DoD Energy and Power Roadmap
Energy & Power Community of Interest

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Dr. Richard Carlin

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.

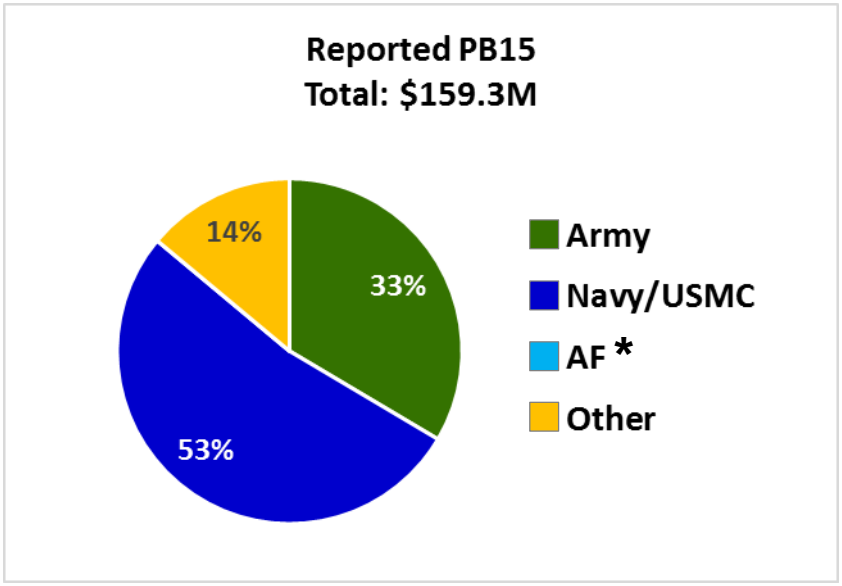
Energy Storage:
Improve electrical and electrochemical energy storage devices to decrease device size, weight, and cost as well as increase their capabilities in extreme temperatures and operating conditions.

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.

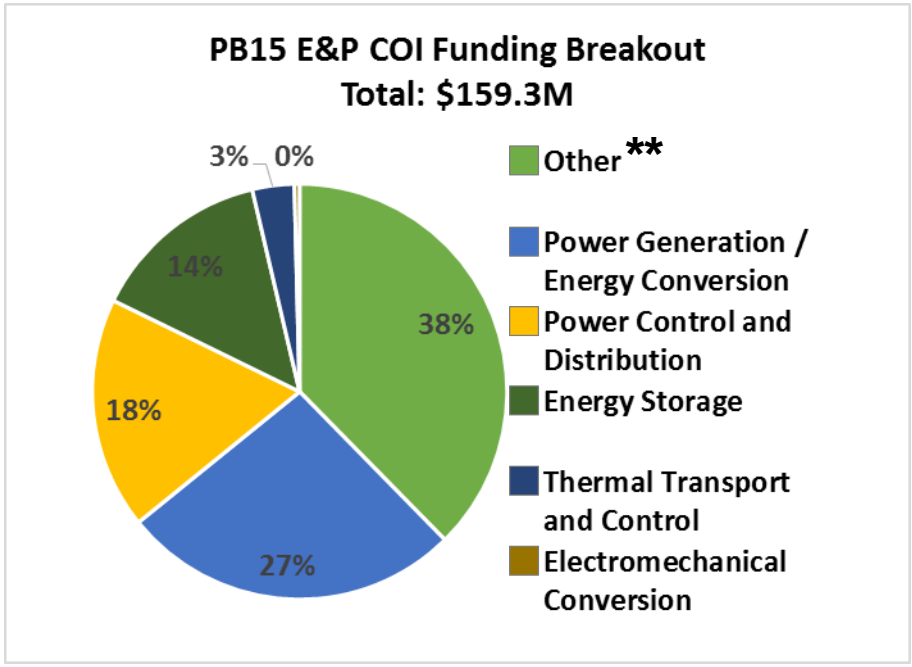
Thermal Transport and Control:
Efficiently manage heat and enable higher power density systems through advanced thermal science and technology: advanced components, system modeling, and adaptive or hybrid-cycle technologies.

