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TARDEC Hybrid Electric (HE) Technology Program
5 Feb 2011

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Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
05 FEB 2011	**N/A**	**-**

4. TITLE AND SUBTITLE	
TARDEC Hybrid Electric (HE) Technology Program	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) **Gus Khalil**	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **US Army RDECOM-TARDEC 6501 E 11 Mile Rd Warren, MI 48397-5000, USA**	8. PERFORMING ORGANIZATION REPORT NUMBER **21479RC**
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) **US Army RDECOM-TARDEC 6501 E 11 Mile Rd Warren, MI 48397-5000, USA**	10. SPONSOR/MONITOR’S ACRONYM(S) **TACOM/TARDEC/RDECOM**
	11. SPONSOR/MONITOR’S REPORT NUMBER(S) **21479RC**

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

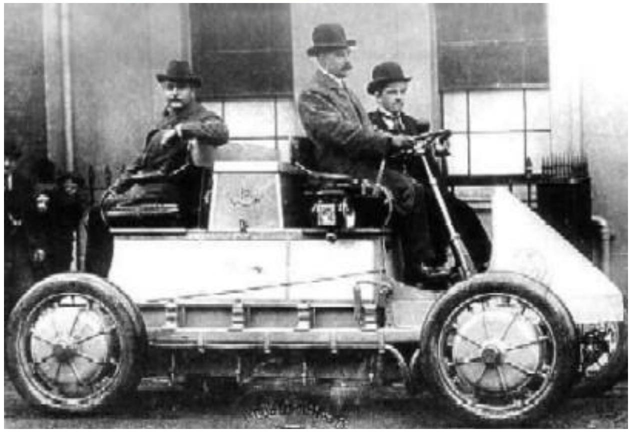
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**SAR**	**62**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Agenda

- Background
- Test Operating Procedure (TOP)
- Statistical Model and data interpretation
- Examples for the Hybrid Electric Vehicle Experimentation and Assessment (HEVEA) Program
- TARDEC hybrid electric program
- Challenges
- Fuel Economy Demonstrator

Background



1900 Lohner-Porsche
4x4 Hybrid Vehicle

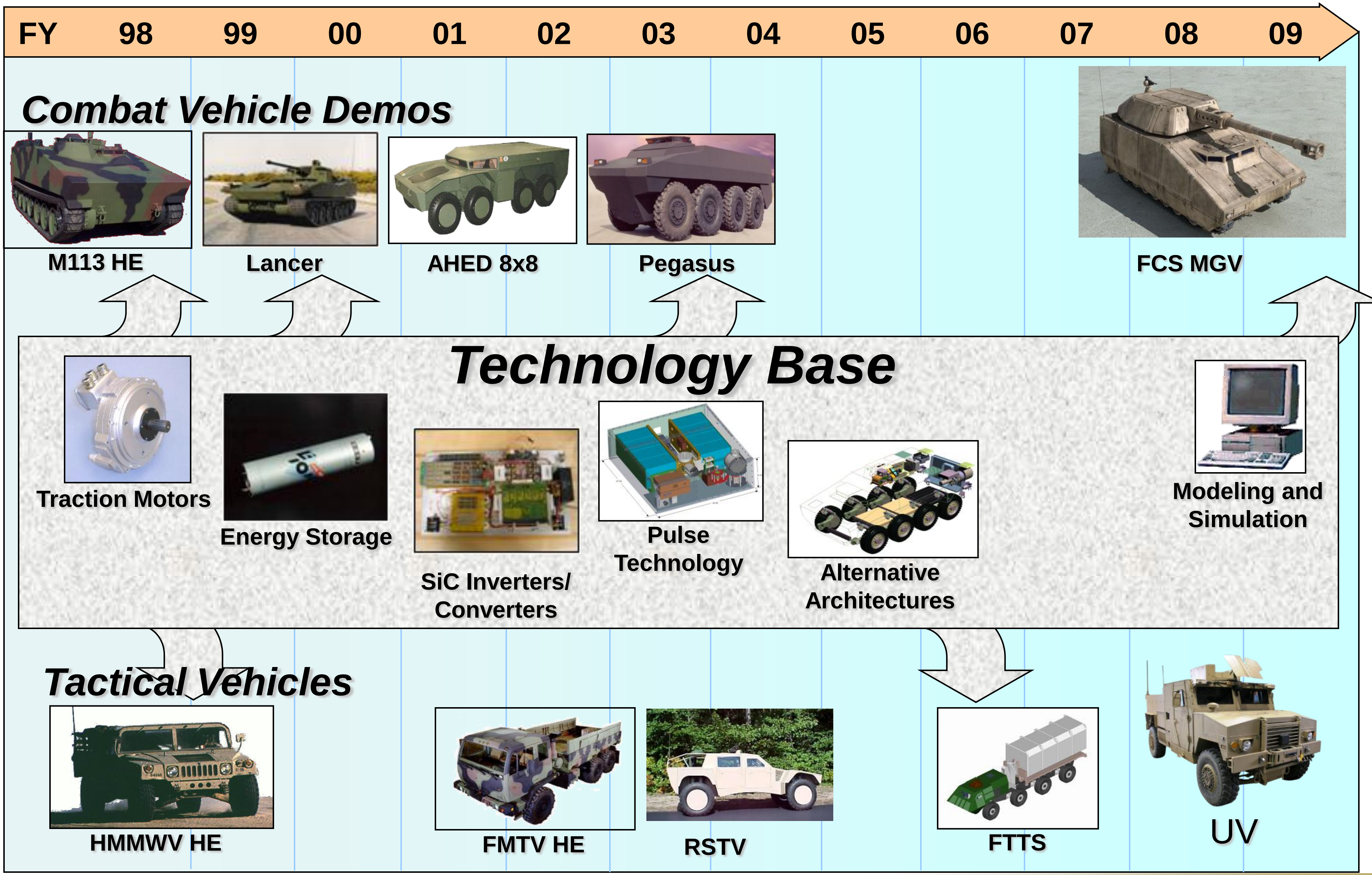
1943 T-23 Electric Drive

1943 Elephant Tank
Electric Drive

1995 Hybrid HMMWV

2008 NLOS-C hybrid electric MGV

Army Hybrid Electric Vehicles



Test Operating Procedure (TOP)

Program Purpose & Objectives

Purpose:

To enhance Tactical Wheeled Vehicle (TWV) mobility for future systems through experimentation, performance analyses and demonstration of Hybrid Electric Vehicle (HEV) capabilities and enabling technologies

Objectives:

- **Baselined fuel economy data and analyses of hybrid electric vehicles**
- **HEV Test Methodology Test Operating Procedure (TOP) using accepted industry practices and DOE processes.**
- **M&S capability to provide a tool to predict hybrid electric drive cycle performance and fuel economy**

HEVEA Fuel Consumption Test Methodology

- The Top defines fuel economy over a spectrum of military terrains and speeds
- Consensus and acceptance of test methodology are sought from government, industry, and academia
- Test data are being used to validate the VPSET models

HEVEA Test Methodology for Evaluating Fuel Economy

- Vehicle Preparation and Preliminary check out Tests
- Definition of Terrains & Test Courses
- Establishment of Hybrid Control Strategy Characteristics
- Test Conduct and methods of measurements
- Expression of Fuel Economy Calculations (Example)
- Development and Revision Process Overview

Test Vehicle Preparation

- **Each vehicle is initially tested to characterize and define its basic automotive performance capabilities.**

- **The tests and parameters to be determined are:**
  - Weight distribution
  - Center of gravity
  - Coast down from maximum road speed
  - Acceleration to maximum road speed
  - Rolling resistance, resistance to tow
  - The Electrical Energy Storage System (EESS) capacity
  - Estimation of frontal area

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Terrains & ATC Test Courses

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Five courses were selected at Aberdeen Proving Grounds. They represent most driving conditions a military vehicle experiences throughout its life cycle

Test Track	Land characteristics	Test	Test Goals	Additional Notes
Perryman – Level Paved road	Flat paved road with 3 mile straight away and banked curve turn arounds	Constant speed of 35, 45, and 55 mph (turn around speed limit ~30mph)	Steady state fuel usage over flat terrain on a paved surface at constant speeds	Performed at Gross Vehicle Weight (GVW) Delta State Of Charge monitored
Munson – Improved Gravel & Paved Road	Level sections connected to 5%, 15% and 30% grades 1.5 miles/lap	Constant speeds starting at 5mp, increasing in increments of 5 mph up to 30 mph	Fuel usage at constant speeds, provides another data point in steady state operation on a standard fuel course.	Performed at GVW. Delta State Of Charge monitored
Perryman- 2 & 3 unimproved Cross Country Roads	Short hills, potholes, sweeping curves and ruts.	Constant speed as dictated by the driver's comfort, i.e. 5-15 mph	Fuel usage at constant speeds on cross country terrain.	Performed at GVW. Delta State Of Charge monitored
Churchville course B – Hilly cross country road	Steep grades up to 29%, terrain is moderate to rough with varied moguls 3.7 miles/lap	Speeds up to 25 mph	Fuel usage at constant speeds on rough terrain and steep grades.	Performed at GVW. Also shows whether the vehicle can negotiate steeper grades and rough terrain.
Harford Loop Public roads	Paved Local Road with grades from 2%-9% 17.1 miles/lap	Speeds up to 30-50mph	Determine paved rolling road fuel consumption with some stop and go due to 1 traffic light and 2 stop signs.	Performed at GVW

Establish Hybrid Control Strategy Characteristics

- **Manufacturer determines selectable modes of operation**
- **Determination of initial high and low SOC for the traction battery**
- **Characterization of energy storage modes for each terrain**
  - Charge Sustaining
  - Charge Depleting
  - Charge Increasing
- **Control strategy – specifics may not be known, but the results are apparent and expressed through test data and observation**
  - Road Speed
  - Fuel Consumed
  - Test Time
  - Change in traction battery energy stored or depleted
  - Other measured parameters

Test Conduct

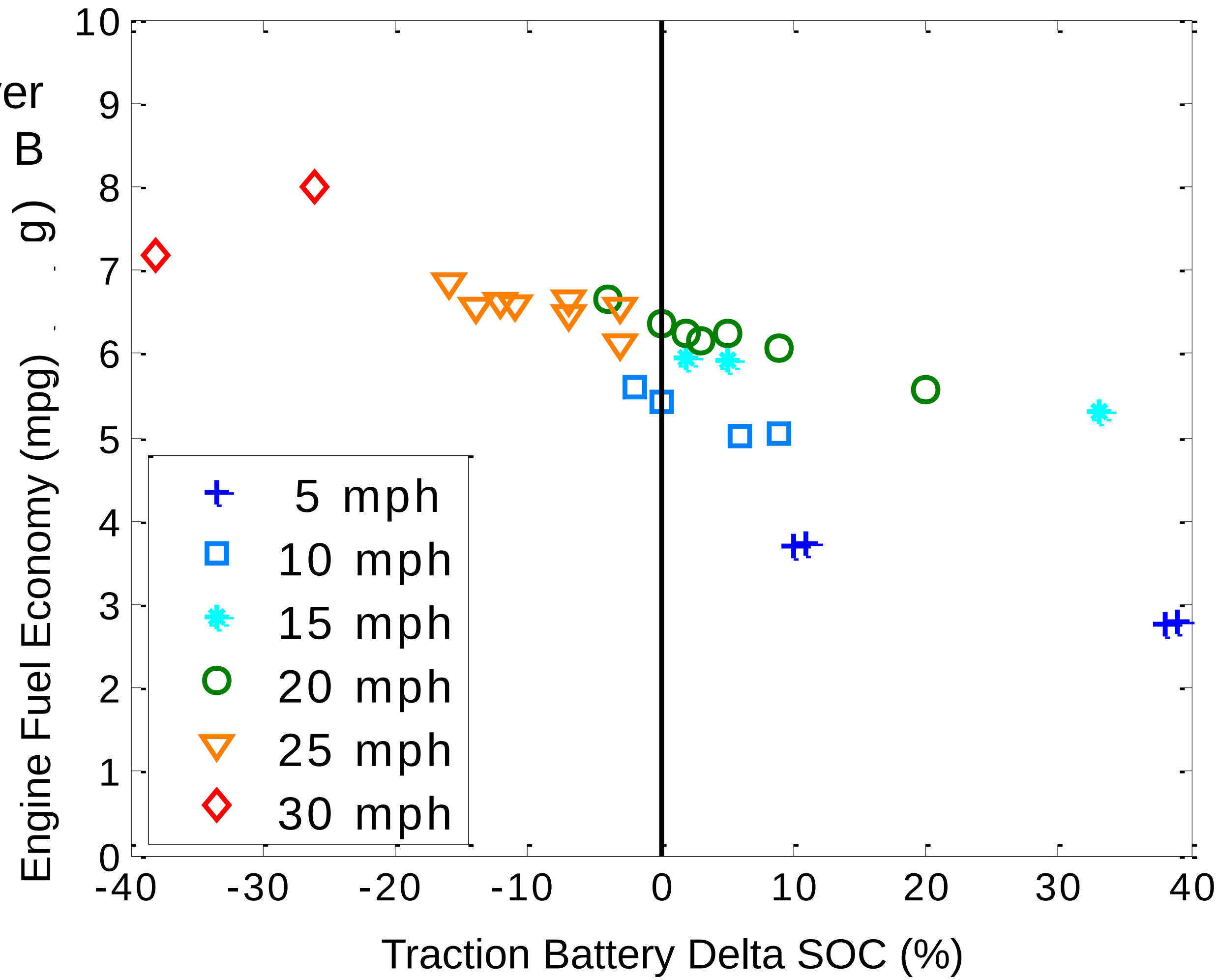
- **Conduct steady state speed test runs at 5 mph increments encompassing entire speed operating range of the vehicle for each terrain**

- **Factors defining operable speed range will include:**
  - Vehicle dynamic stability
  - Ride quality for operator safety
  - Ride quality to prevent damage to test vehicle

- **Test Data:**
  - Engine Fuel Economy (mpg)
  - Delta State of Charge (SOC)
  - Average Road Speed (mph)

Fuel Economy versus Traction Battery State of Charge

XM1124 over Churchville B



- 5 mph incremental road speeds
- Varying initial SOCs

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TOP's Used for HEVEA Testing

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HEVEA Sub-Test	ATEC Test Operations Procedure
Fuel Consumption	TOP 2-2-603
Initial Inspection	TOP 2-2-505
Physical Characteristics	TOP 2-2-500
Center of Gravity	TOP 2-2-800
Weight Distribution	TOP 2-2-801
Acceleration; Maximum Speed	TOP 2-2-602
Braking	TOP 2-2-608
Coast down	TOP 2-2-605
Towing Resistance to Motion	TOP 2-2-605
Drawbar Pull	TOP 2-2-604
Electrical Export Power	MIL-STD-705

Statistical Modeling Overview

Statistical Modeling Methodology

- Derived from ATC test data
- Uses regression analysis methodology to determine a functional relationship between mean fuel economy, average road speed and ΔSOC
  - Estimates mean fuel economy at $\Delta SOC = 0$ for feasible speed and terrain combinations
- Rigorous analysis which includes steps to insure model is good (i.e., not just number-crunching reams of data without human expertise applied)
- Review results as a team to make sure results make sense, are physically possible

Statistical Modeling Benefits

Enables:

- **Graphical/visual representation of relationship between mean fuel economy and average road speed**
  - **Aids in the understanding of the voluminous test data generated**
  - **Helps greatly with interpreting results**
- **Determination of precision of mean fuel economy estimates**
- **Standard statistical methodologies are available to validate the model**
- **Calculation of % improvement in fuel economy for pairings of hybrid electric vs conventional vehicles on test courses**
- **Interpolation of fuel economy at intermediate speeds within range**
- **Substantiation of accuracy of VPSET output through the use of confidence intervals**

STATISTICAL MODELING IS A CRUCIAL INTERMEDIATE STEP IN CONNECTING THE VPSET OUTPUT TO THE RAW TEST DATA INPUT

Relationship Between: Test Data, Statistical Modeling, and M&S

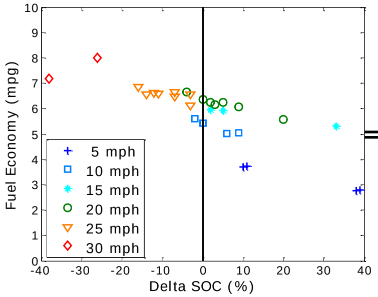
ATC Test Data

Run test vehicles over courses

Data base from vehicle tests

Speed (mph)	Δ SOC	Fuel (mpg)
10.10	9.00	5.04
10.30	0.00	5.43
15.10	33.00	5.32
19.20	-4.00	6.65
19.60	20.00	5.57
27.70	-26.00	8.00

