U.S. ARMY RDECOM®

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US ARMY – RDECOM

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

Small Tactical Electric Power

Technology Advancement – Application - Transition

Selma J. Matthews
CERDEC CPI Power Division
21 OCTOBER 2015

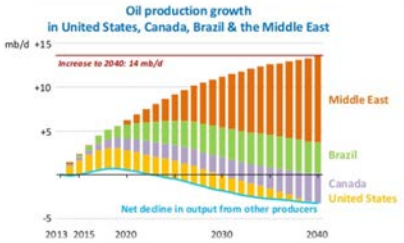
AGENDA

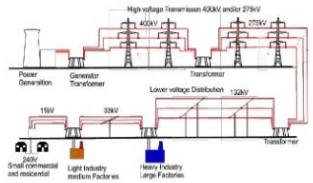
- Capability Gaps – Quantifying / Describing Issues
  - Observations - Commercial Sector vs Tactical Battlefield
  - Army Challenges
- Technology Investments
  - Operational Goals
  - Measures of Effectiveness
  - Design Metrics
- CERDEC S&T
  - Investments
  - Hardware Delivered
  - Metrics Developed
  - Technology Transition to PM E2S2
- Technology Trends – Future Investments

POWER & ENERGY OBSERVATIONS

Commercial

Increased Urbanization & Population





Consumption of energy increasing

- ❖ New C4ISR technologies
- ❖ IED Defeat Systems
- ❖ New weapons (EM guns, lasers)

Energy security problematic

- Cost of fuel skyrocketing
- Politics
- Alternative sources – wind, solar, waste to energy

Operational issues

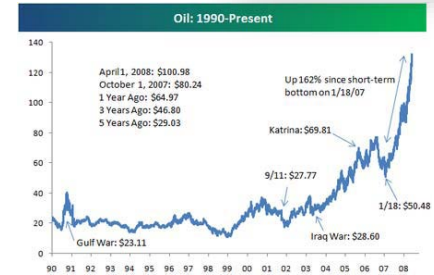
- ❖ Wet stacking and increased maintenance
- ❖ Need for increased mobility
- Energy Density - Battery usage & limitations
- Emphasis on silent (“quiet”) watch
- Emphasis on energy efficiency
- Inefficient management/ distribution of power
- Need for remote start – hybrid sources

Increased emphasis on system power metrics

(low consumption components)

Tactical Battlefield

- ❖ DoD centric



Army (ASA-ALT) Top Challenges

- Greater ***force protection (Soldier, vehicle, base)*** to ensure survivability across all operations
- Ease ***overburdened*** Soldiers in Small Units
- Timely ***mission command & tactical intelligence*** to provide situation awareness and communications in all environments
- Reduce logistic burden of ***storing, transporting, distributing*** and ***retrograde*** of materials
- Create ***operational overmatch*** (enhanced lethality and accuracy)
- Achieve operational ***maneuverability*** in all environments and at ***high operational tempo***
- Enable ability to ***operate in CBNRE environment***
- Improve ***early detection of traumatic brain injury (TBI)***
- Improve ***operational energy***
- Improve ***individual & team training***
- ***Reduce lifecycle cost*** of future Army capabilities

OE Desired Capabilities

- **Increased Platform Fuel Efficiency**
- **Lighter, more powerful Soldier power sources**
- Reduced Logistics Demand
- Energy-efficient structures and devices

OE Technology Enablers

- Advanced turbine engines
- High efficiency drive systems
- Electrochemical power sources for longer lasting power
- Wearable Power (fuel cells, **new battery chemistries, energy harvesting**, distribution) and **recharging capability** for improved mobility
- **Intelligent power management**
- Waste to energy conversion
- Energy loss models and management tools
- **Alternative energy to reduce logistics**
- **Power Generators with multi-fuel use**
- **Materials and design of energy efficient structures**

Key Enablers for Improving Battlefield Power Power

Operational Energy Strategy

1. *More fight, less fuel*: Reduce the demand for energy
2. *More options, less risk*: Expand and secure the supply of energy to military operations.
3. *More capability, less cost*: Build energy security into future force.

