



DoD Energy and Power Roadmap Energy & Power Community of Interest

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Chair, Energy & Power COI Steering Group



BLUF



E&P COI Priorities:

- **Integrated power and thermal management** (higher E&P needs across systems / power ranges)
- **Integrated, intelligent power distribution**
- **Architectures, interfaces, and standards for reconfigurable power** (energy networks / microgrids)
- **Higher power / temperature / efficiency E&P devices and components** (continuous & pulse power)
- **Extended energy storage, harvesting, and recovery**

Current S&T Gaps:

- **Thermal limitations on capabilities, efficiencies, power densities** (need for thermal management)
- **Power distribution flexibility** (need for reconfigurable, adaptive energy networks / microgrids)
- **Indigenous energy** (need for autonomous energy harvesting in operational environments)
- **Resilient power** (need for integrated power & thermal models across platforms and systems)
- **Extended duration / reduced resupply energy** (need for higher energy density storage and greater conversion efficiencies)

Engagement Opportunities for Industry:

- Defense Innovation Marketplace
- NDIA Annual Science & Engineering Technology Conference
- ARPA-E Annual Energy Innovation Summit
- Many service-specific opportunities...



Outline



Overview of the E&P COI

- COI purpose & representation
- Technical taxonomy
- Main government performers and facilities
- Industry landscape vs DoD needs

DoD E&P S&T gaps

- Examples of past successes and current programs
- OE Strategy Implementation Plan
- Using individual service strategies to find gaps
- Present E&P S&T gaps

Overarching E&P COI priorities and way ahead



Energy & Power Community of Interest (E&P COI)



Purpose: The Energy and Power Technology COI's purpose is to provide technologies to enable intelligent power & energy management to enhance operational effectiveness.

The E&P COI provides a framework for DoD scientists, engineers, and acquisition personnel to:

- Engage in multi-agency coordination and collaboration
- Report on the "state-of-health"
- Identify emerging research opportunities
- Measure progress

E&P COI Steering Group:





E&P COI Technology Portfolio



What's driving E&P S&T?

- Operational capability and alignment with DoD *Operational Energy Strategy* and service energy strategies
- High cost of fuel resupply in dollars and lives demands increased efficiency
- Greater electric power demand required by advanced weapons and sensors
- Unique military systems not supported by commercial R&D require dedicated DoD S&T; DoD S&T is also essential to leverage emerging commercial R&D

Technology Taxonomy

Power Generation /
Energy Conversion

Power Control and
Distribution

Thermal Transport
and Control

Energy Storage

Electromechanical
Conversion

*This taxonomy does not include platform prime movers;
those are covered under the Ground & Sea and Air Platform COIs.*



Tier 1 Taxonomy Brief Descriptions



Power Generation/Energy Conversion:

Develop tactical, deployable power systems using conventional fuels, alternative fuels, and energy harvested from renewable/ambient sources.

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 using modeling and simulation tools as well as new, greater capability and efficiency components.

Thermal Transport and Control:

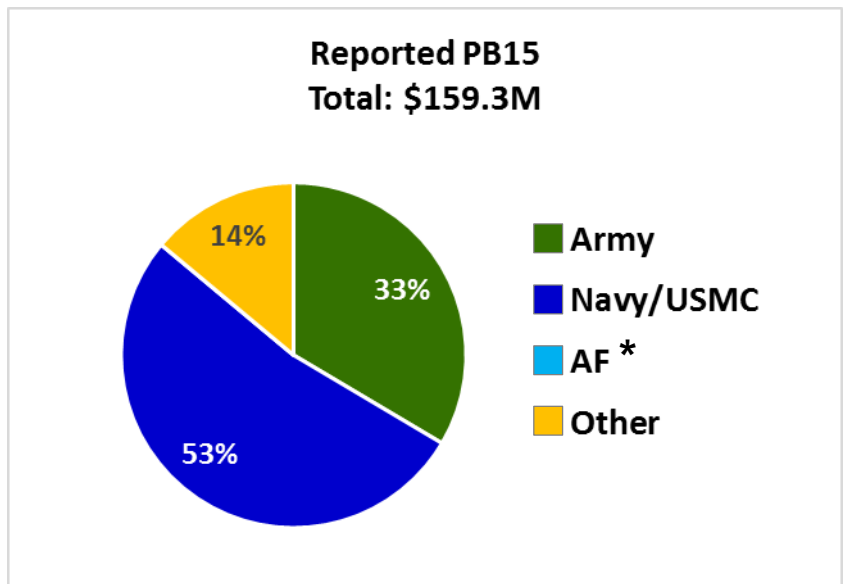
Efficiently manage heat and enable higher power density systems through advanced thermal science and technology: advanced components, system modeling, and adaptive or hybrid-cycle technologies.

Electromechanical Conversion:

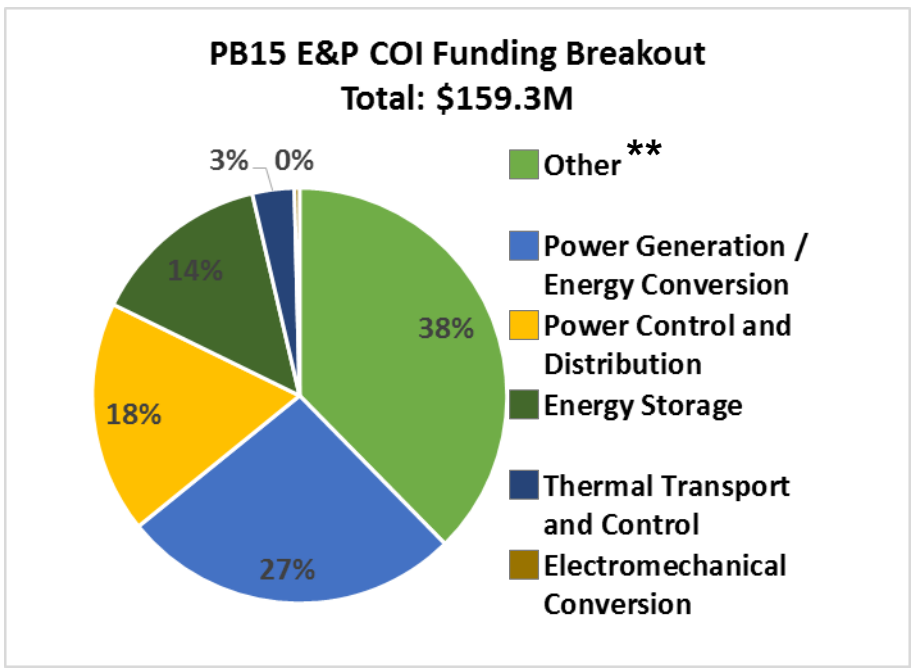
Increase the power density, efficiency, and robustness of motors, generators, and actuators while also reducing their life cycle costs.



