries					
Thermal Mgmt & Power Distribution	 Radiators	 Microgrids	 Power Controllers for Power Management	 Heat Recovery	 Power Converters /Inverters	 Advanced Electronics Cooling	 Thermal Architecture	
Materials	 Lightweight Materials	 Thermal Interface Materials	 Wide Band Gap Materials (SiC)	 High Temperature SiC Modules	 Lightweight Structures	 High Temp Inductors		
Fuels & Lubricants	 Qualifications & Specifications	 Biomass Energy (Renewable)	 Conversion Process	 Single Fuel				

Vehicle Inputs



Plug-in Hybrid Electric
Vehicles (PHEV)

Renewable Inputs



Mobile Encampment Waste to
Electrical Power (MEWEPs)

Generator Inputs



Solar



Tactical Quiet
Generator (TOG)



Electric Power Control and
Conditioning (EPCC)



Supply – Infrastructure - Demand



Increasing Demands and Operational Flexibility
Require Strategic Investments in Key Areas



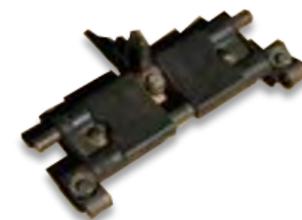
Energy Storage



Power Generation & Control



Thermal Management



Track & Suspension

