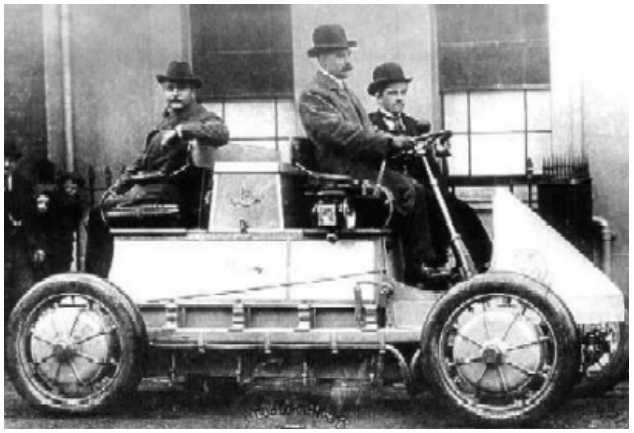
TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

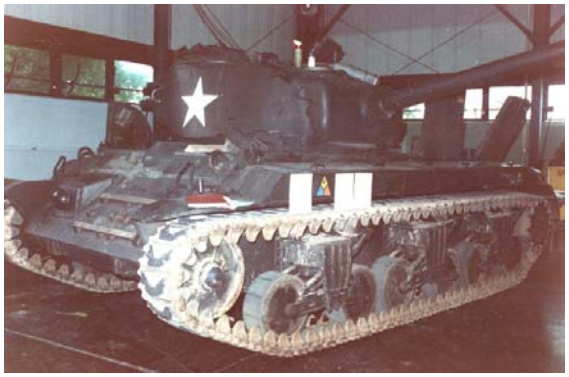
The 5th International IEEE Vehicle Power and Propulsion Conference

