TARDEC Hybrid Electric Program
Last Decade

Gus Khalil
Hybrid Electric Research Team Leader
Ground Vehicle Power & Mobility (GVPM)
Army Hybrid Electric Vehicles

Combat Vehicle Demos

- M113 HE
- Lancer
- AHED 8x8
- Pegasus
- FCS

Technology Base

- Traction Motors
- Energy Storage
- SiC Inverters/Converters
- Pulse Technology
- Alternative Architectures
- Modeling and Simulation

Tactical Vehicles

- HMMWV HE
- FMTV HE
- RSTV
- FTTS
Ground Vehicle Power Needs

Non-Primary Power
- Thermal
- Communications
- Survivability
- Etc...

Mobility

FY02 FY12

Ground Vehicle Power Needs

Non-Primary Power
Estimated Electrical Power Growth

Current
Future

Electrical Power (kw)

JLTV  FCS  Stryker  HBCT  HMMWV

Actual Growth 1995-2007

UNCLASSIFIED: Dist A. Approved for public release
Hybrid Vehicle Challenges

Unprecedented use of emerging technologies never proven in battle field scenarios

• System integration and packaging
   Power densities of components
     Motors, generators, energy storage
     Power electronics

• Thermal management
   Low operating temperature
     Large space claims
     High power demand from the engine/generator

• Silent Watch requirement
   Energy storage shortfalls
   Control strategy and limited power budget

• Onboard Exportable power
   Clean power for Tactical Operating Centers (TOC)
   Power supply from mobile platforms for other applications
Hybrid Electric Component Program

- Traction Motors
- Energy Storage: Li-Ion
- Power Electronics/cooling
- Vehicle tests:
  - ATC
  - AAEF
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<th>FY</th>
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<tr>
<td><strong>Prime Power</strong> kW/kg</td>
<td>0.3</td>
<td>1.5</td>
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<td><strong>Energy Storage</strong> W-hr/kg</td>
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<td><strong>Motors</strong> kW/l</td>
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<td><strong>Power Conditioning</strong> kW/l</td>
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<td><strong>Pulse Power</strong> J/cc</td>
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*Technology Goals*

- **Prime Power**: Engine kW/kg, FY 01 to FY 10.
- **Energy Storage**: Lead Acid W-hr/kg, FY 01 to FY 10.
- **Motors**: Traction kW/l, FY 01 to FY 10.
- **Power Conditioning**: Si dc-dc Converters kW/l, FY 01 to FY 10.
- **Pulse Power**: Capacitors J/cc, FY 01 to FY 10.
Power Electronics

• Thrust is SiC to overcome:
  ➢ Thermal issues
  ➢ Efficiency
  ➢ Low frequency requiring large capacitors
  ➢ Low power density

Approach: Develop power devices using SiC diodes as an interim step
Develop All SiC motor drives and DC-DC converters as the device technology matures

100 kW Si/Si-C hybrid DC-DC converter

All-Si-C motor-drive inverter

SiC PiN Diode Module
The SIL provides capability to accelerate the integration and maturation of critical FCS MGV system technologies in order to meet FCS Performance within the weight and volume constraints.

System Integration into vehicle platform

HOTBUCK platform with FCS hardware
Currently there are no industry or SAE standards for measuring the fuel economy of hybrid vehicles in cross country environments.

**Objectives**

- Develop HEV Test Operating Procedure (TOP) using accepted industry practices and DOE processes
- Determine the fuel economy benefits of hybrid electric vehicles using quantifiable test data
- Develop and Validate TARDEC M&S models

**Testing**

9 conventional and 7 hybrid electric vehicles are being tested

A. Conventional:
- 2 - HMMWVs,
- 2 - 21/2T LMTVs
- 1 - 5T MTV
- 1 – FMTV CVT
- 2 - HEMTTS
- 1 – UV

B. Hybrid Electric:
- 1 – HMMWV
- 1 – RSTV
- 1 - UV
- 1 – UV
- 1 – AH/SS MSV
- 1 – FMTV
- 1 – HEMTT A3
Fuel Economy varies with terrain & driving conditions

Fuel economy comparison on Churchville hilly Terrain

- XM1124 Fuel (Linear Regression)
- M1113 Fuel (Averaged)
- Hybrid HMMWV
- Standard HMMWV

Up to 30% improvement with hybrid HMMWV

Fuel economy comparison on Munson flat paved Terrain

- XM1124 Fuel
- M1113 Fuel (Averaged)
- Hybrid HMMWV
- Standard HMMWV

5 to 17% improvement with hybrid HMMWV
HTUF DOD Tech Model

- Proven process to launch commercial production, focusing on user needs
- Over 80 national fleets, including DOD, involved in process
- Eight National Meetings of top truck OEMs, suppliers, fleets
- First 24 Pre-Production Trucks tested & fielded w/in 3 Years; million miles of experience; directly led to commercial production launch
- Military receiving first in-use hybrid field data from geographically dispersed nationwide deployment
- Six fleet Working Groups active, new Construction Equip Forum launching
- Three additional pilot deployments ready
Energy Storage Requirements & Challenges for Ground Vehicles

Sonya Zanardelli
Energy Storage Team Leader
Ground Vehicle Power & Mobility (GVPM)
There are three distinct requirements for Military Energy Storage:

- **Starting, Lighting and Ignition**
  Batteries provide electric power to start the vehicle power generation (Engines / APUs)

- **Hybrid Vehicle Boost Acceleration and Regenerative Braking Energy Capture**
  In hybrid vehicle powertrains, batteries have the ability to supplement main engine power for burst accelerations.
  In addition, batteries can be used to recover wasted energy in vehicle braking

- **Silent Watch**
  Batteries can provide the energy storage capability to power mission equipment with main engine off while the vehicle is stationary
Energy Storage Team Mission

- Pursue energy storage technology research, development, component test and evaluation for CURRENT and FUTURE ground vehicle fleet

- Identify technology barriers and develop technical solutions

- Provide technical support to customers, other teams and government agencies in all energy storage
Energy Storage Focus Areas

Characterization
- Understand aging mechanism
- Safety limits
- Evaluate and/or develop novel materials (cathode, anode, electrolyte) that promise increased power & energy

Fundamental Understanding & System Development
- Characterize batteries & investigate cell behavior
- Enhanced Battery Management

Manufacturing & Evaluation
- Perform battery and capacitor evaluation testing (charge, discharge and service life testing) for cell, module, and full battery systems at different temperatures and rate.

Ongoing R&D:
- Focused investigations on novel materials (cathode, anode, electrolyte) for increased power and energy & reduced cost
- Develop advanced diagnostic tools and battery management system.
- Develop and apply advanced models for batteries and components
- Advanced battery design techniques
- Advanced battery manufacturing techniques
**Energy Storage**

- Power vs. Energy trade-off design optimization.
- Manufacturing process development and cost control.
- Thermal management.
- Cell & system safety & reliability.
- System control & cell and battery management systems.
- Alternative electrochemical improvements.
- Thermal runaway process and its control.