(Representative subset of data)



Determine additional test requirements

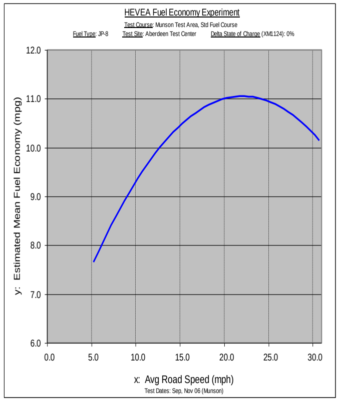
Feedback

Regression analysis

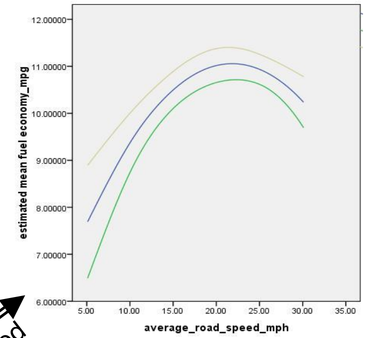
TARDEC Statistical Modeling

Predictive statistical models:
- Derived from test data
- Estimated Mean Fuel Economy = fn (Avg Road Speed, ΔSOC)

Graphical representation of statistical models

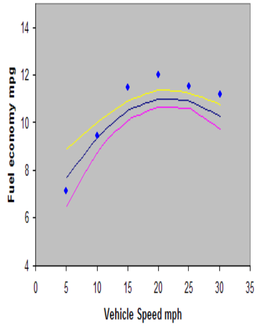


Confidence intervals (upper & lower bounds)



TARDEC M&S (VPSET)

M&S models:
- Derived from engineering & physics principles
- Investigates detailed component performance (from test data)
- Estimates mean fuel economy



VPSET output compared with confidence intervals

- End product - quantified fuel economy for given vehicle / terrain profile
- Relates to OMS/MP

NOTE: All efforts contribute toward the TOP Development for HEVs

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Examples from the HEVEA test data

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Test Vehicle Matrix

TARDEC

Project 2006-DT-ATC-ARSPT-D2644

Hybrid Electric Fuel Economy Methodology Study

26 Jun 08 -- Original Study Vehicles (1 of 2)

		Fuel Consumption Tests								Performance Characterization Tests								
Wt Class	Vehicle	CTA B-Course	Harford Loop	Idle Fuel	MTA SFC	PTA 2&3	Road Load	Full Load, Drawbar Pull	24V Electrical Load	Acceleration	Braking	Coastdown & Regen Braking	Electrical Energy Storage System	Physical Characteristics	Resistance to Motion	Roadway Simulator	Export Power	Vehicle ID #
L	HMMWV M1113	C√	C√	C√	C√	C√	C√	C√	C	C	C	C	NA	C	C	NA	NA	HV-13
L	HMMWV M1152 Up-Armored	C√	C√	C√	C√	C√	C√	C√	C	C	NA	C	NA	C	C	NA	NA	HV-52
L	HMMWV XM1124	C√	C√	C	C√	C√	C√	C√	C	C	C	C	C	C	C	C	C	HE-2
L	RST-V GDLS	C√	C-I	C	C√	C-I	C	C	C	C	C	C	C	C	C	NA	C	RSTV-3
M	FTTS UV AM General				C√											NA		AMG-1
M	FTTS UV International MG	C√	C√	C-I	C√	C√	C√	C√	C	C	C	C	PC	C	C	NA	C	INT-1
M	FTTS UV Lockheed Martin	C√	C√	C	C√	PC	C√	C	C	C	C	C		C		NA		LM-1
M	LMTV, 2.5T LSAC, M1078															NA	NA	LSAC-L
M	LMTV, 2.5T/FMTV M1078 LMTV	C√	C-I	C√	C√	C-I	C√	C√	C	C	C	C	NA	C	C	NA	NA	ESL-1
M+	HEMTT A3 OTC Uparmored	C√	PC	C	C√		C√	C	C	C	C	C		C	PC	NA	C	HA-3
M+	HEMTT A2 Up-Armored	C√	PC	C√	C√		C√	C	C	C	C	C	NA	PC	C	NA	NA	HA-2AC
M+	HEMTT A2	C		NA	C		C	NA	NA	C	NA	C	NA	C	NA	NA	NA	HA-2
M+	HEMTT A4 (a)												NA			NA	NA	HA-4
M+	FMTV CVT BAE, 2.5T LMTV	NA		C	NA	C	C	NA	C	C	C	C	NA	C	NA	NA	NA	CVT
M+	FMTV M1084 MTV	C√	C√	C√	C√	C√	C√	C√	C	C	C	C	NA	C	C	NA	NA	ESMC-1
M+	FMTV HE BAE Systems M1086	C√	C√	C√	C√	C√	C√	C√	C	C	C	C		C	C	NA	NA	BAE
M+	FTTS MSV BAE	C-R	C-R	C	C	C	C	C	C	C	C	C		C	C	NA	PC	MSV-1

NOTES: AMG-1: Initial inspection conducted 24 Jun; front struts will have to be charged, or replaced and charged. HA-3: Vehicle expected to return to ATC the week of 7 Jul. CVT: Safety approval paperwork expected in hand by 27 Jun, after which testing on Harford Loop will be conducted.

KEY / NOTATIONS:

Note: All pairings are part of this study, other than those designated "NA"

(a) = Awaiting response on availability to test

C = Testing Complete

PC = Testing Partially Complete

NA = Not Applicable

* = Updated from previous report

(green) = ALL testing & statistical models complete

√ = Statistical model complete

-I = Insufficient data for statistical model

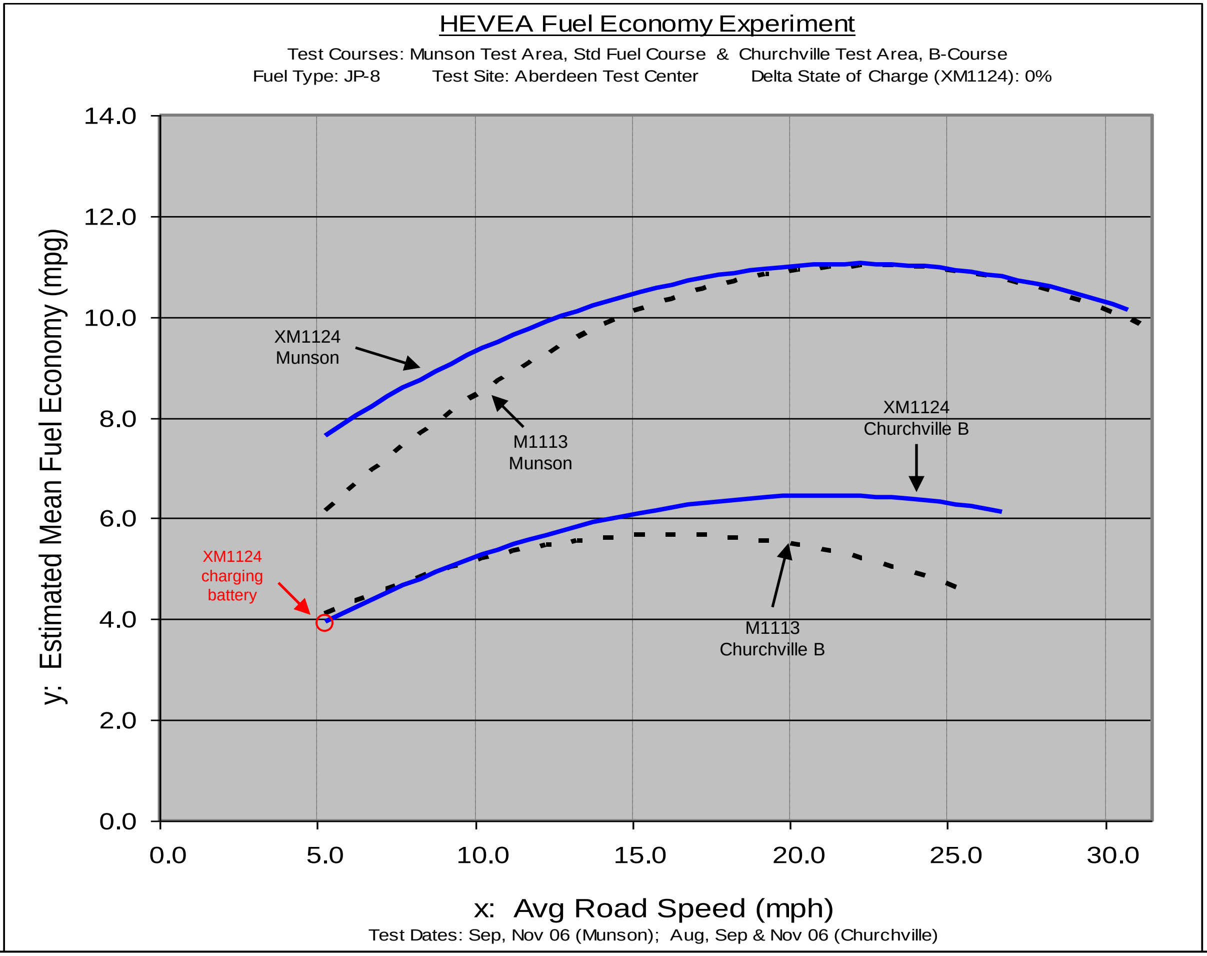
-R = Test runs to be repeated if possible

Statistical Models for Conventional & HE HMMWVs -- Munson & Churchville B

MUNSON (Improved gravel, paved):
- **Hybrid 4.2% improvement over Conventional (averaged over common speed range)**

CHURCHVILLE B (Hilly cross-country):
-**Hybrid 10.9% improvement over Conventional (averaged over common speed range)**

Key Test Vehicle Characteristics	M1113	XM1124
Type	Conv Mech	Series Hybrid
Test wt (lbs)	11,500	11,500
Engine	6.5L Turbo 190 hp	2.2L Turbo 139hp
Battery capacity	N/A	15 kWh Li Ion
On-bd pwr (DC)	5.6 kW	2.8 kW
Export pwr (AC)	N/A	30 kW



Notes:

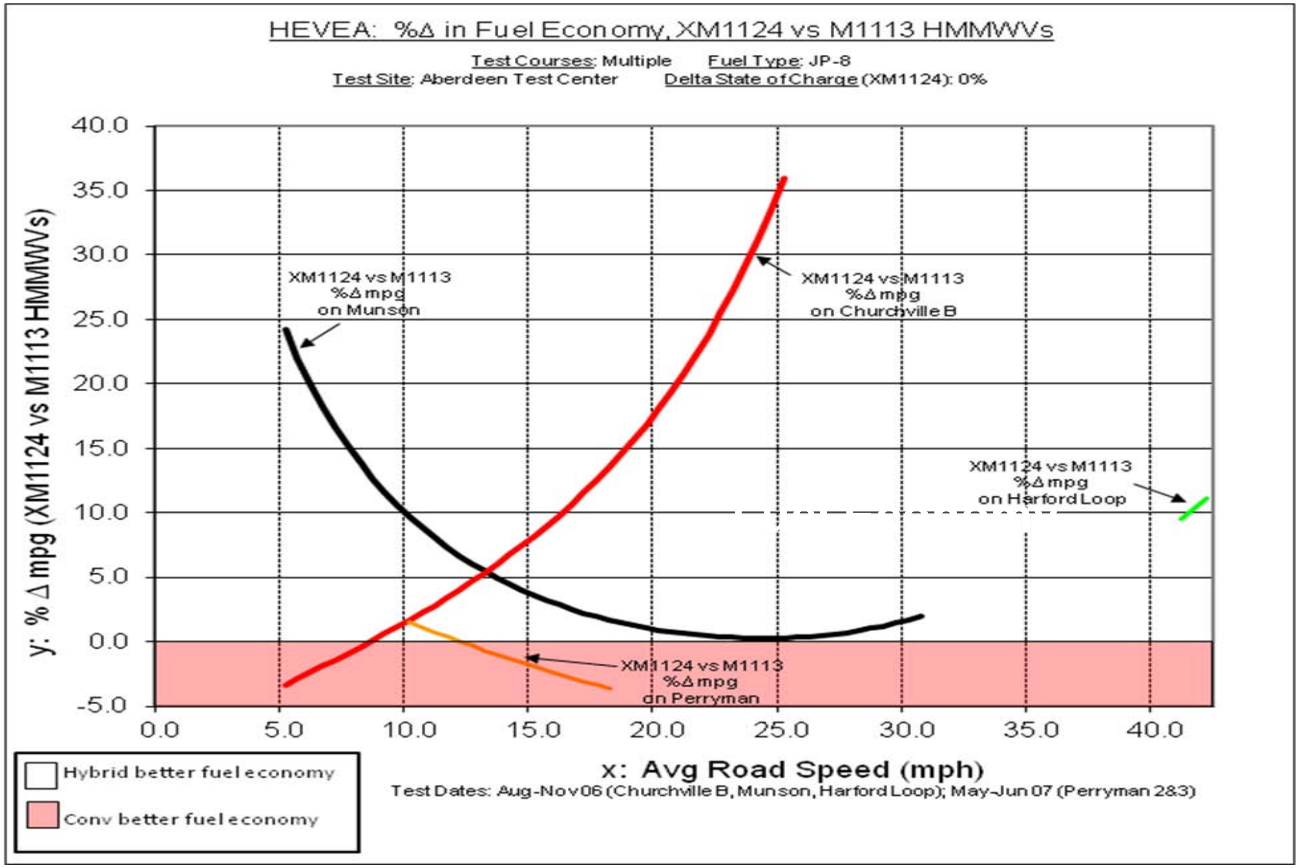
-The hybrid HMMWV provides a significant amount of silent watch capability

-HE does better on Munson up to 20 mph because the efficiency gain in the electric drive system is higher at low speeds; at >20 mph, there is an increased cooling load on the hybrid, which allows the mechanical drive to be more efficient. The hybrid does better up to the first 5 mph because there is a great deal of loss due to the hydrokinetic transmission in the conventional vehicle that the hybrid vehicle does not experience. After the torque converter locks up, conventional drivetrain efficiency improves significantly.

-The HE system demonstrates more benefit on Churchville B due to the hilly terrain. The system captures energy on downhill runs (regen) and can use the energy on uphill runs. At low speeds the hybrid electric is using all of the power from the battery and engine to make it up the hill, then using fuel and the engine to charge the battery. At higher speeds, the hybrid system reaches steady state and becomes more efficient.

