Overview of DoD Energy & Power S&T

Energy & Power Community of Interest

December 2017

Energy & Power COI Overview

"If you are going to use energy as a weapon, you better have plenty of it."

Enduring S&T Gaps

- Thermal limitations on capabilities, efficiencies, power densities
- High voltage, high frequency, high rate pulse power
- Extend duration to reduce energy resupply
- Power distribution flexibility
- On-station autonomous energy harvesting

What's driving E&P S&T?

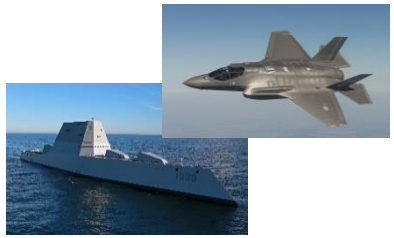
- ***Greater electric power requirements for advanced weapons and sensors***
- Unique military systems not supported by commercial R&D require dedicated DoD S&T; DoD S&T essential to leveraging emerging commercial R&D
- Demand to enhance mission effectiveness and reduce operational risk through more effective and efficient use of operational energy

COI Purpose

Provide technologies to enable intelligent power & energy management and enhance operational effectiveness

Warfighter Opportunity Areas

Energy Optimized Platforms



Electric Weapons and High Power Sensors

Adaptive Power Networks

Autonomous Systems Power

Tactical Unit Energy Independence

Tier 1 Taxonomy Brief Descriptions

Power Generation/Energy Conversion:
Develop tactical, deployable power systems using available fuel and renewable/ambient sources to generate electrical energy.

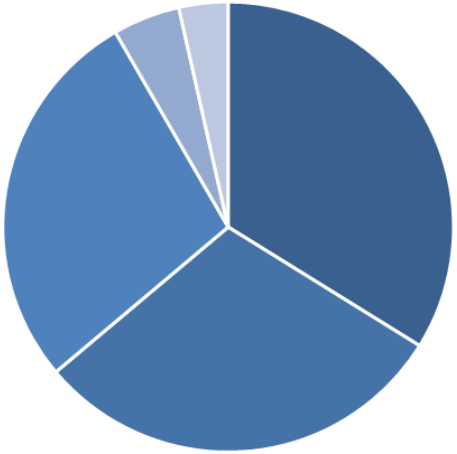
Energy Storage:
Improve electrical and electrochemical energy storage devices to decrease device size, weight, and cost as well as increase their capabilities in extreme temperatures and operating conditions.

Power Control and Distribution:
Enable smart energy networks for platforms, forward operating bases, and facilities through new, greater capability and efficiency components as well as modeling & simulation tools.

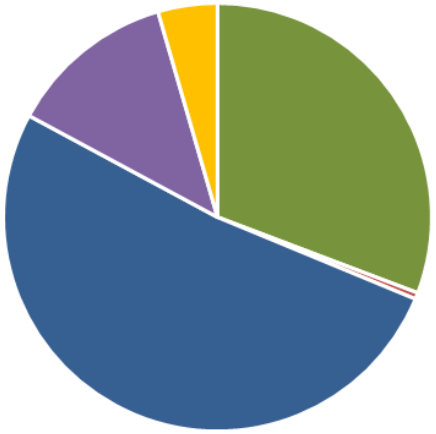
Thermal Transport and Control:
Efficiently manage heat and enable higher power density systems through advanced thermal science and technology: advanced components, system modeling, and adaptive or hybrid-cycle technologies.

Electromechanical Conversion:
Increase the power density, efficiency, and robustness of motors, generators, and actuators while also reducing their life cycle costs.