Gus Khalil
US Army TARDEC
Hybrid Electric program

Background



1900 Lohner-Porsche
4x4 Hybrid Vehicle



1943 T-23 Electric Drive

1943 Elephant Tank
Electric Drive

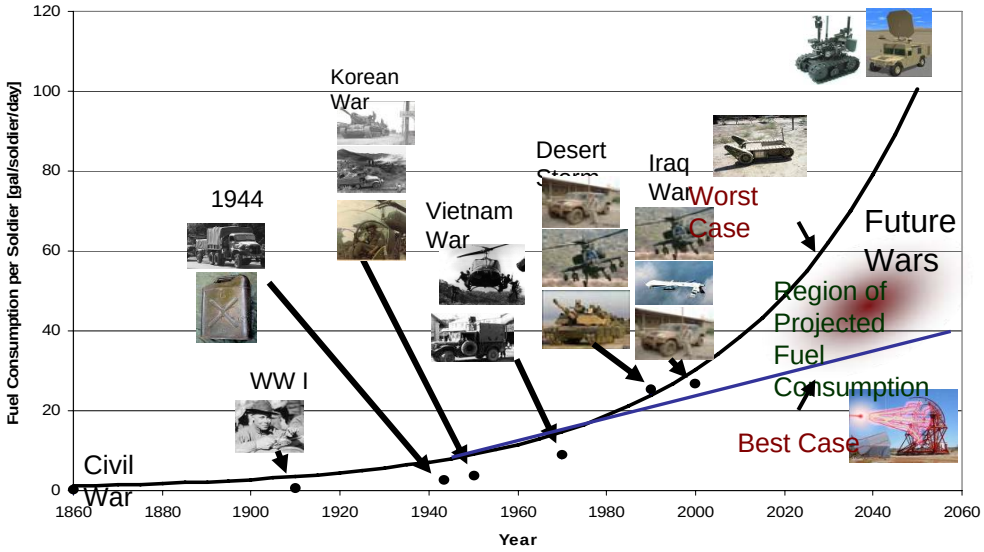
1995 Hybrid HMMWV

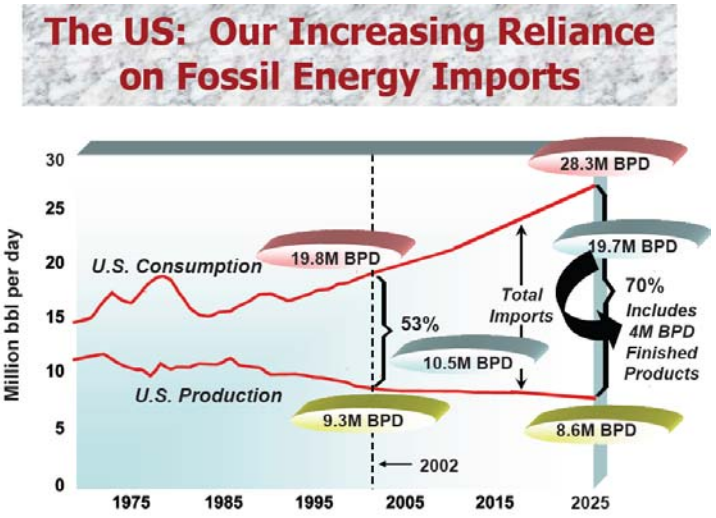
2008 NLOS-C hybrid electric MGV

Power & Energy Trends

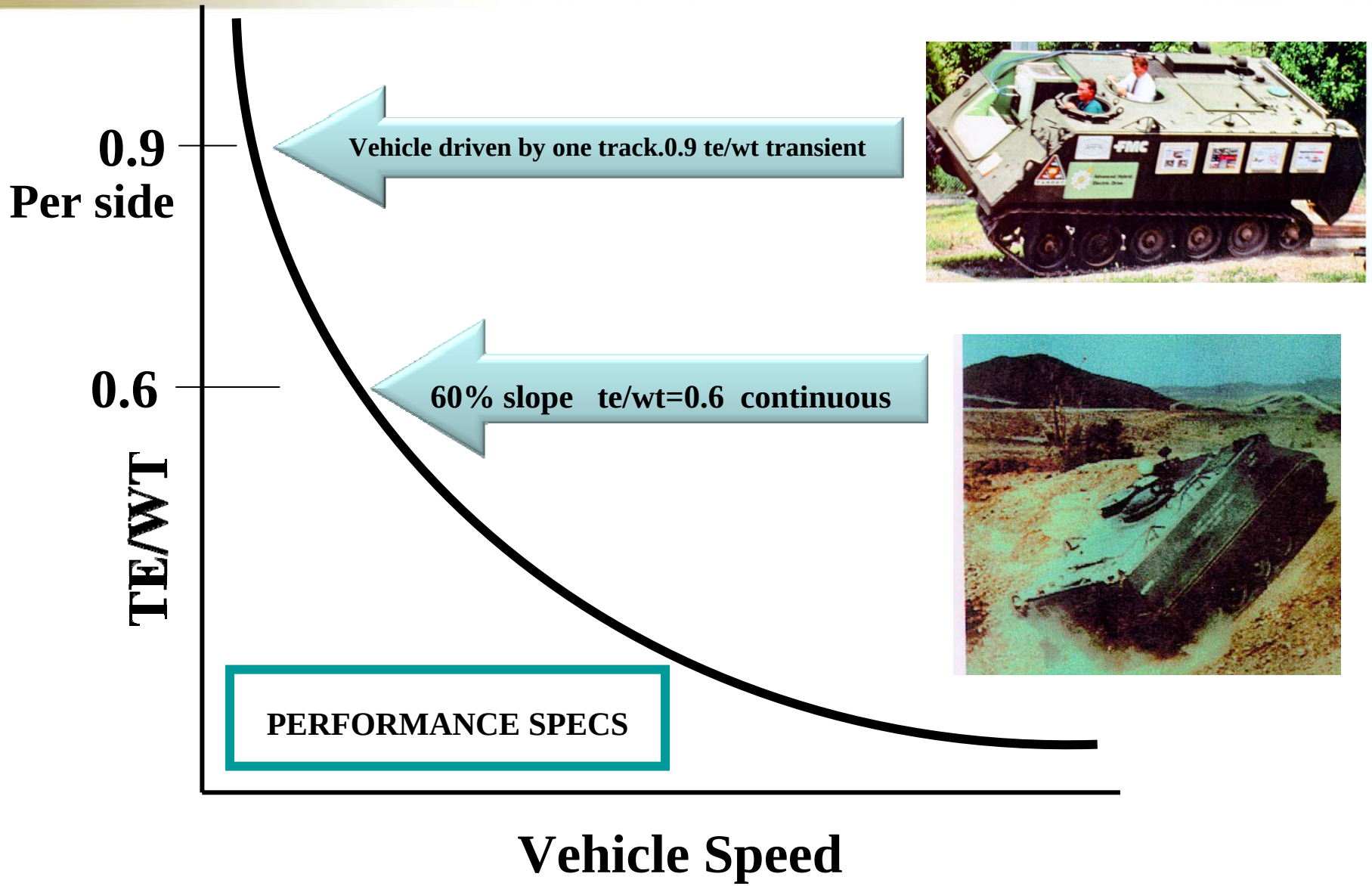
The Challenges

- Battlefield consumption of energy increasing
  - New C4ISR technologies
  - IED Defeat Systems
  - New weapons (EM guns, lasers)
- Energy security problematic
  - Increasing dependence on foreign oil
  - Alternative sources sought – wind, solar, bio-mass, waste to energy
- Operational issues
