Power and Energy Strategy White Paper

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REPLY TO
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MEMORANDUM FOR SEE DISTRIBUTION

SUBJECT: Power and Energy Strategy

1. The enclosed white paper provides a framework to guide development of power and energy capabilities which support Army requirements in the near, mid and long-term. The document projects operational needs; identifies important performance attributes; assesses relevant technology opportunities; recommends priorities for future investment; and describes an implementation approach linking ongoing initiatives and plans with a coordinated path forward.

2. The underlying analysis reflects collaboration across operational, technical and logistical disciplines, primarily in the context of a Power and Energy Innovation Workshop co-sponsored by the Director, Army Capabilities Integration Center (ARCIC); Deputy Chief of Staff of the Army, G-4; Director, United States Army Tank Automotive Research, Development and Engineering Center; and Commander, Research Development and Engineering Command. Nearly one hundred subject matter experts representing government, industry and academic sectors, gathered to assess current and anticipated technology opportunities in the context of operational needs in the near, mid and long-term.

3. Beyond its consideration of individual technologies, this analysis identifies crosscutting insights and needs. Most significantly, the Army must establish capabilities and procedures to manage power and energy utilization as an integral aspect of its operations. Moreover, we need to identify those critical performance measures corresponding to operational challenges beyond the historical focus upon cost and environmental impacts. Military requirements demand that we consider additional criteria, such as power and energy densities, logistics, ease of integration into military applications, safety, security, reliability, availability, flexibility, and adaptability.

4. Considering the complexity of modern military systems and operating environments, there is no reason to expect a “silver-bullet” solution. To remain as the world’s most effective fighting force, the Army will require multiple solutions, integrated through a systems engineering framework. This systematic approach will enable incremental improvements in power and energy density and efficiency, while pursuing higher-risk opportunities to deliver disruptive capabilities.

ATFC-ET
SUBJECT: Power and Energy Strategy

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I. SUMMARY

Power and energy grow ever more important to our military capabilities; they enable every system that supports Soldier and unit performance, from mobility and weapons systems to surveillance and communications – not to mention simple heating and cooling. In recent years, several factors have emerged which further complicate the engineering and logistics challenges associated with power and energy; such as, asymmetric threats to logistics and infrastructure, increasing competition for the world's oil supply and concern about global climate change.

This paper examines power and energy as they relate to Army operational challenges today and well into the future (2030+). It reflects a collaborative effort among the Army Capabilities Integration Center (ARCIC), Army G-4, Research, Development and Engineering Command (RDECOM) and other stakeholders who participated in a focused, 3-day workshop which, in turn, leveraged results of previous and ongoing initiatives. The report seeks to delineate a top-level strategy for investment in power and energy solutions, based upon operational need. It identifies critical challenges in each area, assesses prospective approaches and recommends investment priorities; it represents an initial step in an Operational Energy campaign.

Army operations span a diverse range of tasks and operating environments, from enduring activities and infrastructure under little threat, to expeditionary operations and sustained campaigns in hostile zones. The Army Capstone Concept[1] observes that:

> *Operational adaptability will depend, in large measure, on ensuring that Army forces retain freedom of movement and action across wide areas. . . . Effective sustainment can have far-reaching and significant direct and indirect impacts on the entire campaign, especially in terms of cost, Soldier health, diplomatic relations, reconstruction activities, and the ultimate success of the mission.*

Especially with respect to energy and water, the first step is to find ways to reduce demand. The Army has established a "Warfighting Challenge"[2] to enhance sustainment through reduced logistics demand. It admonishes:

> *The Army must explore new capabilities that will fundamentally change the demand characteristics of the force to include capabilities that will allow the demand to be satisfied at the point of need thereby decreasing the requirement to forecast stock and distribute stocks and services.*

GRAND CHALLENGES

Considering current and foreseeable trends, a few capability advancements may be considered as "grand challenges":

1. *Give Soldiers and leaders a means to manage – measure, monitor and control energy status, usage and system performance; prioritize and redistribute resources. This challenge includes building awareness and training, integration of power and energy management into operational planning and execution and developing interfaces and media which enable energy to be transferred readily among systems for the mission and situation at hand.*

[1] TRADOC Pamphlet 525-3-0, The Army Capstone Concept - Operational Adaptability: Operating Under Conditions of Uncertainty and Complexity in an Era of Persistent Conflict, 2015-2028, p 21, 21 December 2009.
[2] Army Warfighting Challenge: Logistics/Demand Side Sustainment, Training and Doctrine Command, 2009.