Power Generation & Conversion


Fuel Cells & **Reforming**

Alternative & Renewable Energy Conversion

Electro-Mechanical Generation

Micro / Man Portable Power

Energy Storage

Primary Batteries

Rechargeable Battery

Reserve Battery

Capacitors

Li-Ion/UltraCap Hybrid

Flywheels

Power Control & Distribution


Power Switches & Electronics

Power Converters

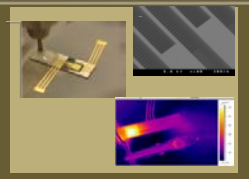
& Inverters

Power Distribution

Intelligent Power Management

Magnetics / Other

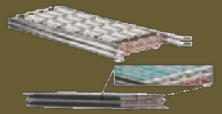
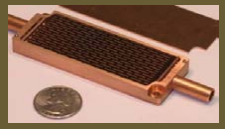
Power & Thermal Management



Heating & Cooling

Power Electronics

Sub-System Thermal Management

Army Net Zero Energy Strategy for base camps and installations

ARMY GOALS / OBJECTIVES

Goal

- To establish a new family of tactical electric, soldier portable, signature suppressed power systems in the 500 – 2000 Watt range
  - That enable direct power and hybrid, silent watch, and battery charging applications in the forward tactical battlefield areas.
  - That increase the operational flexibility of the battle commander
- To take advantage of emerging solutions from applied and advanced research initiatives that show promise in making dramatic improvements on logistics, cost, and mission capability for all services

Objectives

- **Reduce Weight / Size**
- **Improve Reliability**
- **Reduce Total Ownership Costs**
- **Enhance / Increase Platform Capability**

MEASURE OF EFFECTIVENESS

TACTICAL ELECTRIC POWER CAPABILITIES PRODUCTION DOCUMENT

approved Jun 2011

Man Power Burden
Supportability
Scalability
Impact on O&S Costs

Key Performance Parameters	ARMY Metric
KPP#1. **System Power Quality, Sizes & Modes**	**05 – 3.0 kW** 50 / 60 Hz Utility Class 2C per MIL-STD-1332B.
KPP#2. **System Weight. (dry)**	Reduce by average of 25%
KPP#3. **Fuel Consumption**	Reduce by 25%
KPP#4. **Reliability & Maintainability**	MTBF: 500 hr Median Time to Repair: $\leq$ 0.5 hours

KEY PERFORMANCE PARAMETERS

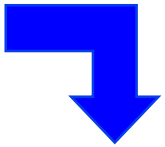
Key Performance Parameters	ARMY Metric	2-3 kW DED MTG/TQG	ARMY S&T PROOF OF CONCEPT – Deliverables at TRL 6/7	BREAKTHROUGH / APPROACH
KPP#1. System Power Quality, Sizes & Modes	**05 – 3.0 kW** 50 / 60 Hz Utility Class 2C per MIL-STD-1332B.	**2 kW** : 28 V_{DC} 120 V_{AC}, 1 Φ, 3 wire **3 kW** : 120 V_{AC}, 1 Φ, 3 wire 120/240 V_{AC} 1 Φ, 4 wire	**0.5 / 1.0 / 2.0 / 3.0 kW** **Switch selectable** • 28 V_{DC} • 120 V_{AC}, 1 Φ, 3 wire • 120/240 V_{AC} 1 Φ, 4 wire w/ GFCI convenience receptacle	• Fuel Processing Techniques / Combustion Augmentation • Power Electronic Controls • Advanced Materials
KPP#2. System Weight. (dry)	Reduce by average of 25%	2 kW 123.5 lb 3 kW 304.0 lb	0.5 kW 35 lbs 1.0 kW 50 lbs 2.0 kW 100 lbs 3.0 kW 150 lbs	• Use of Nanomaterials for thermal management • Adaptation of COTS power components / systems
KPP#3. Fuel Consumption	Reduce by 25%	2.0 kW 0.33 gal/hr 3.0 kW 0.33 gal/hr	0.5 kW 0.12 gal/ hr 1.0 kW 0.20 gal/hr 2.0 kW 0.26 gal/hr 3.0 kW 0.28 gal/hr	• Advanced materials • Combustion Augmentation • Automatic load following controls • On-board preconditioning fuel processor to enable multi-fuel
KPP#4. Reliability & Maintainability	MTBF: 500 hr Median Time to Repair: ≤ 0.5 hours	MTBF: 2.0 kW 818 hr 3.0 kW 500 hr	TBD MTBF: 750 hr - goal	• Integrated thermal management • Electronic Controls to ensure greater precision/stability in governing engine speed • Controls for part load operation