E&P COI FY18 Funding

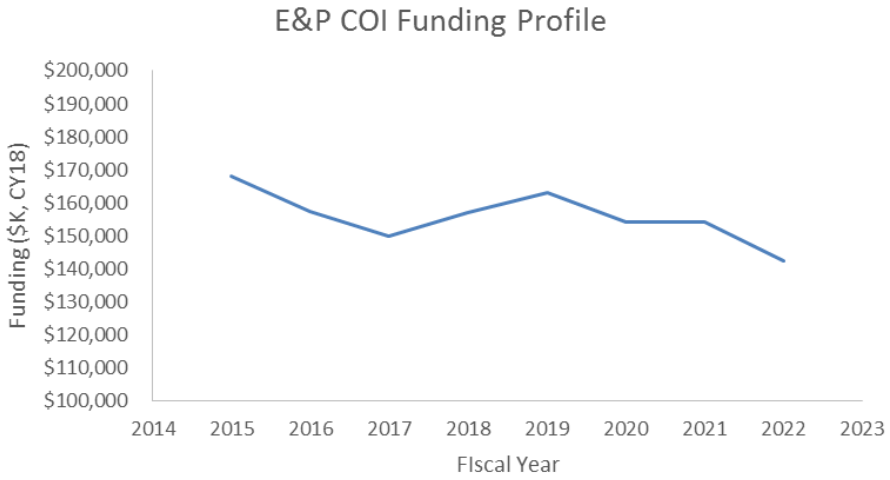


Power Control and Distribution	34%
Energy Storage	30%
Power Generation/Energy Conversion	28%
Thermal Transport and Control	5%
Electromechanical Conversion	4%



Army	31%
MDA	<1%
Navy	52%
OSD	13%
SOCOM	4%

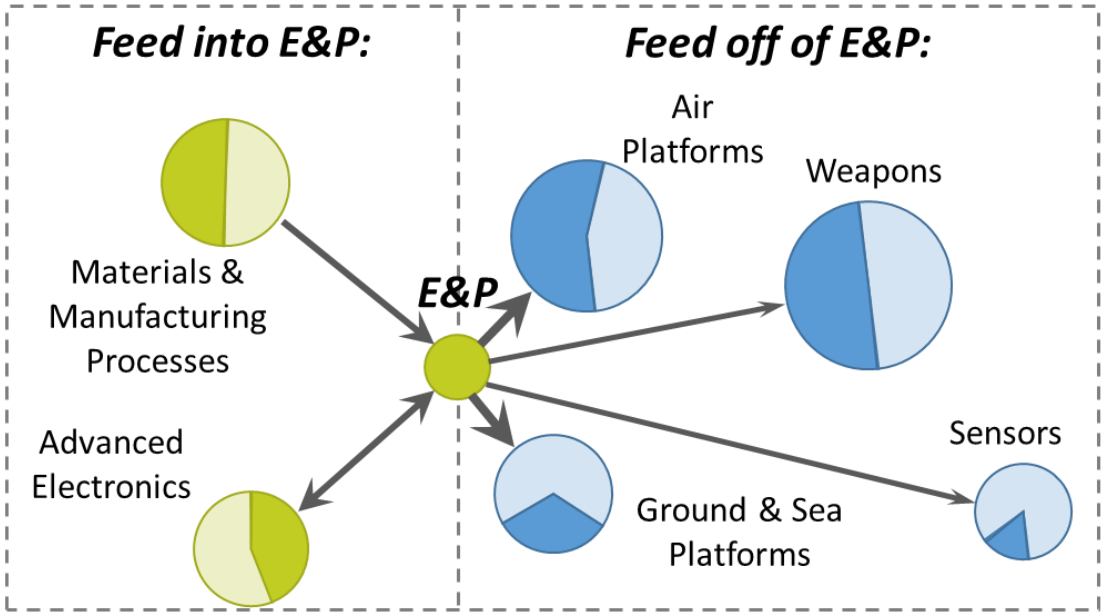
Air Force $$ binned under Air Platforms COI



Investment profile:

- PB18 $156.8M, 54% BA 2 & 46% BA 3
- Significant USAF Thermal Transport and Control funding aligned with Air Platform COI.

