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

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### Directions In Engine-Efficiency and Emissions Research (DEER) Conference

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- c. This Page: unclassified

**Limitation of ABSTRACT:** Same as Report (SAR)

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Our Army Ground Community

What We Do
- **Acquisition**: Program Management
- **Logistics**: Industrial Operations, and Contracting
- **Technology**: 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.
### Tactical Vehicles

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

### Non-Tactical Vehicles

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

- 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

Systems Level Analysis, Integration and Testing
Army Technical Challenge
More Mobile, Fuel Efficient, Safer Vehicles

Power, Energy & Mobility

- Vehicle Dynamics
- Hi-Energy, Hi-Density Energy Storage
- Comprehensive Thermal Management of Propulsion & Cabin

Soldier & System Survivability

- Multi-Physics Optimization
- Active Protection Systems
- Holistic Occupant Centric Protection
- Affordable, Multi-hit Ceramic Armor

- Fire and Toxic Fume Resistant Materials
- High Power Density, Low Heat Rejection & Fuel Efficient Engines

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

Newton-Euler Equations of Motion
\[
M\ddot{q} + C(q, \dot{q})\dot{q} + G(q) = Q
\]

Solve for vehicle mobility and component loads.

\[
\begin{bmatrix}
M & C(q, t) & q \\
C(q, t) & 0 & \dot{q}
\end{bmatrix} = \begin{bmatrix}
Q_1 \\
Q_2
\end{bmatrix}
\]

Vehicle Dynamics

Multi-Physics Optimization

Active Protection Systems

Holistic Occupant Centric Protection

Affordable, Multi-hit Ceramic Armor

Fire and Toxic Fume Resistant Materials

High Power Density, Low Heat Rejection & Fuel Efficient Engines
Army/DOE Signs Charter to Achieve Energy Efficiency

### 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

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.
Achieving Common Goals Faster and More Effectively

Technical areas for potential joint activity:

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</thead>
<tbody>
<tr>
<td>High density, energy efficient powertrain</td>
<td>Reduce weight to improve performance</td>
<td>Cost Improved efficiency, manage heat generation</td>
<td>Standardization &amp; security</td>
<td>Efficiency improvements</td>
<td>Assessment/Design Trades</td>
</tr>
<tr>
<td>Extreme gains in engine efficiency</td>
<td>Cost reduction for consumer market</td>
<td>Efficiency gains through waste heat recovery</td>
<td>Efficiency gains through advanced oil formulations</td>
<td>CAEBAT Project</td>
<td>Permanent Magnetic Project</td>
</tr>
<tr>
<td>Spray Visualization Project</td>
<td>Carbon Fiber Project</td>
<td>Thermoelectrics and Enabling Engine Project</td>
<td></td>
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</tbody>
</table>

Driving results through collaboration
Advancing Platform Energy Efficiency & System Knowledge

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

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

Fuel Efficiency Demonstrator (FED)
OSD Sponsored, Army Implemented

- FSD Shocks +1%
- Electrified Accessories +2%
- Superfinished Driveline +1%
- Non-Geared Hubs +5%
- New Low RR Tire +3.5%
- ISG +2.5% (6.3% @ 20kW)
- High Efficiency Driveline +4%
- Best in Class COTS Tires +5%
- 6sp Automatic +9%
- High Efficiency Engine +24%

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

Composite MPG

Fuel Efficiency Demonstrator (FED)
OSD Sponsored, Army Implemented

- FSD Shocks +1%
- Electrified Accessories +2%
- Superfinished Driveline +1%
- Non-Geared Hubs +5%
- New Low RR Tire +3.5%
- ISG +2.5% (6.3% @ 20kW)
- High Efficiency Driveline +4%
- Best in Class COTS Tires +5%
- 6sp Automatic +9%
- High Efficiency Engine +24%

Cooling Vests @ Full HVAC Load
6.7% gain outside drive-cycle

Driver Feedback
5-10% gain outside drive-cycle
Fuel Efficient Demonstrator (FED)

Engine Energy Balance
- Coolant: 18%
- Charged Air: 10%
- Friction: 3%
- Usable Power: 31%
- Exhaust: 38%

Vehicle Energy Balance
- Aero Drag: 9%
- Brakes: 6%
- Driveline: 25%
- Accessories: 27%
- Rolling Resistance: 33%

Analysis
- External Power
- Energy Recovery
- Driver Behavior
- Power Generation
- Parasitic Losses
- Mass Reduction
- Cooling Heat Recovery
- Regenerative Braking
- Regenerative Damping

Efficiency Measures

M114 Estimates
Fuel Efficient Demonstrator (FED)

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

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

Electric Turbo-Compounding utilizes wasted heat energy.

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

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

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.
**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**

- **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
Army Efforts...Integral to Installation and Operational Energy Security

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

<table>
<thead>
<tr>
<th>Hawaii’s Energy from Oil</th>
<th>90%</th>
</tr>
</thead>
<tbody>
<tr>
<td>HI Imports 51 million barrels of Oil Annually</td>
<td>$7B</td>
</tr>
<tr>
<td>Hawaii’s Supply of Oil (at any given time)</td>
<td>14-21 Days</td>
</tr>
</tbody>
</table>
U.S. Army Aloha Microgrid 1

- 25 kW Solar Carport
- 5 kW Mobile Solar
- Diesel Generators
- Grid
- 4 Plug in, Bi-directional Electric Vehicles, 6kW/each
- Building Load s

U.S. Army Aloha Microgrid 2

- 25 kW Solar
- 75 kW Diesel Generators
- Grid
- H2 Station Schofield
- 2 Plug-in, Bi-directional Electric Vehicles; 80 mile range w/single charge

Hydrogen Fuel Cell Vehicles

- 10 Hydrogen Fuel Cell Vehicle- GM
- Tri-service H2 Network
- DC
- Energy Storage

Hydrogen Vehicles with Internal Combustion Engines (H2ICE)

- H2 Station JBPHH
- 15 H2ICE vehicles

2004
- Existing CONUS vehicles arrive in Hawaii
- Created the H2ICE network and tested

2008
- 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
- FCV deployed to Hawaii
- U.S. Army Aloha Microgrid 1; In operation in November

2011
- EPTO used by Marines in August 2011
- General Motors Fuel Cell Vehicles; In Operation Starting August 2011
- U.S. Army Aloha Microgrid 2; Planned operational for January 2012

2012
- TARDEC Hydrogen Station; Planned operational for March 2012
- SPIDERS JCTD
It’s All About the Warfighter

Non Tactical Vehicle to Grid Technologies

Vehicle to Grid
- Demo bi-directional power for grid services (HI)
- 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)

Interface standards
- Physical, communication, cybersecurity (SPIDERS – Ft. Carson)
Excellence in Vehicle Mobility & Energy Efficiency

Increasing Demands and Operational Flexibility Require Strategic Investments in Key Areas

- Weight
- Fuel & Power Demand
- Threat

- Up Armored HMMWV
- HMMWV
- MRAP
- JLTV

- Capability
- Ground Combat Vehicle
- Desert
- Urban
- Jungle/Mountains

- Energy Storage
- Power Generation & Control
- Thermal Management
- Track & Suspension

UNCLASSIFIED. Distribution A.
Technology & Energy Efficiency
Drive Excellence