BENEFITS ASSOCIATED WITH THE APPLICATIONS OF BREAKTHROUGHS

R&D Nanomaterials

- Thermal Management

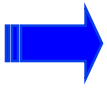
- Reduction in Operating Temperature
- Reduction of Overall Package Size
- Increase in System Efficiency



- Advanced Materials

CarbAl™ composite

- Low Coefficient of Thermal expansion
- Thermal Properties as good or better than Copper
- Lighter weight than Aluminum
- Easily Integrated into Existing Systems

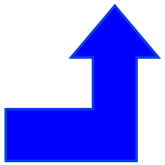


Increased Reliability Survivability & Efficiency

- Direct Print Circuits with Integrated Thermal Management:

Combine CarbAl™ with Advanced circuit assembly

- Reduction in overall Thermal Impedance
- Integration of Thermal Management at the Circuit Board Level
- Reduced Component Temperatures
- Smaller Heat sinks = Weight Reductions
- Compatible with high-efficiency Inverters



Benefits Associated With The Applications Of Breakthroughs

R&D Power Electronics:

- Engine/Generator Controls:

  Controls alternator output, metering of fuel, Load Sensing

  →
  - Reduction in Fuel Consumption
  - Reduction in Total Ownership Cost
  - Reduction of Wet Stacking

R&D Alternator:

- Alternative Material: Rare Earth Free Magnet

  High Temperature Tolerance
  Reduction in I^2R losses
  Lighter Weight

  →
  - Readily available in US / globally
  - Robust, durable and cost effective
  - Reduction in component costs

  Increased
  - Efficiency
  - Affordability
  - Availability
  - Reliability

- Parallel Path Magnetic Technology

  Conventional construction
  More useable flux from same magnet
  Performance equal to or better than PMG design
  Compatibility w/ advanced Engine & Power Electronic Designs - TBD

  →
  - Drop in mechanically.
  - Standard manufacturing techniques

Benefits Associated With The Applications Of Breakthroughs

R&D Combustion Enhancement Techniques

- Operational compatibility with Logistic Fuels
  - Electronic Fuel Injection
  - Fuel Reformation
  - Fuel Conditioning
- Easy Use of COTs based Balance of Plant components

→
- Reduction in Fuel Consumption
- Reduction in Total Ownership Cost
- Reduction of Wet Stacking

→ Increases Operational Flexibility

R&D Alternative Prime Movers

- Reduced Noise and IR signature
- Lower Emissions
- Low Vibration
  - Increased Life

→
- Reduction in Maintenance
- Negligible Wet Stacking

→ Fills Power Gap
- Availability
- Survivability

Results of Army S&T System Investments

Efficient JP-8 compatible 500W - 1.5 kW Watt Power Systems

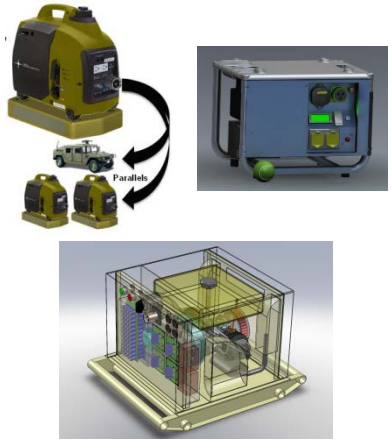
- Design and prototype an ultra-compact (1/2 C-cell size) JP-8 conversion kit to enables a lightweight SI engine to operate on JP-8/DF-2.

ultra Lightweight Field Generator Set (uLFG), 1 – 2kW

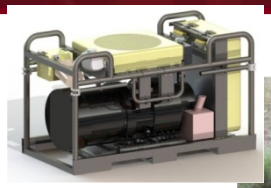
- Combine recent advances in small heavy fueled UAV engines with advanced hybrid power electronics to create a multi-fueled (JP-8/DF-2) portable genset featuring selectable DC output and load following capability.