2. *Significantly reduce requirements to transport fuel and water in an expeditionary environment. The need is clear, given experiences in Iraq and Afghanistan. The approach will require a concerted effort involving a combination of efficiency improvements, alternative sources and other technologies.*
3. *Build resilience and flexibility into force capabilities to continue operating in the face of energy disruption. These disruptions can occur at the national, regional or local level and affect bases, platforms and Soldiers. Army forces must still prevail, even in the face of disruptions due to enemy action, weather, shifting priorities, or energy availability.*

ENABLING STRATEGIES

- *Identify a single proponent* to align concepts, requirements, capabilities, policies, research and acquisition for the energy and power to support Army operations;
- *Establish a holistic model to manage power and energy*. Analyze operational concepts to identify operationally relevant metrics for power and energy, such as fully-burdened cost of fuel (FBCF), usage rate, availability, weight and safety. Integrate these measures into CONOPS, design, training and operations.
- *Combine and integrate technologies in order to optimize system characteristics that support military requirements*. Leverage characteristics of different technologies, such as solar heating and thermal batteries; combine functions to reduce cost, weight and complexity.
- *Improve and package capabilities to recycle and to utilize local resources*. These measures reduce the need for logistic fuel, provide resilience and may mitigate tactical signature.
- *Investigate energy storage/distribution alternatives to petroleum fuels.* Alternative technologies such as synthetic fuels, biofuels and/or nuclear energy may satisfy high power operational military requirements without continued reliance on petroleum fuels.
- *Improve operational performance and efficiencies of existing system/component architectures,* recognizing that JP-8 will be the standard for at least the next decade.
- *Leverage investment by coordinating each development activity to address as many capability needs and component (DOTMLPF) solutions as possible*.

The following sections provide an operational perspective to guide power and energy capability development, from the Soldier level to major installations. Power and energy provided the spark for both the industrial revolution and modern warfare; they are an essential part of the equation to maintain US military dominance in support of national security.

II. INTRODUCTION

Energy was a critical factor during many of the major battles and campaigns of World War II. We have since become even more dependent upon the resource; yet, often take it for granted. Army vehicles consume unprecedented amounts of fuel for mobility and on-board power. Average fuel demand per soldier has increased from about 1 gallon per day (WW-II) to 20 gallons (OEF/OIF 2007), roughly half of which is used to generate electrical power. This dependency translates to a vulnerability, as a significant proportion of US combat casualties in OIF and OEF may be attributed to resupply operations.

In addition to expeditionary issues, a recent Defense Science Board Study[3] expressed strong concern about our military dependency upon a vulnerable US power grid, concluding:

- *Operations suffer from unnecessarily high, and growing, battle space fuel demand which degrades capability, increases force balance problems, exposes support operations to greater risk than necessary, and increases life-cycle operations and support costs.*
- *Military installations are almost completely dependent on a fragile and vulnerable commercial power grid, placing critical military and Homeland defense missions at unacceptable risk of extended outage.*

These concerns superimpose upon existing challenges to satisfy the ever-growing demand for electrical power on combat and non-combat platforms, especially for auxiliary power, and the compelling quest for compact, high capacity power sources for our overburdened Soldiers.

We must now factor in global energy constraints and diminishing resources. No one can gauge precisely when world oil production will decline, but demand is already overtaking production. Over the past century, modern militaries migrated to petroleum energy due to its ease of handling and worldwide availability. We now must consider alternatives in order to ensure availability, mitigate price risk and even to consider environmental responsibility.

The Army already has promoted the priority of energy performance and formed various working groups. In 2008, the Army established a governance structure for energy policy, guided by a Senior Energy Council and facilitated by the Deputy Assistant Secretary of the Army for Energy and Partnerships. In February 2009, the Council issued an Army Energy Security Implementation Strategy, including five Strategic Energy Security Goals (ESGs): [4]

ESG 1 - Reduced energy consumption
ESG 2 - Increased energy efficiency across platforms and facilities
ESG 3 - Increased use of renewable/alternative energy
ESG 4 - Assured access to sufficient energy supplies
ESG 5 - Reduced adverse impacts on the environment.

Ongoing and emerging initiatives address power and energy needs ranging from reduced cost and expanded use of renewable sources to extending the range and staying power for Soldiers and vehicles in the field. Energy performance metrics and directives historically have focused on consumption, cost and energy diversity, explicitly exempting operational systems to avoid inappropriate constraints on Army operations. Recent efforts to identify operational energy objectives highlight a lack of existing systems analysis to identify mission-related attributes, such as resilience, agility and flexibility – important, not only in an expeditionary environment, but on domestic installations in a “flattening” world.

The Operational Energy Campaign must establish a capability-based approach to energy and power that integrates all DOTMLPF aspects and identifies performance parameters based upon analysis of operational concepts. This will require both operational analysis and a comprehensive assessment of baseline energy use and performance, providing the basis for modernization priorities and improvement goals, as well as management tools and training.