E&P S&T Funding Distributions



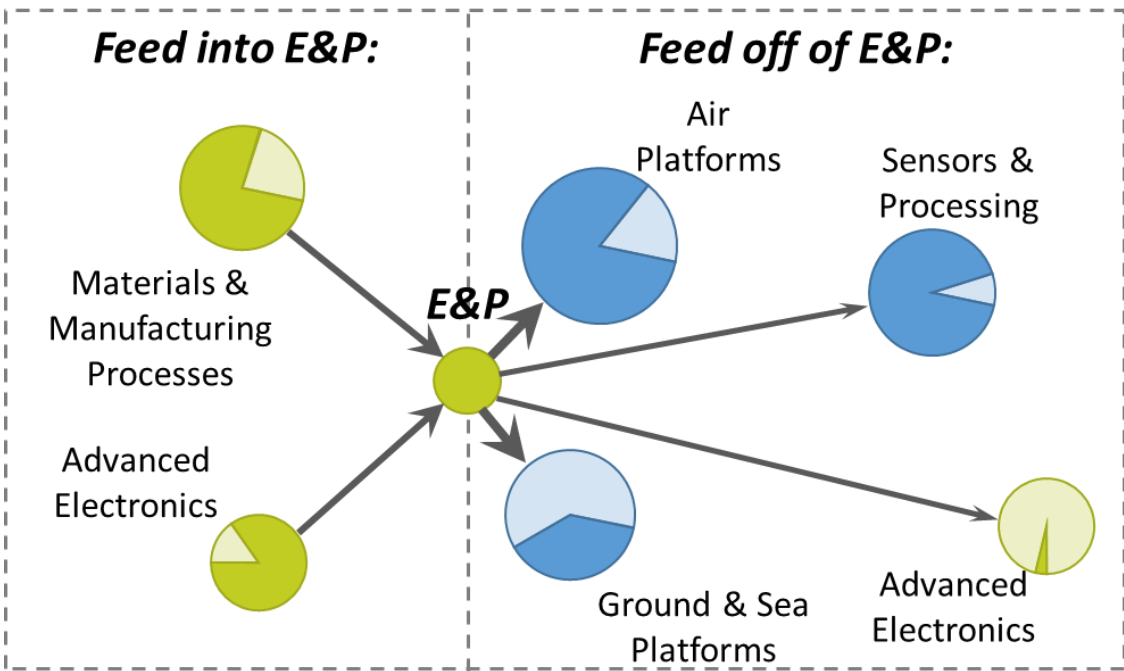
****AF budget listed under the Air Platforms COI***



*****These projects have components which reach into multiple taxonomy areas.***



E&P S&T Portfolio Interdependency with other COIs



Only first-order relationships represented.

	Capabilities		Extent of portfolio related to E&P		Relative size of overall S&T Budget
	Fund. Tech.				

E&P develops fundamental technologies, which

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

The remaining COIs either

- have a second-order relationship (e.g., C4I through Sensors & Processing),
- or are ubiquitous, such as Engineered Resilient Systems.



COI Roles and Past Community Successes



International Defense S&T Interactions

- **US-Singapore Information Exchange Agreement**
Signed May 2014,
preceding workshops March 2014 and May 2012;
Soldier Power & Microgrids is a topic
- **US-UK S&T Stocktake**
E&P COI representative participated in Oct 2014 meeting in UK

OGA Interactions

- **DoD/DOE MOU**
Upcoming Big Ideas Summit
- **Interagency Advanced Power Group (IAPG)**
DoD, DOE, NASA, NIST, and others
- **Propulsion and Power Systems Alliance (PPSA)**
DoD, NASA, DOE, FAA



COI Roles and Past Community Successes



**Commission
& Participate
in S&T
Studies**

- **DSB studies**
“Energy Systems for Forward/Remote Operating Bases” *Ongoing*
“More Fight – Less Fuel” Feb 2008
- **JASON studies**
Reducing DoD Fossil-Fuel Dependence (JSR-06-135)
Portable Energy for the Dismounted Soldier (JSR-02-135)
Power Sources for Ultra Low Power Electronics (JSR-98-130)

**Participate
Directly in
Cross-Service
Efforts**

- **DoD/ARPA-E Hybrid Energy Storage Module (HESM)**
E&P COI initiative, started 2012
- **Advanced Vehicle Power Technology Alliance (AVPTA)**
E&P COI involved starting 2014
- **DDR&E Wearable Power Prize**
Topic proposed by E&P COI; executed jointly by Army, Navy, & Air Force; awarded Fall 2008
- **SiC High Efficiency Power Switches (HEPS)**
Started as DMS&T, Joint Service ManTech program underway, E&P COI involved through IAPG and has been since 2002



Key DoD Service Labs, Centers



Critical S&T Capabilities/Facilities

• Army

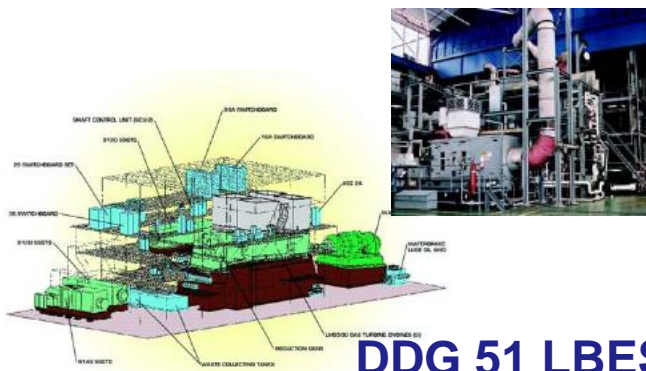
- TARDEC – Ground Systems Power and Energy Laboratory (GSPEL)
- CERDEC – Soldier and Mobile Power and Energy Labs
- ARL – Microfabrication Facility (Clean Rooms); High Voltage-Pulse Power Test Facility

• Navy

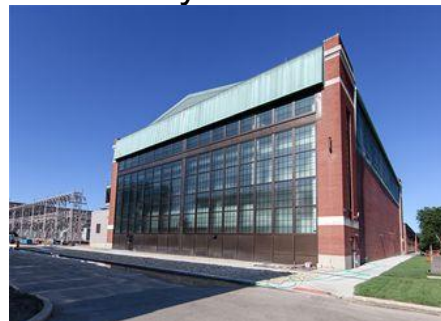
- NSWC CD Philadelphia – DDG51 Land Based Engineering Site (LBES)
- Electric Ship Consortium – Hardware-in-the Loop M&S, High Voltage, Adv Prototyping
- NRL Autonomous Systems Lab – Multiple test environments, R&D labs, prototyping
- NSWC Dahlgren – EM Rail Gun Facility
- NUWC Newport – Electric Propulsion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

• Air Force

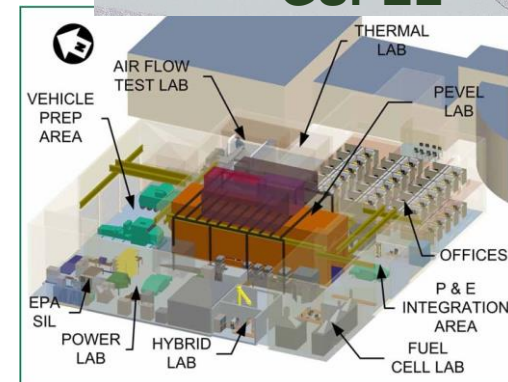
- AFRL – Advanced Power and Thermal Research Laboratory
- AFRL – INVENT Systems Integration Facility



DDG 51 LBES



AFRL Adv Power and Thermal Research Lab





DOE National Labs

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.