Advanced Small, Lightweight Multi-Fueled 1 – 3.0 kW Variable Speed Load Following Man-Portable Power Unit

- Design, develop and demonstrate an advanced small, lightweight man-portable multi-fueled variable speed generator set that is capable of providing 1 – 1.5 kW of 120 V_{AC} and 28 V_{DC} via selectable switch.
- Leverage advancements in UAV, small lightweight IC engines, fuel conditioning techniques, composite materials for packaging, start of the art alternators and power electronics, and thermal management.



Results of Army S&T System Investments



Stirling Engine Development

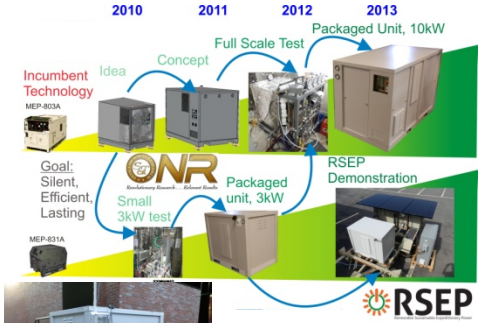
- Integrated 2-kWe JP-8 or DF-2 Fueled, External Combustion Power Source
- Addressed thermal management / heat transfer to augment combustion

Migrating Combustion Chamber Engine Development

- Integrated 2-kWe JP-8 or DF-2 Fueled Power Source
- High Power Density – 47 pound system (dry)
- 120 Vac / 28 Vdc Controls

Tubular SOFC

- Designed to TQG size and weight with targeted efficiency of > 30% with the potential for water export.
- Scalable to meet size/weight limits of current 3 kW TQG.
- Leverages fuel conditioning / reformation techniques to enable start, stop, operation on JP-8 fuel.
- Deliverable demonstrates – silent operation, interfaces with renewable energy based systems, very low emissions.



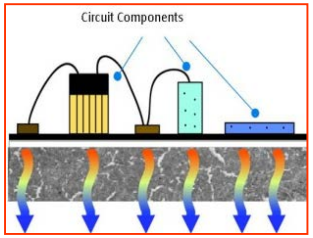
S&T Investments
Components / Subsystem

3 kW Rare Earth Free Alternator

- Design 17% - 20% lighter alternator using “high energy” ferrite magnets with very low lanthanum content.
- Integrate onto 3 kW TQG to demonstrate compliance with operational / performance requirements

Nanotechnology Enabled Thermal Management Materials for Power Electronics on a 3kW TQG.

- Using carbon-aluminum nanocomposite materials to replace existing circuit board base for electronics cooling, size reduction, and increase reliability.



Heuristic Generator

- Develop system to monitor operational characteristics of 10 kW genset such as fuel and oil levels, status of filters, generator electrical quantities, & vibration.
- Learns normal operation and will detect deviations to initiate repair or anticipate and avert imminent malfunction

S&T METRICS - ELECTRICAL

ELECTRICAL	
Standard	MIL STD 1332B Class 2C
Output Power	500 - 3000 Watts
Output Voltage	120 V_{AC}, single phase 3 wire with GFCI convenience receptacle
	120/240 V_{AC} 4 wire with GFCI convenience receptacle
	28 Vdc
	3-way selectable power outputs of AC only, DC only, or simultaneous AC & DC
Rated Power Factor	0.8
Voltage Regulation	3%
Frequency	60 $\pm$ 0.06 Hz
Waveform Deviation	5%
Harmonic Distortion	2%
Deration	Rated load at 4000 ft 95 ^{o} F <23% at 8000 ft 95 ^{o} F
Power Electronics	Variable speed option - minimize wet stacking and reduce fuel consumption
Start (Pull Start required as back up to Electric start)	< 5 min with or without battery under all environmental conditions noted in next section Pull start at – 10°C (14 F) with no assist (for $\leq$ 2 kW) Electric Start at -25 ^{o}F required for 3 kW