  - Battery usage & limitations – energy & power density
  - Demand for auxiliary power on-board vehicles
  - Emphasis on silent ("quiet") watch
  - Unmanned vehicles (air/ground)
  - Unattended sensors
  - Inefficient management/ distribution of power
  - Demand for soldier-wearable power
- Increased emphasis on system power metrics (KPPs, low consumption components)





Military Environment



Field Testing

CRTC

Aberdeen

Robust

Environment

Yuma

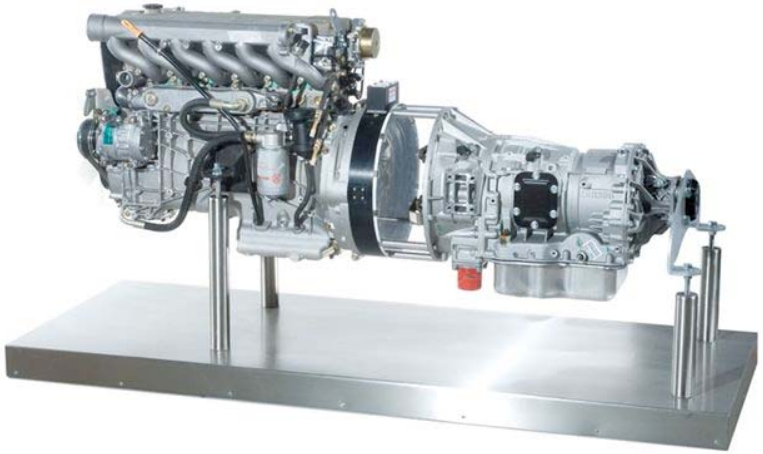
Hybrid Electric Payoffs

- Onboard and Export Power
- Fuel Economy
- Flexibility and Packaging Efficiency
- Synergy with Pulsed Power Loads
- Silent Operations