E&P S&T Portfolio Interdependency with other COIs



The remaining COIs have a second-order relationship (e.g., C4I through Sensors)

E&P develops fundamental technologies, which

- directly feed into the capabilities developed in the non-Space platforms, Weapons, and Sensors COIs
- and rely on improvements in materials, manufacturing, and electronics.

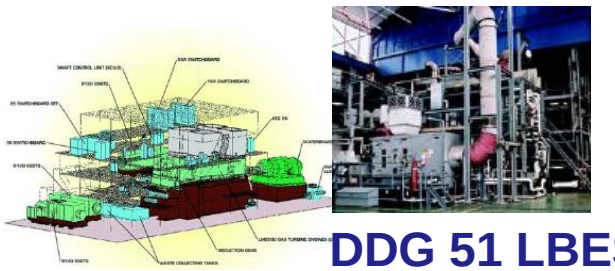
New advancements will result additional direct relationships:

- Cyber CoI on the cyber resiliency of intelligent power and energy systems
- Autonomy CoI on advanced energy behaviors for Autonomous systems

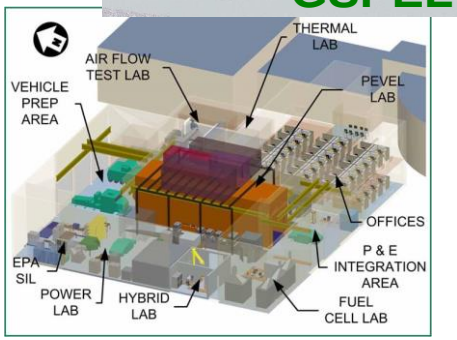
Key DoD Service Labs, Centers

- **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; Center for Research in Extreme Batteries (CREB)
  - ERDC-CERL – Center for the Advancement of Sustainability Innovations (CASI)
  - NSRDEC – Doriot Climatic Chambers
  - Contingency Basing Integration Technology Evaluation Center (CBITEC, Ft. Leonard Wood)
  - Base Camp Integration Lab (BCIL, Ft. Devens)
- **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
  - NAS Pax - Naval Power, Avionics, and Thermal (NPATH) Lab
- **Air Force**
  - AFRL – Advanced Power and Thermal Research Laboratory
  - AFRL – Systems Integration Facility