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3 “More Fight – Less Fuel”, Defense Science Board Task Force on DoD Energy Strategy, US Dept of Defense, OUSD AT&L, Washington, DC, February 2008.

4 Army Energy Security Implementation Strategy, The Army Senior Energy Council, 13 January 2009 (http://www.asaie.army.mil/Public/Partnerships/doc/AESIS_13JAN09_Approved%204-03-09.pdf).

KEY TERMS

Energy – the capacity of a physical system to perform work. Energy exists in several forms such as heat, kinetic, mechanical or electrical. *In the military context, energy sources of importance include:*

- ***Petroleum*** – naturally-occurring oil and gas; the primary source of hydrocarbon fuels which power operational needs. With further investment, "synthetic" fuels, produced from biomass or other carbon sources, may displace a significant proportion of petroleum fuel.
- ***Coal*** – a mainstay of electricity production. As available US oil reserves decline, our coal reserves remain substantial, however coal combustion of coal releases disproportionately large quantities of carbon dioxide to the atmosphere.
- ***Renewables*** – energy sources that notionally are not depleted with use, such as solar and wind energy. Renewable energy sources are generally perceived to be "environmentally friendly" and due to their diffuse nature, lend themselves to distributed use.
- ***Nuclear*** – energy released by splitting (fission) or combining (fusion) the nucleus of an atom. Twenty percent of US domestic electricity production derives from nuclear fission (compared to 80% in France). Nuclear energy requires significant infrastructure investment, and poses particular challenges with respect to safety and waste disposition.

Fuel – a means of storing energy; not a source, per se. Traditional fuels include flammable or combustible materials such as wood, petroleum and other chemicals such as hydrogen, hydrazine or ammonia; modern use includes other energy forms, such as nuclear fuel.

Power – a unit of energy delivered over time. We express power in watts, horsepower or BTUs/hour; and energy as joules, kilowatt-hours (kW-hr) or British Thermal Units (BTUs). In general, power challenges relate to high voltages and current flows required to support end applications, such as rapid discharge (billions or trillions of watts) for emerging technologies such as directed energy weapons.

Water – Water comprises an even greater volume than fuel in the tactical supply chain. While distinct from fuels, water supply, production and use is almost always related to energy and therefore, must be considered in concert.

III. OPERATIONAL CONTEXT

Power and energy are critical enablers across the range of military missions and operational environments. This analysis considers a 20-year planning horizon in order to transcend the constraints of existing programs and organizational structures, and open the window to significant technology innovation.

Military operations are growing more complex and unpredictable, largely as a result of globalization. FM 3-0 attributes equal importance to stability and combat operations, creating a significant shift in required capabilities. The Army Capstone Concept (p 15) predicts that "(t)echnological advantage will remain a vital component of military effectiveness," making the continued growth in power and energy demands inevitable. Technology continues to advance and proliferate so that many countries, as well as non-state actors, are gaining access to sophisticated sensors, communications technologies, information systems and precision munitions. In order to consistently prevail, we must maintain the technology edge across the board, perpetuating the energy challenge.

Strategic assessments predict a continued trend away from major combat operations conducted within reach of major seaports – historically enjoying generous deployment schedules - to distributed operations involving lower intensity conflict and stability operations "in urban settings or harsh, inaccessible lawless areas.[5]" The Adaptive Brigade is a useful construct to help visualize requirements for a resilient, flexible, full-spectrum expeditionary force. With a modular architecture, this force could be tailored to the anticipated mission and situation, but would readily adapt to changes on the ground. Given strategic lift and sufficient landing sites (sea or air), this notional force could deploy anywhere and begin operating within 4 days. The concept suggests use of multipliers such as information and unmanned systems, and "outsourcing" not only fire support but any other functions as prudent to reduce its own footprint.

Energy and water represent a significant proportion of typical US ground force resupply demand in theater, representing key challenges for the Adaptive Brigade. Targeting a 30% reduction from today's levels, Brigade elements would meet future energy and water requirements through local/renewable energy and water resources and organic compact energy sources. Many of the remaining sustainment requirements, such as food, spare parts and medical support, while lesser in volume, are nevertheless essential. However, a dramatic reduction in supply volume would allow for emerging capabilities such as telemedicine, precision aerial resupply and joint heavy lift to be developed as practical options, thus providing the requisite flexibility and resiliency for a force operating in remote locations.

This paper describes power and energy requirements in the context of enduring and expeditionary operations, organized into "use cases" of infrastructure, platforms, and Soldiers. Sustainment functions, such as fuel and battery supply, crosscut these categories, and mission command concepts provide the essential elements of awareness, understanding and control needed to manage and integrate energy during real-world operations (Figure 1).