Improved Fuel Economy

Hybrid Electric Vehicle Experimentation and Assessment (HEVEA) Program

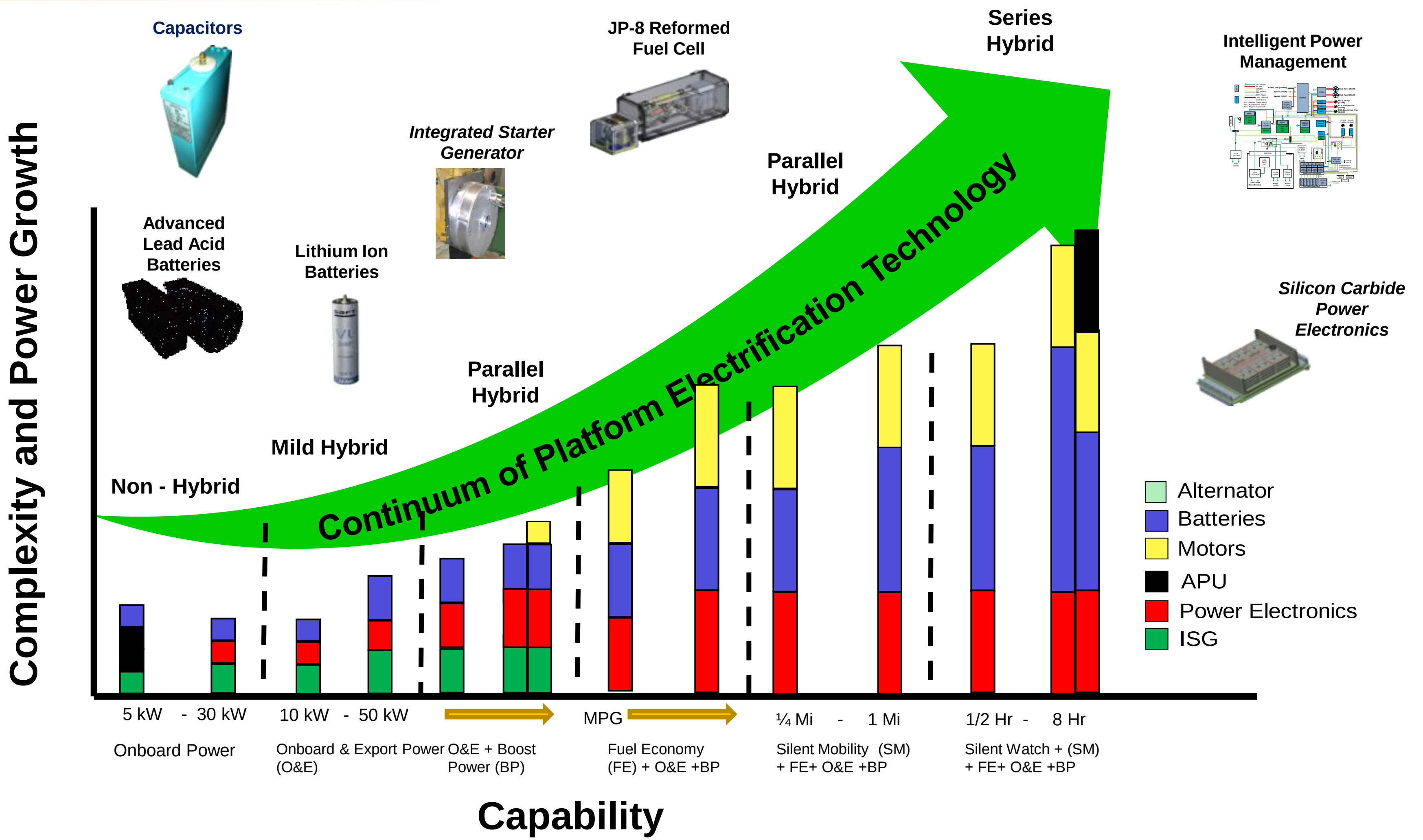


HMMWV Series HE

Hybrid Electric Drive HMMWVs demonstrated a 4.2 – 10.9% Fuel Economy Improvement over various military courses under HEVEA program.

TARDEC Hybrid Electric Program

Platform Electrification Technologies

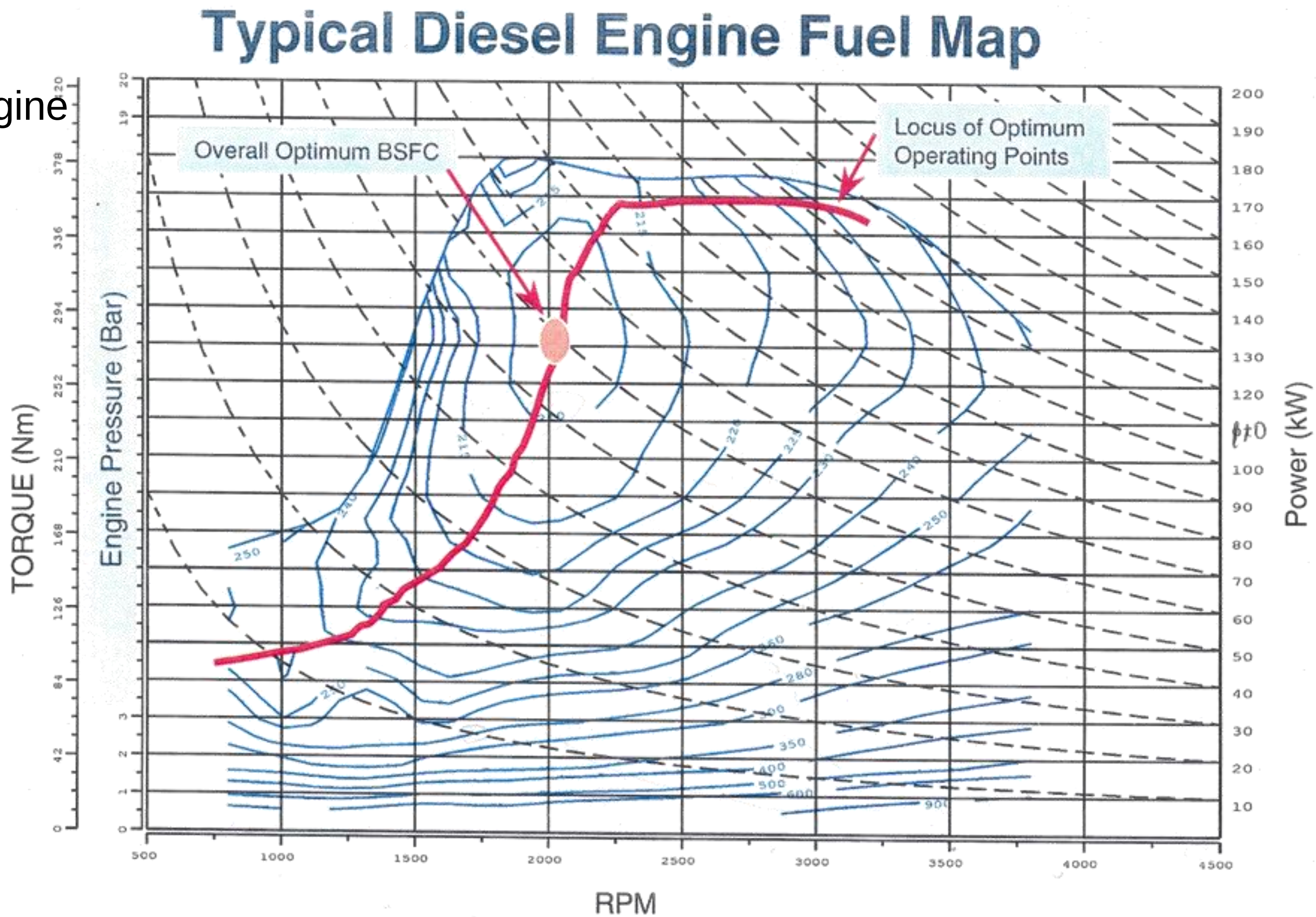


Hybrid Electric Drive Configurations Can Vary to Fulfill Desired Capability

Fuel Economy

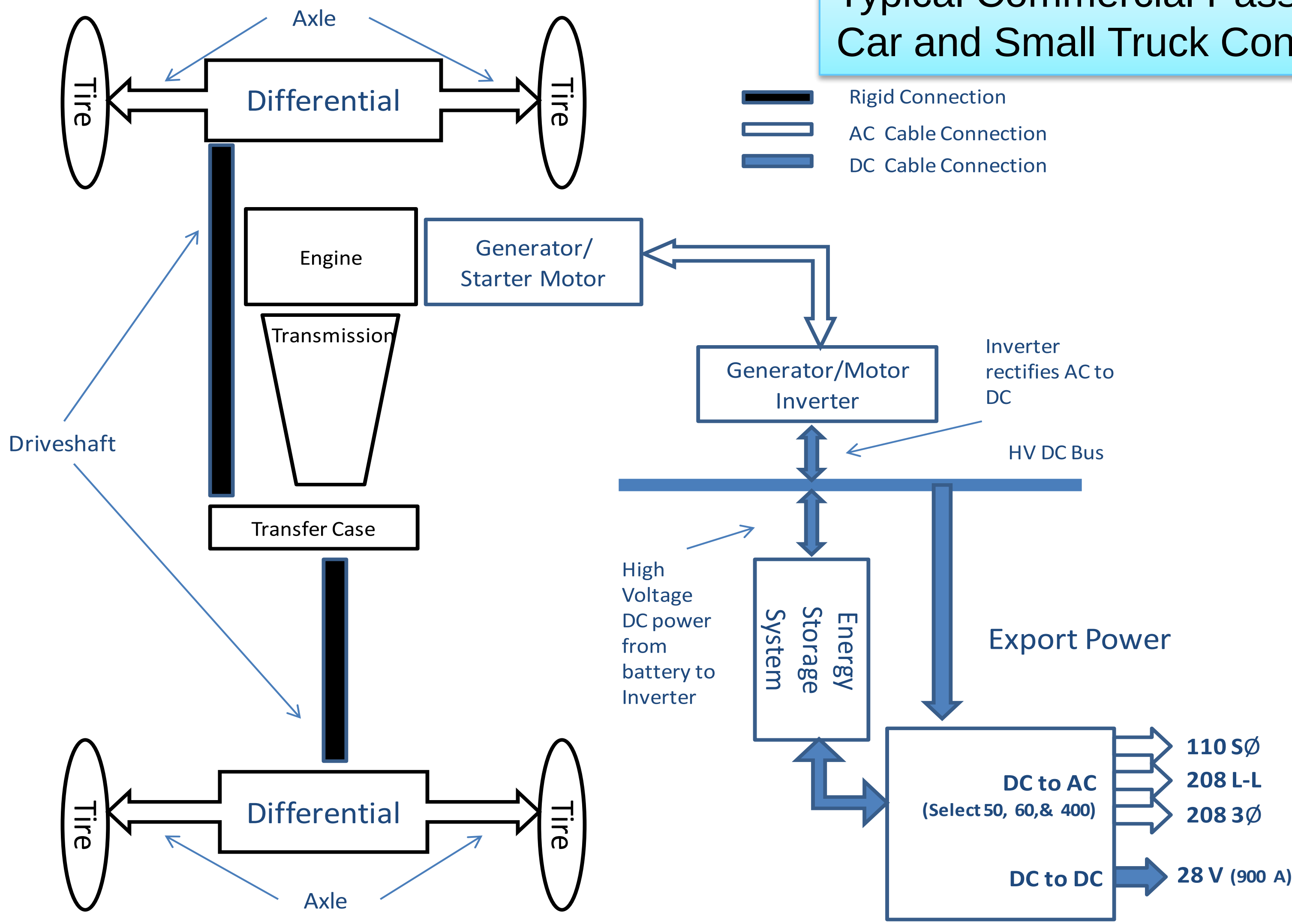
1. Optimized Engine Performance

2. Brake Energy Recovery



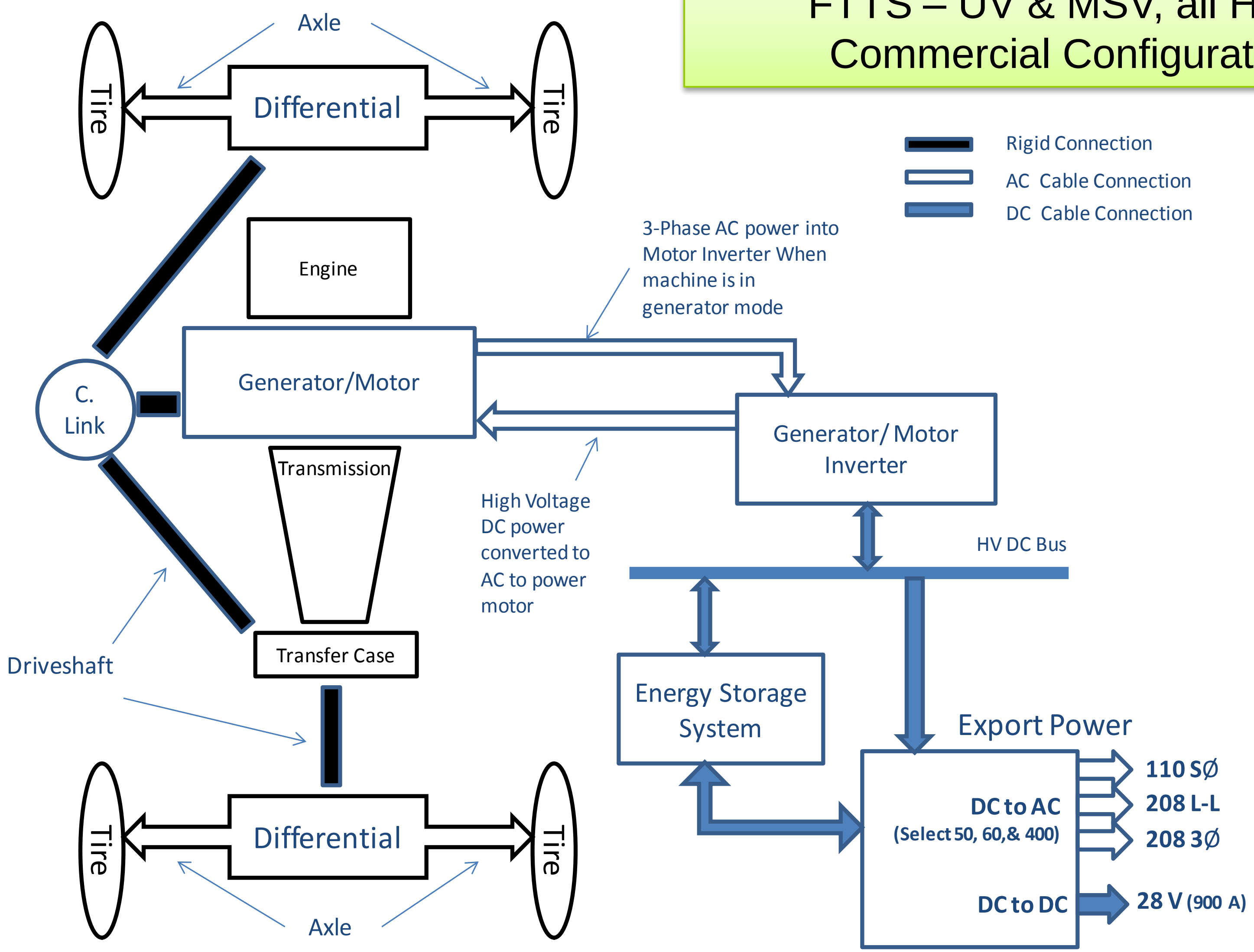
Mild Hybrid Electric Drive Propulsion

Typical Commercial Passenger Car and Small Truck Configuration



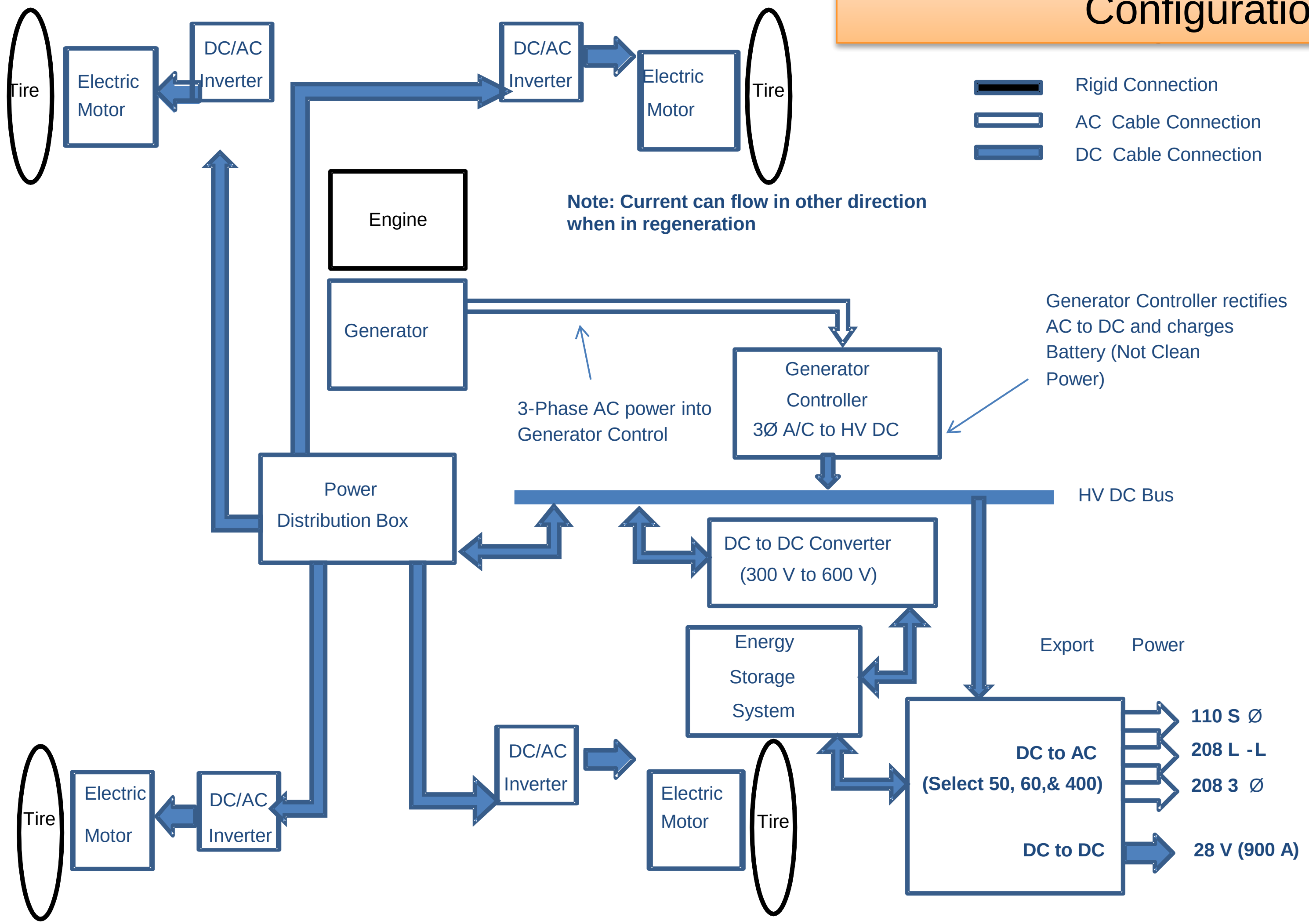
Parallel Hybrid Electric Drive Propulsion