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

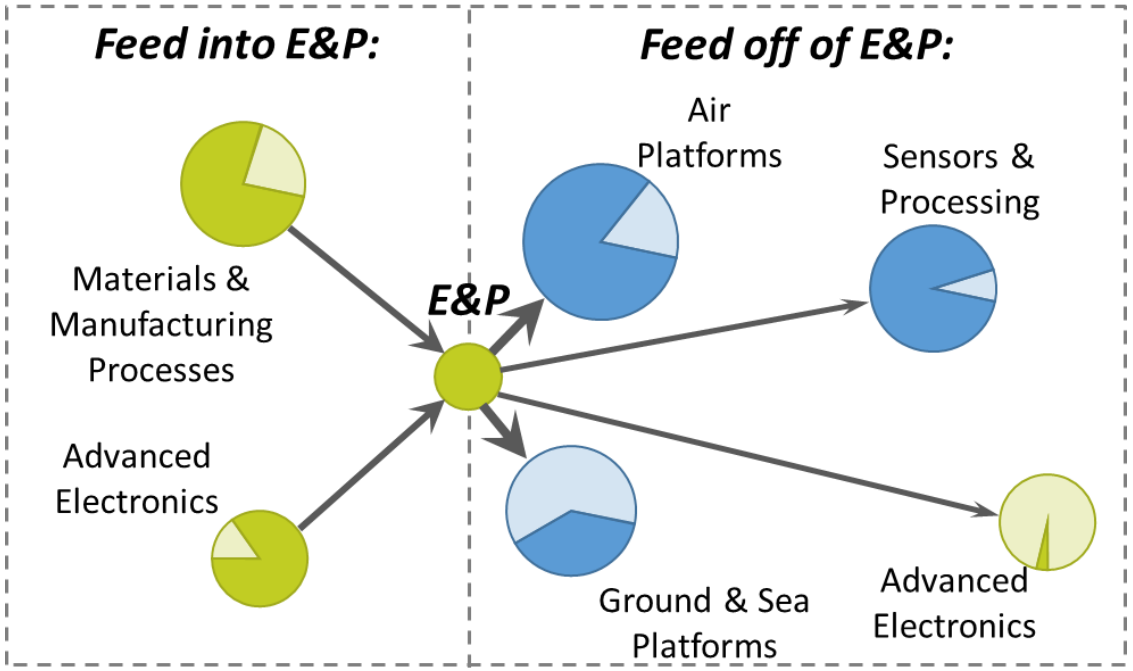


**AF budget listed under the Air Platforms COI*



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

E&P S&T Portfolio Interdependency with other COIs



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

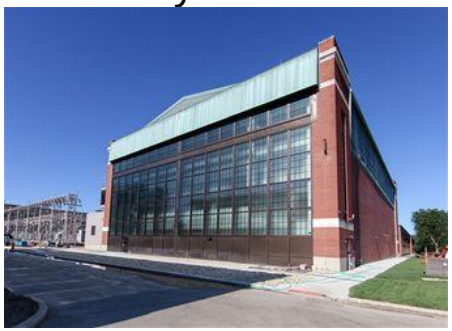
- **DoD/ARPA-E Hybrid Energy Storage Module (HESM)**
  E&P COI initiative, started 2012
- **Advanced Vehicle Power Technology Alliance (AVPTA)**
  E&P COI involved starting 2014
- **DDR&E Wearable Power Prize**
  Topic proposed by E&P COI; executed jointly by Army, Navy, & Air Force; awarded Fall 2008
- **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

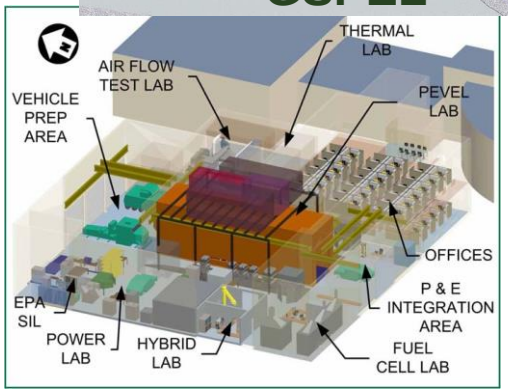
Critical S&T Capabilities/Facilities

- **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.

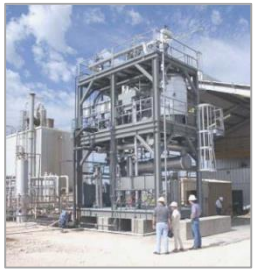
INL's new Energy System Lab focuses on bioenergy, hybrid energy systems and advanced vehicle and battery testing.

PNNL's Electricity Infrastructure Operations Center (EIOC).

