U.S. Military Energy and Power S&T

Presented to:
Session 2: Innovative Energy Solutions for the Military: Emerging Technology Challenges

Innovative Energy Solutions for Military Applications (IESMA 2014)

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DoD Research & Engineering (R&E) Strategic Guidance

• Provides strategic guidance for DoD components to shape their R&E programs

  • Why we do R&D? “Three Enduring Principles”:

    1. *Mitigate* or eliminate current and emerging threats to national security

    2. *Affordably* enable new or extended military capabilities

    3. Create *technology surprise* through science and engineering


Energy and Power S&T

Provide energy and power technologies to enhance operational effectiveness and accelerate development of critical military platforms and weapons

What’s driving E&P S&T?

- High cost of fuel resupply, in dollars and lives, demands increased efficiency
- Greater electric power demand required by advanced weapons and sensors
- Military unique systems not supported by commercial R&D require dedicated DOD S&T; DOD S&T essential to exploit/leverage emerging commercial R&D

Technology Taxonomy

- Power Generation / Energy Conversion
- Energy Storage
- Power Control and Distribution
- Thermal Transport and Control
- Electromechanical Conversion
**Operational Energy**

**Operational Energy Needs**
- Improved Soldier power
- Energy management processes
- High efficiency energy conversion
- Tactical energy conversion and distribution
- High power, high density energy storage
- Power sources interoperability
- Alternative energy sources

**Operational Energy** is the energy and associated systems, information, and processes required to train, move, and sustain forces and systems for military operations.
**S&T for Operational Energy**

**Challenge:** Operational Energy new area for DoD
- Evolving approaches and portfolios
- Innovation is key for reducing risks, expanding capabilities
- Identify energy technologies for added investment
- Align S&T portfolios to address OE challenges/opportunities
- S&T to consider integrated security constructs & use of modeling and simulation

**Selected S&T Challenges**
- High Efficiency Energy Conversion & Harvesting
- Energy Integrated Design and Simulation
- High Efficiency Propulsion and Platform Design
- Environmental Control Systems
- Flexible and Adaptive Power Distribution

**Tasking:** Target 3, “Promote Operational Energy Innovation”
- Identify top overarching energy and power technology gaps affecting all services
- Use: Help inform OSD and Service energy and power S&T investment priorities
Operational Energy: US Army S&T Perspective

BASIC RESEARCH
• Underlying technology support for all domains
• Examples: wide bandgap materials, multi functional energy harvesting

SOLDIER
• Electrochemical power sources for longer lasting power
• Wearable Power and recharging capability for improved mobility
• Alternative energy, wireless power

BASING
• Generators with multi-fuel use
• Improved efficiency equipment, and energy efficient shelters
• Intelligent power management

GROUND
• Power generation and energy storage
• Power and thermal management
• Fuel characterization for engines

AIR
• Advanced turbine engines
• High efficiency drive systems
• Advanced Rotors
US DoD Key Service Labs, Centers

Critical S&T Capabilities/Facilities

• Army
  • TARDEC – Ground Systems Power and Energy Laboratory (GSPEL)
  • CERDEC – Soldier and Mobile Power and Energy Labs
  • ARL – Microfabrication Facility (Clean Rooms); High Voltage-Pulse Power Test Facility

• Navy
  • NSWC CD Philadelphia – DDG51 Land Based Engineering Site (LBES)
  • Electric Ship Consortium – Hardware-in-the Loop M&S, High Voltage, Adv Prototyping
  • NRL Autonomous Systems Lab – Multiple test environments, R&D labs, prototyping
  • NSWC Dahlgren – EM Rail Gun Facility
  • NUWC Newport – Electric Propulsion System Testing Facility

• Air Force
  • AFRL – Advanced Power and Thermal Research Laboratory
  • AFRL – INVENT Systems Integration Facility
New/Select User Facilities at DOE Labs

NREL recently opened its Energy Systems Integration Facility. NREL has user facilities for PV, fuel cells, vehicles, fuels, biomass, wind and others.

INL’s new Energy System Lab focuses on bioenergy, hybrid energy systems and advanced vehicle and battery testing.

PNNL’s Electricity Infrastructure Operations Center (EIOC).