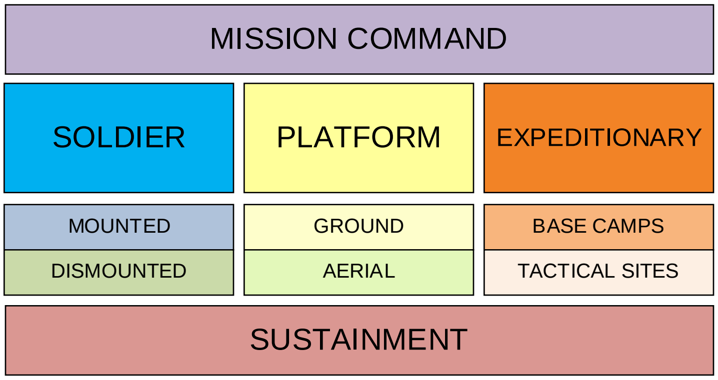

Figure 1- Operational energy "use cases"

IV. DISCUSSION

ENDURING INFRASTRUCTURE POWER

Enduring infrastructure systems comprise "permanent" installations, which support force generation and projection and, increasingly, provides timely operational support functions. The security situation is often presumed to be stable and secure, compared to the expeditionary case. Scale may range from a remote office with one or a few individuals to major installations that support combat training and housing for tens of thousands of Soldiers and their families.

5 Operational Environment 2009-2025, US Army Training and Doctrine Command, v6, p 8, January 2009.

The primary energy-related functions are to provide electrical power to buildings and other infrastructure facilities, and to distribute fuel for transportation and space heating. Cost and environmental compliance are common performance metrics.

Requirements

Primarily legislative mandates such as Energy Policy Acts of 2005 Energy Independence and Security Act of 2007 and Executive Orders 13423 and 13514 along with Army regulations and policies dominate enduring operational energy and environmental requirements. These respective laws and policies call for:

- decrease in energy consumption
- decreased dependency upon petroleum fuel
- increase in the use of renewable energy sources
- progress toward a “Net Zero posture - five energy self sufficient Army installations by 2014, fifteen by 2024, and all installations by 2030.

The Army has made significant progress toward energy conservation over the past decade, but did not make the goals in FY 09. Two emerging factors are raising concern about other parameters, such as assured availability. First, enduring activities support more and more operational missions, such as space, information operations, intelligence or nuclear command and control. Unmanned system operators guide systems in theater from CONUS locations, virtually in real time. Second, we have begun to recognize vulnerabilities to asymmetric attack, not only against primary mission facilities and personnel, but also cascading effects of an attack on supporting systems and infrastructure. The 2008 Defense Science Board report is not the only predictor of large-scale effects and potentially existential impact of an attack on critical nodes within the US power grid. Energy Security encompasses both fixed and expeditionary installations for mission accomplishment and accommodations for Soldiers, civilians and contractors.

Except for national command structure functions, the traditional approach to provide for continuity of operations in “mission critical facilities” has been to equip them with backup generators and a few days’ fuel supply. In the aftermath of the 9/11 attacks, critical infrastructure managers have begun shifting toward a systems approach that considers supporting functions, such as communications, transportation, food and security.

Concepts such as “Net Zero” or “islanding” seek to make installations essentially self-sufficient, especially in the event of a major disruption. In addition to these useful concepts, we must address interrelationships between operational missions, mutual support with local communities and higher-order impacts – even domestic contingency missions that may emerge due to the situation. Army Critical Infrastructure managers analyze these critical operations and infrastructure on an ongoing basis; in general, the results drive capabilities to:

- Continue mission essential functions in the event of interrupted external energy supplies, or due to damage to, or failure of, a single node (minimize dependency);
- Supply energy in useable form and sufficient quantities to support critical military missions and essential off-site functions in the event of extended interruption to off-site supply (assure availability);

These requirements apply not only to facilities themselves, but to critical transportation/ mobility functions as these also require fuels/energy. Ground and air vehicles are important components in enduring operations; they also rely entirely upon energy resources in order to fulfill their functions.

Assessment

The Army is working to integrate its management structure and focus for power and energy on installations. Responsibilities are clear, for example, among the installation command chain, Installation Management Command, the Army Energy Executive (Deputy Assistant Secretary of the Army for Energy and Partnerships) and the Senior Energy Council. The community also needs to follow through and establish consistent policies, metrics and partnerships to effectively manage energy performance.

To improve our energy performance, we must identify energy reporting measures of performance; educate Soldiers and leaders about their influence on outcomes; and provide effective feedback mechanisms. In a simple example, setting back a room thermostat could be expected to reduce energy consumption; however, we rarely delegate control to building users, nor provide them feedback or incentives regarding their contributions to energy savings. Communications means and command awareness for power and energy consumption need further development.