ORNL's National Transportation Research Center

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

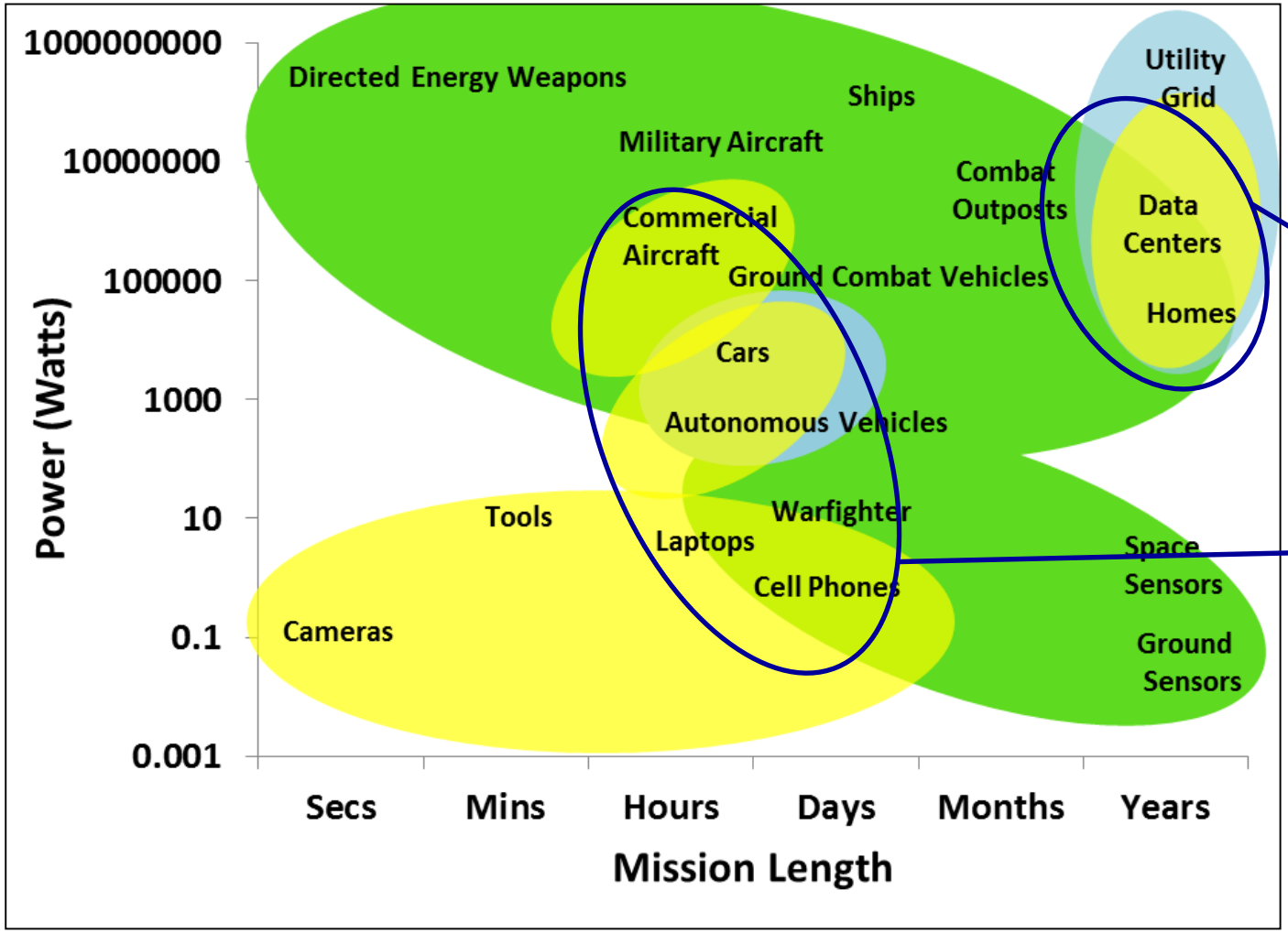
Sandia PV System Evaluation Lab (PSEL)



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

Commercial Focus

DOE Focus

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 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

Microgrid

$40B microgrid market by 2020[8]

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

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.

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.

*Foreign Owned Companies

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DoD E&P S&T gaps

- **Examples of past successes and current programs**
- **OE Strategy Implementation Plan**
- **Using individual service strategies to find gaps**
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Overarching E&P COI priorities and way ahead

Past E&P COI Technology Successes

S&T Gaps:

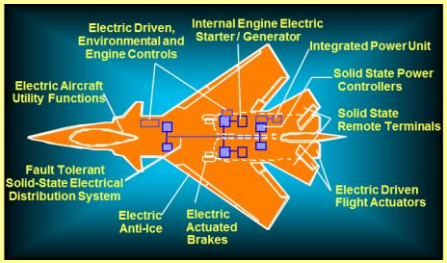
Overburdened
Warfighter

2008 DDR&E Wearable Power Prize

E&P COI Submitted Topic

High-maintenance
hydraulics & pneumatics

More Electric Aircraft (MEA) R&D Started 1993

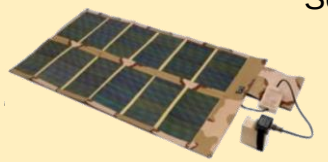


S&T Projects:

ARL, CERDEC, and NSWC-Caderock

SWIPES Conformal Batteries

Soldier Power Manager



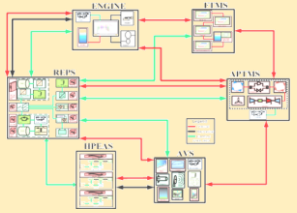
Rucksack Enhanced Portable Power Systems (REPPS)

JSF / Integrated Subsystems Technology Program

Solid State Power Controllers

Fan Duct Heat Exchanger

Starter-Generator on Engine



Hardware-in-the-Loop M&S

Electro Hydrostatic Actuators

Resulting PORs:

Army

- ISPDS
- NETT Warrior
- SUP

USMC

- MEHPS
- SPACES
- GREENS
- SPM

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:

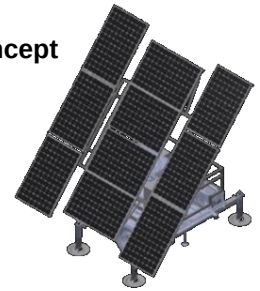
- Focus on platform electrical & thermal systems, components, and integration
- Support increased warfighter requirements while reducing the amount of necessary fuel
- Minimize platform thermal constraints

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)

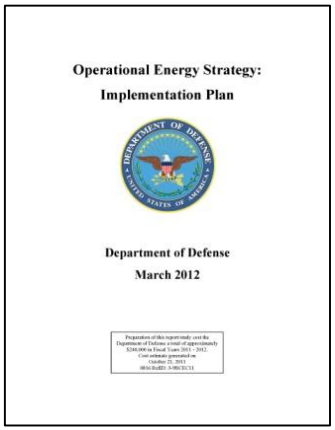
REDUCE
(Stowed for travel;
fully deployed)

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


Operational Energy Strategy:
Implementation Plan

Department of Defense
March 2012

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

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
- Consortiums/Working Groups
- Collaborations
- Integrate new S&T
- Develop new S&T/Models

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

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*

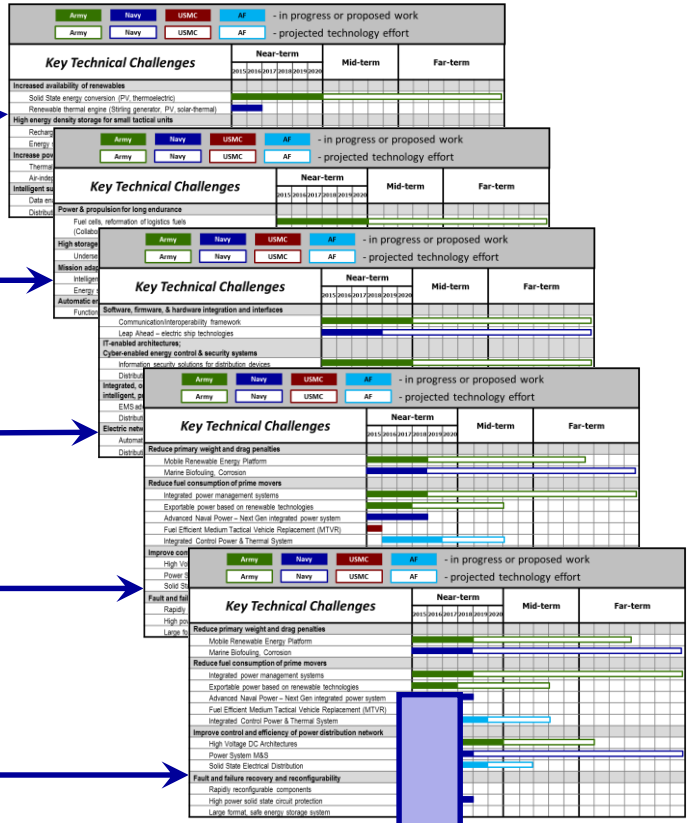
Autonomous Platform Power	
Key Technical Challenges	*Technical Goals and Metrics*