FTTS – UV & MSV, all Honda Commercial Configurations



Series Hybrid Electric Drive Propulsion

AGMV, RSTV, and FCS - MGV Configuration



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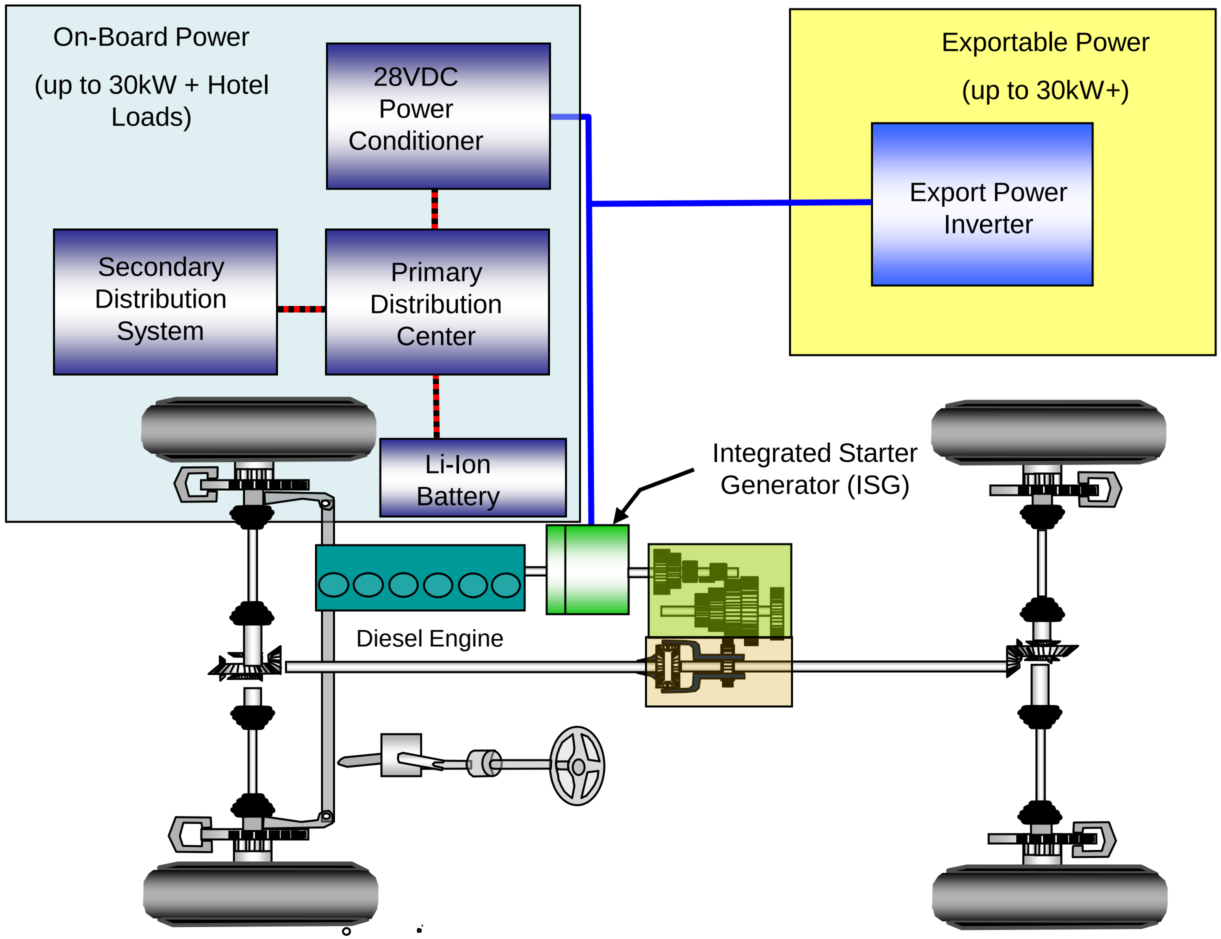
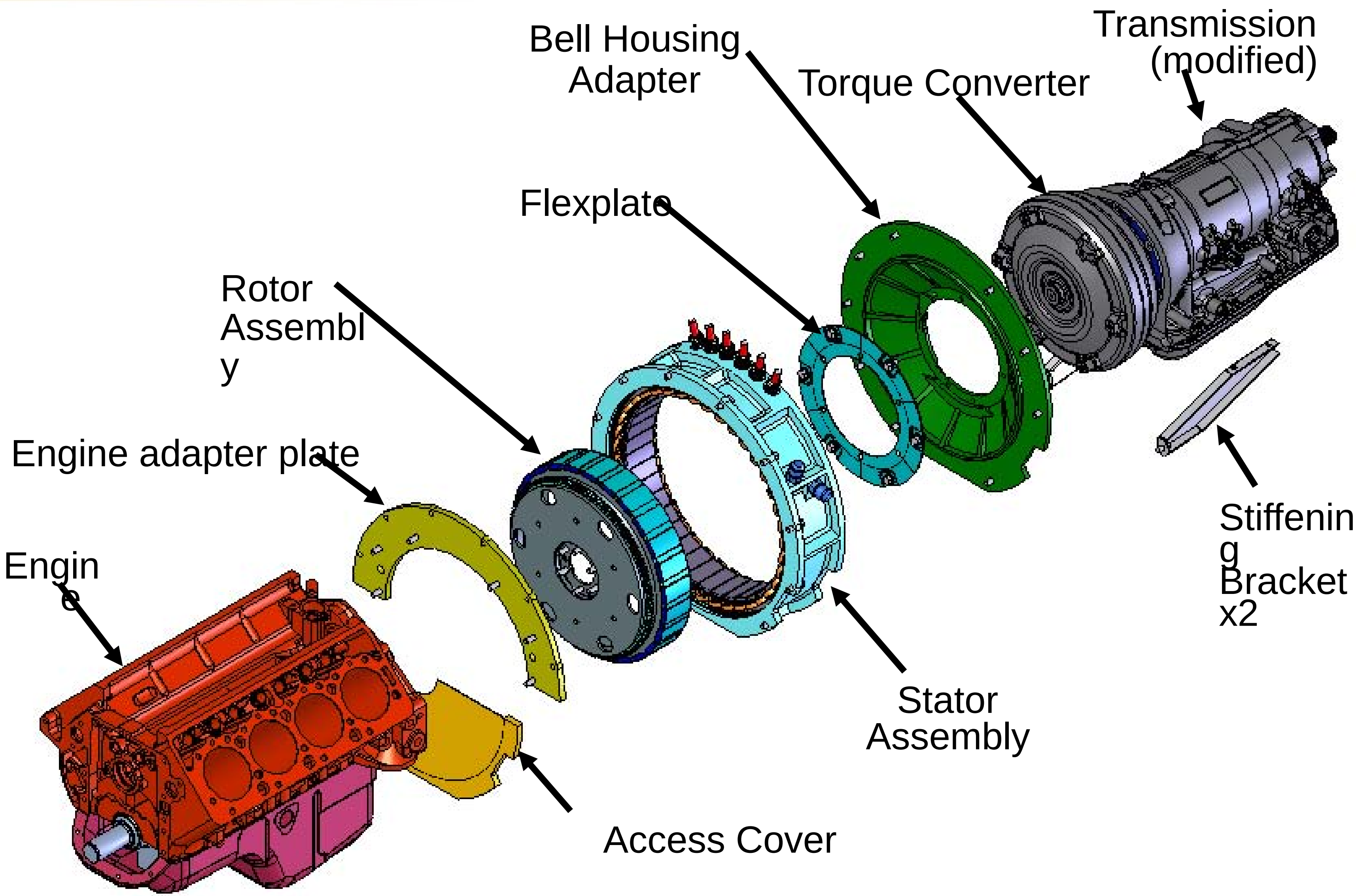
Military TWV Application
Joint Light Tactical Vehicle (JLTV)



Typical JLTV Architecture configured to satisfy Vehicle Power Generation Requirements

Engine/Generator/Transmission Assembly



Challenges

Technical challenges

Power electronics operating temperature and space claim

Integration issues related to thermal management

Unproven reliability

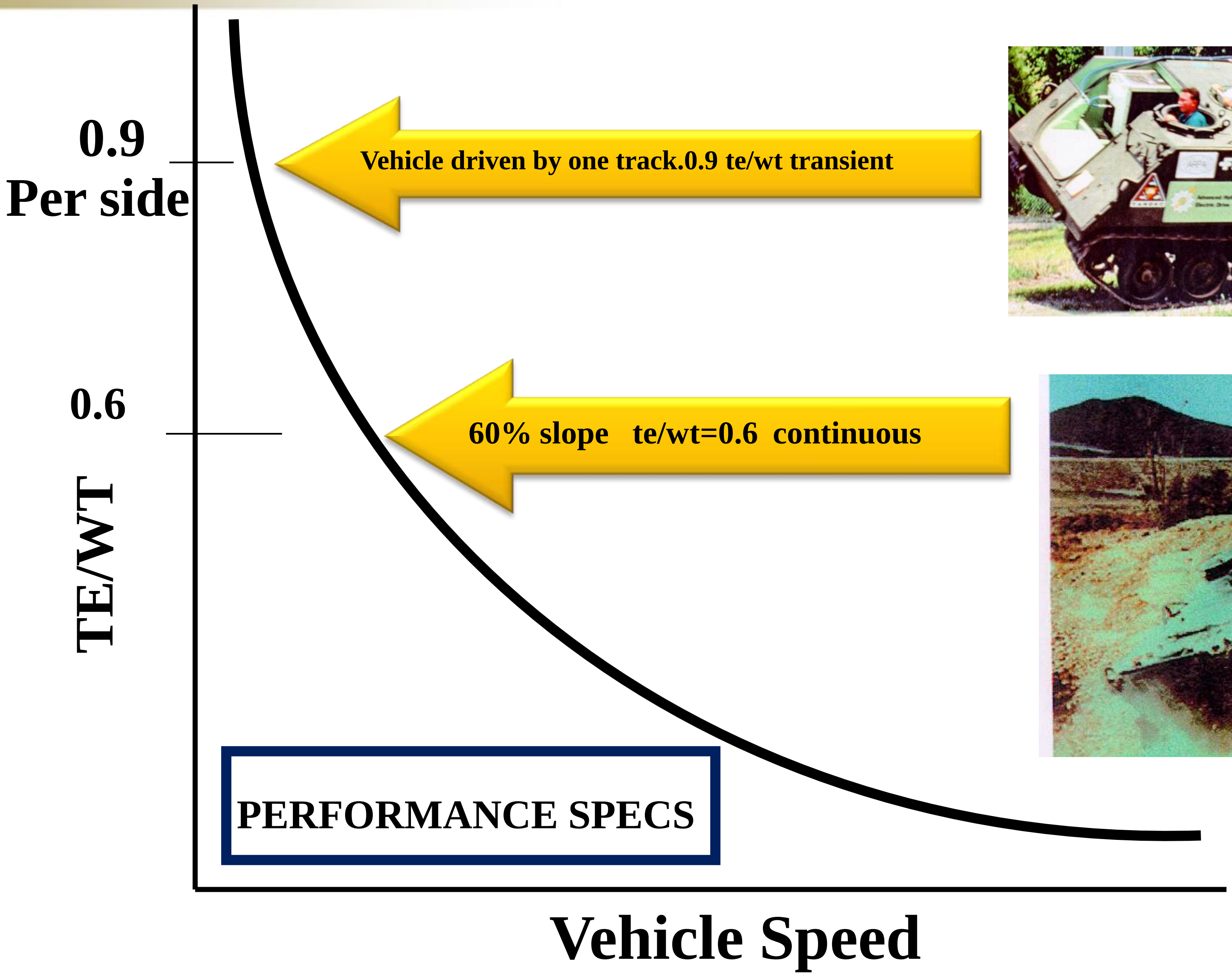
Cost

Energy Storage limited energy density

Safety

High voltage control and management

Military Environment



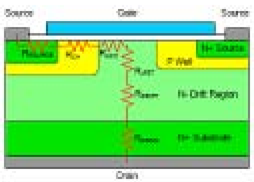
Hybrid Vehicle Challenges

Unprecedented use of emerging technologies never proven in battle field scenarios

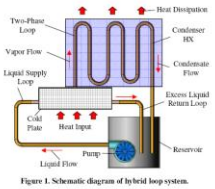
- System integration and packaging
  - Power densities of components
    - Motors, generators, energy storage
    - Power electronics
- Thermal management
  - Low operating temperature
    - Large space claims
    - High power demand from the engine/generator
- Silent Watch requirement
  - Energy storage 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

High Power density motor

SiC MOSFET



Phase change cooling



Li-Ion Battery Pack

Tactical Operation Center (TOC)

Hybrid SiC/Silicon DC-DC Converter

Battery Bus Bars

Controller Board

PPL Bus Bars

Power, Signal and Cooling Connection Area

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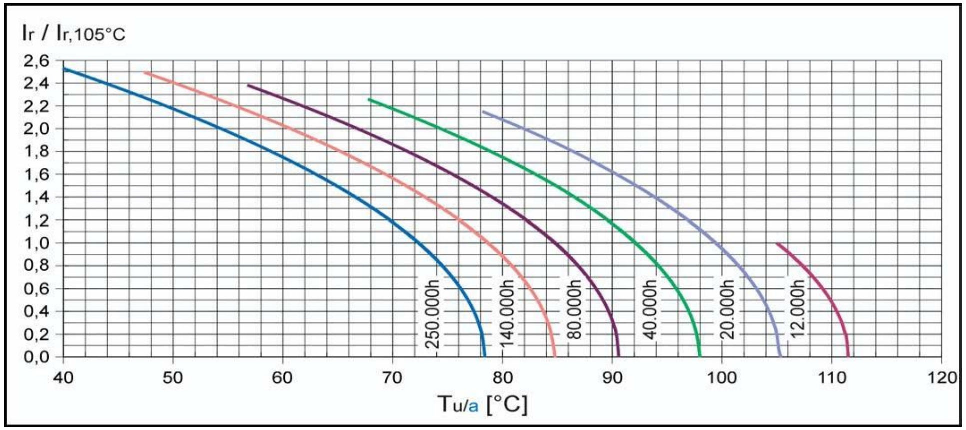
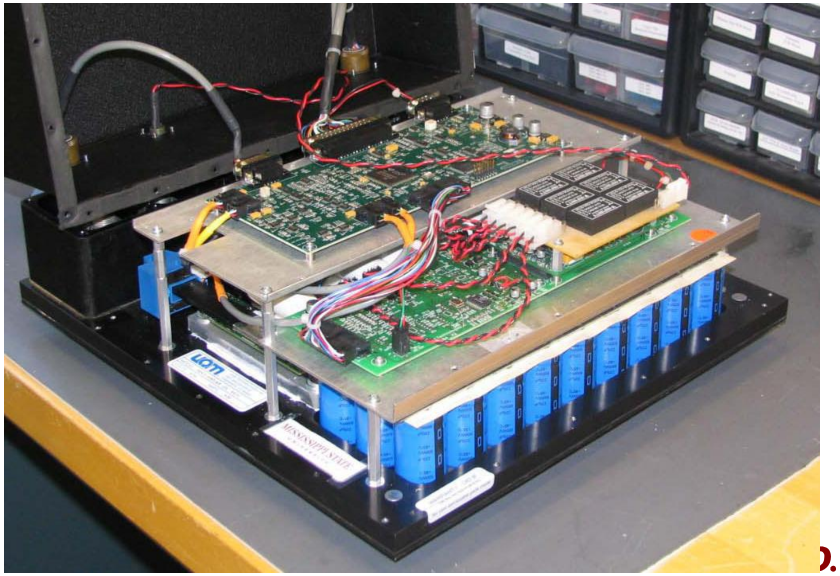
Other High Temperature Components