PNNL's Electricity Infrastructure Operations Center (EIOC).



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



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



ORNL's National Transportation Research Center



Sandia PV System Evaluation Lab (PSEL)

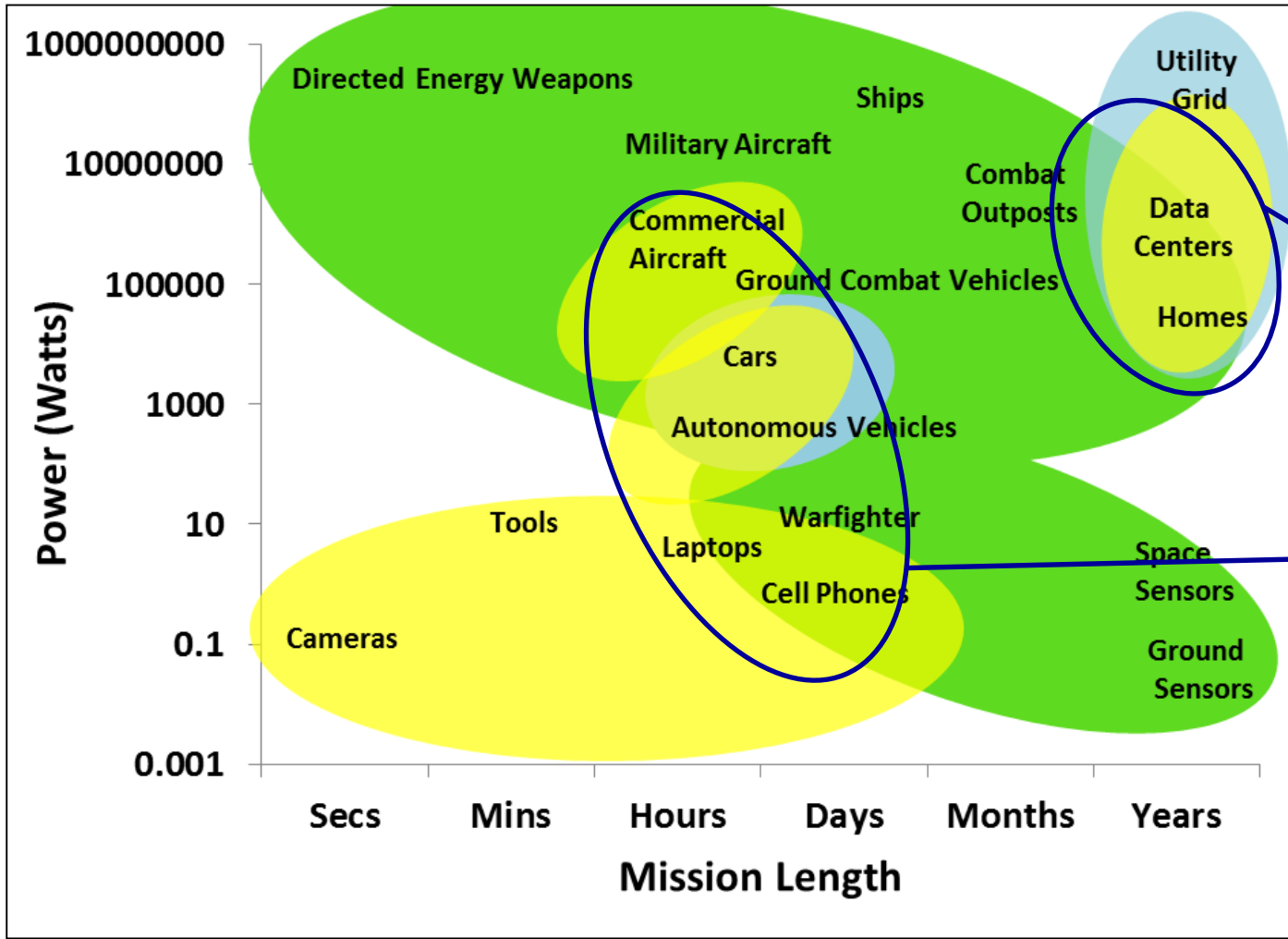


NETL
-Solid Oxide Fuel Cell Experimental Lab
-Hybrid Performance Lab

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



Commercial-DoD Leverage in Energy and Power Technology



Technology Leverage

- Microgrids
- Power management
- Power distribution
- HVAC
- Photovoltaics
- Batteries

- Batteries
- Engines
- Power management
- Power distribution
- HVAC

- DoD Focus** (Green)
- Commercial Focus** (Yellow)
- DOE Focus** (Blue)

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.



Commercial Energy and Power Market Space



Rechargeable batteries

\$31.4B Li ion market in 2015¹ (Est. \$1.8B IR&D)
98% Asian manufacturers⁹

- **Panasonic**
- **LG Chem**
- **BYD**
- **Johnson Controls**
- **24M**
- **Solid Energy**
- **A123**
- **Altairnano**

Power Mgmt. & Power Elect.

\$20B power electronics market in 2012⁵
(Est. \$2.4B IR&D)

- **Infineon**
- **Maxwell**
- **Vishay**
- **HP**
- **Cree**
- **Transphorm**
- **Adaptec**

Engines and Generators

\$300B ICE market in 2012² (Est. \$14B IR&D)

- **General Motors**
- **Toyota**
- **Lycoming**
- **Westinghouse**
- **Achates**
- **Pinnacle**
- **EcoMotors**
- **Transonic**

Photovoltaics

\$85B PV market in 2013⁶, 9 of top 10 are Asian¹⁰
(Est. \$3.0B IR&D)

- **Trina Solar**
- **Sharp Solar**
- **Yingli Energy**
- **First Solar**
- **Spectrolabs**
- **Semprius**

Microgrid

\$40B microgrid market by 2020⁸

- **Encorp Inc.**
- **Pareto Energy**
- **Power analytics**
- **Viridity Energy**
- **GE**
- **EDF**

Heating, Ventilation, Cooling

\$8.2B high eff. HVAC in 2012³
\$79.6B total HVAC market in 2012⁴
(Est. \$1.5B IR&D)

- **Daikin Industries**
- **Gree Electric Appliances**
- **United Technologies**
- **Clarke**
- **AAON**
- **Lennox Int.**

Industry does not work in all areas to meet DoD needs. Several technology areas are heavily foreign owned. Title III and other major national investments are not sufficient to maintain S&T advantage for military operations.