Meanwhile, the Science and Technology community is pursuing a portfolio of prospective solutions to address installation power and energy needs. Given the growing commonality between performance objectives among enduring installations and expeditionary bases, the P& E Innovation Workshop participants evaluated technologies for both cases as a single effort; see "assessment" results described under the expeditionary base camp section, below.

Proposed Solutions

Strengthen energy management processes:

- Provide resources to enable success. MILCON, Acquisition, O&M and Reset resources are needed to address the challenges and opportunities;
- Coordinate an interagency agreement with the Department of Energy to investigate/advance energy technologies to meet military needs by ensuring the Army's two labs (RDECOM/ERDC) are fully engaged to leverage their on-going work;
- Establish energy security performance measures, monitoring and reporting processes relevant to operational needs;
- *Promote behaviors that improve energy performance:* Educate Soldiers, civilians and contractors about energy metrics and how their behaviors impact consumption and mission accomplishment;
- Educate facility managers about recommended practices and Leadership in Energy and Environmental Design (LEED) certification building techniques;
- Encourage collaboration by establishing online collaboration opportunities on Army Knowledge Online to facilitate sharing of metrics, modeling, and simulation tools and reports;
- Provide effective feedback and incentives that drive further investment.

Enable installations and Army leadership to optimize investments by evaluating respective sites for suitability to deploy alternative and renewable technologies. Consider alternative system technology mixes through integration modeling tools such SimCity™. Make sure all the stakeholders have common operating picture.

Promulgate policy to support performance goals, such as requiring that all new MILCON administrative and housing facility designs include a 65% energy reduction beyond the current American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) 90.1 standard; or setting aside a portion of the small business innovation research/ small business technology transfer program (SBIR/STTR) funding for advanced energy concept development.

Establish "test bed(s)" to study "novel" energy technologies, with hands-on Soldier input. Invite industry and academic partnerships through both RDT&E and capitalization methods.

Improve decision and investment processes by providing actual performance feedback and incorporating life-cycle energy models. Strengthen ability to invest in facilities based upon life-cycle energy footprint, mitigating constraints of the budget process and military construction timelines and approval processes.

EXPEDITIONARYBASE CAMPS

Our national security will continue to require capabilities to conduct expeditionary operations across the spectrum of conflict. Future operating environments likely will be characterized by ever-increasing distributed operations driven by threats with improved capabilities which will require significant changes in the way we support power and energy demands. An increase in the use of general purpose forces rotating to austere locations for long periods of time necessitates a re-examination of energy with our "Base Camp" design and capabilities portfolio.

Theater infrastructure and sustainment operations involve tremendous amounts of material and personnel. The vast majority of supplies travel by sea and land, which require establishment of ports and other intermodal nodes and staging areas. Lines of communication must be protected as supplies spend days or weeks in transit. In theater, base camps provide space and security for maintenance, resupply, housing and a life support functions – each of which is energy-intensive.

Base camps come in all shapes and sizes. Some forward operating bases in Iraq support as many as 20,000 personnel. At the other end of the spectrum, small units at the company level and below are establishing combat outposts to enhance local operations. While there are functional parallels among nearly all base camps, such as life support and force protection, it is important to note that tactical and geographic situations preclude that a "cookie cutter" approach to expeditionary power.

Forward operating bases (FOBs) generally support a brigade or larger population. They are semi-permanent and tend to grow more intensive over time with growing energy demand. FOBs typically have temporary or semi-permanent structures, electrical power grids, water and sewage systems, and force protection systems. Operational, administrative, housing, and recreational facilities all require energy for lighting and heating/air conditioning. Energy conservation directives applicable to enduring facilities largely do not apply to FOBs. The Army needs relevant standards and practices to replace ad-hoc programs such as retrofit "spray foam" insulation to significantly curtail energy demand growth.

Combat outposts (COPs) sustain small units essentially in their operational space for extended periods. These encampments have a short lifecycle and are nearly all unique. Most employ tents for shelter along with select components of the Force Provider system. Commanders determine location, size and other attributes based upon the mission, terrain and threat, as well as availability of local or imported materials. In most cases, these camps provide protection, shelter, sanitation and dining. Infrastructure is likely to comprise portable generators, temporary wiring, water storage, crude toilets and showers. Although services are considerably more Spartan than in larger camps, the energy and water systems tend to be inefficient, therefore representing significant demand reduction opportunities.

Both forcible and early entry operations are characterized by multiple sites operating over wide areas in a distributed fashion, complicating electrical power generation and energy resupply in general. Solutions to this situation are complex, and energy demand and supply must be balanced to facilitate effective warfighting. Reducing power demand is a significant part of the equation, as is developing the means to provide supply.