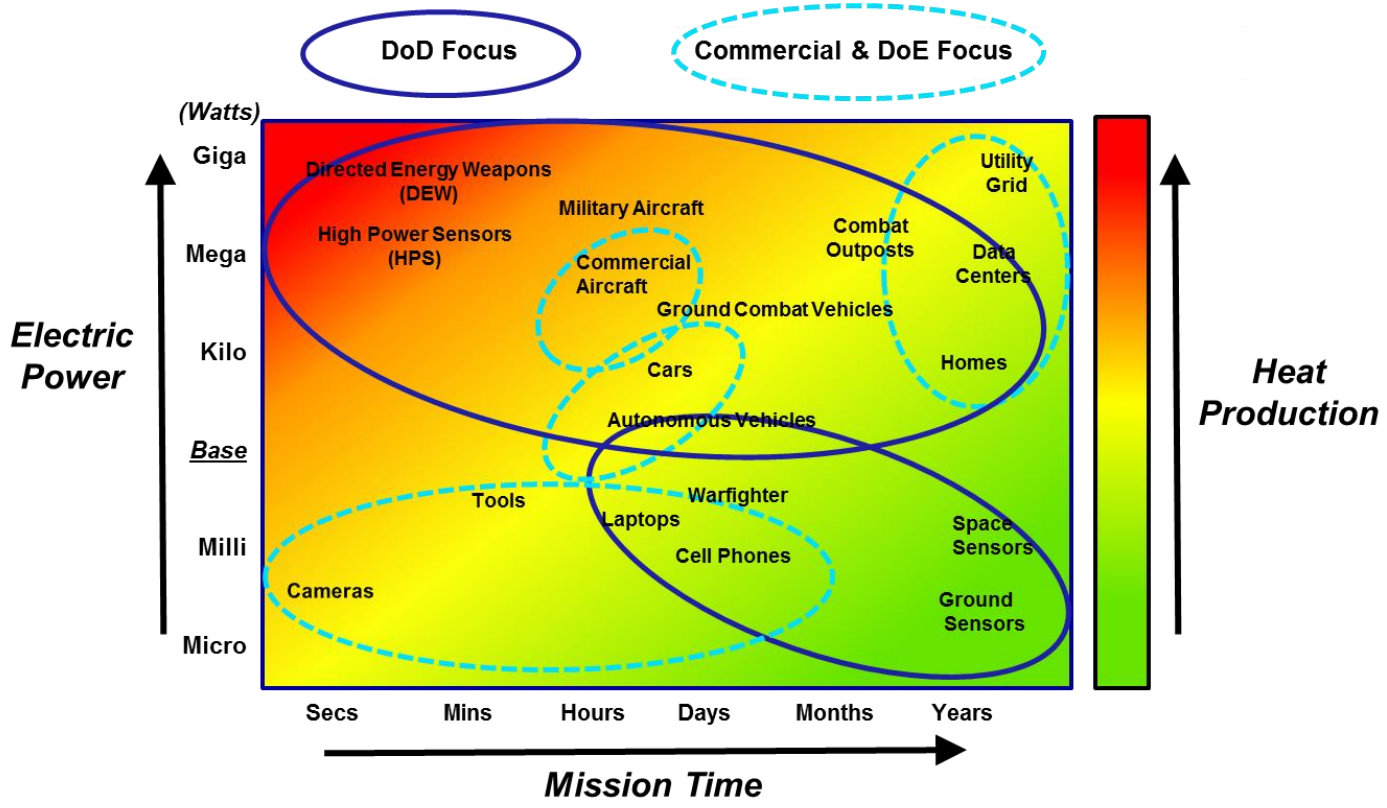

GSPEL


DDG 51 LBES


AFRL Adv Power and Thermal Research Lab



Unique DoD Energy and Power Technologies



- ***Directed energy weapons*** **and their intended platforms are areas where the DoD must perform or fund its own Energy & Power R&D.**
- **There are opportunities for collaboration with NASA & FAA efforts to develop** ***more efficient aircraft propulsion*** **for the commercial sector.**

Energy & Power COI
Warfighter Opportunity Areas (WOA)

Energy Optimized Platforms: *Optimizing platforms to keep the fight unfair.*

- Novel Metal-Ion and Aqueous Battery Chemistries
- Electric Ship Research and Development Consortium (ESRDC)
- MegaWatt Tactical Aircraft (MWTA) Program

Electric Weapons and High Power Sensors: *Enable asymmetric capabilities.*

- Ultra High Density Hybrid Energy Storage Module (UHD HESM)
- Open System for Controls of Integrated Propulsion, Power, and Thermal (OSCIPPT)
- Thermally Enabling Architecture for Pulse-Power Systems (TEAPPS)

Autonomous Systems Power: *Enable long-duration, autonomous operation in unique and challenging environments.*

- Compact Military Power (UGV)
- Hydrothermal Vent Exploitation for Undersea Energy (HTVE-UE)
- Quiet Propulsion (Great Horned Owl, GHO) & Eyes Below the Weather (Tactical Off-Board Sensing, TOBS)
- Multi-Day Endurance of Group 2 Unmanned Aerial System (Hybrid Tiger)

Tactical Unit Energy Independence: *Extending the reach of energy and power systems to untether Warfighters.*

- Advanced Integrated Solider Power (AISP) Science & Technology Objective (STO)
- Self-Sustaining Soldier Power (S3P) STO
- Multifunctional, Structurally Integrated Flexible Energy Storage

Adaptive Power Networks: *Automating energy management for optimized mission performance.*