S&T METRICS - PHYSICAL

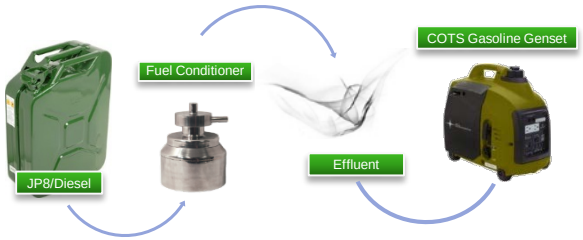
PHYSICAL	
Fuel	Hot Swappable, Multi fuel capable - JP-8 / DF-2 / Gasoline, compatible with operation on mixed fuels
Fuel Consumption 0.5 kW 1.0 kW 2.0 kW 3.0 kW	 0.12 gal/ hr (0.45 liters / hr) 0.2 gal/hr (0.76 liters/hr) 0.26 gal / hr (0.98 liters / hr) 0.28 gal/hr (1.06 liters/hr)
Drain	Fuel / Oil
External Fuel Tank	Stand alone, remote op capability
Dry Weight	500 W: 35 lbs 1000 W: 50 lbs 2000 W : 100 lbs 3000 W: 150 lbs
Protection Circuits	Voltage, Frequency, Overload, Short Circuit, etc.)
Reliability	750 hrs MTBF
Life / Durability	2500 - 3500 hours with multiple start/stops with multiple fuels and fuel quality (i.e. mixed fuel; varying fuel sulfur levels; etc)
Repair Time	TBD

S&T METRICS - ENVIRONMENTAL

ENVIRONMENTAL	
EMI / EM compatibility	MIL-STD-461E - Army ground
Audible Noise	< 62 dBA @ 7m 70 dBA at 0.9 m
Operating Temp	-32 C to 59 C (-25 F to 138 F)
Storage Temp	-51 C to 71 C (-60 F to 160 F)
Solar Loading	Up to 355 BTU/ft^2 solar radiation
Wind	Gusts to 95 ft/s
Ice glaze and freezing rain	Up to 0.5 in accumulation
Rain	Up to 5 inches of rain per hour impinging on the set at angles from the vertical up to and including 90 degrees from the vertical
Operating at Incline	0 to 15 degrees inclination
Salt, Fog, Sea Spray	Salt fog or sea-spray environment tested IAW MIL-STD-810F
Sand and dust	• Blowing sand/dust particle concentrations of up to 1,400 mg/m^3 • Particle diameter sizes: < 74 to 1,000 micrometers, with bulk of particles ranging in size from 74 to 350 micrometers
Relative humidity	Up to 95%

SUCCESS STORY

0.5 kW JP-8 Fueled Man Portable Generator Set"



FOCUS: conditioning middle distillate fuels for use in COT SI engine driven systems

Physical and Operational System Metrics

Power Output	700 – 900 W
Weight	< 40 lbs
Power Quality, Output and Modes	MIL-STD-1332B
Operating Temperature	-32°F to 140 °F (-36°C to 60°C)
Fuel	DF2, JP8 & Gasoline
Fuel Consumption	< 0.21 gals/hr
Acoustic Noise	65 dBA @ 7 m

Technical Approach

- Design and develop a fuel processing technique that will enable commercial gasoline engine driven generator sets to start and operate on middle distillate fuels - DF2 and JP8.
- Leverage advancements in UAV, small lightweight IC engines, fuel processing techniques, composite materials for packaging, start of the art alternators and power electronics, and thermal management.

Program Objective

- Demonstrate multi-fuel capability: gasoline, DF2 and JP8.
- Demonstrate load following capability and improved combustion on fuels.

"So What"

- Lightweight (<36 lbs), robust, single soldier - portable and cost effective power generator that fills the power gap between 500 and 2000 W
- Multi-Fuel Capability (JP8, DF2, Gasoline)
- Reduced potential for wet stacking at lighter loads
- Selectable DC output and load following capability

Transition:

PM-E2S2 – Small Tactical Electric Power Acquisition

PM-Soldier - Soldier Power Program (0.5-1 kW)

TECHNOLOGY TRENDS

Power Generation & Conversion:

- Alternative energy solutions are good; integrating them through networked energy systems is crucial to making them easy to use and realizing their full potential
- Micro/Nano power is an emerging area that may need more investigation
- Future generator programs need to have open-source control systems that can be integrated in energy networks

Energy Storage:

- Continue efforts toward scalable, hybrid energy storage
- Core battery and capacitor S&T capability required to address unique military applications