Onboard and Export Power

Hybrid HMMWV powering a Tactical Operations Center

Onboard power from ISG

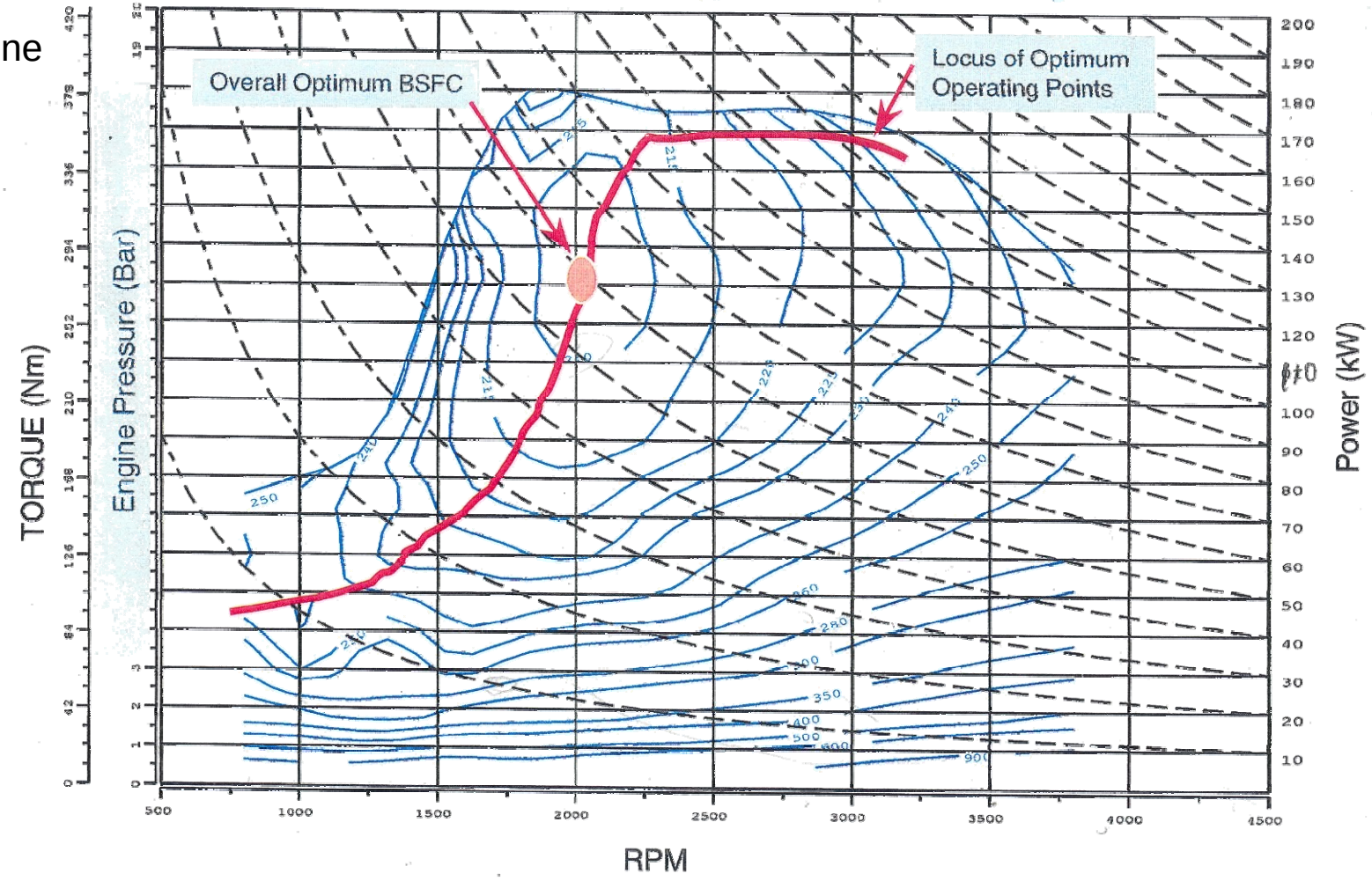


Fuel Economy

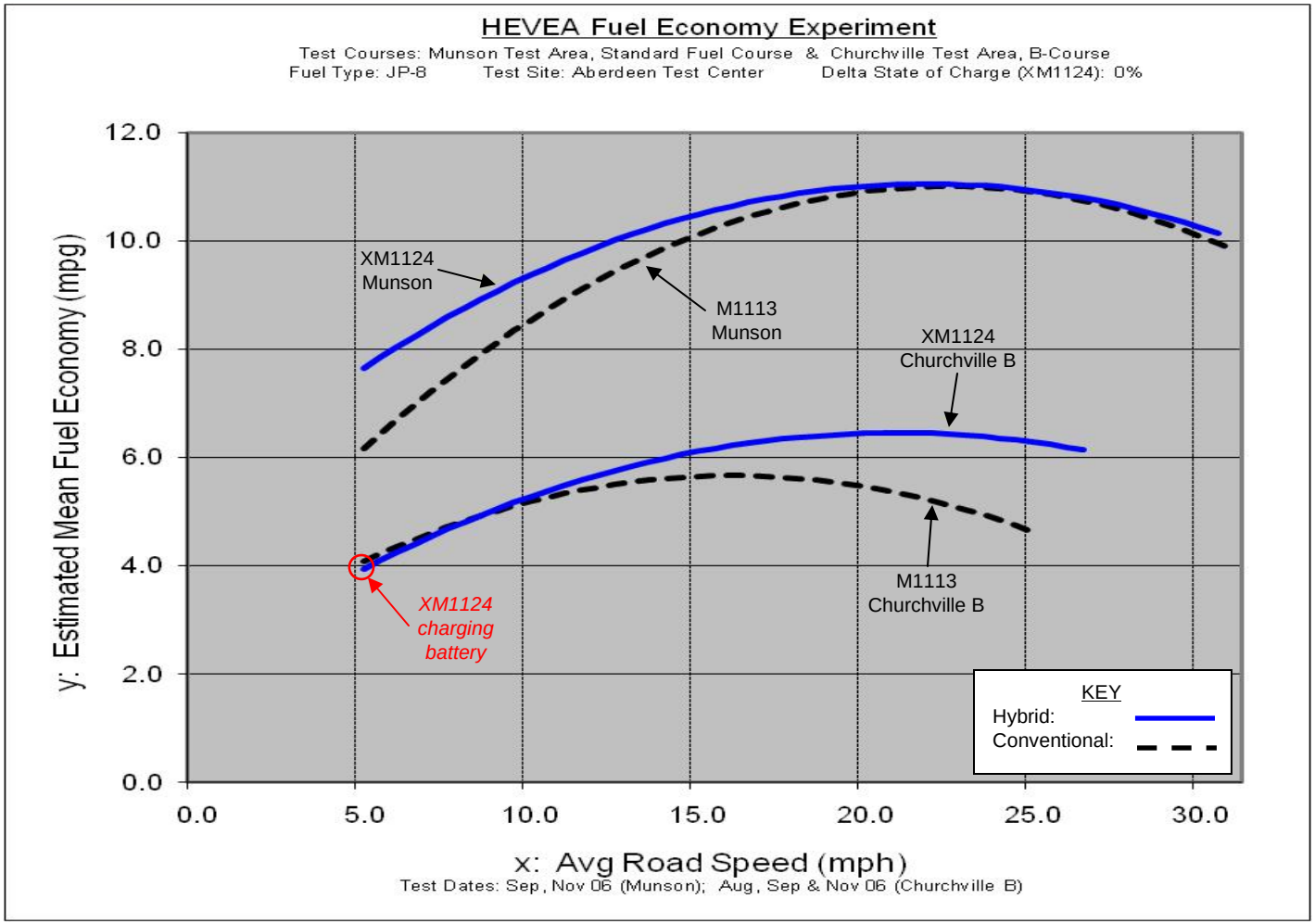
1. Optimized Engine Performance

2. Brake Energy Recovery

Typical Diesel Engine Fuel Map



Fuel Economy Measurements



COURSE DESCRIPTIONS:

Churchville B:
- Hilly cross-country
- Longitudinal grades up to 29%