Sandia PV System Evaluation Lab (PSEL)

Sandia’s Distributed Energy Tech Lab (DETL) includes configurable microgrids

E&P S&T community well-engaged with DOE labs and capabilities

ORNL’s National Transportation Research Center

NETL Solid Oxide Fuel Cell Experimental Lab

- Hybrid Performance Lab
Selected E&P S&T University Affiliations with US DoD

Ohio Center for Advanced Propulsion and Power
- Ohio State University (Lead)
- Case Western Univ.
- University of Cincinnati
- Univ. of South Carolina

Center for Integrated Thermal Management of Aerospace Vehicles
- Purdue Univ. (Lead)
- Univ. of Illinois
- Univ. of Dayton
- Univ. of Texas
- Wright State Univ.

Automotive Research Center
- University of Michigan (Lead)
- Wayne State Univ.
- University of Iowa
- Clemson Univ.
- Virginia Tech

Center of Excellence for the Advancement of Fuel Processing Technology (FuelWorks)
- Univ. of Maryland

High Heat Flux Thermal Management
- NC State Univ.
- Univ. of Central Florida

Center for Optimally Resource-Secure Outposts (CORSO)
- Georgia Tech

Electric Ship Research Development Consortium
- Florida State Univ. (Lead)
- Univ. of Texas - Austin
- Purdue Univ.
- USNA
- Naval Postgraduate School
- MIT
- Univ. of South Carolina

Vertical Lift Research Center
- Penn State (Lead)
- Georgia Tech
- University of Maryland

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### Commercial Energy and Power Market Space

#### Rechargeable batteries
$31.4B Li ion market in 2015\(^1\) (Est. $1.8B IR&D)
98\% Asian manufacturers\(^9\)
- Panasonic
- LG Chem
- BYD
- Johnson Controls
- 24M
- Solid Energy
- A123
- Altairnano

#### Engines and Generators
$300B ICE market in 2012\(^2\) (Est. $14B IR&D)
- General Motors
- Toyota
- Lycoming
- Westinghouse
- Achates
- Pinnacle
- EcoMotors
- Transonic

#### Power Mgmt. & Power Elect.
$20B power electronics market in 2012\(^5\)
(Est. $2.4B IR&D)
- Infineon
- Maxwell
- Vishay
- HP
- Cree
- Transphorm
- Adaptec

#### Photovoltaics
$85B PV market in 2013\(^6\), 9 of top 10 are Asian\(^10\)
(Est. $3.0B IR&D)
- Trina Solar
- Sharp Solar
- Yingli Energy
- First Solar
- Spectrolabs
- Semprius

#### Heating, Ventilation, Cooling
$8.2B high eff. HVAC in 2012\(^3\)
$79.6B total HVAC market in 2012\(^4\)
(Est. $1.5B IR&D)
- Daikin Industries
- Gree Electric Appliances
- United Technologies
- Clarke
- AAON
- Lennox Int.

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*Industry does not work in all areas to meet US Defense Department needs. Several technology areas are heavily foreign owned. Major national investments are not sufficient to maintain S&T advantage for military operations.*

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DOD looks for opportunities to leverage commercial technology where applicable. Identifying commercial technology suitable to military use/environment is a challenge; it must be carefully evaluated to ensure requirements unique to DOD systems are met.
**Technical Challenges:**
- Increase throughput, decrease cost of WBG devices (material growth, high-yield fabrication)
- Increase SiC wafer/epi-layer diameter and area yield
- Increase voltage, current/power ratings
- GaN based material growth and device development for power applications
- Reduce dislocations and defects in WBG materials

**Warfighter Impact:**
- Gain platform size, weight and power (SWAP) margin
  - Reduced cooling loops / integration
  - WBG operates >2x temp vs. Si devices
- Higher conversion efficiencies save fuel
  - WBG eliminates ~90% of power losses vs Si
- Enables advanced electric / EM weapons, sensors & protection
  - (WBG >10x voltage / power vs. Si devices)

**Key Performers:**
- **DMST Joint Manufacturing Technology (ManTech) project (SiC High-Efficiency Power Switches):** Army-ARL, TARDEC/Navy-ONR, NRL/Air Force-AFRL
- Partners: Cree, Inc., GE, PowerEx, APEI