- **Military export power applications require high capacitance when available energy storage is minimal or absent**
  - High temperature electrolytic power capacitors – progress in this area shown to the right
  - Address capacitance per unit volume for power density
- **Other required high temperature devices**
  - Integrated circuit chips
  - Current sensors
  - Signal capacitors

Capacitor Life/Temp Curves

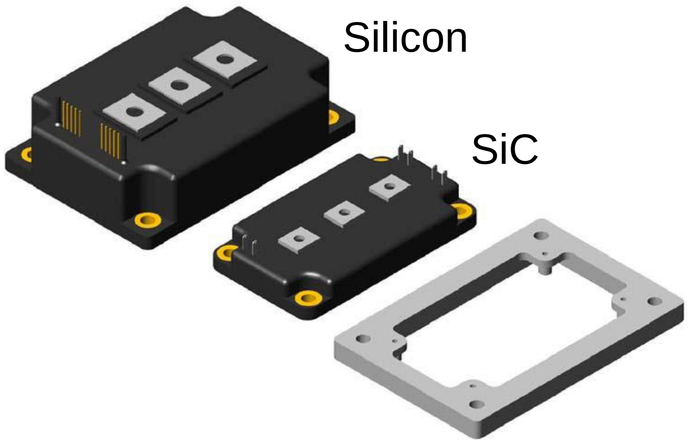


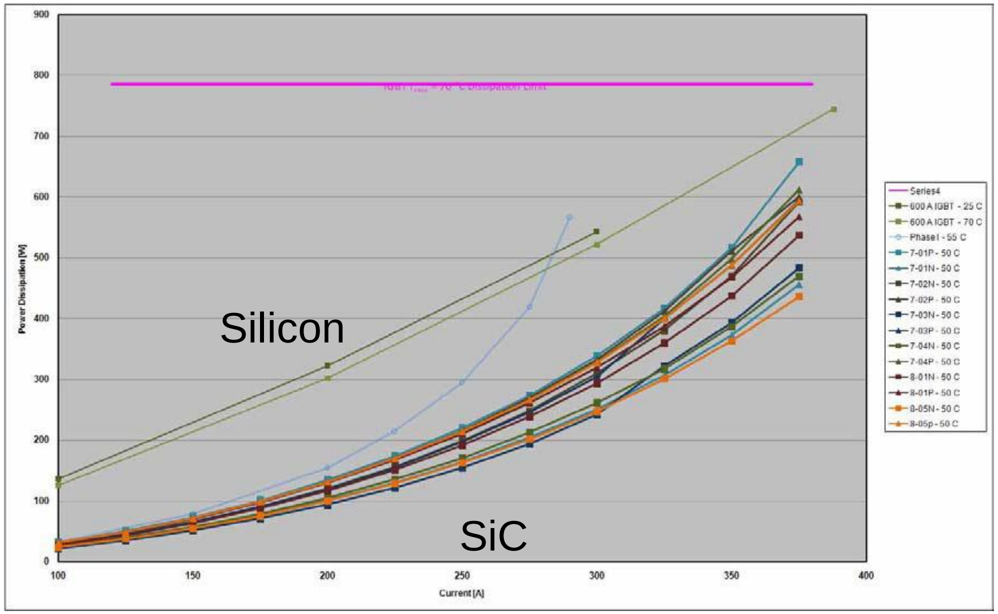


Silicon Carbide Efficiency

- **Technology successfully demonstrated by UQM/MSU team:**
  - 30 kW of power from SiC JFETs
  - Reduced losses compared to silicon IGBT technology

- **Next Generation devices now available**
  - 1200 V enhancement-
    mode JFETs ("normally off")
  - Larger die size (<0.1 Ω)
    Leading to manufacturing improvement
  - Maximum junction tempera- ture of 200 degrees C





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Silicon Carbide Development
Issues

- **Material Quality and Size**:
  - SiC material has high concentrations of dislocation defects
  - Micropipe density is still routinely 2-5/cm^2 which limits current carrying capacity to about 20 Amps
    (material with fewer defects is available at higher cost)
  - Material improvement is essential to improve yield and reduce costs
  - Significant cost reduction possible if size can be increased to 150 mm. diameter

- **Device Development**
  - MOSFETS: Historically have reliability issues at high temperatures.
    Cost and yield are still issues
  - JFETs: no known critical reliability issues
  - BJTs: unreliable due to basal plane defects, but material has been improved
  - Thyristors: may be useful for very high power applications (utilities and pulsed power)

- **Current Ratings**
  - 20A SiC MOSFETS are commercially available
  - 20A – 50A SiC diodes are commercially available
  - 15 A Normally-off JFETs are available now (higher current devices are not yet available)

Ultimately 50-200A individual switches and 300A-1400A switch modules are required

Silicon Carbide Power Converter Development

• OBJECTIVES:

Reduce Thermal Burden on Vehicles
Reduce Converter Operating Power

• APPROACH:
Develop compact, efficient, lightweight, high-temperature power converters using advanced SiC semiconductor power modules at power ratings needed for high-power military applications

• TARGET APPLICATIONS:

- 200 kW Traction Motor Drive Inverter
- 50 kW Motor Drive Inverter for pumps, fans
- 30 kW Bi-directional DC-DC converter (300Vdc to 28Vdc
- 180 kW Bi-directional DC-DC converter (300V Battery-to-600V Bus)
- 30 kW AC Export Power Inverter 300Vdc-to -60Hz
  @ 110Vac, 220Vac & 208Vac (3-phase)

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Silicon Carbide Devices

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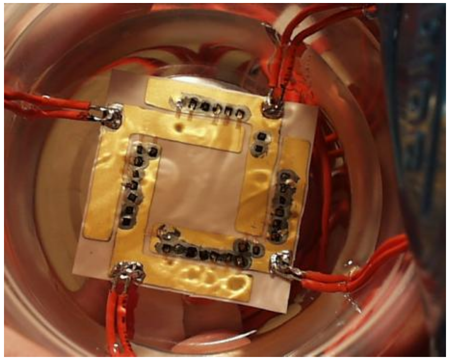
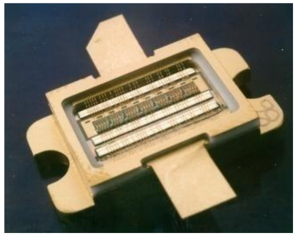


2.7kV, 25kW
SiC Rectifier

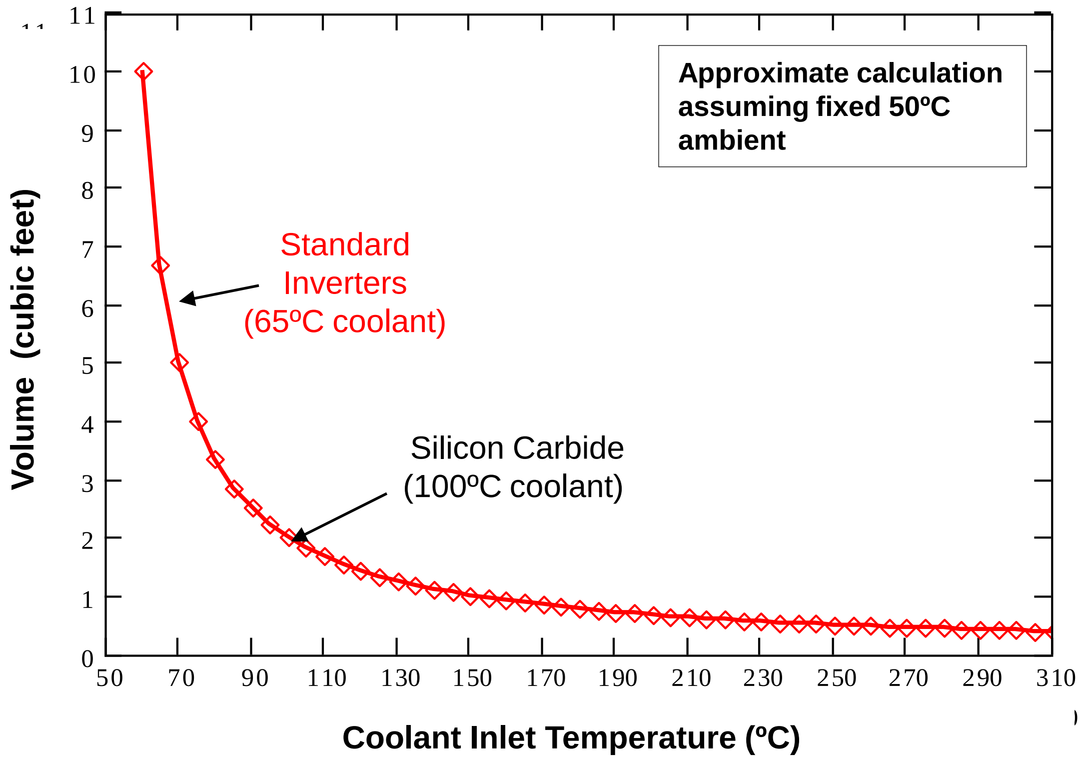
SiC JFET



MOSFET

Temperature Impact on Cooling System

Radiator Volume vs. Coolant Temperature



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

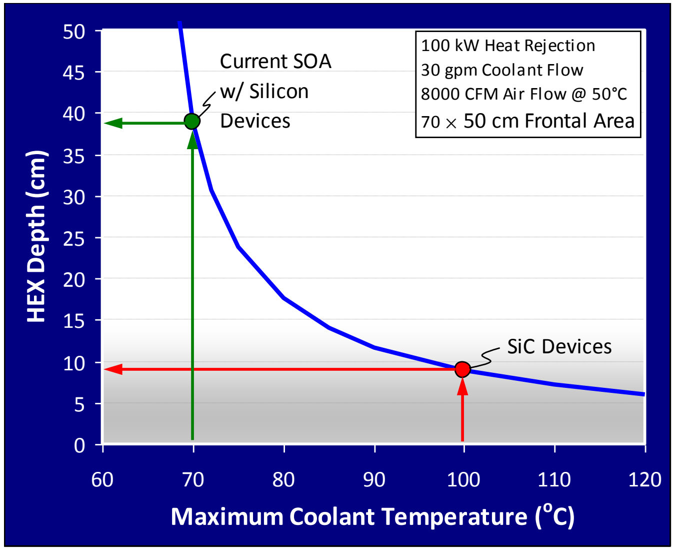
For One 400 kW Traction Inverter

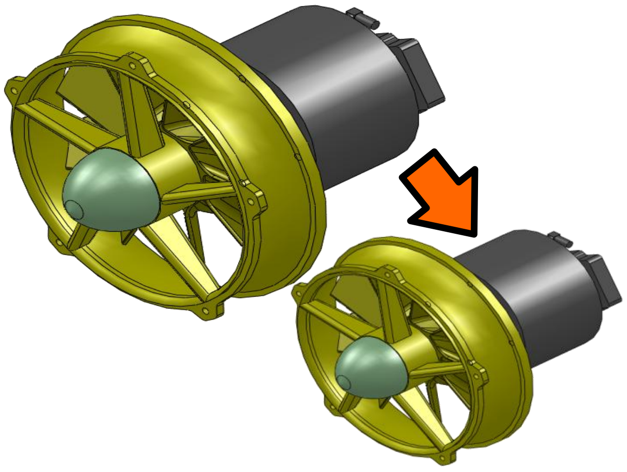
- **70 ºC to 95 ºC => 56% reduction**
- **95 ºC to 130 ºC => 44% reduction**

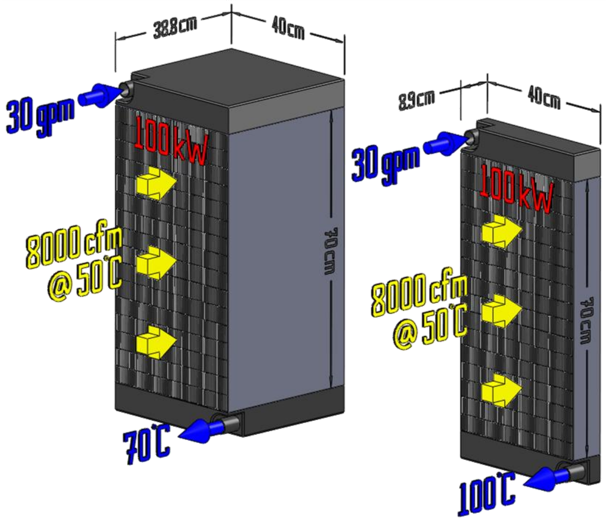
Improved Power Electronics Attributes

- Si based power electronics require coolant inlet Temperature not to exceed 70°C resulting in large cooling system size

- SiC can operate at much higher temperatures ≥ 100°C thus reducing the size of The cooling system by half





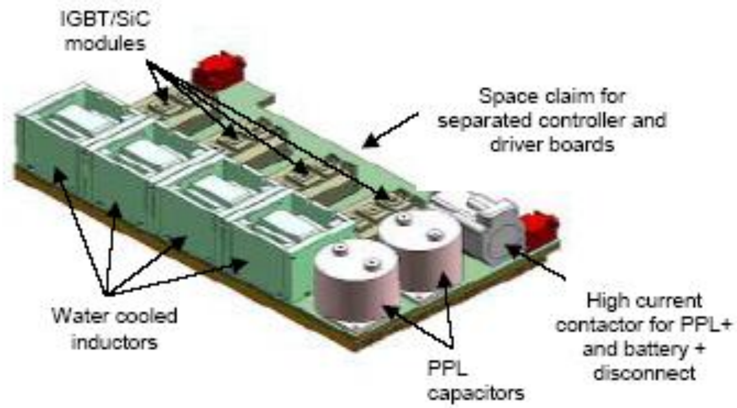


Advanced SiC Components will Reduce the Power Electronics Cooling Burden

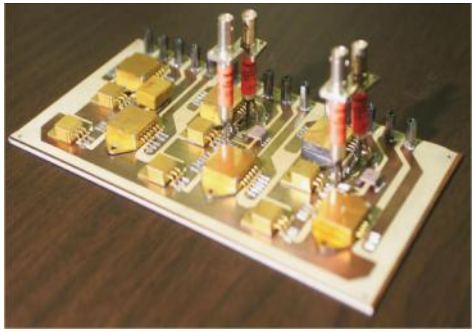
Power Electronics

- 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

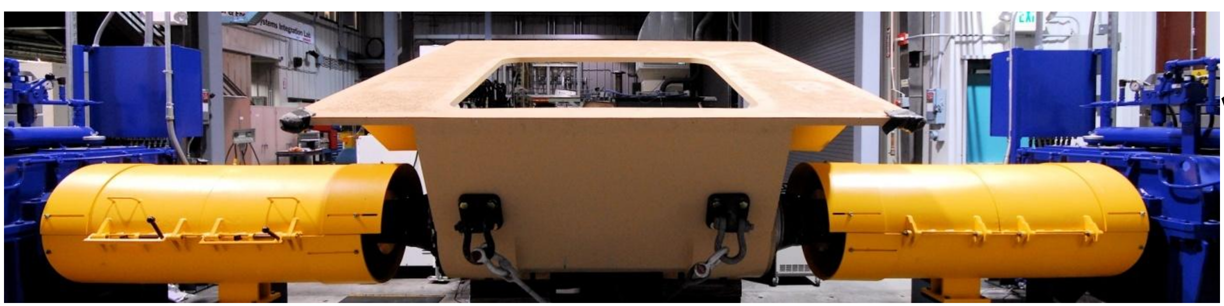
TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

Power and Energy SIL

The SIL provides capability to accelerate the integration and maturation of critical hybrid-electric system technologies in order to meet vehicle performance within the weight and volume constraints

System Integration

System integration into vehicle platform



HOTBUCK platform with Hybrid hardware

Fuel Economy Demonstrator (FED)