Munson:
- Improved gravel, paved
- Longitudinal slopes of 5% and 30%

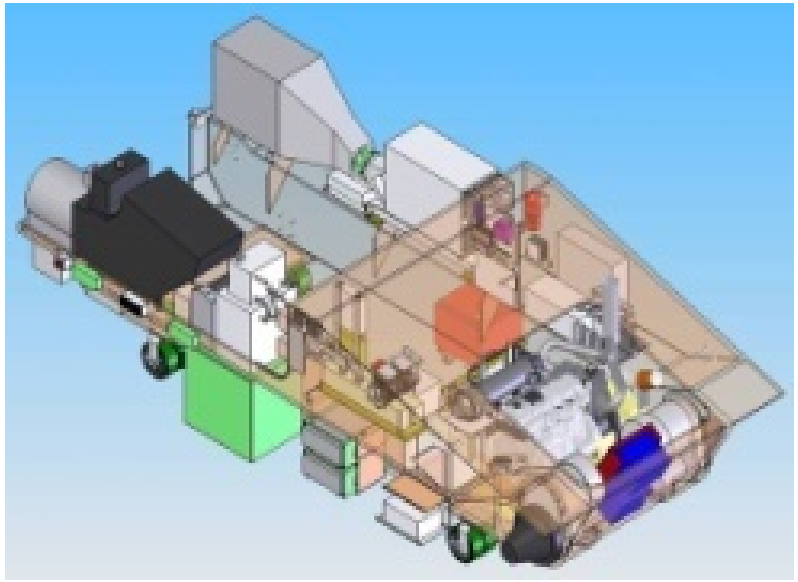
Based on the given statistical models of the test data over the range of speeds, the Hybrid HMMWV showed the following % improvement in Mean Fuel Economy over the Conventional HMMWV:

Munson: 4.2% [Common interval 5.1-30.7 mph]

Churchville B: 10.9% [Common interval 5.1-25.0 mph]