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- Technical taxonomy
- Main government performers and facilities
- Industry landscape vs DoD needs

DoD E&P S&T gaps

- **Examples of past successes and current programs**
- **OE Strategy Implementation Plan**
- **Using individual service strategies to find gaps**
- **Present E&P S&T gaps**

Overarching E&P COI priorities and way ahead



Past E&P COI Technology Successes




S&T Gaps:

S&T Projects:

Resulting PORs:

Overburdened Warfighter

2008 DDR&E Wearable Power Prize



E&P COI Submitted Topic

ARL, CERDEC, and NSWC-Caderock



SWIPES Conformal Batteries



Rucksack Enhanced Portable Power Systems (REPPS)



Soldier Power Manager

Army

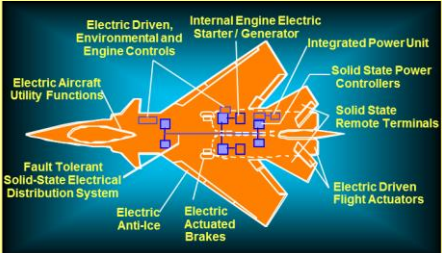
- ISPDS
- NETT Warrior
- SUP

USMC

- MEHPS
- SPACES
- GREENS
- SPM

High-maintenance hydraulics & pneumatics

More Electric Aircraft (MEA) R&D Started 1993



Electric Aircraft Utility Functions

Electric Driven, Environmental and Engine Controls

Internal Engine Electric Starter / Generator

Integrated Power Unit

Solid State Power Controllers

Solid State Remote Terminals


Fault Tolerant Solid-State Electrical Distribution System

Electric Anti-ice


Electric Actuated Brakes

Electric Driven Flight Actuators

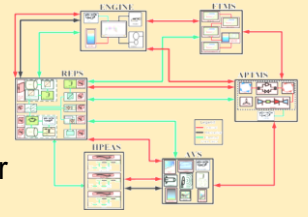
JSF / Integrated Subsystems Technology Program




Solid State Power Controllers




Starter-Generator on Engine



Hardware-in-the-Loop M&S



Fan Duct Heat Exchanger



Electro Hydrostatic Actuators

Air Force



F-35

- Capability Enabler
- Reduced Aircraft Volume
- Reduced Ground Support Equipment



Energy & Power Warfighter Opportunity Areas



Tactical Unit Energy Independence:

- Develop renewable and sustainable operational tactical unit power
- Modular systems for onsite assembly and maintenance
- Fuel flexibility, onsite fuel, and energy harvesting



Autonomous Platform Power:

- Support long endurance, undersea, ground, or high and low altitude unmanned operations with power and energy solutions
- Includes power for propulsion, sensor packages, weapons, and autonomous operation



Adaptive Power Networks:

- Power networks for both mobile and fixed power installations
- Utilize a variety of power sources for load requirements ranging 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 necessary fuel
- Minimize platform thermal constraints



Electric Weapons and High Power Sensors:

- Support the use of advanced sensor systems and electric weapons



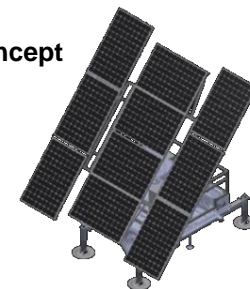
Energy & Power Warfighter Flagship S&T Programs



Tactical Unit Energy Independence:

- Renewable Sustainable Expeditionary Power (RSEP) FNC
- Lightweight Portable & Soldier Power Systems (Small Unit Power, SUP)
- Individual Soldier Power Distribution Systems (ISPDS, formerly SWIPES)

RSEP Concept



Autonomous Platform Power:

- Long Endurance Air-Independent Propulsion for UUVs
- Extended Mission Capability for Small UGVs
- Power and Thermal Management for Small/Micro UAS



Power for small UAVs:
Solar Powered Class I UAV

Adaptive Power Networks:

- Energy Informed Operations (EIO)
- Renewable Energy for Distributed Under-supplied Command Environments (REDUCE)
- Vehicle to Grid (V2G) technology

Energy Optimized Platforms:

- Integrated Vehicle Energy Technology (INVENT)
- Advanced Propulsion with Onboard Power Project (APOP)
- Electric Ship Research and Development Consortium (ESRDC)

REDUCE
(Stowed for travel;
fully deployed)



Electric Weapons and High Power Sensors:

- Wide Bandgap (WBG) High Efficiency Power Switches
- Solid State Active Denial Technology (SS-ADT)
- Laser Induced Plasma Channel (LIPC)

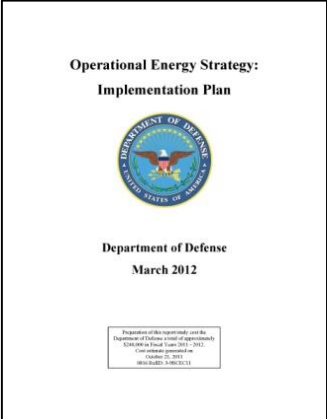


INVENT –
Enabling special
mission loads

**Address the DoD's most pressing needs
from a Warfighter and acquisition perspective**



US DoD (ASD(R&E)) Operational Energy S&T Gap Summary in support of OE Strategy



Tasking: “Promote Operational Energy Innovation”

Identify top overarching energy and power technology gaps affecting all services with recommendations for options

Use: Help inform OSD and Service energy and power S&T investment priorities

Gaps
Gap 1: High Efficiency Energy Conversion & Harvesting
Gap 2: Energy Integrated Design and Simulation
Gap 3: High Efficiency Propulsion and Platform Design
Gap 4: Environmental Control Systems
Gap 5: Flexible and Adaptive Power Distribution

Developed S&T Operational Energy Gap Assessment for ASD(OEPP) and ASD(R&E)

- Five overarching DoD energy and power gaps (and numerous lesser gaps)
- Action plans to address Top 5 Gaps
- Difficult challenges not easily addressed by incremental device & component improvements

Gap Action Plans

- Studies/Surveys
- Consortia/Working Groups
- Collaborations
- Integrate new S&T
- Develop new S&T/Models



Gap Analysis Architecture

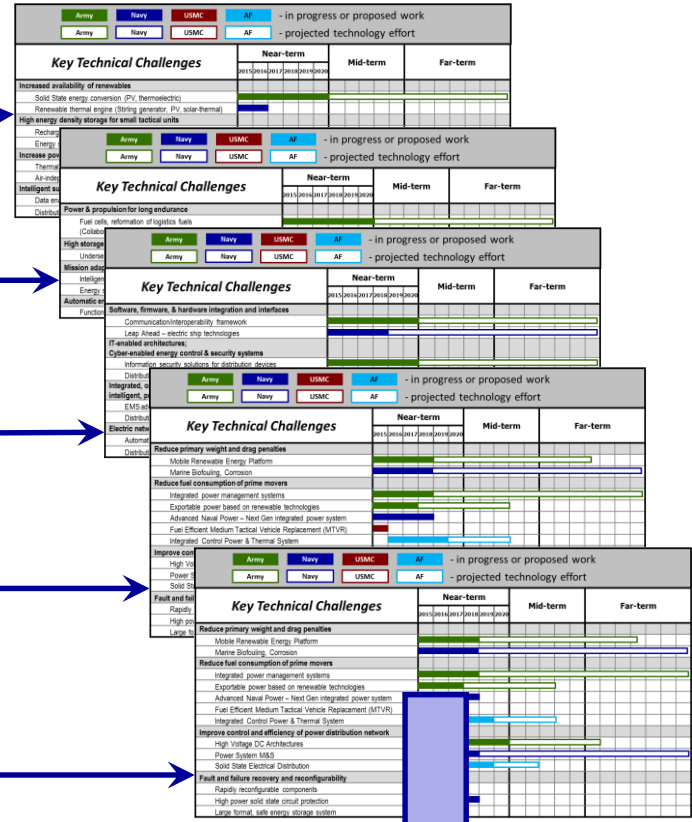
Service defined needs

ARMY	
Operational/ Mission Need	Capability, Systems Performance Requirements
Air Force	
Operational/ Mission Need	Capability, Systems Performance Requirements
NAVY	
Operational/ Mission Need	Capability, Systems Performance Requirements
USMC	
Operational/ Mission Need	Capability, Systems Performance Requirements