Giving Soldiers, at all levels, the tools to manage their energy situation flexibly and effectively within the full spectrum of conflict is essential. Developing, learning and proliferating solutions within this cross-cutting environment will produce a number of very cost effective solutions quickly. These solutions and tools must be clearly communicated to, and embraced by Army leaders and Soldiers in training to identify applicability and utility in operations where we can maximize their benefits**.**

Requirements

- Establish electrical supply capability to support base camp functions, either from imported generators or by purchasing local power. Importing fuel involves substantial expense and security risks, but civilian power grids may lack excess capacity to sell to US forces. Setting up generators and distribution systems require significant amounts of material, construction equipment and specialized labor. Camp grids must be modular, simple and robust; setup and maintenance must be within the capabilities of the average Solider.
- Camps must incorporate “smart-grid” control technology to enable commanders/staffs to effectively manage their electrical generation, distribution and use. Grids will facilitate energy storage, and prioritization of loads. At the COP level, these systems should provide for a camp “silent” operation capability if needed.
- Import and/or export power to civilian systems. In a growing proportion of operational situations, this capability would enhance mission success, either directly or indirectly by generating goodwill in local populace, security through improving local conditions and better situational awareness.

US Army Training and Doctrine Command (TRADOC) identified several technology-oriented Warfighter Outcomes for expeditionary base camps, including:

- Reduce theater camp generator fuel consumption and transportation or distribution 30% by 2015;
- Establish power management processes and tools to determine, monitor, and adjust load and demand;
- Examine innovative alternative energy sources that minimize or replace current hydrocarbon energy systems; eliminate generators by 2030;

- Examine lightweight, low volume, and highly reliable dense power sources;
- Establish expeditionary power grids for recharging portable/mobile batteries/fuel cells;
- Establish an automated fuel accountability system to validate baseline fuel consumption and provide enterprise level fuel asset visibility.

Assessment

Every theater camp is different, and there is little incentive in the field to standardize. The diverse range of mission objectives and diversity among regions further complicates this issue. Performance measures and monitoring of power and energy performance would, however, be a key enabler to support the introduction of new technologies and could help break through some of these standardization challenges.

While we use liquid fuels to store and distribute energy, military systems increasingly are supplied by an electrical power network. The Army must continue to work to develop its electrical power integration approach, including component design (e.g., controls, switching and storage) and integration approaches such as modularization and smart grids. The multi-energy solution will provide a significant contribution toward increased ground force flexibility and adaptability. Many Expeditionary Power solutions can be developed in the near-or mid-terms, and timeframes can be accelerated through collaboration with DOE in areas of smart grids and fuel cells.

Proposed Solutions

Conservation / Demand Reduction / NetZero

- Develop a simple, Soldier friendly efficient and effective power “backbone” for expeditionary camps that provides visibility, capacity and control to effectively manage energy on site with a minimal need for outside contracted support.
- Conduct an in-theater camp baseline energy and water assessment; integrate analysis into ongoing base camp design efforts. This alone may enable reductions in camp life support energy demand by as much as 30%.
- Provide two design options for flexibility: adaptation of local infrastructure/materials using intelligent plug-n-play control devices, or modular, reusable “COP kits.”
- Reduce life support energy demand through the use of LED lighting and high efficiency HVAC systems coupled with modular re-locatable insulated structures. This could reduce JP8 consumption for camp electrical generation by 30-50%.
- Provide smart grid compatible alternative energy sources for camp electrical generation that extend the camp’s mission operating time or reduce the need for periodic liquid fuel resupply to base camps. Incorporate device planning factors into COP grid planning tool to facilitate tactical planning in support of operations with these devices.
- Efficient heating, ventilation and air conditioning (HVAC), environmental control units (ECU) commonly known as heat pumps with additional air-to-air heat exchangers could be implemented in both enduring and expeditionary installations by 2014.
- Thermal insulation represents a great savings opportunity, especially in expeditionary facilities. The initiative to insulate tents in FOBs should be expanded to include other

structures and to consider new insulation materials, such as aero gels, ceramics, low efficiency coatings or insulating fabrics.

- Fund examination of new technologies, such as variable speed generator sets, *in-situ* materials, and biomimicry inspired shelters for possible employment into future or upgraded theater camps to better manage energy and demand reduction that are matched to ECUs and shelters.

Micro-grid / Islanding / Distributed Generation (Cross-cutting & enabling)

Design a flexible, scalable, smart grid capability for base camps. Enable smart grid and supporting controls to provide “plug-and-play” capability for, renewable energy and storage devices to contribute to installation electrical grids. Develop an automated tool to complement a smart grid capability enabling users to plan for, capture and communicate camp electrical grid design, layout, performance and maintenance. Smart grid technologies should leverage National Institute of Standards and Technology (NIST) standards as a starting point. Military net-centric common architecture, two way communications and information assurance should be designed into distributed generation technologies.