Power Control & Distribution:

- Intelligent power management has a real potential to improve capability (Intelligent power management is more than just microgrids; it is also for Soldier worn power, outposts, camps, vehicles. It is data-enabled to work in an interconnected manner.)
- S&T has made substantial progress in WBG technology - ready for acquisition integration

Thermal Management:

- Thermal limits are more frequently dictating operational capabilities
- Limited progress in thermal management technologies

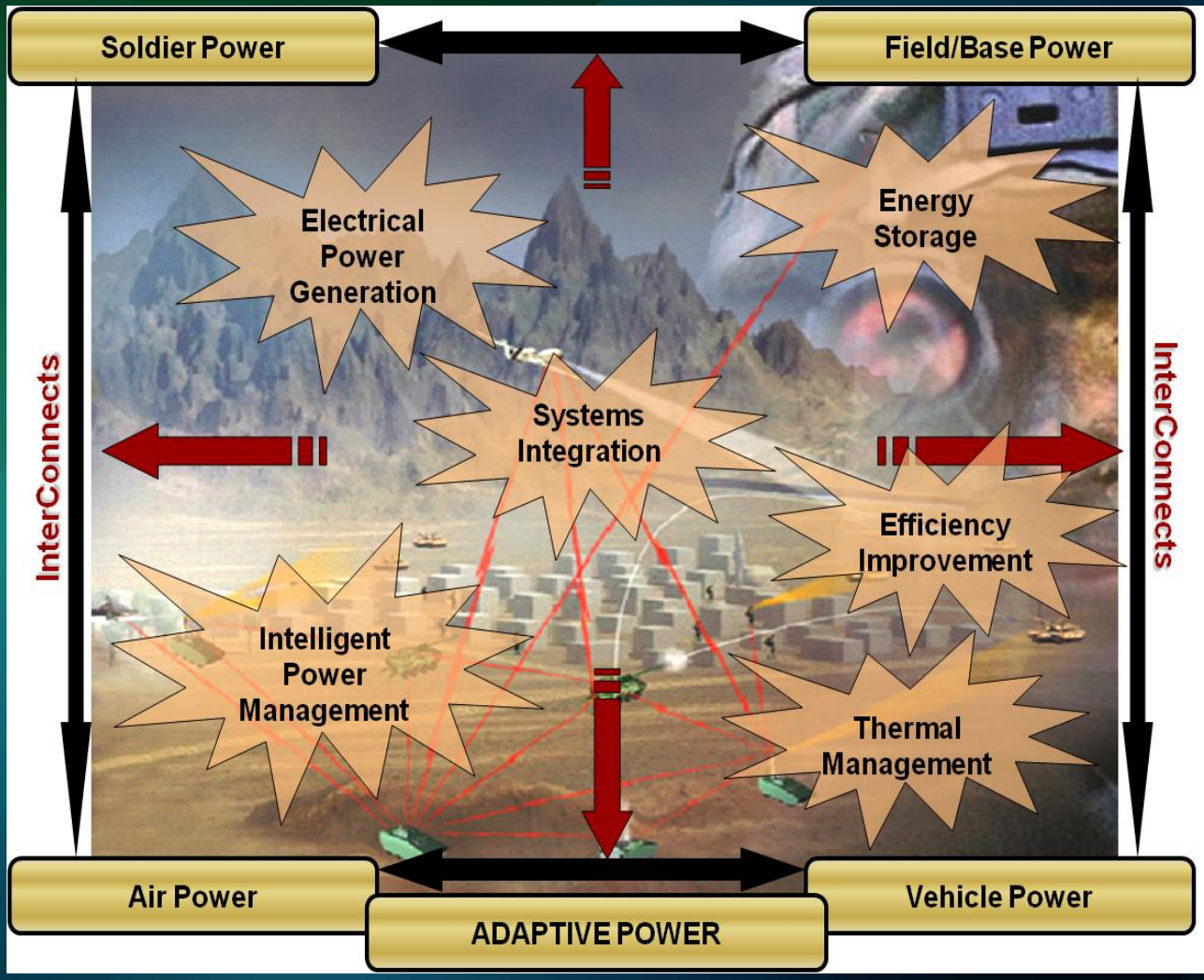
Fuels:

- Focus is primarily on alternative fuels qualification, not development of alternative fuels

Back - Up

P&E Warfighter Outcomes

- Enhance ground force effectiveness
- Reduce sustainment footprint
- Increase flexibility
  - Alternative energy
  - Recycling energy, water and waste
  - Redistributing resources
- Reduce size and number of Soldiers & systems
- Integrate power & energy situational awareness and management functions



Optimize energy use and enable energy-informed operations

Tactical Power Generation Needs

- **Advanced Electrochemical Materials** (Higher Energy/Power & Enhanced Safety)
  - >250 Wh/kg Advanced Lithium Ballistic Rechargeable, >450 Wh/kg Primary Conformal Wearable Battery
  - Optimization of Anode/Cathode Materials for Lithium Batteries, Li-Si, Li-$Li_xMn_2O_{4-y}Cl_z$
  - Optimization of CFx /CFx-MnO2 Blends
  - Development of Li-Air mission extender, 800Wh/kg, Li/S rechargeable & Ballistic Materials for Wearable Power Sources
  - Li-Ion Ultracapacitor, >50 Wh/kg

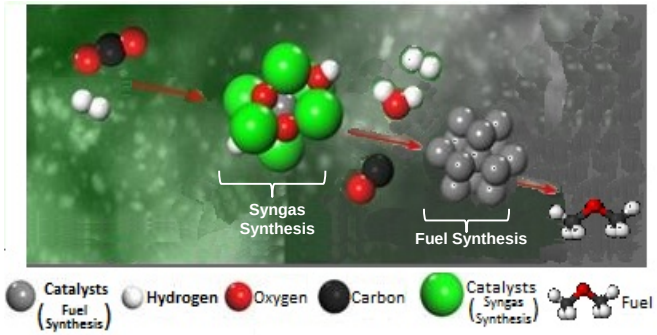
Conformal Battery

- **Multi-Fuel Portable Power Source**
  - 20-50W Alane fueled Conformal Wearable Fuel Cell, 170 W/kg, 900 Wh/kg 72 hrs
  - 1kW, <30lb Flex Fuel Man Portable Generator- JP-8, gasoline, propane, alcohols

Manwearable Fuel Cell

Portable Flex-Fuel
1 KW Generator

- **Fuel Reformation & Combustion**
  - CO_2 to fuel – H2 and Butanol
  - Fuel Reformation for Fuel Cells – JP8 to H2 (100Wh/Cartridge)
  - Design and fabrication of fuel synthesis catalysts



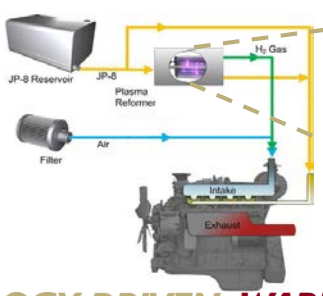
- **Energy Harvesting**
  - Solar & Wearable Kinetic Energy Harvesting for Soldier

- **Wireless Power & Power Distribution**
  - Soldier & Vehicle Battery Charging and E-Textiles

Energy Harvesting

Power Managers

Wireless Power Distribution
Transmission/Charging



Plasma Reformer

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

Characterization Testing

Physical Size / Weight Verification
MIL-STD-705C, Test Method 503.1 - Start and Stop Test
MIL-STD-705C, Test Method 601.4 - Voltage Waveform Test (Harmonic Analysis)
MIL-STD-705C, Test Method 601.5 - Voltage Waveform Test (Voltage Deviation Factor)
MIL-STD-705C, Test Method 602.1 - Voltage Modulation Test
MIL-STD-705C, Test Method 608.1 - Frequency and Voltage Regulation, Stability and Transient Response Test (Short Term)
MIL-STD-705C, Test Method 619.2 - Voltage Dip and Rise Rated Load Test
MIL-STD-705C, Test Method 661.2 - Sound Level Test
MIL-STD-705C, Test Method 670.1 - Fuel Consumption Test
MIL-STD-705C, Test Method 701.2 - Starting and Operating Test (Moderate Cold Battery Test)
MIL-STD-705C, Test Method 710.1 - High Temperature Test