E&P COI Warfighter Opportunity Areas

Tactical Unit Energy Independence	
Key Technical Challenges	Technical Goals and Metrics
Autonomous Platform Power	
Key Technical Challenges	Technical Goals and Metrics
Adaptive Power Networks	
Key Technical Challenges	Technical Goals and Metrics
Energy Optimized Platforms	
Key Technical Challenges	Technical Goals and Metrics
Electric Weapons and High Power Sensors	
Key Technical Challenges	Technical Goals and Metrics

Joint Service investments



Priorities and Gaps



Tactical Unit Energy Independence

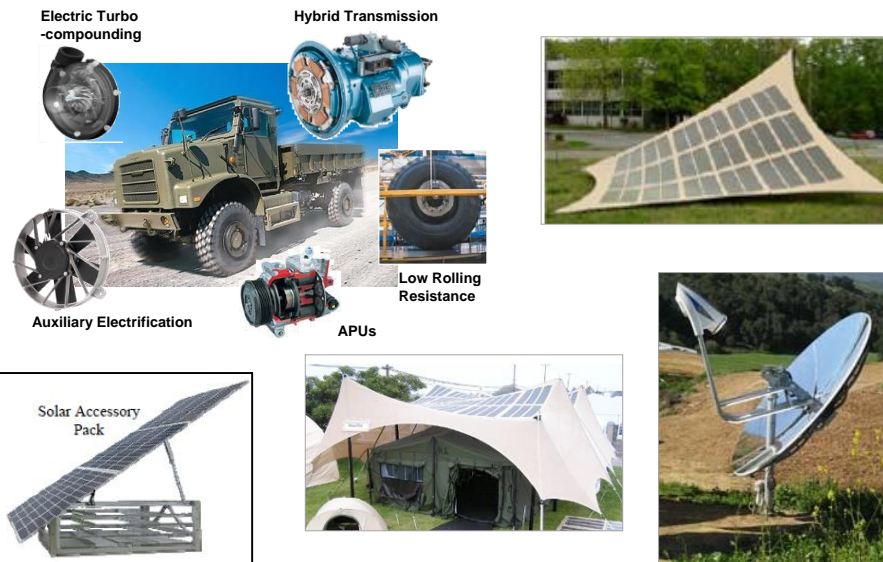


Objectives:

- Use of locally-available energy sources for company and below (<150 individuals)
- 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
- Reduce fuel required to sustain organic base operations

Operational Opportunities:

- Improve operational energy assurance (availability and reliability)
- Reduce re-supply burden and logistics vulnerability
- Minimize waste remediation burden
- Improve mission effectiveness through efficient use of personnel and resources



Technical Challenges:

- Increase availability of renewables in the tactical unit energy portfolio
- High energy density storage for small tactical units
- Increase power density and efficiency of power sources, including generation equipment
- Intelligent supply/demand management



Tactical Unit Energy Independence Goals and Metrics



Objectives:

- Use of locally-available energy sources for company and below (<150 individuals)
- 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

Key Technical Challenges	Goals and Metrics			
	Motivation / 2015 status	Near (to 2021)	Mid	Far
Increase availability of renewables in the tactical unit energy portfolio	Less than 3% of energy from renewable sources	5-10% renewable use	Power Stability with 15-20% renewable integration	Power Stability with 25% renewable integration using multiple sources
High energy density storage for small tactical units	Improve small tactical unit flexibility, capability, adaptability; Energy modularity	Reduce deployable energy storage types by 20%; Improve energy density by 5%; Incorporation of hybrid systems to accommodate peak mission loads	Reduce deployable energy storage types by 50%; Improve energy density by 10%; Integrated storage and small unit distribution systems	Reduce deployable energy storage types by 75%; Improve energy density by 30%; Storage system capable of supporting demand peaks.
Increase power density and efficiency of power sources, including generation equipment	8 gal of fuel per day per tactical Service member	Generators: 5% power density improvement; avg fuel-electric eff 15%; 40% improvement in fuel efficiency relative to fielded 3 kW TQG.	Generators: 10% power density improvement; avg fuel-electric eff 20%; 40% improvement in efficiency by 2025	Generators: 15% power density improvement; avg fuel-electric eff 30%; 50% improvement in efficiency by 2030
Intelligent supply/demand management	Lack of capability to automatically match load to demand	Source and Demand Detection	Source and Demand Auto-identification	Fully Automated Control of Source and Demand



Tactical Unit Energy Independence



Army

Navy

USMC

AF

- in progress or proposed work

Army

Navy

USMC

AF

- projected technology effort

Key Technical Challenges	Near-term						Mid-term	Far-term
	2015	2016	2017	2018	2019	2020		
Increased availability of renewables								
Solid State energy conversion (PV, thermoelectric)	Army							
Renewable thermal engine (Stirling generator, PV, solar-thermal)	USMC							
High energy density storage for small tactical units								
Rechargeable batteries	Army							
Compact High Density Tactical Energy Storage	USMC							
Increase power density & efficiency of power sources								
Thermal management (power electronics circuit cooling)	Army							
Lightweight Power Sources	USMC							
Intelligent supply/demand management								
Data enabled energy & power systems	Army							
Energy Systems Technology Evaluation Program (ESTEP)	Navy							



Tactical Unit Energy Independence Priorities, Gaps



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

S&T Gaps

- Hybridize energy storage with small tactical sources
 - Mid-Term Goal/Metrics: Reduce deployable energy storage types by 50%
 - Mid-Term Goal/Metrics: Improve energy density by 10%
- Compact, lightweight, wearable power generation sources
 - Mid-Term Goal/Metrics: 5-10 % power density improvement and 40% conversion efficiency improvement

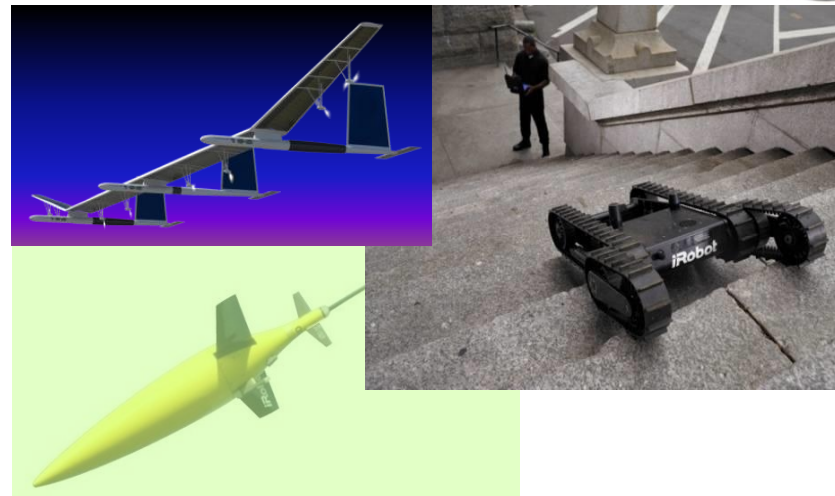


Autonomous Platform Power



Objectives:

- Develop power and energy systems to enable next-generation autonomous platforms
 - Long endurance
 - High reliability & scalable
 - Low maintenance power systems
- Mission adaptable power



Operational Opportunities:

- Undersea, underground, or high and low altitude operation
- On-station energy harvesting
- Carry enhanced payloads
- Battlefield environments
- Enhance reliability, availability, maintainability
- Unattended sensors

Technical Challenges:

- Power and propulsion for long endurance, including in extreme environments
- High storage density oxidizer & fuel source for air-independent platforms
- Mission adaptable power (on-demand power for critical mission tasks)
- Automatic energy & power use optimization (high efficiencies, low signatures)



Autonomous Platform Power Goals and Metrics



Objectives:

- Develop power and energy systems that enable next-generation autonomous platforms
 - Long endurance; High Reliability & Scalable; Low maintenance power systems
- Mission adaptable power

Key Technical Challenges	Goals and Metrics			
	Motivation / 2015 status	Near (to 2021)	Mid	Far
Power and propulsion for long endurance (Very high energy density for endurance w/o refueling/recharging in extreme environments)	UAV: Generators <10% engine output available for payloads	UAV: lighter generators 20% engine output available for payloads	UAV: >20% efficient engines in 250-3000W power range	UAV: Highly power dense (< 15 lbs), JP8 fueled 1kW power source
	UUV: 100 wh/kg baseline	UUV: 300 wh/kg	UUV: 500 wh/kg	UUV: 1,000 wh/kg
	UGVs/Unattended sensors/MAST: increase electrification of UVs. Fuel flexibility.	Power Generation: Specific Power ~ 1.5 hp/lb , SFC ~ 0.4 lb/hp	Power Generation: Specific Power ~ 2.0 hp/lb , SFC ~ 0.3 lb/hp	Power Generation: Specific Power ~ 2.5 hp/lb , SFC ~ 0.2 lb/hp
High Storage Density Oxidizer & fuel source for air-independent platforms	Need for improved safe oxidizers & fuel storage & generation	High pressure gaseous H ₂ & O ₂	Novel oxidizers & sulfur-free logistics fuels	Logistics fuels & liquid H ₂
Mission Adaptable Power (Power adaptability; power on-demand for critical mission tasks)	Need for improved range and power for mission payload; reduced thermal loads	Intelligent controls ; smart reconfiguration; load monitoring; multisource	Enhanced lightweight energy storage that extends platform endurance by 50% with no reduction in payload.	Intelligent power system that both carries onboard energy and scavenges energy from the environment, with mission endurance tripled with no payload reduction.
Automatic Energy & Power Use Optimization (High efficiencies, low signatures)	Inefficient processes that don't provide for desired mission duration	Optimization techniques for the integrated use of hybrid storage devices	Lighter power systems capable of unanticipated demand profiles	Optimized power systems that result in 2x reduction of power and distribution during any mission scenario



Autonomous Platform Power



Army

Navy

USMC

AF

- in progress or proposed work

Army

Navy

USMC

AF

- projected technology effort

Key Technical Challenges	Near-term						Mid-term	Far-term
	2015	2016	2017	2018	2019	2020		
Power & propulsion for long endurance								
Fuel cells, reformation of logistics fuels (Collaboration between Army, Navy, and AF)								
Long endurance power systems for air/hand-launched SUAS								
Small, heavy fuel engine technology								
High storage density oxidizer & fuel source for air-indep. platforms								
Undersea Warfare Power & Energy (fuel cells)								
Mission adaptable power								
Intelligent power management								
Power & Energy Materials Research								
Hybrid electric UAV propulsion/power system development								
High power/high energy safe Li-Ion battery technology								
Automatic energy & power use optimization								
Energy Efficiency & Alternative Energy Research								
Multifunctional, structurally integrated flexible energy storage								



Autonomous Platform Power Priorities, Gaps



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)

S&T Gaps

- Higher energy density storage
 - Mid-Term Goal/Metrics: Enhanced lightweight energy storage that extends platform endurance by 50% with no reduction in payload.
 - Mid-Term Goal/Metrics: 500 Wh/kg Storage Density Oxidizer & fuel source for air-independent platforms
- Greater energy and power conversion efficiency
 - Mid-Term Goal/Metrics: UUV >20% power conversion
 - Mid-Term Goal/Metrics: 20% efficient UAV engines in 250-3000 W power range
 - Mid-Term Goal/Metrics: Highly power dense (Ground: 80 lbs; Air: 15 lbs), JP8 fueled 1 kW power source
- In-situ, autonomous energy harvesting
 - Mid-Term Goal/Metrics: Intelligent power system that both carries onboard energy and scavenges energy from the environment, with mission endurance tripled with no payload reduction.



Adaptive Power Networks



Objectives:

Reduced demand and improved efficiency through integrated, intelligent power distribution and management

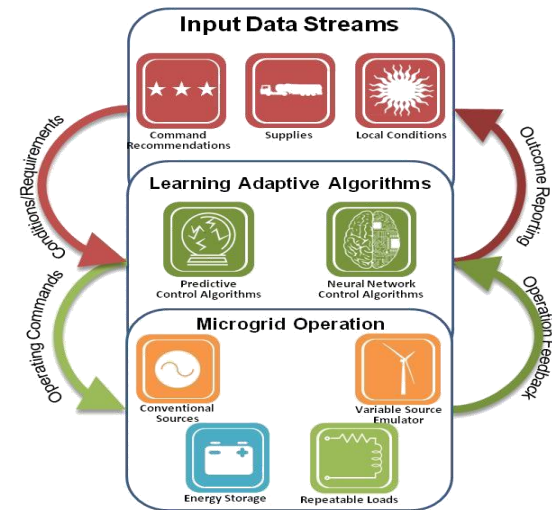
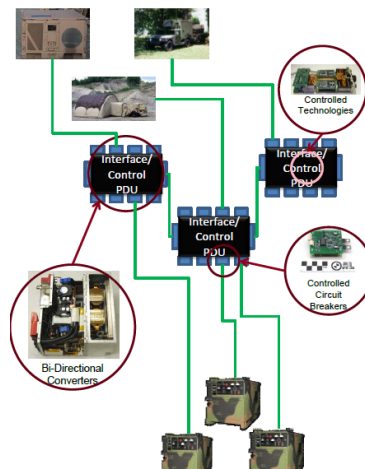
- Automatic reconfiguration and adaptable on demand
- Predictive control

Enhanced mission effectiveness

- Survivable, reliable, and resilient

Reduce the man/machine interface

- Reduce costs and logistics
- Increase survivability



Operational Opportunities:

- Effectively use all available and emerging energy and power sources
- Self-sufficient Forward Forces
- Optimize operational and functional performance of grid assets
- Increase mission capability with ad hoc power and energy control

Technical Challenges:

- Software, firmware, and hardware integration and interfaces
- IT enabled architectures; Cyber enabled energy control and security systems
- Integrated, open architecture design and intelligent, predictive, automatic control and management; plug and play
- Electric network reconfigurability, scalability, and modularity



Adaptive Power Networks Goals and Metrics



Objectives:

- Reduced demand and improved efficiency through integrated, intelligent power distribution and management
- Enhanced Mission Effectiveness: survivable, reliable, resilient
- Reduction in man/system interface: reduces costs and logistics, increases survivability

Key Technical Challenges	Goals and Metrics			
	Motivation / 2015 status	Near (to 2021)	Mid	Far
Software, firmware, and hardware integration and interfaces	Limited data on fuel usage and demand in current configurations	Universal generator control interface; grid storage capabilities	Distributed control, phase balancing; standardized protocols and messaging	Plug & play, load balancing, real time control; Hybrid, intelligent AC-DC Architectures
IT enabled architectures; Cyber enabled energy control and security systems	Sensitive to small perturbations; grid instability. Not cybersecure	Communications protocols; Managed graceful network decline; limited prognostics and diagnostics; cyber enabled	Mesh networking; Real-time threat warning; prognostics and diagnostics for most devices; robust cyber; integrated .mil	Leveraged cloud computing for adaptive grids; Reconfigurable, cyber physical security; robust prognostics and diagnostics
Integrated, open architecture design and intelligent, predictive, automatic control and management; plug and play	Grid faults require manual repairs; reconfiguration; lack of baseline	Reduce system manning for set-up time and operation by 10x; limited low cost P&D	Decreased workload through automatic, protocol driven reconfiguration	Autonomous self-configuration and optimized power network
Electric network reconfigurability, scalability, and modularity	Fuel savings	Standardized modules	Intelligent, multi-level recognition	Automated, intelligent sensing and reconfiguration



Adaptive Power Networks

Army

Navy

USMC

AF

- in progress or proposed work

Army

Navy

USMC

AF

- projected technology effort

Key Technical Challenges	Near-term						Mid-term	Far-term
	2015	2016	2017	2018	2019	2020		
Software, firmware, & hardware integration and interfaces								
Communication/interoperability framework	[Green bar]							
Next Generation Integrated Power Systems	[Blue bar]							
IT-enabled architectures; Cyber-enabled energy control & security systems								
Information security solutions for distribution devices	[Green bar]							
Energy Systems Technology Evaluation Program (ESTEP)	[Blue bar]							
Integrated, open architecture design & intelligent, predictive, automatic control & management								
EMS advanced control system expansion to plug load & devices	[Green bar]	[Green bar]						
Power Distribution & Control Architectures (MVDC)	[Blue bar]							
Electric network reconfigurability, scalability, and modularity								
Automatic reconfiguration for stand alone operation	[Green bar]	[Green bar]						
Distribution/Control of Power Science	[Blue bar]							



Adaptive Power Networks

Priorities, Gaps



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

S&T Gaps

- Automatic reconfiguration, adaptable on demand
 - Mid-Term Goal/Metrics: Intelligent, multi-level recognition
 - Mid-Term Goal/Metrics: Decreased workload through automatic, protocol driven reconfiguration
 - Mid-Term Goal/Metrics: Automated, intelligent sensing
- Electrical transient management within an energy network
 - Mid-Term Goal/Metrics: Phase balancing; real-time threat warning
- Affordable prognostics and diagnostics leading to predictive control
 - Mid-Term Goal/Metrics: Autonomous self-configuration and optimized power network



Energy Optimized Platforms



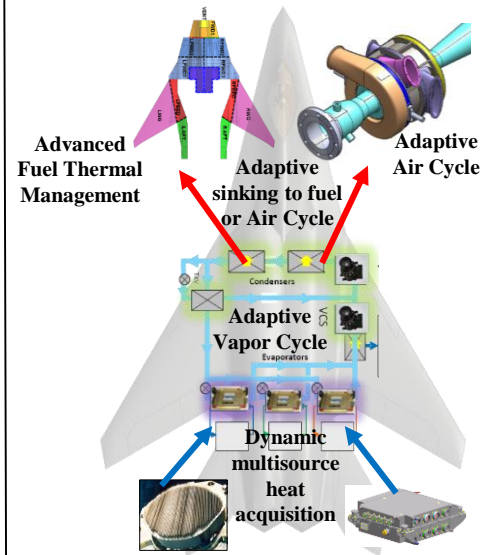
Objectives:

- 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)

Operational Opportunities:

- Reduce energy costs
- Reduce refueling requirements
- Enhance mobility and mission flexibility
- Improve survivability and signatures
- Increase mission effectiveness
- Enable next generation mission loads for A2AD environment

Adaptive Power & Thermal Management System (APTMS)



Technical Challenges:

- Reduce primary weight and drag penalties for air, ground, and sea vehicles
- Reduce fuel consumption of prime movers
- Improve control and efficiency of power distribution network
- Fault and failure recovery and reconfigurability



Energy Optimized Platforms Goals and Metrics



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)

Key Technical Challenges	Goals and Metrics			
	Motivation / 2015 status	Near (to 2021)	Mid	Far
Reduce primary weight and drag penalties for air, ground and sea vehicles	Capability growth, but with size and weight increase beyond design	Decrease resistive losses by 5-8%	Decrease resistive losses greater than 10%	Reconfigurable Outer Mold Lines (OMLs) / Outer Skin [of aircraft]
Reduce fuel consumption of prime movers (engine efficiencies)	Carnot limited off peak SFC; Conventional-cycle, point design; More electric	Advanced propulsion systems integrated with more electric power and thermal; Limited-application variable/adaptive subsystems	Increase use of hybrid power plants to optimize SFC; Pervasive variable/adaptive cycle and hybrid power plants	Hybrid power plants operating at peak SFC; Advanced cycles beyond Carnot/ Brayton operating at optimum mission-weighted thermal efficiency
Improve control and efficiency of power distribution network	Uni-directional power systems	Increase electrification of platform; Reduce thermal burden by 10%	Bi-directional power control; reduce thermal burden by 10%; standards for reconfigurable architecture	Intelligent reconfigurable architecture with energy-integrated structures; Very high efficiencies through integration, power management and control
Fault and failure recovery and reconfigurability	Improved operational availability	Fast time diagnostics	P&D and sensing integrated inputs to control algorithms	Intelligent / IT-enabled prognostics with automated rerouting



Energy Optimized Platforms

Army	Navy	USMC	AF	- in progress or proposed work
Army	Navy	USMC	AF	- projected technology effort

Key Technical Challenges	Near-term						Mid-term	Far-term
	2015	2016	2017	2018	2019	2020		
Reduce primary weight and drag penalties								
Mobile Renewable Energy Platform								
Lightweight Structural Materials & Marine Biofouling								
Reduce fuel consumption of prime movers								
Integrated power management systems								
Exportable power based on renewable technologies								
Next Generation Integrated Power System								
Fuel Efficient Medium Tactical Vehicle Replacement (MTVR)								
Integrated Control Power & Thermal System								
Improve control and efficiency of power distribution network								
High Voltage DC Architectures								
Power Distribution & Control Architectures (MVDC)								
Solid State Electrical Distribution								
Fault and failure recovery and reconfigurability								
Rapidly reconfigurable components								
High power solid state circuit protection								
Large format, safe energy storage system								