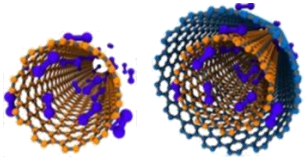
- Energy Informed Operations (EIO)
- Intelligent Power Components & Integration
- Tactical Microgrid Standards Consortium (TMSC)

Energy Optimized Platforms

Objectives:

- Improve platform efficiency through the use of on-demand power architectures
- Increase power system reconfigurability
- Provide energy source flexibility
- Eliminate platform thermal constraints

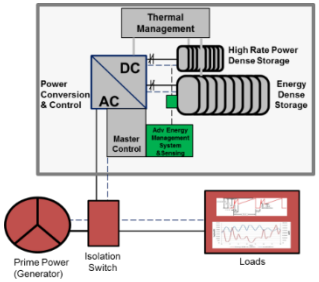
Advanced Circuit Protection



Carbon-Based Conductors

10 kV SiC MOSFET

Thermal Science



Hybrid Energy Storage Module (HESM)

Optimizing platforms to keep the fight unfair

Operational Opportunities:

- Enhance mobility and mission flexibility
- Reduce refueling requirements
- Improve survivability and signatures
- Increase mission effectiveness and endurance
- Enable next generation mission capabilities

Technical Challenges:

- Increased power density to improve platform capability
- Improve control and efficiency of integrated power & thermal systems
- Improve fault and failure mitigation
- Develop integrated physics-based models to enable systems engineering driven by increased electrification

Energy Optimized Platforms Priorities & Challenges

Priorities

- Power and thermal management integrated with advanced propulsion systems
- Develop M&S tools to enable integrated design and architectures
- Higher power architectures to enable new capabilities, reduce weight, and improve efficiency
- More capable power components able to operate at higher temperatures and higher voltages, more efficiently
- On-demand power architectures for increasingly energy-hungry mission systems

S&T Challenges

- Integration of and V&V for adaptable hardware-in-the-loop power and thermal models
- Adaptable power, thermal, & controls for on-demand mission requirements
- Develop high density electrical & thermal energy conversion & storage

Potential Future Focus Areas

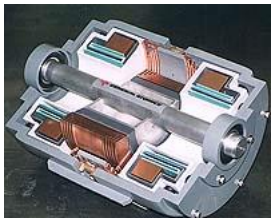
- Continuous availability of high power on-demand mission capabilities
- Enabling increased platform design flexibility and scalability through more capable power & thermal systems

Electric Weapons and High Power Sensors

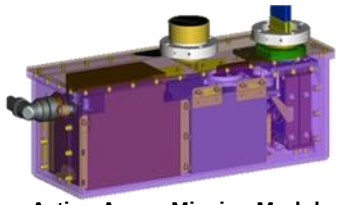
Objectives:

- Extend continuous and pulse-enabled protection and lethality systems
  - Multi-MW power level capabilities
  - Support pulse [µs - ms] & continuous power
  - Increased repetition rates
- Minimize size and weight of high power & thermal systems

Multi-function Energy storage Advance Power Link Module



36.5 MW Superconducting DC Homopolar Motor



Active Armor Mission Module

Enable asymmetric capabilities

Operational Opportunities:

- High power sensors
- Directed energy weapons (laser, RF)
- Electromagnetic weapons

Technical Challenges:

- Very high density power sources and energy storage for high rate pulsed power
- Power & thermal management for dynamic, high rate pulsed power
- Efficient platform power and thermal system operations during pulses, idle, and in-between
- Mega/Giga-Watt power generation & thermal management
- Safety and containment of pulsed power systems

Electric Weapons and High Power Sensors Priorities & Challenges

Priorities

- M&S of the dynamic response of thermal management systems to extreme and pulsed loads
  - Thermally Enabling Architectures for Pulse Power Systems (TEAPPS) OECIF Project
- Increase the power density of electrical generation for air and ground platforms with constrained size and weight limits
- Coordinate with capability & platform communities to define electrical and thermal interface standards for current & upcoming EW & HPS systems across all domains
  - Open Systems for Control of Integrated Propulsion, Power, and Thermal (OSCIPPT) OECIF Project