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

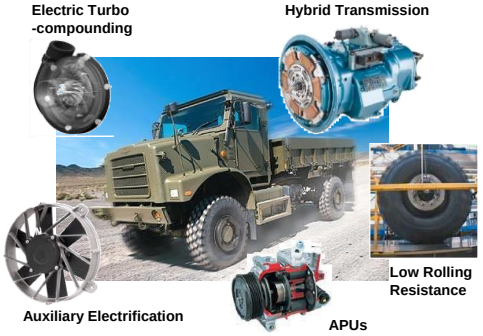


Priorities and Gaps

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

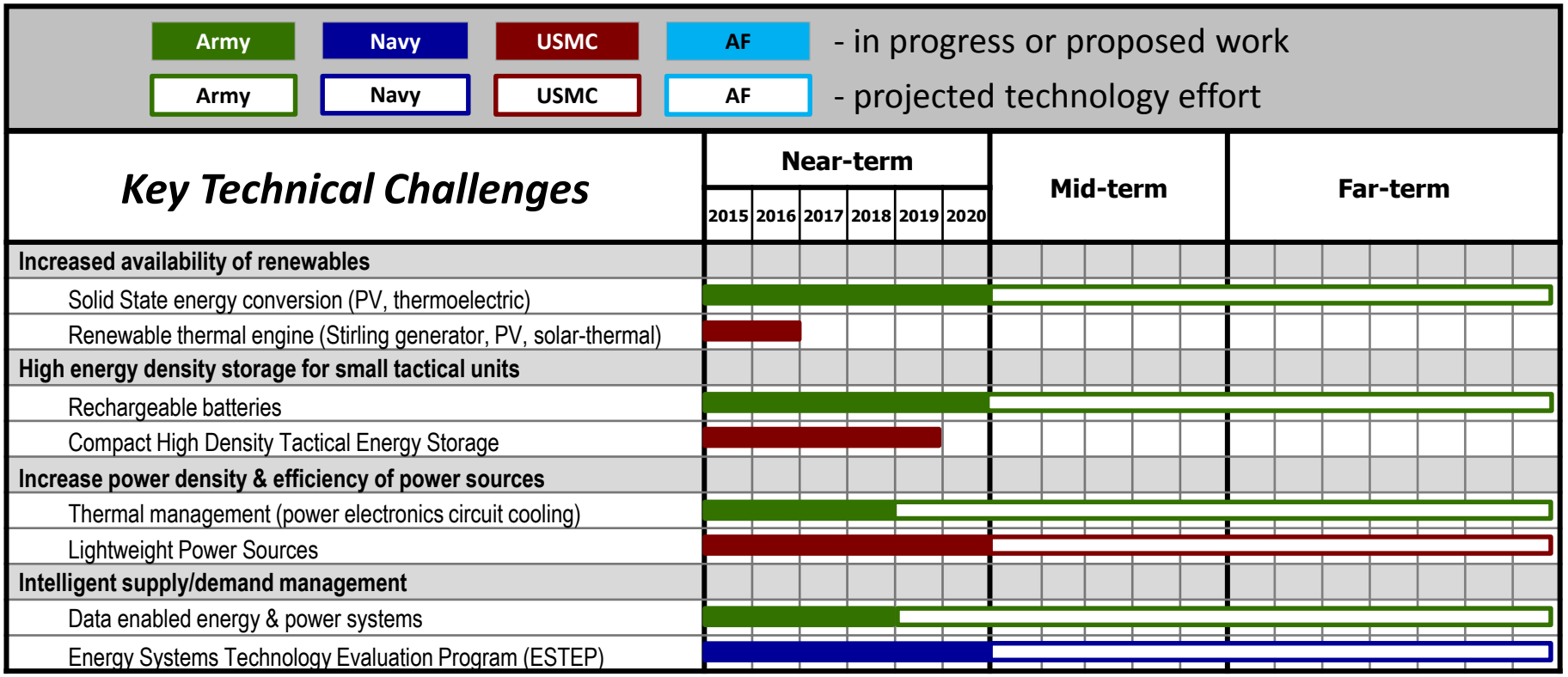
Tactical Unit Energy Independence Goals and Metrics

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



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

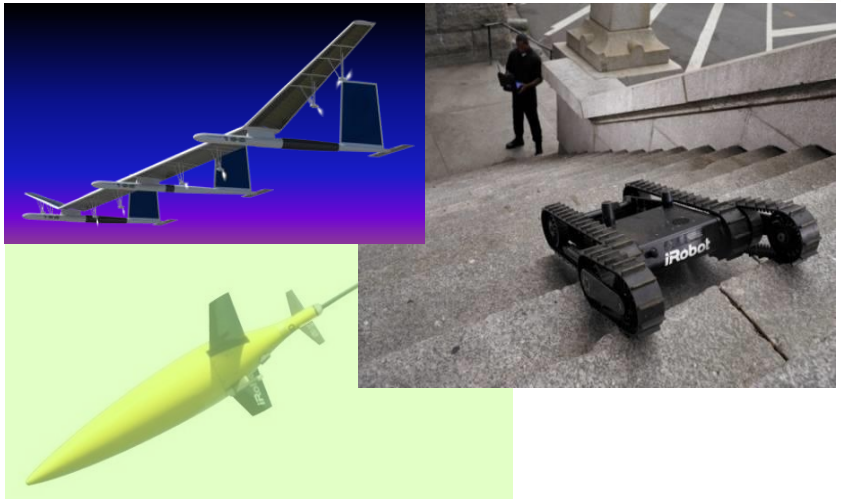
S&T Gaps

- 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:

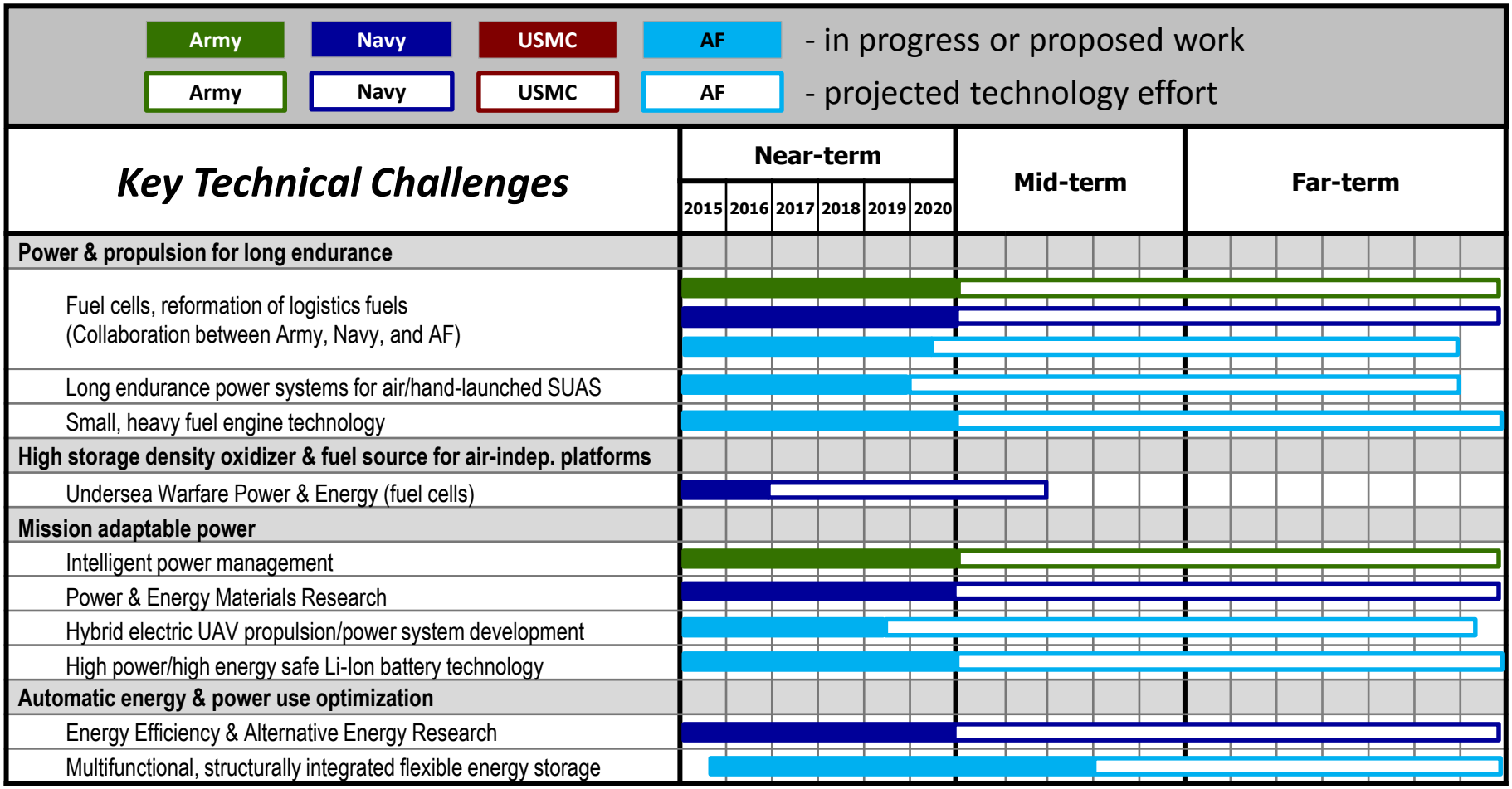
- **Develop power and energy systems that enable next-generation autonomous platforms**
  - **Long endurance; High Reliability & Scalable; Low maintenance power systems**
- **Mission adaptable power**

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



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

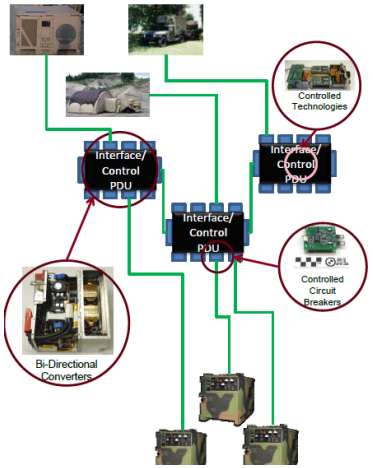
- Automatic reconfiguration and adaptable on demand
- Predictive control