Renewable Energy / Energy Storage

- Leverage commercial and DOE solutions for energy storage and retrofit camp smart grids with a significant, low maintenance, electrical energy storage capability. At the COP level, size the device to provide at least 12 hours of “silent ” power capability for the camp’s life support and operations (C4I) functions.
- Flow batteries will offer load leveling capability for small scale applications for 2014 and large scale applications starting in 2024, and beyond; ultra capacitors are an alternative source of load leveling;
- PV integrated military shelter items exist now with additional structure insulation, and offer reduced electrical demand by cooling loads by reducing solar insolation on the shelter while simultaneously producing low kW level power. Efforts continue to increase conversion efficiency of the flexible PV modules and reduce weight;
- Nano-photovoltaic (PV) coating is one possible future for flexible solar panels and may be ready for introduction into theater camps by 2024;
- Biofuels are already available, but additional development is required to improve process efficiency so that they are competitive with traditional fuels. With the addition of biofuels, TRADOC and RDECOM should examine distribution, storage and handling (cross contamination) issues of using multiple fuel types.
- Waste to Energy (WTE) technology gasifies organic waste (plastic, cellulose, and food) yielding a syngas that can power standard generators displacing up to 85% of JP8 used to operate the generator. The waste disposal benefits could be as compelling as the energy aspects. Based upon an historical production rate of 4 to 12 pounds of waste per soldier per day, a battalion level camp might produce 60-200kW of power from its waste. With funding, WTE could be introduced in 2015.
- Micro-hydro plants and wind turbines will have use in appropriate geographic regions.
- Use of low technology passive solar hot water and solar air heating units made from low weight plastics

These renewable energy and storage solutions should be combined to maximize efficiency and avoid power disruptions.

Nuclear / Space Based Solar / Other

- Nuclear energy should be evaluated through a joint venture with DOE and other government branches. Nuclear power has unique characteristics and considerations, such as high energy content, low signature, security, infrastructure requirements and complexity which, collectively warrant a deliberate, objective analysis.
- Space-based solar would require a significant program investment, and transmission technology would require further development.
- Wireless energy transmission has potential for short range applications by 2024 with range extension through 2030.

Recommendation

The greatest and most important challenge is to empower each member of the team as an energy manager. Smart grid technology would support this goal while itself improving efficiency, interoperability and reliability. Ultimately, energy management should encompass energy sources, fuels, storage devices, distribution networks and applications, and should be integrated into the way we operate. By establishing *one or more "test beds*", the Army could enable Soldiers to develop the most useful combinations and operational approaches for energy, power and associated water production technologies. The Army should continue to leverage existing technology solutions with balanced investment in longer-term research and development. There will be no "silver bullet" solution.

Enduring Infrastructure and Expeditionary Power Solutions

	2014	2024	2030+
Infrastructure	• Remote Energy Management • Micro-grid (Import / Export to Local Community - Demo and Live) • Waste to Energy (WTE) • Biofuels Plant (Demo) • Small Scale Flow Batteries for Energy Storage • Advanced Insulation Materials • > 7.5% Renewable Energy Generation per EPACT 2005 thru 3rd Party Financing	• Biofuels (Displace 5%) • Advanced Energy Storage Devices • Large Scale Flow Batteries for Energy Storage • Vertical axis wind turbines • LEED redesign/retrofit buildings with green roofs. • POM Funding for >25% Renewable Generation – EISA 2007 mandate	• Generation 4 Nuclear Power Demo (2027-2030 time frame) • Space Based Solar Plant (Demo) • Biofuels (Displace 20%)
Expeditionary * * Small expeditionary power and energy requirements are addressed in Soldier solutions.	• Remote Energy Management • Micro-grid (Import / Export to Host Nation - Demo and Live) • Waste To Energy (WTE) • Energy Efficient Modular Structure • Modeling / SimCity Planning Tool • Small Scale Flow Batteries for Energy Storage • Advanced Installation Matls	• Distributed Generation of Renewables (10%) • Bio-Mimicry Inspired Shelters and Building Materials • Nano-PV(Photovoltaic) Coatings • Direct Current Powered Camps (100%)	• Distributed Generation of Renewables (20%) • Sustainable Theater Camp Operations – local energy sourcing.

PLATFORMS

The Army is reconsidering air and ground vehicle design options, in light of today's increasingly distributed, asymmetric conflicts. The trend is to develop flexible, multifunction platforms that can be readily configured for the mission. Observation helicopters are being armed; tactical wheeled vehicles up-armored; and combat vehicles such as Stryker, used to transport supplies. Unmanned systems are proliferating on and above the battlefield, enabling new approaches to operations and logistics, but also presenting new energy challenges, especially in terms of desired maneuverability and endurance. This dynamic situation complicates an already demanding set of expeditionary power and energy challenges.