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**Example of Highly Integrated DOD S&T Effort**

**WBG High Efficiency Power Switches**

**DOD S&T and MS&T efforts providing foundation for establishing Next Generation Power Electronics National Manufacturing Innovation Institute**

**Combat Vehicle Traction Drive**

**Ship-based Radar**

**Combat Aircraft Actuator Drive**

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Hybrid Energy Storage Module (HESM)

Collaborative R&D between DoD & ARPA-E (DoE) to develop scalable hybrid energy storage for military and commercial applications

Warfighter Impact:
- Enables Advanced Weapons and Sensors
- Improved fuel efficiency, power reliability
- Fuel & Maintenance Reduction vs. tactical quiet generator baseline
- Generator Reliability Improvement vs. strike aircraft baseline (improved availability / reduced costs)
- Shipboard fuels saving vs. DDG-51

Technical Challenges:
Develop and demonstrate HESM System functionality, operational control, and safety using SOA components
- Variable charge and discharge rates
- Modular-reconfigurable packages
- Assured life and safety

ARPA-E Advanced Management & Protection of Energy storage Devices (AMPEd) program:
- Assess technology integration, quantify benefit of HESM system designs for commercial applications

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Combustion-based Thermophotovoltaics

WHAT IS IT?
• Small scale combustion of logistics fuel and thermophotovoltaic energy conversion.

WARFIGHTER IMPACT:
• Reduced size and weight power source for small systems and Soldier power
• High energy density: 3 times higher than existing rechargeable battery
• Multi-fuel capability including JP-8
• Instant refueling

TECHNICAL APPROACH:
• Efficiency $\eta_{TPV} = \eta_{thermal}\eta_{spectral}\eta_{cavity}\eta_{PV-cell}$
• Portable and Lightweight

- Hybrid heterogeneous and homogeneous combustor and integrated heat recuperation research for efficient, small scale heat generation
- Develop hybrid microcombustor to convert JP-8 and other fuels
- Identify bimetallic catalysts based on conversion of JP-8 and sulfur tolerance
- Selective emission research using photonic crystals to tailor emission for optimum photovoltaic cell response
- Spectral Efficiency = 31%
- Spectral Efficiency = 83%
- Low bandgap photovoltaic cells and surface texturing research will enable more thermal radiation to be converted
- Lattice mismatched InGaAs materials and devices development
- Sub wavelength features to optimize transmission

Integration and Prototype Development
Propane fueled, high temperature burner with heat recuperator and doped ceramic emitter rods. Will use 0.72eV GaSb photovoltaic cells

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Electrotextiles

Purpose: Create a textile incorporating fibers that generate electricity to power devices, charge batteries or store energy for future use. The fabric can be integrated with traditional Soldier-borne electronic networks.

Warfighter Impact:
- Improve fight-ability, agility, and versatility by providing lightweight materials to reduce Warfighter’s load
- Reduce the number of external snag-hazard cables
- Provide an integrated renewable power source to extend mission
Photovoltaic Textiles

WHAT IS IT?
• Power-harvesting textiles utilizing
  • Photovoltaic fibers
  • Photovoltaic tapes
• Solar cells in novel form-factors
• Portable power with three axis flexibility

TECHNICAL APPROACH:
• Increase the efficiency of the 1st gen fibers via active layer polymer formulations and hi-index claddings
• Increase usable fiber lengths via more conductive electrodes
• Develop an automated connection scheme to bring PV fibers from the lab to a production environment

WARFIGHTER IMPACT
• A light-weight, flexible power source with textile characteristics
• A means of reducing logistical burdens associated with batteries and small generators
• May enable new applications not formerly possible

• PV tape approach currently uses two interwoven tape types: PV tapes and BUSS bar tapes
  • Fault tolerant woven design provides multiple redundant electrical pathways
  • Simple clamp style electrical termination
  • Proposed dual PV tape design would solve PV tape shadowing = higher power output