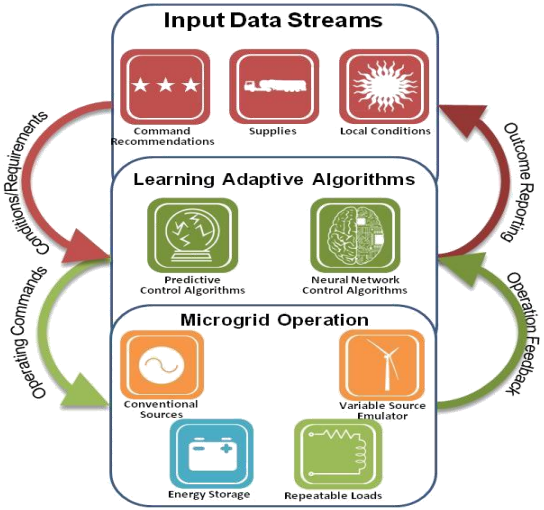
Enhanced mission effectiveness

- 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

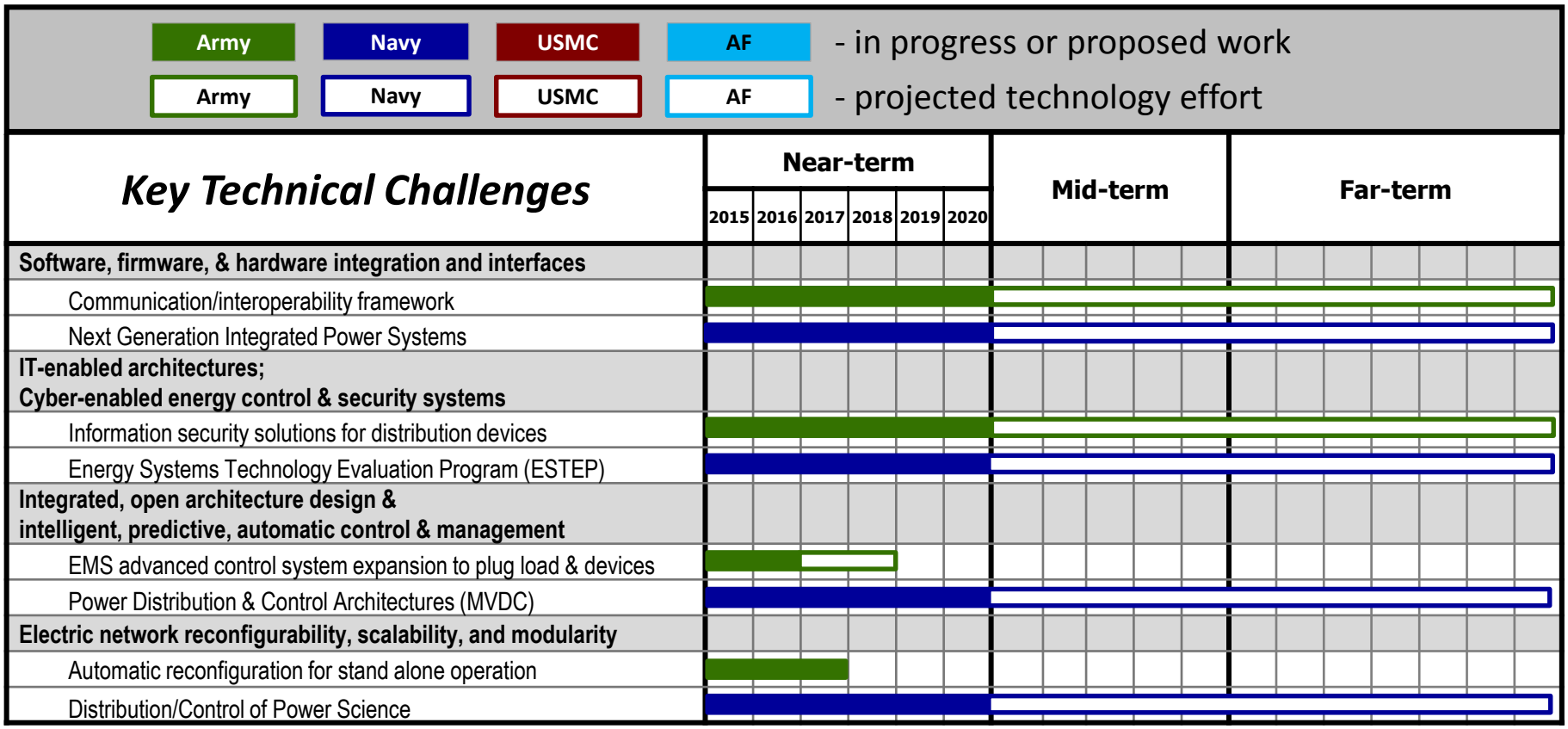
Adaptive Power Networks
Goals and Metrics