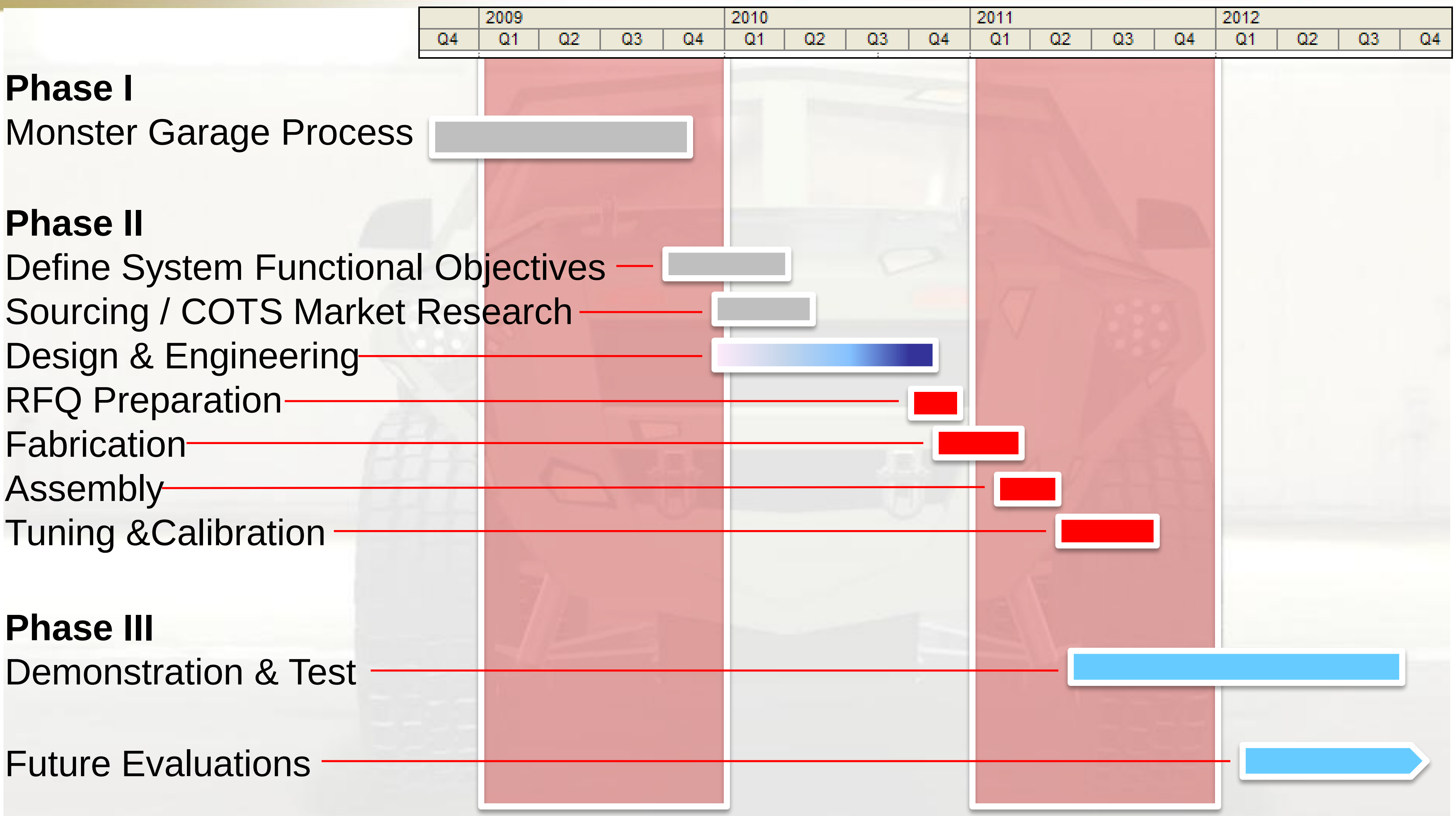
Monster Garage Fuel Efficient Demonstrator

Executive Review

RDECOM

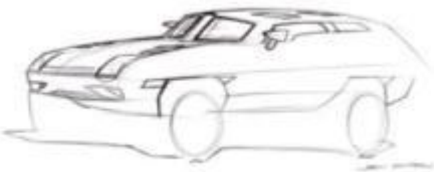
Overall Timing

TARDEC



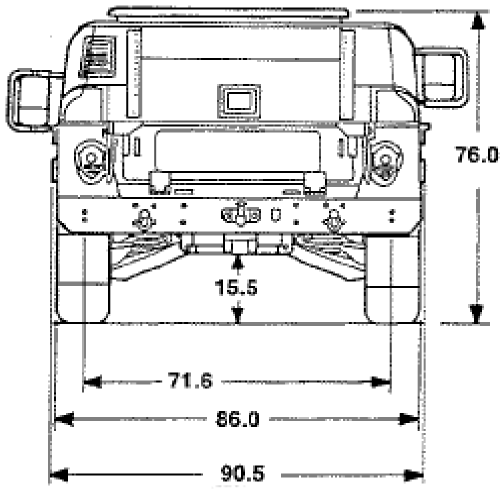
TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

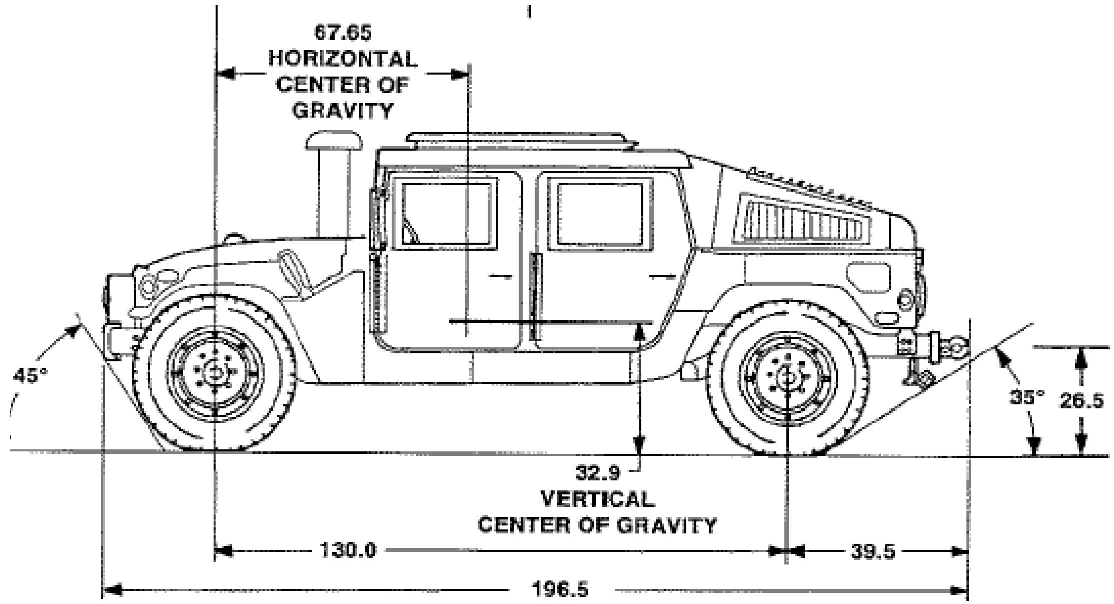
Final Exterior Design

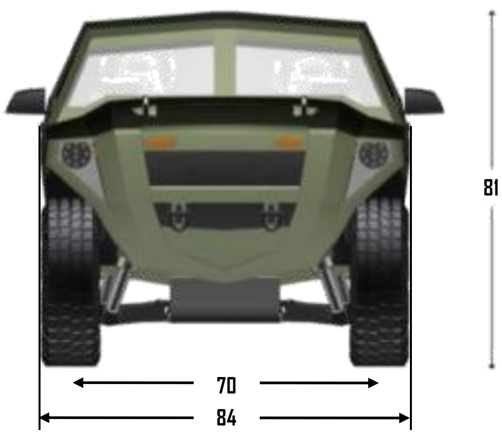


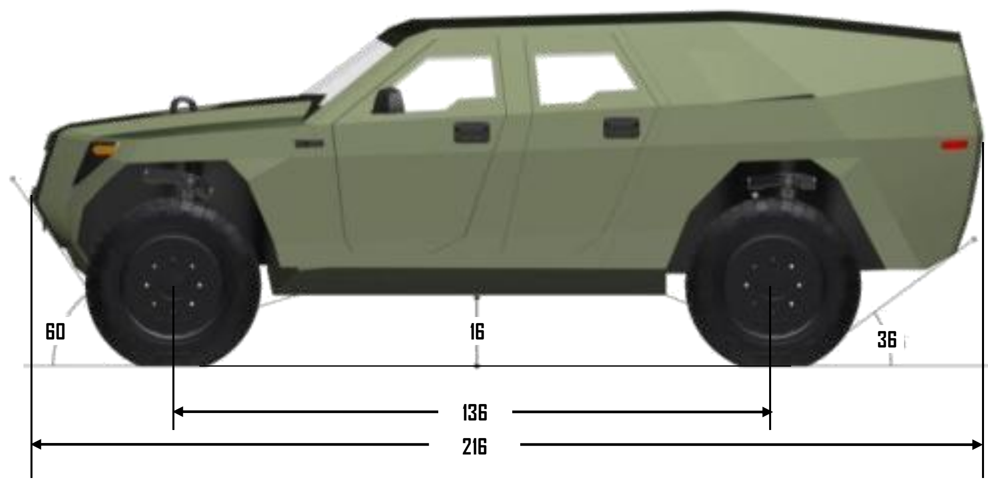
8 Months from Sketch to CAD

Vehicle Dimensions









Vehicle Level Specifications

Parameter	Specification
Wheelbase	136 inches
Track Width	70 inches
Length	216 inches
Width (Body)	84 inches
Height	81 inches
Turning Circle	50 feet
Curb Weight	12,500 lbs
Gross Vehicle Weight	16,760 lbs
Weight Distribution (F/R)	50% / 50%
Seating Capacity	4 Crew
Headroom (F/R)	43.3 / 43.3 inches
Legroom (F/R)	42.5 / 34 inches
Shoulder Room (F/R)	76.2 / 76.2 inches
Min. Ground Clearance	13" to16+"
Approach Angle	60 degrees
Departure Angle	36 degrees
Break-over Angle	28 degrees

*All dimensions measured at 16" ride height & GVW

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

Relevant Capability

Survivability

- Integral V-hull (w/ 16” clearance)
- Upgradeable B-kit
- Emergency Egress Windows
- Blast Mitigating Seats
- Propulsion System Redundancy
- Roof Crush Resistance

Mobility

- 18” Step Climb
- 60+% Grade
- 40+% Side Slope
- Adjustable Ride Height
- 5+ Miles Silent Mobility

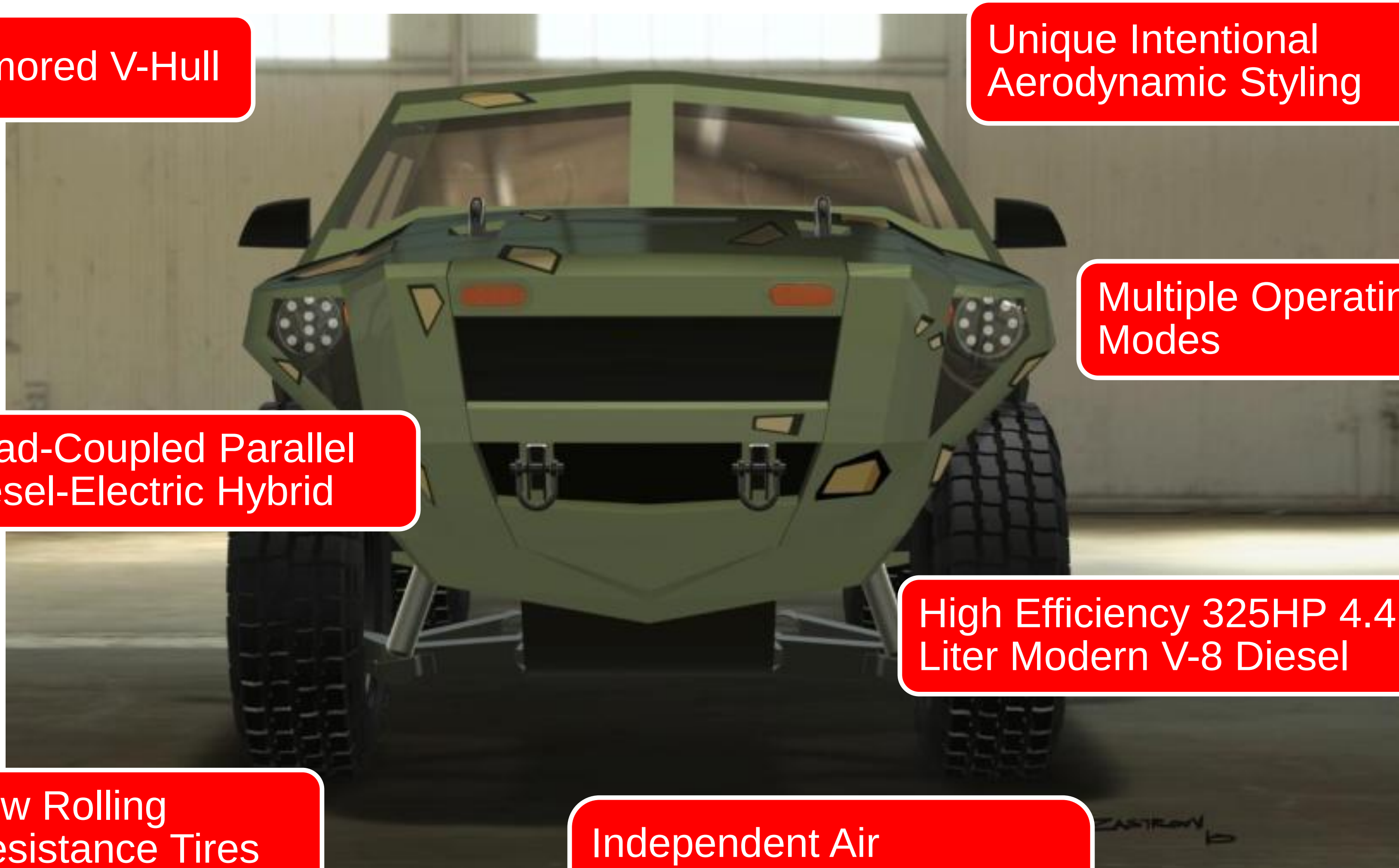
Performance

- 0 – 50 mph 15 sec
- 80+ mph
- 55+ mph 5% Grade
- 45+ mph Lane Change
- 55-0 Braking 211 feet

Electrical

- 5+ kW of 24V Power for C4ISR
- 5+ hours of Silent Watch on Full Charge
- High efficiency 12V Ultracap & Battery System
- 6kW of 110V Export Power – Expandable to over 30kW

Vehicle Highlights



Armored V-Hull

Unique Intentional Aerodynamic Styling

Multiple Operating Modes

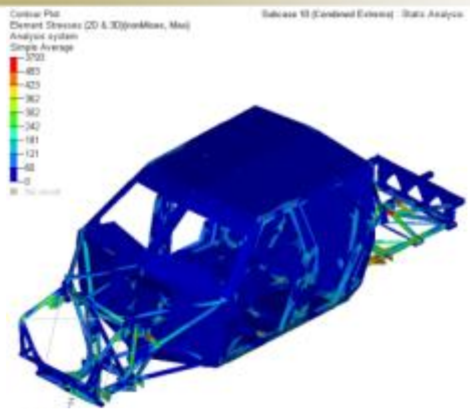
Road-Coupled Parallel Diesel-Electric Hybrid