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Novel Fuel Cell Research

Alkaline Fuel Cells:
State-of-the art research – Materials by Design

Unit Bi-Cell in Stack/System

Research areas:
- Quantum chemistry: model compounds for polymer synthesis
- Molecular processes: reactive transport, polymer structures & charge transfer
- Morphology and interfaces: effects on transport stability
- Component & device performance

Alane Fuel Cells:
Portable Soldier Power

Wearable, energy dense power source

Development area:
- 20 W Conformal Alane-fueled fuel cell
- High energy density over 72 hour mission profile
- Low temperature PEM design
- Wearable, small form factor, with significant weight reduction over batteries for mission duration

Solid Oxide Fuel Cells:
Outpost Power

Demonstration 10 kW SOFC

Development area:
- Tubular SOFC power unit
- Compact replacement for outpost and FOB tactical quiet generators
- Low acoustic and visible signature
- High efficiency
- Navy (ONR) and Army (CERDEC) cooperative effort
Managing Base Camp Energy

**CONTINGENCY BASING GOALS**

- Understand Functional Systems & System Dynamics
- Reduce Resource Requirements
- Reduce Environmental Liabilities
- Increase Modularity, Scalability, Adaptability, Reusability, Durability, Reliability
- Enhance Survivability
- Improve Sustainability
- Improve Deployability
- Improve Redeployability

**Virtual Forward Operating Base**

VFOB is a research effort at ERDC that seeks to integrate design and analysis functions for contingency base camps within a systems analysis architecture.

**Deployable Metering & Monitoring System (DMMS)**

- Wireless Metering
- Contingency Base – Energy Management System (CB-EMS)
- Energy Planning and Analysis Toolset (Wide Area Visualization Environment (WAVE))

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Portable Small UAS
Fuel Cell-Battery Hybrid Power

**Goal:** Development of a logistically-fueled, fuel cell-based power system capable of providing prime power and propulsion for a S-UAV (50 – 150 lbs) for extended duration missions.

**Developing Hybrid Power Systems**
- High energy component (Fuel Cell) to provide a steady state power and recharge the high power density component.
- High power component (Battery) to provide peak power requirements – for UAVs peak power is needed for take offs, altitude changes and high speed dashes.
- Power manager to increase the efficiency of the system.

**Technical Challenges**
- Increase System Level Power Densities
- High Performance Operation with Sulfur-Containing Fuels
- Improve reliability (MTBF)

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**Diagram:**
- High Energy System (Fuel Cell)
- Hybrid Power System
- High Power (Battery)
- Smart DC/DC Converter
- Power Management

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Technology Trends

• **Power Generation/Energy 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 Distribution and Control:**
  - 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

• **Thermal Transport and Control:**
  - Thermal limits are more frequently dictating operational capabilities
  - Limited progress in thermal management technologies

• **Electromechanical Conversion:**
  - Historically reliant on industry development/investment in this area

*Multi-scale modeling and simulation of energy devices/components/systems will pay dividends*
Power Generation/Energy Conversion S&T

OBJECTIVES:
• Advance energy harvesting technologies
• Develop tactical, deployable power systems (3-5 kW) utilizing conventional and alternative fuels and renewables
• Scalable, long endurance air independent energy dense (3-5X) propulsion power (5-10 kW)
• Modular solid-oxide fuel cells for tactical power; fuel cells (10 kW- 100 kW) with > 40% efficiency

TECHNICAL CHALLENGES:
• Compact desulfurization technology for fuel cells to enable the use of logistics fuels (JP8)
• Integration complexity of fuel cell systems
• Integration and fielding of energy harvesting technologies.
• High efficiency energy harvesting solutions.
Energy Storage

OBJECTIVES:
• Rechargeable batteries that are safe and provide higher energy and power densities
• Develop hybrid high power, high energy storage for cold starting requirements, peak load on generator, and high-power weapons/sensors
• Long-life pulse power and power conditioning capacitors operable at higher temperatures
• Extreme-temperature operations (both very low and very high) for batteries

TECHNICAL CHALLENGES:
• Stability and safety of high voltage electrolytes, electrode materials, and electronic characteristics in extreme and abusive environments
• Cycle life at elevated temperatures and power capability at very low temperatures for rechargeable batteries
• Understanding dielectric break-down mechanisms
• Multi-scale computation and modeling to identify new capacitor materials and explain observed phenomena

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Power Distribution and Control

**OBJECTIVES:**
- Develop real-time & non-real-time modeling & simulation to support designs, with high adaptability to multiple components, devices and systems.
- Develop Wide Bandgap (WBG) power electronics for higher power, efficiency, and temperature.
- Investigate source/load characteristics to determine holistic prognostic/diagnostic and control approaches.