Design Flexibility

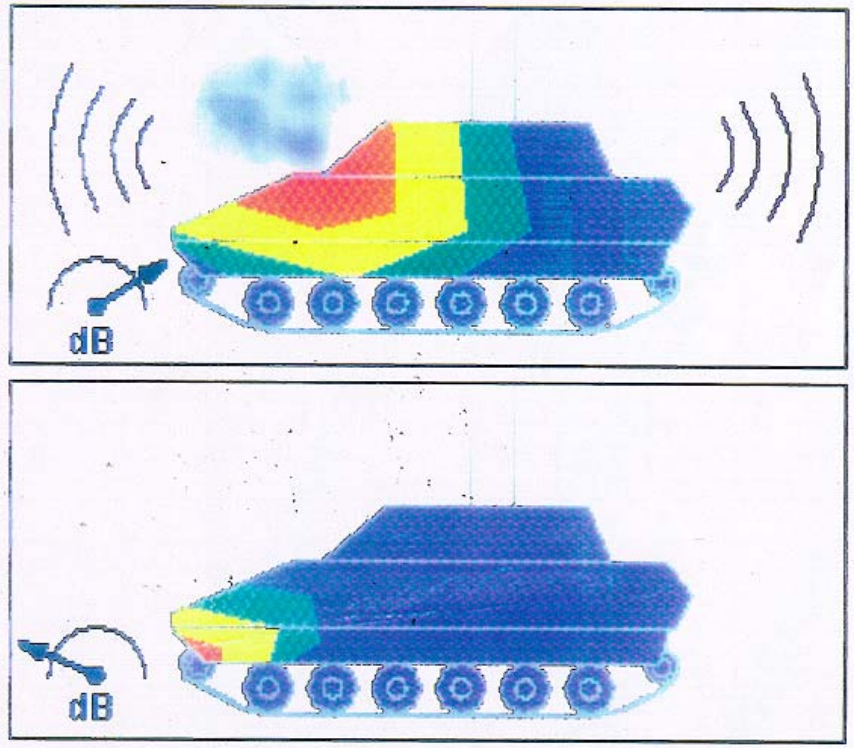
- Most of the connections are wire
- Minimum rigidity
- Modular architecture



Silent Operations

Electric Drive Can Reduce Thermal, Acoustic and Exhaust Signatures

- Stealth operation and true silent watch for extended periods.
- Engine speed independent of vehicle speed — only as fast as needed to meet power requirement.
  - Engine normally runs at lower, more constant speed
  - Tuned exhaust system for improved noise attenuation
  - Reduced exhaust smoke and thermal signature
- Flexibility for configuring the hull frontal shape.
- No hydraulic pump noise from mechanical transmission.
- Lower cooling fan noise.