High Efficiency 325HP 4.4 Liter Modern V-8 Diesel

Low Rolling Resistance Tires

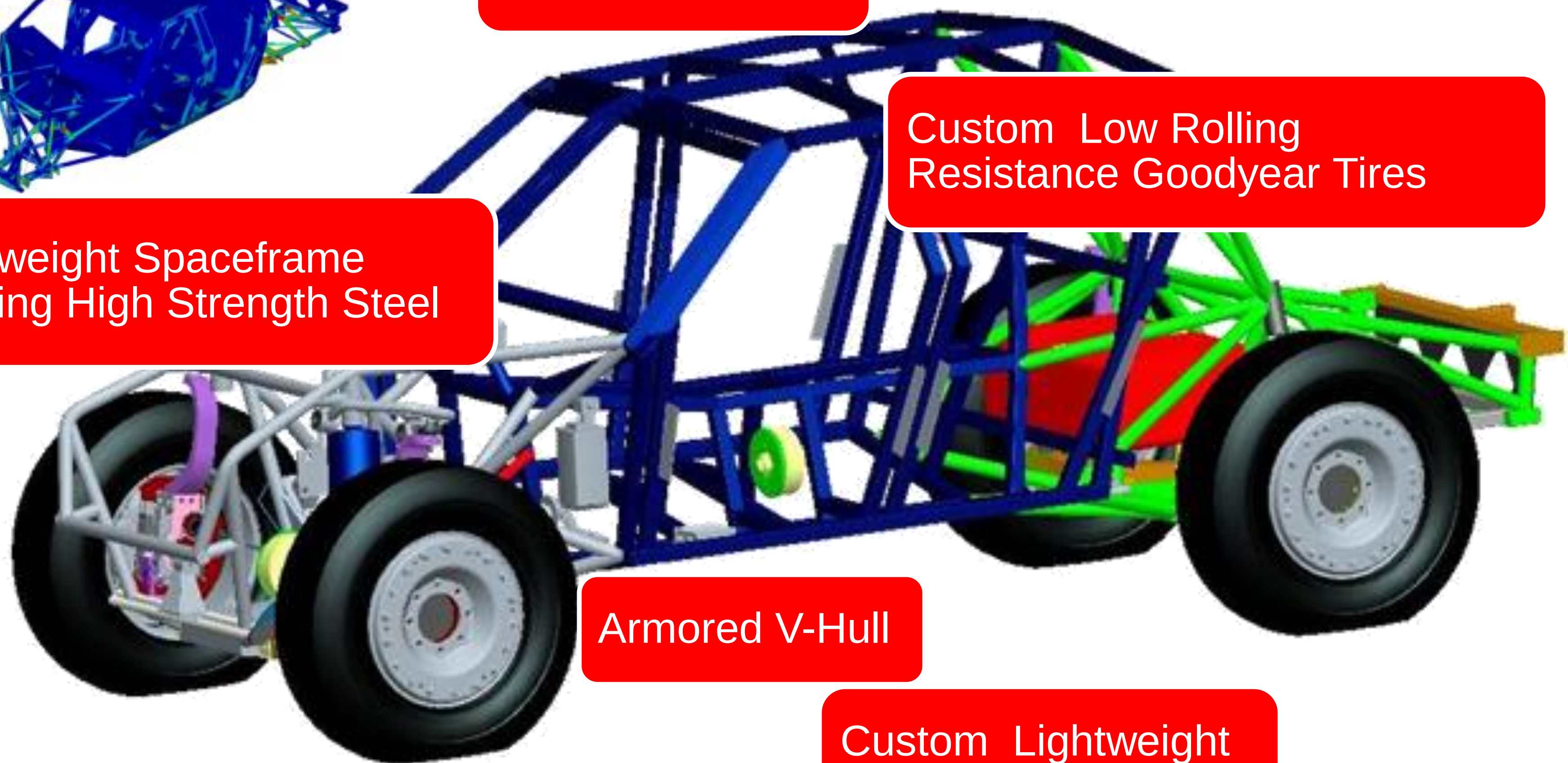
Independent Air Suspension with Adjustable Ride Height

Chassis



TARDEC Roof Crush Analysis

Integrated Roof & V-Hull



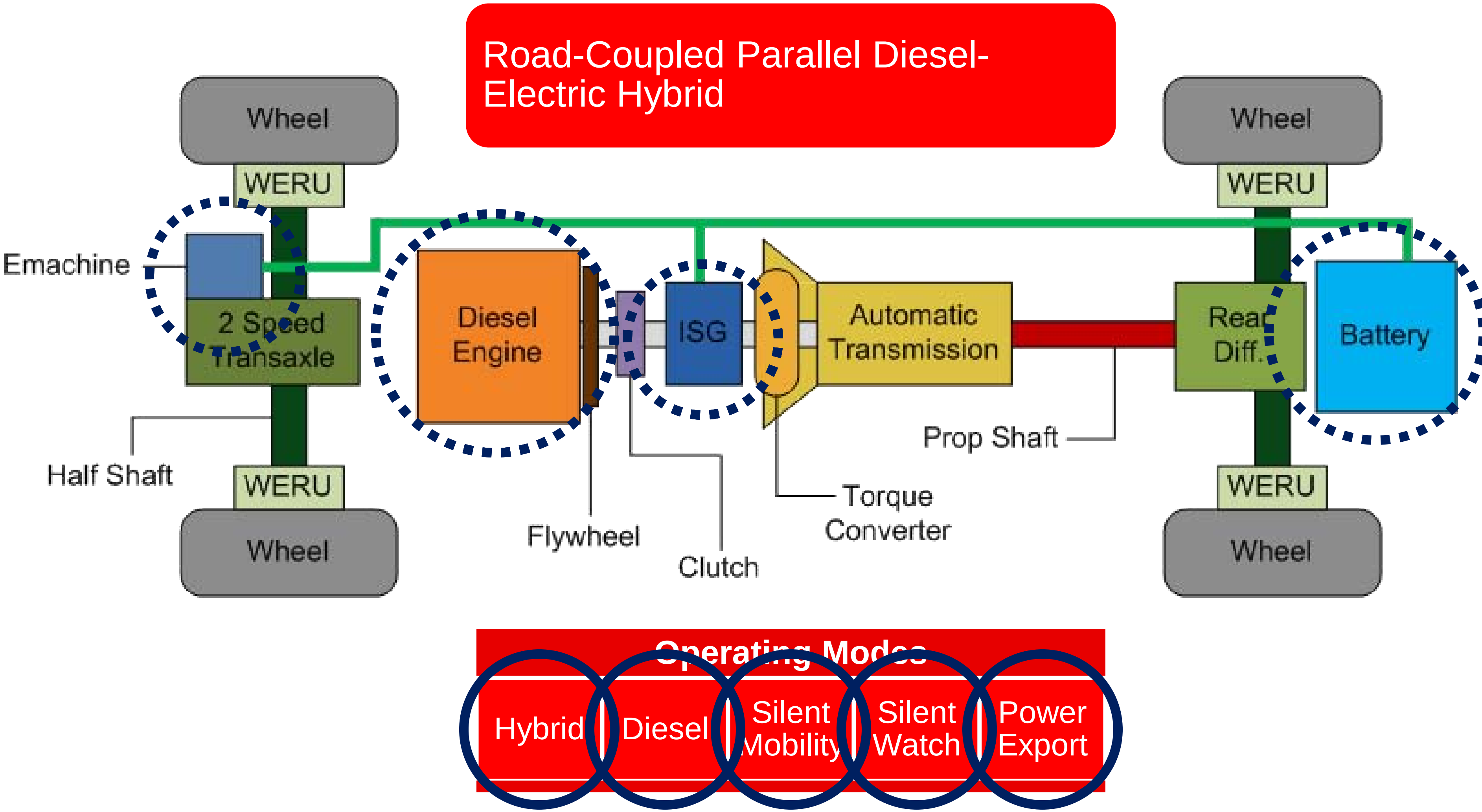
Custom Low Rolling Resistance Goodyear Tires