**TECHNICAL CHALLENGES:**
- Bi-directional power control, at power densities suitable for platform implementation.
- Robust and flexible medium voltage DC (MVDC) distribution for ships.
- Data-enabled peer-to-peer energy networks.
- Dynamic & transient electric system stability and fault protection for military unique loads.
- Manufacture large area, low cost, low defect WBG device wafers.

Many Existing Microgrid R&D Efforts

HI-Power Open Architecture
Thermal Transport and Control

OBJECTIVES:

• Advance thermal science and technology to efficiently manage heat and enable higher power density systems.

• Develop advanced evaporators, condensers, phase separators, pumps, and control systems required for closed-loop phase change cooling system.

• Enable adaptive or hybrid-cycle technologies to mitigate thermal challenges on current/future platforms.

• Thermal system modeling at various length scales

TECHNICAL CHALLENGES:

• Two-phase systems often limited by hydrodynamic instabilities and critical heat flux.

• Efficient and environmentally friendly cooling techniques to minimize additional HVAC systems.

• Adaptive subsystems require “on-demand” components and advanced subsystem control methodologies, compatible with engine systems.

• Limited materials and fluids available with good thermal properties
**OBJECTIVES:**

- Increase power density, efficiency, and robustness of motors, generators, and actuators
- Develop alternative magnetic materials, including replacements for rare earths
- Improve component reliability

**TECHNICAL CHALLENGES:**

- High-fidelity methodologies for powertrain energy analyses including electric/hybrid systems
- Optimizing materials properties (magnetic strength, temperature compatibility, purity, rare-earth-free magnetics)
- Wide-temperature operational requirement
- Fault management in high speed, high power induction machines
- High power density electric actuation
Energy & Power Warfighter Opportunity Areas

Tactical Unit Energy Independence:
• Develop renewable, sustainable, operational tactical unit power
• Modular systems for onsite assembly and maintenance
• Fuel flexibility, onsite fuel and energy harvesting

Autonomous Platform Power:
• Provide power and energy solutions to support long endurance, undersea, ground, or high and low altitude unmanned operations
• Includes propulsion, sensor packages, weapons, and autonomous operation

Adaptive Power Networks:
• Power networks for both mobile and fixed power installation
• Utilize a variety of power sources and load requirements that range from platforms (Soldier, ship, aircraft, ground vehicle) to mobile FOBs and fixed installations

Energy Optimized Platforms:
• Focus on platform electrical & thermal systems, components, and integration
• Support increased warfighter requirements while reducing the amount of fuel used
• Minimize platform thermal constraints

Electric Weapons and High Power Sensors:
• Support the use of advanced sensor systems and electric weapons (e.g., PFN)
**Energy Optimized Platforms**

**Objectives**
- Increase electrification
- On-demand power architectures to improve efficiency by 20%
- Increase power system reconfigurability
- Provide energy source flexibility
- Eliminate platform thermal constraints (i.e., hot fuel)
- Reduce energy costs and refueling requirements

**Priorities**
- Power & thermal management integrated with advance propulsion
- Higher voltage architectures
- More capable power electronic components and devices
- Sufficient onboard electrical power for increasingly energy-hungry mission systems
- Energy recovery systems

**Areas of Research Interest**
- Integrated, adaptable power and thermal models, simulations, and demonstrators for platforms
- Auxiliary power for engine-off missions (silent watch)
- More thermally rugged systems that lessen cooling demands
Tactical Unit Energy Independence

Objectives

- Use of locally-available energy sources for company and below (150 individuals and below)
- Expand the range and endurance of the Tactical Unit through size, weight, and efficiency improvements
- Rapidly reconfigurable with intelligent power management to balance supply & load
- Reduction in fuel required to sustain organic base operations