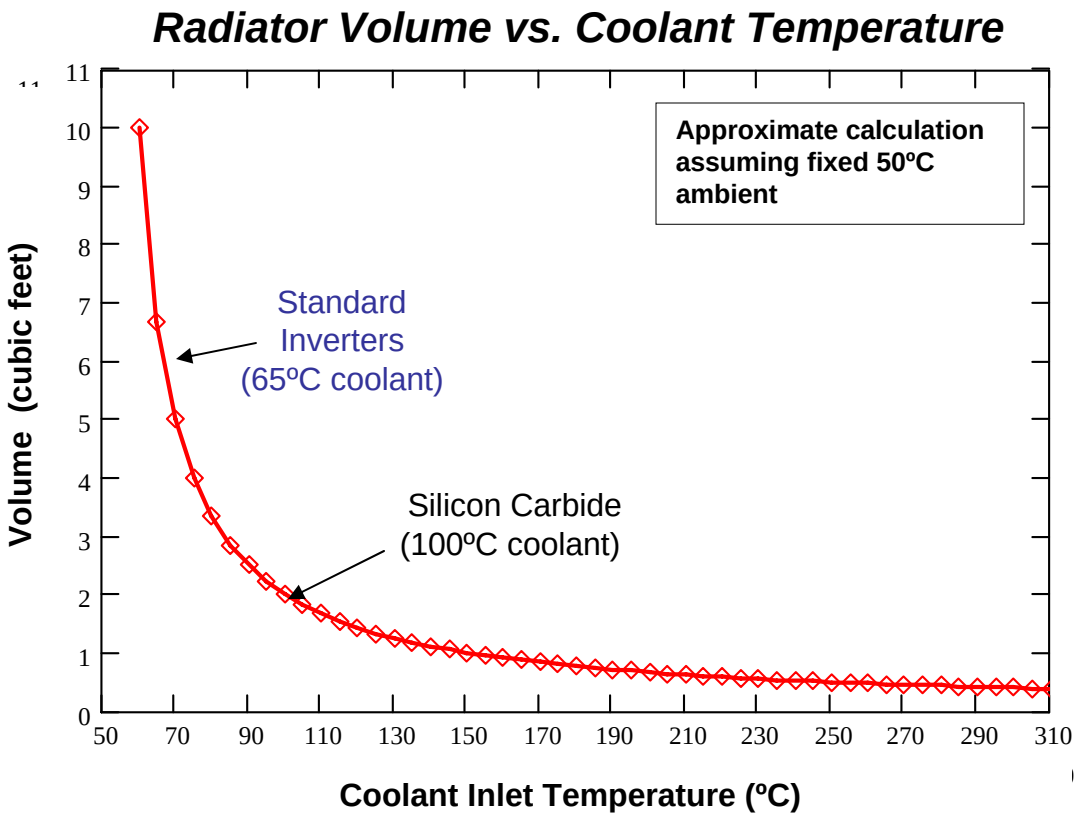


Comparison of conventional (top) and hybrid-electric drive combat vehicles

Challenges

- **Thermal Management**
- **Cooling System Size and Complexity**
- **Power Density and Specific Power**
- **Energy Storage**
- **Reliability**
- **Cost**

Temperature Impact on Cooling System

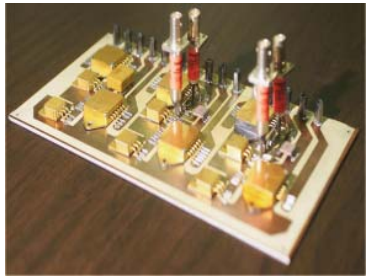


For One 400 kW Traction Inverter

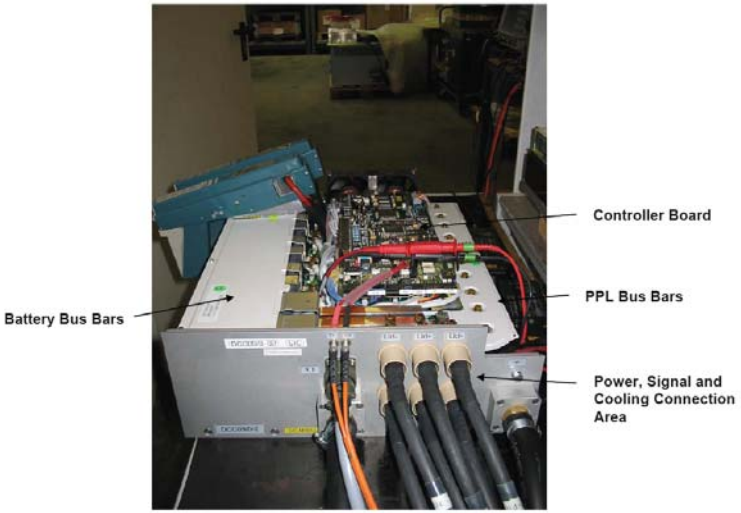
- **70 ºC to 95 ºC => 56% reduction**
- **95 ºC to 130 ºC => 44% reduction**

Approximate Northrop Grumman calculations for 600 shaft hp (about 500-550 kW Inverter)