Lightweight Spaceframe Utilizing High Strength Steel

Armored V-Hull

Custom Lightweight Aluminum Wheels

Propulsion - Architecture



Propulsion

Road-Coupled Parallel Diesel-Electric Hybrid

Ford High Efficiency Modern Twin Turbo Diesel Engine

A123 Systems Prismatic Lithium Ion 22.5 kW-hr Battery

50 kW Rear ISG

145 kW Front E-Machine

System Level Optimization

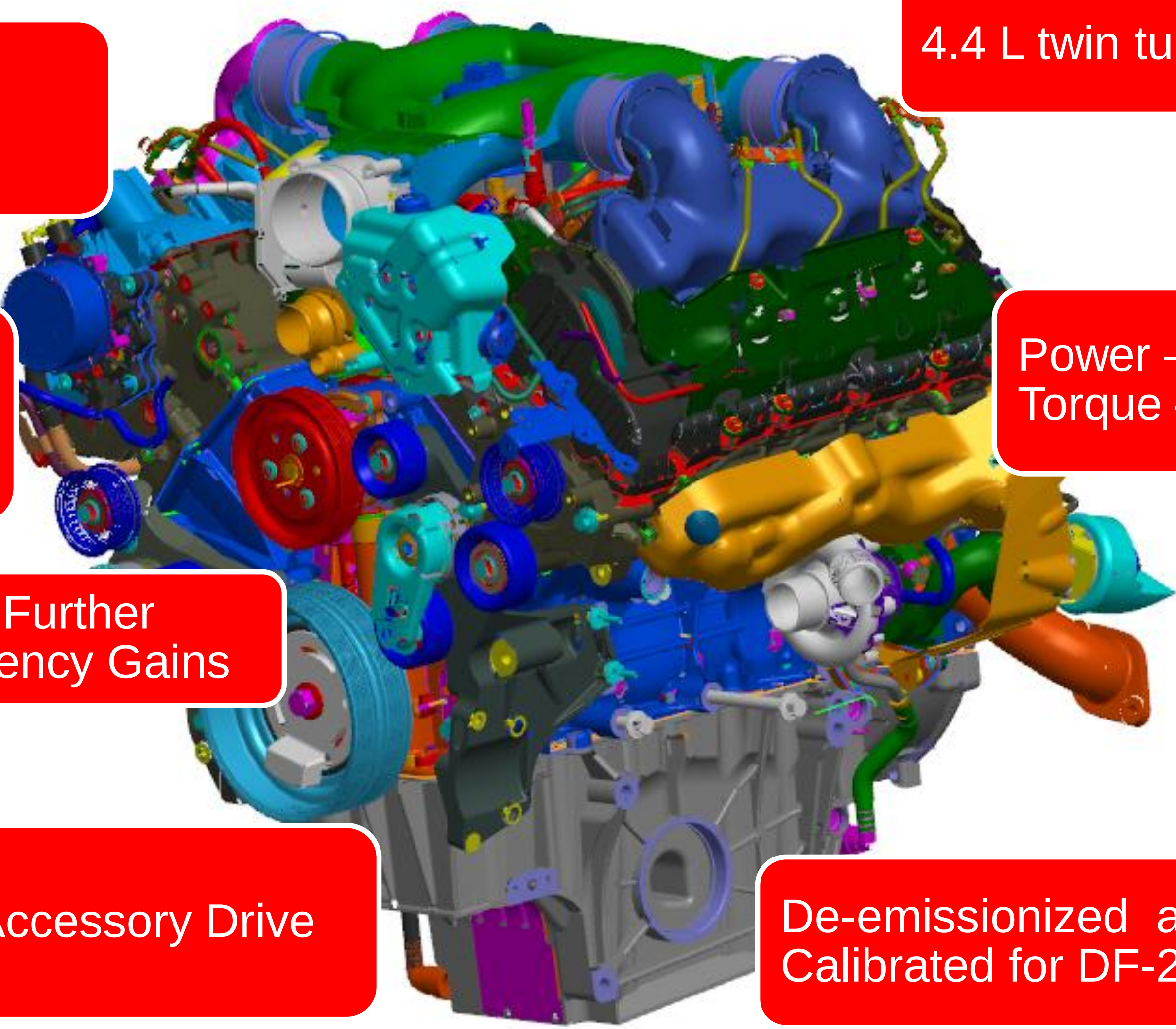
Propulsion – Engine

All New Engine Controller Development

Calibration Source Code Provided

Calibrated for Further Thermal Efficiency Gains

Electrified Accessory Drive

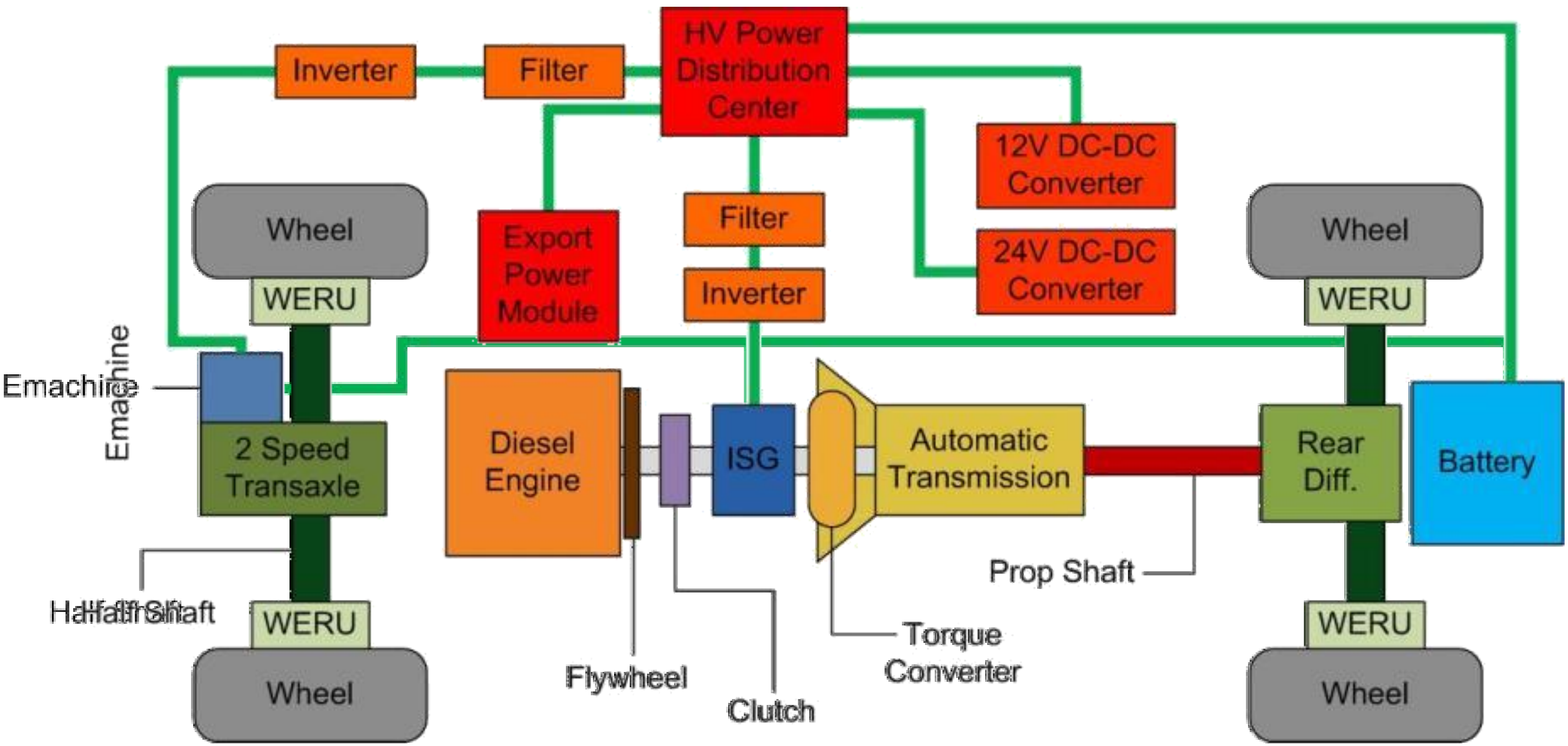


4.4 L twin turbo V-8

Power – 325 hp
Torque – 553 lb-ft

De-emissionized and Calibrated for DF-2 & JP8

Propulsion - Electrical

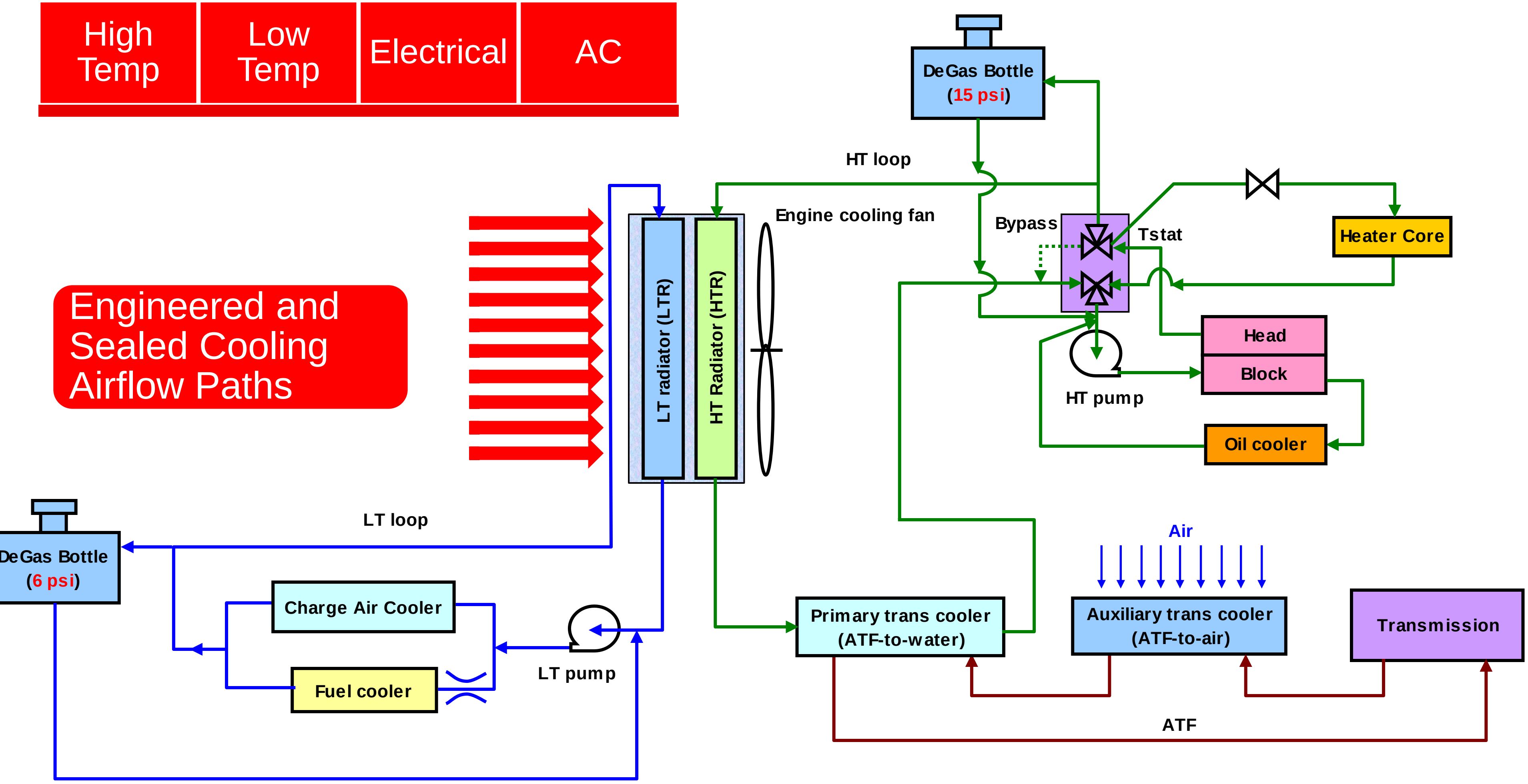


TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

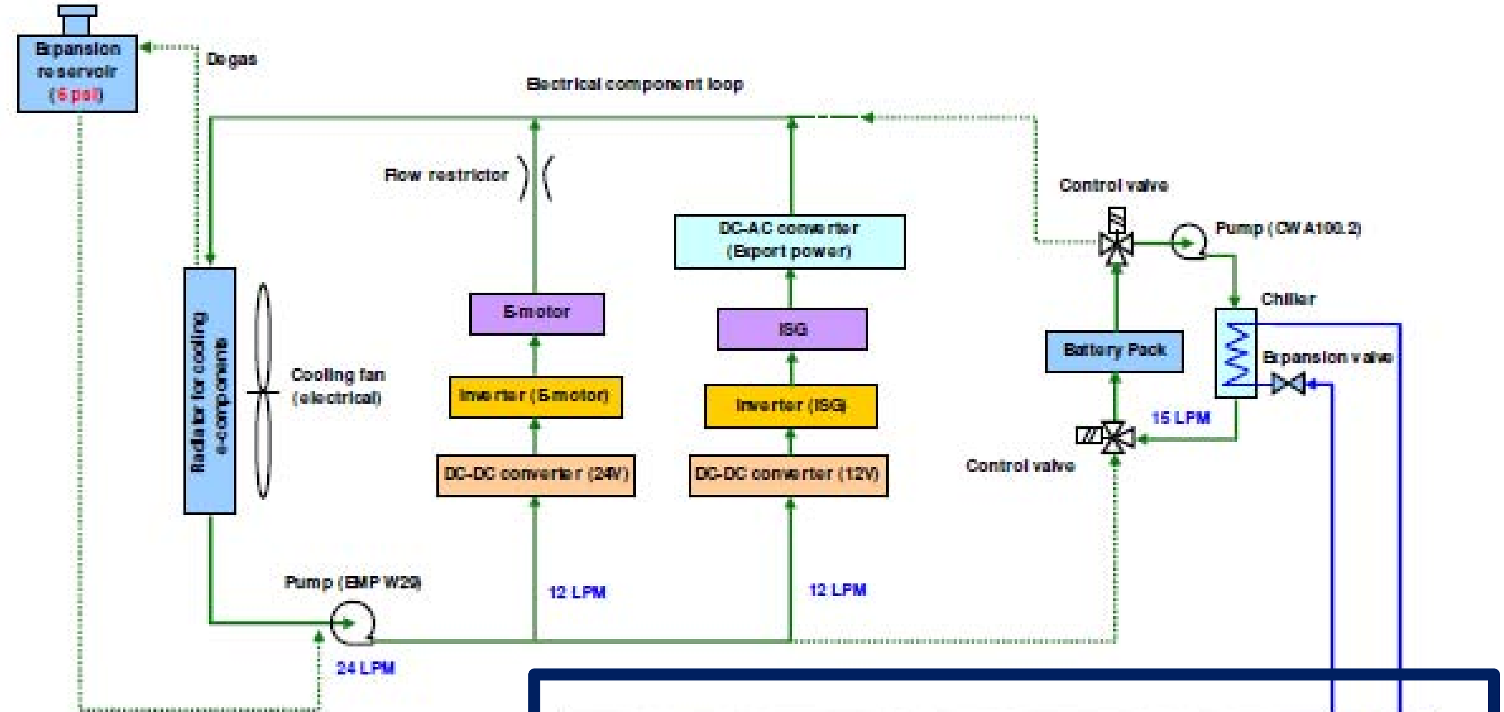
Thermal - Front

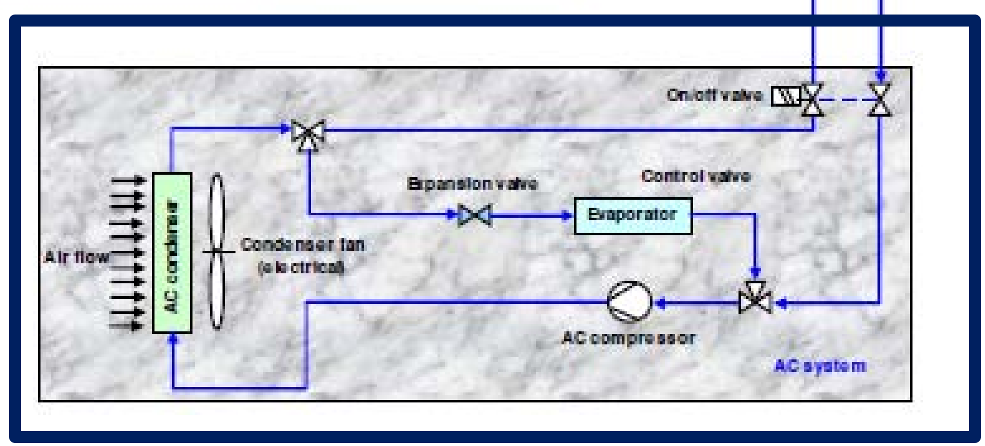
Cooling Loops			
High Temp	Low Temp	Electrical	AC

Engineered and Sealed Cooling Airflow Paths



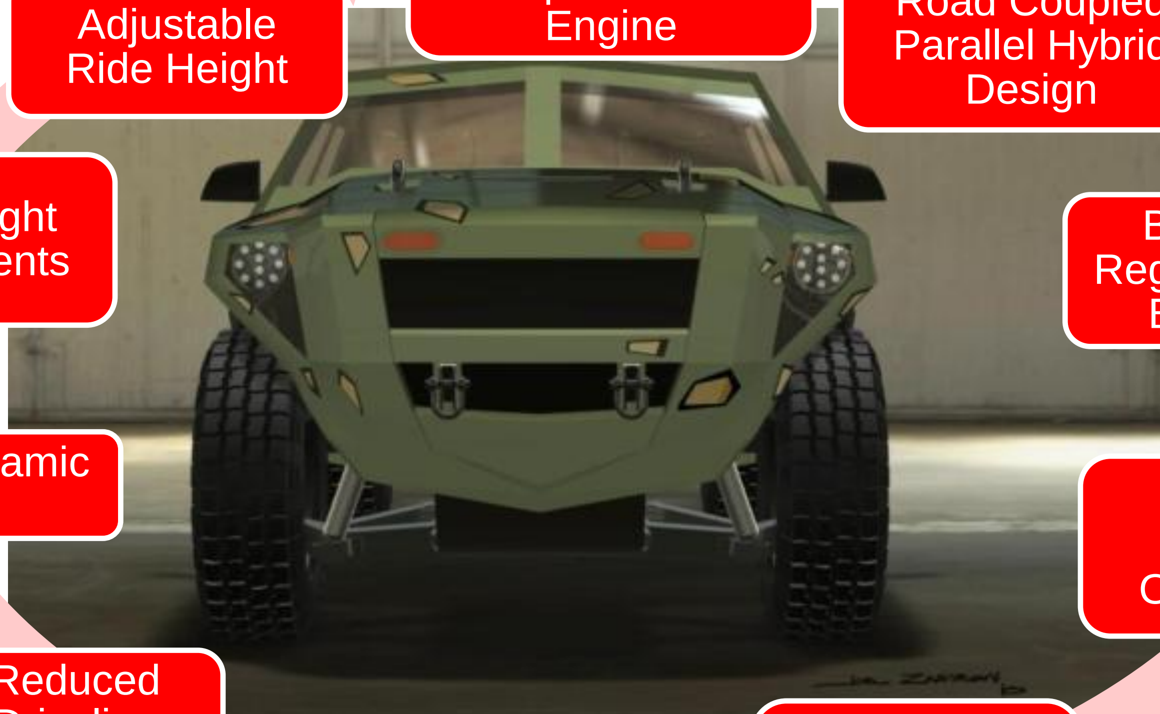
Thermal - Rear





Cooling Loops			
High Temp	Low Temp	Electrical	AC

Fuel Efficiency - Enablers



Higher Efficiency Smaller Displacement Engine

Road Coupled Parallel Hybrid Design

Blended Regenerative Braking

Hybrid Controller Optimization

Independently Driven Front Electric Drive

Prismatic Lithium Ion Battery

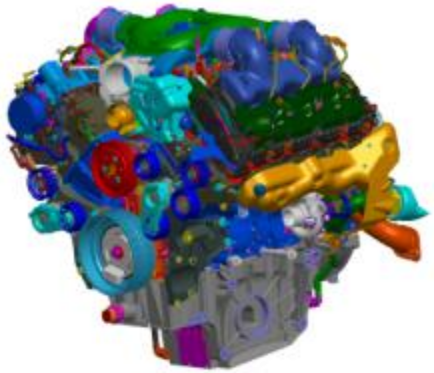
Reduced Driveline Friction

Low Aerodynamic Drag

Lightweight Components

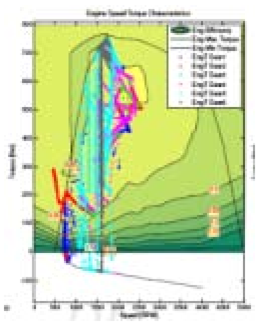
Adjustable Ride Height

Optimization Process



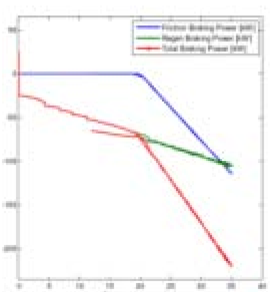
Mechanical matching of component torque & speed

Gear ratio selection to match road load to engine maximum efficiency island

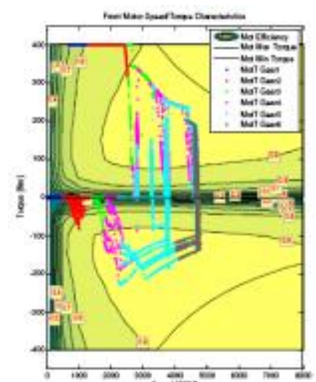


Optimize engine operating point with motor blending

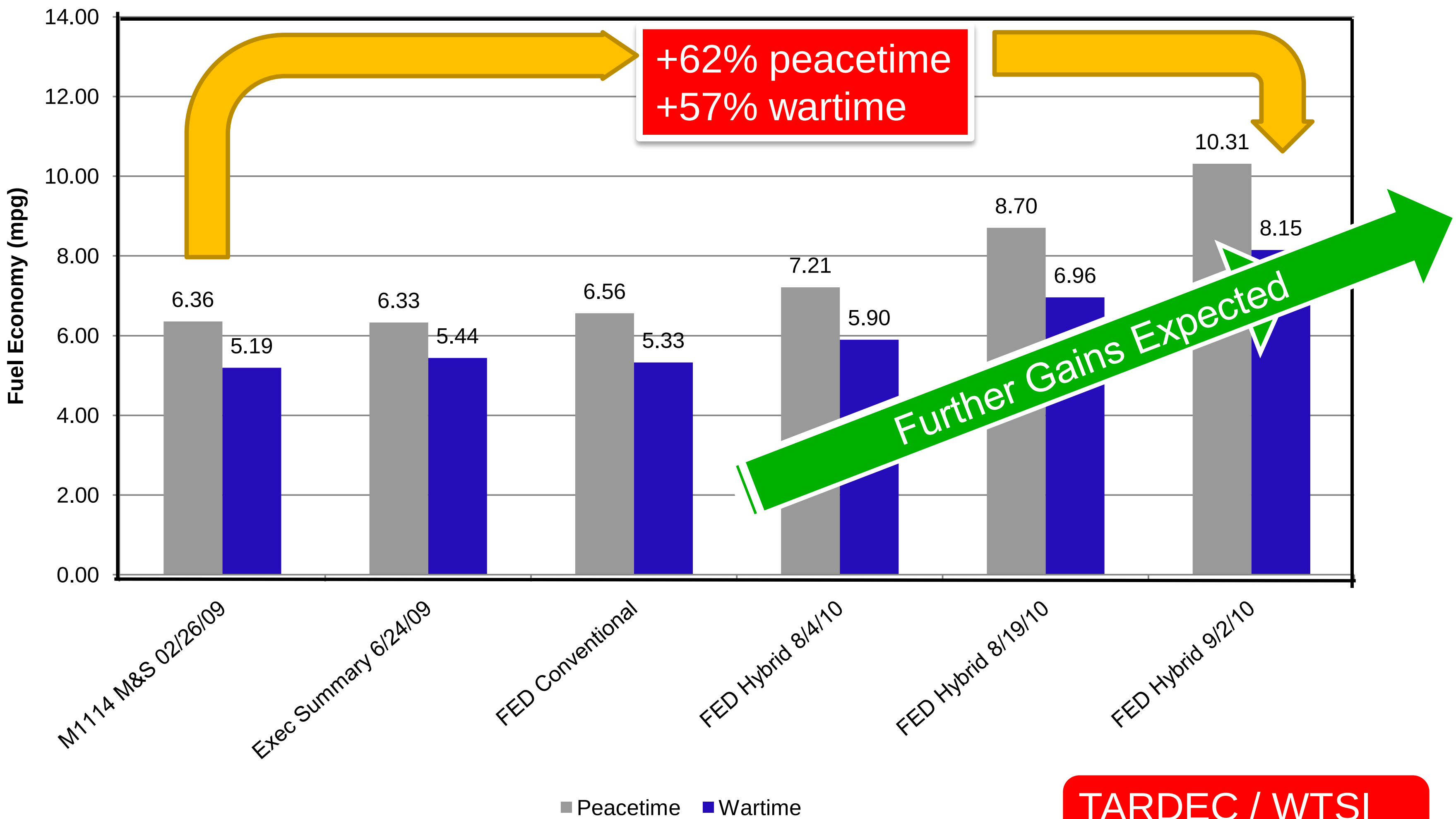
Motor selection to match motor and engine efficiency maps



Maximize regenerative braking potential with blending optimization



FE Trajectory (Composite)



TARDEC / WTSI
M&S Analysis

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.