S&T Challenges

- Technologies and architectures for dissipating thermal energy generated by electronic systems to meet both static and dynamic loads within SWAP constraints
- Integrated architectures and controls for propulsion, electrical power, and thermal systems to meet mission system needs
- High density power generation to meet high power requirements within SWAP constraints
- High density energy storage to meet the needs of both dynamic and stochastic loads
- Modeling & Simulation to provide improved understanding of dynamic response of thermal management and electrical power systems to extreme and pulsed loads

Potential Future Focus Areas

- Continuous/high duty cycle vs. single shot/low duty cycle operations
- Miniaturization of power & thermal for expanded deployment
- Enable distributed platforms for collaborative, combined effects

Autonomous Systems Power

Objectives:

- Develop power and energy systems to enable next-generation autonomous systems across all domains
  - Long mission endurance
  - High reliability & scalable
  - power systems with low total ownership cost
- Mission adaptable power
- Energy self-sufficiency

Hydrothermal Vent Exploitation

Enable long-duration autonomous operation in unique and challenging environments

Operational Opportunities:

- Long duration, forward deployed missions
- Enable enhanced system capability through greater power & energy availability
- Unattended sensors
- Sustained inter-operability between manned and unmanned systems

Technical Challenges:

- Power and propulsion for long endurance, including in extreme environments
- High storage density oxidizer & fuel source for air-independent platforms
- On-demand, mission adaptable power
- Autonomous energy & power optimization
- On-station energy transmission and transfer
- Cooperative energy behaviors

Autonomous Systems Power Priorities & Challenges

Priorities

- High energy and power density
- High storage density oxidizer & fuel source for undersea and high altitude platforms
- On-station, autonomous energy harvesting/scavenging
- Hybridized power systems for energy efficiency
- Fuel cell operation on logistic fuels (JP-X)

S&T Challenges

- Hybridized high energy density storage with on-demand high power capabilities
- Greater energy and power conversion efficiency
- On-station, autonomous energy harvesting/scavenging
- Mitigate safety hazards for high density energy systems
- Improve energy and power system non-functional characteristics, e.g., reliability and maintainability

Potential Future Focus Areas

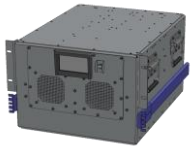
- Wireless power transfer
- Multifunctional energy structures
- Cooperative energy sharing to enable higher power autonomous system capabilities

Tactical Unit Energy Independence

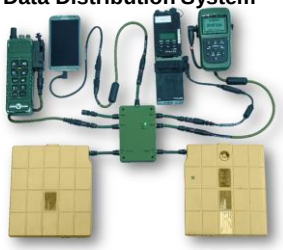
Objectives:

- Safe, conformal, wearable power sources
- Effectively utilize indigenous energy resources
- Increase utility of renewables in the tactical unit energy portfolio
- Intelligent, integrated soldier power & energy systems

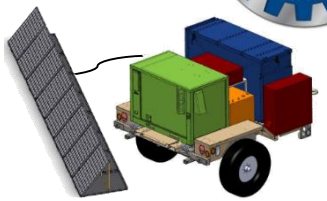
USMC Composite Energy Storage Containment System



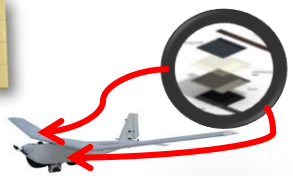
Hybrid Energy Storage Module II



Integrated Soldier Power & Data Distribution System



Renewable Sustainable Expeditionary Power System



Structurally-Integrated, Safe Advanced Battery

Extending Reach of E&P to Untether Warfighters

Operational Opportunities:

- Improve operational energy assurance (availability and reliability)
- Extend unsupported operations beyond 72 hours
- Reduce re-supply burden and logistics vulnerability