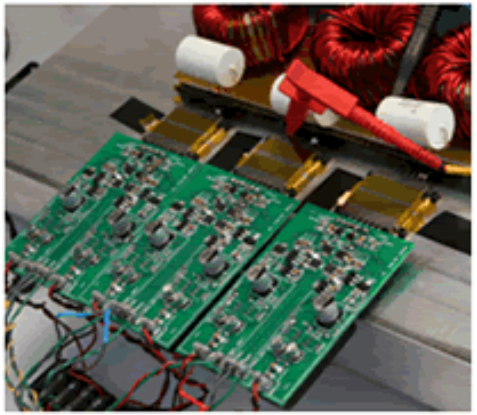
Silicon Carbide Development



SiC Motor Inverter



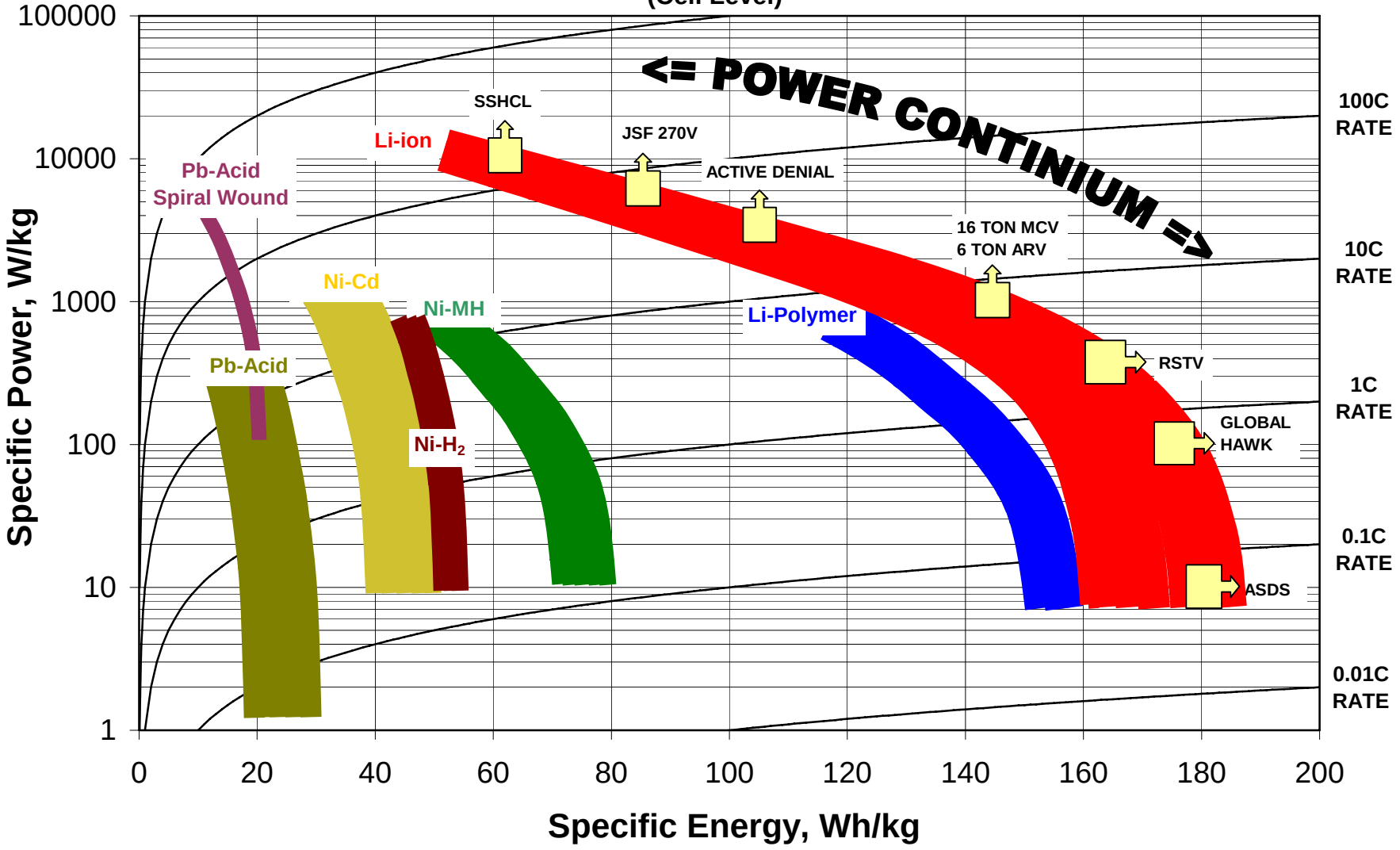
Hybrid Si/SiC Converter



Current SiC Converters (APEI)

- **High junction temperature operation ≥ 175^{0}C**
- **High frequency ≥ 50 kHz**
- **High efficiency**
  - Lower on-state resistance
  - Faster reverse recovery
- **More robust and higher reliability**

Energy Storage



Technology Goals

Prime Power

1.5 kW/kg 0.3

Engine 

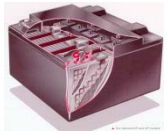
MTU 1 kW/kg

3X

1.5

Energy Storage

200 W-hr/kg 45



Lead Acid

Li-Ion Batteries 

4X

200

Motors

10 kW/l 3

Traction

In-Hub

Field Weakened PM Motor 3X

10

Power Conditioning

6 kW/l 0.75

Si DC-DC Converters 

SiC DC-DC Converter 

6X

6

Pulse Power

2.5 J/cc 0.67

Capacitors

Solid State Output Switch 4X

2.5

Thank you!