Priorities

- Common architecture and interfaces to support reconfigurable power
- Intelligent supply/demand management
- Increase power density of renewables
- Improved conversion efficiency of power sources, including fuels and renewables
- Energy storage density and stability

Areas of Research Interest

- Hybridize energy storage with small tactical sources
- Compact, lightweight, wearable power generation sources
Objectives:
• Develop power and energy systems that enable next-generation autonomous platforms.
  • Long endurance
  • High Reliability & Scalable
  • Low maintenance power systems
• Mission adaptable power
• Automatic energy and power use optimization
• Autonomous energy harvesting

Priorities
• High energy and power density
• High storage density oxidizer & fuel source for undersea and high altitude platforms
• On station energy harvesting
• Defined hazards & mitigations for advanced high energy density solutions
• Operation on logistic fuels (JP-X)

Areas of Research Interest
• Higher energy density storage
• Greater energy and power conversion efficiency
• In-situ, autonomous energy harvesting
### Objectives

- Reduced demand and improved efficiency through integrated, intelligent power distribution and management
  - Adaptable, automatic reconfiguration
  - Predictive control
- Enhanced mission effectiveness
  - Survivable, reliable, resilient
- IT enabled architectures; Cyber enabled energy control and security systems
- Integrated, open architecture design and intelligent, predictive, automatic control and management; plug and play

### Priorities

- Integrated, intelligent power distribution and management
- Effective utilization of all available and emerging energy and power sources
- Standards and standardized interfaces
- Power converters and inverters for interoperability

### Areas of Research Interest

- Automatic reconfiguration, adaptable on demand
- Electrical transient management within an energy network
- Affordable prognostics and diagnostics leading to predictive control
Electric Weapons and High Power Sensors

Objectives
- Extend continuous and pulse-enabled protection and lethality systems
  - Multi-MW power level capabilities
  - Support pulse power [$\mu$s - ms] & continuous duty
  - Increased repetition rate
- Enable load-leveled, right-sized platform power with increased efficiency

Priorities
- Dynamic power - widely varying instantaneous peak power demand & power quality
- Dynamic thermal - megawatt thermal management system
- Integrated with platform/engine system
- Extreme power density
- Pulsed power components

Areas of Research Interest
- Fast response thermal management and materials
- Dynamic power management with load balancing for multiple pulse applications
- Increased energy and power dense storage, conversion, and switching components

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**US DoD Energy and Power Overarching S&T Priorities**

- Integrated power and thermal management - handle surging high energy and power density needs for multiple systems/power ranges
- Integrated, intelligent power distribution and management
- Architectures, interfaces, and standards for reconfigurable power (energy networks / microgrids)
- More capable, higher power/temperature/efficiency power devices & components and devices (e.g., WBG for continuous & pulse power)
- Extended energy storage, harvesting, and recovery
E&P S&T Key Recommendations

• Thermal management for increasingly power dense devices and systems
  • Recommendations: (1) Invest in materials research for very high thermal tolerance; (2) Incorporate thermal constraints into early design and acquisition criteria

• Automatic reconfiguration, adaptable on demand, power networks for tactical applications
  • Recommendations: (1) Investigate modular reconfigurable energy network building blocks and interfaces; (2) Leverage industry Smart Grid technologies

• Autonomous energy harvesting, in and from challenging environments, while operationally deployed
  • Recommendation: Increase efforts to reduce size and weight, and increase efficiency, of energy harvesting technologies & systems

• Integrated power and thermal models and simulations usable across a range of systems and platforms
  • Recommendation: Conduct study examining model re-usability/model sharing, addressing scalability and applicability

• Higher energy density storage and greater energy and power conversion efficiency
  • Recommendations: Shape, leverage and adapt selected commercial and OGA efforts where appropriate
Summary

• Maintaining S&T superiority is a *foundation* of the US DoD research and engineering strategy

• In an increasingly electrified battlefield, energy and power S&T is more important than ever before ….. *an essential underpinning technology*

• With funding and economic stress challenging defense departments world-wide, the *need for international collaboration increases*

• Energy and Power is an area *well-suited for collaborative research and development!*
Energy & Power Main Performers  
(DOE – ARPA-E)