Energy Optimized Platforms

Priorities, Gaps



Priorities

- Power and thermal management integrated with advance propulsion systems to eliminate platform thermal constraints
- Higher voltage architectures
- More capable power electronic components and devices able to operate at higher temperatures and higher voltages, more efficiently (e.g., SiC and other wide bandgap material devices)
- Sufficient onboard electrical power for increasingly energy-hungry mission systems
- Energy recovery systems

S&T Gaps

- Integrated, adaptable power and thermal models, simulations, and demonstrators for platforms
 - Mid-Term Goal/Metrics: up to 10% reduction in platform drag/resistance losses
 - Mid-Term Goal/Metrics: Prognostics & diagnostics and sensing integrated inputs to control algorithms
- Auxiliary power for engine-off missions (silent watch)
 - Mid-Term Goal/Metrics: bi-directional power control
- More thermally rugged systems that lessen cooling demands
 - Mid-Term Goal/Metrics: up to 10% reduction in thermal management burden



Electric Weapons and High Power Sensors



Objectives:

- Extend continuous and pulse-enabled protection and lethality systems
- Enable load-leveled, right-sized platform power with increased efficiency



Operational Opportunities:

- High power radar (search and engagement)
- Laser programs (lethality, self defense, force protection)
- Active denial directed energy (non-lethal defense)
- High power microwaves (destroy or disrupt; counter-IED, electronic attack)
- Electromagnetic kinetic weapons and launch

Technical Challenges:

- Very high density power sources for dynamic power operation
- Manage high power pulse loads
- Enable load-leveled, right-sized platform power with increased efficiency
- Extreme voltages, currents, power levels



Electric Weapons and High Power Sensors Goals and Metrics



Objectives:

- Extend continuous and pulse-enabled protection and lethality systems
- Enable load-leveled, right-sized platform power with increased efficiency

Key Technical Challenges	Goals and Metrics			
	Motivation / 2015 status	Near (to 2021)	Mid	Far
Very high density power sources for dynamic power operation	Dedicated high power supply	Incorporate storage for pulse systems	Integrated platform system architecture	Plug & play, load balancing, real time control
Manage high power pulse loads	Active thermal management-limited	Increase switching speeds for conventional Si based electronics	Wide-bandgap high power switching for PFN's	Integrated design of power distribution and PFN architecture
Enable load-leveled, right-sized platform power with increased efficiency	Volatile peak demand due to load uncertainty	Air/Sea/Ground: M&S capability to support integrated studies of short/fast dynamics in a multiphysics approach tied to platform	Air/Sea/Ground: M&S capability to support integrated short/fast dynamics in a multiphysics approach tied to platform	Air/Sea/Ground: Application of complete systems which have greater thermal range as well as enhanced cooling scenarios at poor delta T.
Extreme voltages, currents, power levels (Components, rapid breakers, insulation, materials)	High stress, electrical, thermal, mechanical systems	Increase use of solid state & hybrid breakers; 10X speed increase for arc fault protection	Life cycle durability and safety certified; Arcless fault protection	Reduced footprint; very high power and thermal densities



Electric Weapons and High Power Sensors Priorities, Gaps



Priorities

- Dynamic power - widely varying instantaneous peak power demand & power quality
- Dynamic thermal - thermal management systems
- Dynamic power/thermal integrated with platform/engine system
- Extreme power density
- Pulsed power components (switches, passives, conductors, bulk and PFN energy storage)

S&T Gaps

- Increased energy and power dense storage, conversion, and switching components
 - Mid-Term Goal/Metrics: Wide-bandgap high power switching for PFNs
- Load-leveled, right-sized, efficient platform power
 - Mid-Term Goals/Metrics: M&S capability to support integrated short/fast dynamics in a multiphysics approach tied to platform



Outline



Overview of the E&P COI

- COI purpose & representation
- Technical taxonomy
- Main government performers and facilities
- Industry landscape vs DoD needs

DoD E&P S&T gaps

- Examples of past successes and current programs
- OE Strategy Implementation Plan
- Using individual service strategies to find gaps
- Present E&P S&T gaps

Overarching E&P COI priorities and way ahead



Energy and Power COI Overarching Priorities



- **Integrated power and thermal management capable of handling increasing energy and power density needs across multiple systems and power ranges**
(ref.: Energy Optimized Platforms, Autonomous Platform Power)
- **Integrated, intelligent power distribution and management**
(ref.: Tactical Unit Energy Independence, Adaptive Power Networks)
- **Architectures, interfaces, and standards for reconfigurable power (energy networks / microgrids)**
(ref.: Adaptive Power Networks, Tactical Unit Energy Independence)
- **More capable, higher power/temperature/efficiency power devices and components (e.g., wide bandgap electronics for continuous & pulse power)**
(ref.: Energy Optimized Platforms, Electric Weapons & High Power Sensors)
- **Improved energy storage, harvesting, and recovery systems**
(ref.: Energy Optimized Platforms, Autonomous Platform Power, Adaptive Power Networks, Electric Weapons & High Power Sensors, Tactical Unit Energy Independence)



Possible Future Areas for E&P COI Consideration



There are some futuristic capabilities being considered that will require new perspectives and different focus for the E&P S&T Community

- **Power for UxV and loitering/reconfigurable munitions capabilities**
- **Wireless power transfer**
- **Platform-based, high repetition rate, very dense power and energy for next generation capabilities**
- **Power for Warfighter wearable augmentation**
- **Unlimited mission endurance without energy resupply requirements**



E&P COI Way-Ahead



- **Continue robust engagement with DOE**
 - Example: DoD/DOE Big Ideas Workshop
- **Use Emerging Capabilities Technology Demonstrations (ECTDs) construct to address:**
 - Energy networks – advanced architectures, energy sensing, communications, prognostics & diagnostics, intelligent controls
 - Safe, high voltage distribution in all manner of platforms
 - Compact, high density pulse power sources, conditioning, switching, forming networks – push limits of electrical capabilities
- **Identify additional areas for collaborative international R&D**
 - Example: NATO Energy Security Centre of Excellence (ENSCOE)
- **Develop energy systems M&S with more universal applicability**



Engagement Opportunities

COI

1. Defense Innovation Marketplace
2. NDIA Annual Science & Engineering Technology Conference
3. ARPA-E Annual Energy Innovation Summit

ARMY

4. Army-TARDEC / DOE-VTO Advanced Vehicle Power technology Alliance (AVPTA)
5. Demonstration of production ready energy systems and devices at the annual Army Network Integration Exercise (NIE)
6. Demonstration of prototype energy systems at the annual Army Expeditionary Warrior Experiment (AEWE)

NAVY

7. Energy System Technology Evaluation Program (ESTEP)

MARINES

8. Expeditionary Energy Concepts (E2C)

AIR FORCE

9. Air Force Basic Expeditionary Airfield Resources (BEAR)
10. Annual May Energy Optimized Aircraft Steering Committee Meeting with Industry in Dayton, OH