Technical Challenges:

- High density energy storage with dual-purpose functionality
- High power density and efficiency of power sources and energy conversion
- Intelligent supply/demand management
- Increase availability of alternative sources in the tactical unit energy portfolio
- Energy systems safety & containment

Tactical Unit Energy Independence Priorities & Challenges

Priorities

- Extending fuel and energy flexibility, including using alternative sources and harvesting
- Increased power source conversion efficiency
- Improved energy storage density, including from dual-purpose functionality

S&T Challenges

- Hybridize energy storage with small tactical sources or other functional purposes
- Safe, compact, lightweight, high efficiency power generation sources
- Fuel flexibility and alternative methods for JP-8 conversion
- Extend perovskite photovoltaic lifetime through improve material stability

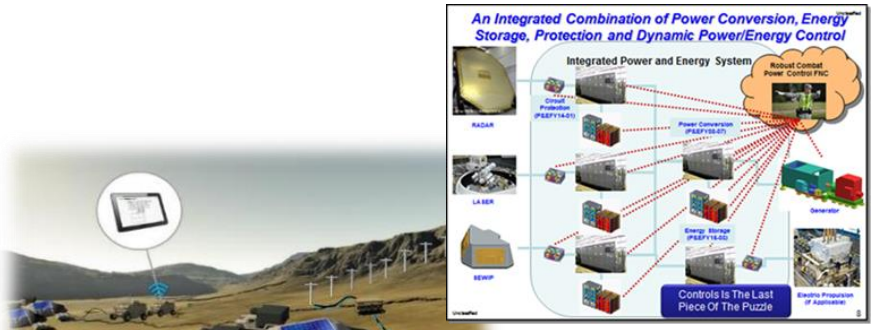
Potential Future Focus Areas

- Forward deployed adaptive power transfer
- Commonality of tactical power & energy systems to reduce logistics burden
- Flexible, conformal, and robust power for the augmented Warfighter

Adaptive Power Networks

Objectives:

- Meet demand through integrated, intelligent power distribution and management
- Reduce the man/machine interface with self-aware power systems and components
- Adaptable power interfacing for flexible and high-power mission systems



Automating energy management for optimized mission performance

Operational Opportunities:

- Integrating and interfacing with available energy sources to extend mission capability
- Optimize operational and functional performance of distributed power systems
- Leverage intelligent controls for adaptable power & energy
- Autonomous energy sharing to reduce logistics tether

Technical Challenges:

- Software, firmware, and hardware integration and interfaces
- Networked, intelligent energy control architectures
- Secure cyber-physical energy systems
- Energy situation awareness
- Electric network reconfigurability, scalability, and modularity

Adaptive Power Networks
Priorities & Challenges

Priorities

- Predictive controls for automated energy networks
- Prognostics and diagnostics for energy resiliency
- Effective utilization of all available and emerging energy and power sources
- Secure interfaces to mission capabilities, including cyber-physical interfaces
- Adaptable and intelligent power distribution and conversion designs

S&T Challenges

- Robust predictive controls and algorithms
- Energy network situational awareness & anomaly detection
- Data management, including latency
- Automatic reconfiguration, adaptable on demand
- Electrical transient management within an energy network
- Affordable prognostics and diagnostics leading to predictive control

Potential Future Focus Areas

- Multi-domain dynamic power & energy networks
- Energy recharge of autonomous systems

Summary

Current E&P COI Priorities:

- Improve power density and thermal management for air and ground platforms with significant size & weight constraints
- Secure interfaces (including cyber-physical) to mission capabilities for tactical microgrids and surface ship power & energy networks
- On-station, autonomous energy harvesting/scavenging

Potential Future Research Areas:

- Power and thermal requirements of collaborative electric weapon effects
- Energy recharge of autonomous systems
- Enabling increased platform design flexibility and scalability through more capable power and thermal systems
- Multifunctional energy structures
- Flexible, conformal, and robust power for the augmented Warfighter