ARPA-E current areas of focus
Programs applicable to DOD; all work outsourced

- **ADEPT** - Agile Delivery of Electrical Power Technology
- **AMPED** - Advanced Management and Protection of Energy Storage Devices
- **BEEST** - Batteries for Electrical Energy Storage in Transportation
- **BEETIT** - Building Energy Efficiency Through Innovative Thermodevices
- **Electrofuels** - Microorganisms for Liquid Transportation Fuel
- **GENI** - Green Electricity Network Integration
- **GRIDS** - Grid-Scale Rampable Intermittent Dispatchable Storage
- **HEATS** - High Energy Advanced Thermal Storage
- **METALS** - Modern Electro/Thermochemical Advances in Light Metals Systems
- **MOVE** - Methane Opportunities for Vehicular Energy
- **PETRO** - Plants Engineered to Replace Oil
- **RANGE** - Robust Affordable Next Generation Energy Storage Systems
- **REACT** - Rare Earth Alternatives in Critical Technologies
- **Solar ADEPT** - Solar Agile Delivery of Electrical Power Technology
- **SWITCHES** - Strategies for Wide-Bandgap, Inexpensive Transistors for Controlling High-Efficiency Systems

-New Programs:
- **FOCUS** - Full-Spectrum Optimized Conversion and Utilization of Sunlight (Feb 2014)
- **REBELS** - Reliable Electricity Based on ELectrochemical Systems (Nov 2013)
DOD FFRDCs

DoD FFRDCs
- Lincoln Laboratories (MIT)
- Studies and Analyses Center (Institute for Defense Analyses)
- National Defense Research Institute (RAND Corp.)
- National Security Engineering Center (MITRE)
- Software Engineering Institute (Carnegie-Mellon Univ.)

Air Force FFRDCs
- Aerospace Federally Funded Research and Development Center (The Aerospace Corp.)
- Project Air Force (RAND Corp.)

Army FFRDC
- Arroyo Center (RAND Corp.)

Navy/Marine Corps FFRDC
- Center for Naval Analyses (The CNA Corp.)

Examples of current/recent E&P engagement with DOD FFRDCs:

- Studies and Analyses Center (IDA) supported the E&P COI Gap Development
- Lincoln Labs (MIT) is supporting Navy’s OECIF-funded EEOMC project
- Lincoln Labs (MIT) recently completed a study for NSWC-Carderock on Tactical Power
- Arroyo Center (RAND) is working on a study for Army G-4 on energy-related decision support tools/models
- Lincoln Labs (MIT) is supporting Army-CERDEC Energy Informed Operations Project
- National Security Engineering Center (MITRE) is supporting Reliance 21 roadmapping efforts
- National Defense Research Institute (RAND) recently completed a study for ASD(R&E) on Rechargeable Soldier Portable Batteries

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Intelligent Power Management: Key to Tactical Energy Networks

Next Microgrid Technologies (future collaboration ideas)

1. Power management architecture
2. Plug-and-Play devices and power distribution
3. Advanced cost effective prognostics and diagnostics
4. Advanced WBG electronics
5. Decentralized controls

Close collaboration to change the base camp energy paradigm

6.1-6.2 Research

1. Architectures: AC-DC, DC-DC energy networks: M&S; universal, distributed, matrix converter designs
2. High power packaging and circuitry
3. Cost-effective device ID, reliability and predictive sensors; learned behavior and pattern recognition algorithms
4. Power Devices, Components and Modules; WBG technology; hybrid energy storage
5. Device and component intelligence modules

6.2-6.3 Development

1. AC-DC conversion devices for AMMPS, to support DC microgrids
2. Microgrid control and interfacing to enable plug-and-play connections
3. Integration of advanced ID and prognostic/diagnostic programs for microgrid controls, with associated control hardware; integration of legacy fleet
4. WBG power conversion devices that enable DC microgrids using legacy generation
5. Ad hoc, reconfigurable, mobile energy network

Solving the OE Strategy challenge: Integrating energy management through networking, advanced sensors, control software and hardware, and power devices to provide PM-E2S2 with a 21st Century mobile, adaptable energy network!