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



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

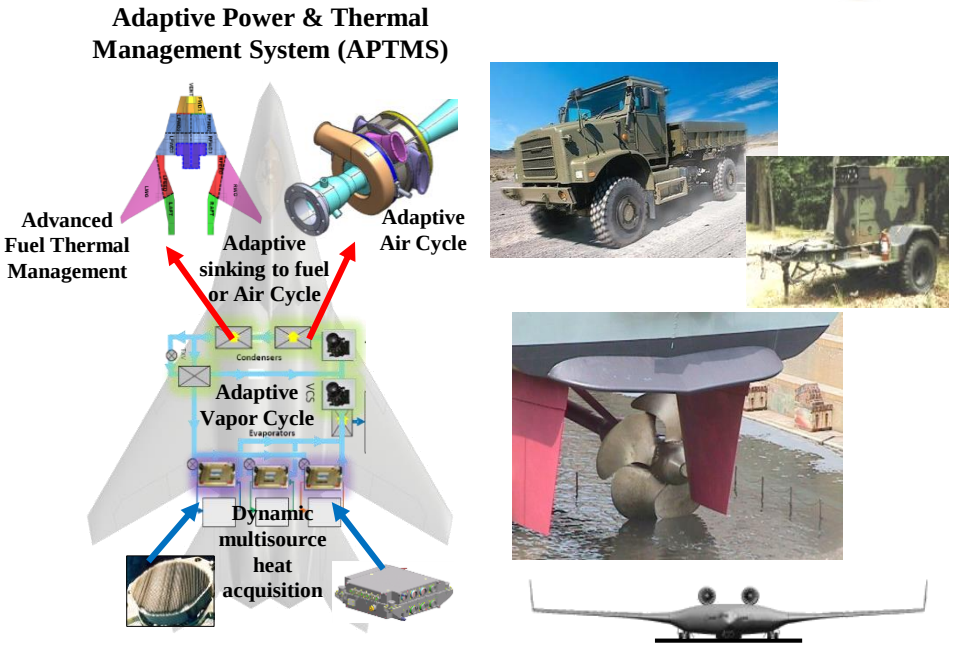
S&T Gaps

- 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

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:

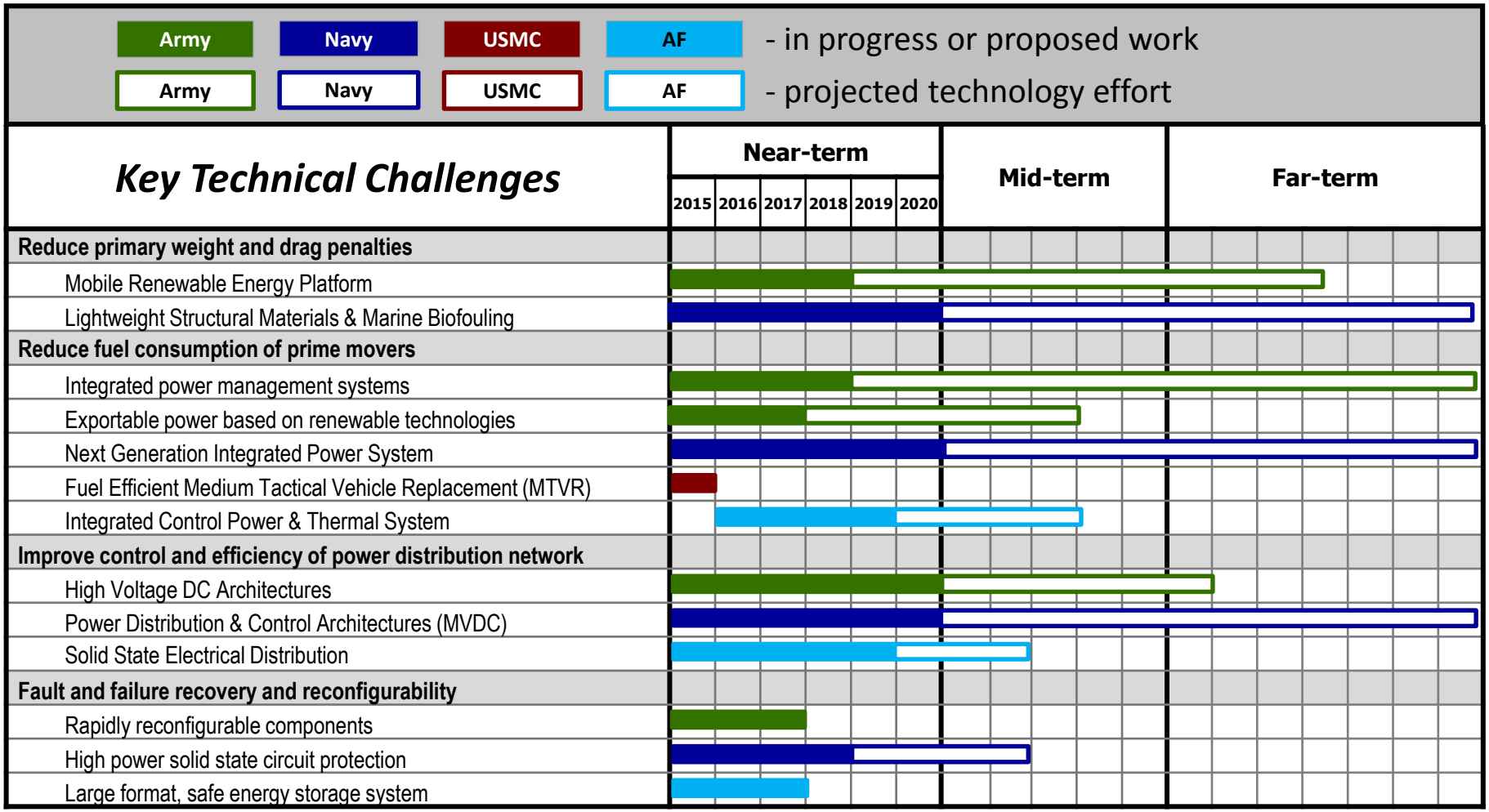
- **Increase electrification**
- **On-demand power architectures to improve efficiency by 20%**
- **Increase power system reconfigurability**
- **Provide energy source flexibility**
- **Eliminate platform thermal constraints (i.e., hot fuel)**

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 loses 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



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