GROUND VEHICLE POWER

Ground vehicles consume a significant portion of the Army's energy budget. Tactical and combat vehicles are used to haul troops and cargo, protect Soldiers, attack combatants, and support facility operations on bases. They provide mobility and power for an ever-increasing array of operational systems, such as sensors, communications systems, computers, weapons and environmental control systems. They must perform these functions under a number of constraints, such as: limited space claim for the propulsion system, utilization of a single battlefield fuel, and operation in extreme conditions ranging from low temperature to desert-like operating conditions. Many of these vehicles are being used for multiple purposes increasing the need for more flexible designs in the future.

Requirements

- Provide sufficient electrical power and cooling for hosted systems on the move and when halted – including combat vehicles to have a 3+ hours of "quiet" power when parked, and exportable power to reduce the need for stand-alone generators in base camps;
- Provide pulsed power at levels needed to support new systems such as directed energy, electromagnetic armor and other pulsed systems;
- Limit overall vehicle weight and power demand of on-board systems to minimize fuel consumption commensurate with transportation and mobility demands.

Efficiency goals established for current systems include:

- Abrams Tank Key Performance Parameter 5 requires fuel efficiency improvements to support one (threshold) to two (objective) days of combat operations using only on-board fuel. This could reduce the Abrams fuel burden on the Heavy Brigade Combat Team by up to five HEMTT fuelers per day.
- Stryker CDD's Key Performance Parameter 7 requires a 330-380 mile cruising range for fully-loaded vehicles (without add-on armor); a 15% improvement;
- JLTV Increment I will achieve 60 ton-miles per gallon, an increase of 15-20 ton-miles per gallon over the HMMWV; JLTV Increment II requires an additional ten ton-miles per gallon and an objective reduction in idling fuel consumption of 25% compared to HMMWV.

JLTV's On-board Power Generation will also be capable of recharging on-board energy storage (batteries, ultra-capacitors, and other power sources) while providing exportable power at the level and quality of power provided by the Tactical Quiet Generator and not negatively impacting vehicle mobility.

Recently established Ground Combat Vehicle (GCV) Key Performance Parameters (KPP) include a requirement for a threshold fuel economy at 30 mph on primary roads based on vehicle weight and a sustained electrical load of 45 kW, a ~12% reduction in moving fuel consumption over a Bradley Fighting Vehicle of equal weight. Several technologies mentioned in the paper are possible candidates for GCV, though their incorporation will be a function of the final vehicle specifications and allotted development time period.

Assessment

Thermal management is a major vehicle design consideration. Each energy-consuming system ultimately rejects heat in some manner that requires fans and radiators to accommodate the associated thermal management burden. This can be a particular challenge for combat vehicles, where propulsion systems and subsystems are typically protected by the armored vehicle hull, and heat exchangers are protected by ballistic grills. Electronic components and high-current electrical devices, such as those in hybrid propulsion systems are particularly vulnerable to high temperatures under desert like operating conditions (as high as 125 ºF).

Proposed Solutions

Because of the breadth of vehicle characteristics and mission profiles, technology approaches vary dramatically, especially with respect to powertrain design and equipment support. There are, however, a number of common challenges and prospective solutions.

Alternative Propulsion

The range of vehicle applications justifies a multi-prong approach, pursuing incremental improvements to existing technologies along with new approaches, such as hybrids. Development options must be evaluated holistically to avoid a single focus on fuel economy.

- Transmission and engine development should focus on traditional mechanical architectures in the short and mid-term, leveraging multiple incremental improvements. Military systems currently enjoy greater design flexibility than civilian applications due to exemptions from certain environmental constraints.
- Hybrid propulsion systems have been demonstrated on vehicle test beds, but require additional development and operational testing. Silicon carbide material technology could enable hybrid power trains to meet the unique power and heat rejection requirements that currently exist if such materials can significantly increase their operating temperature.

Alternative Power

We currently use generators and vehicle alternators to convert energy from liquid fuels to the electrical power used in most military systems. Fuels cells offer the prospect of greater efficiency and reduced noise, but they must be integrated into a complete system. Technical challenges (depending upon fuel cell design) include:

- Generally need to convert jet or diesel fuel into another chemical form that can be used by the fuel cell through processes such as “reforming”, and remove any sulfur, which can “poison” the cell;
- Power density for an integrated fuel cell system is generally lower than an internal combustion engine;
- Solid oxide fuel cells operate at very high temperature, requiring warm-up time and posing potential safety challenges;

Power Management

Vehicles and components tend to be designed around an optimum operating condition and duty cycle. In the real world, both vary. Some vehicles are constantly on the move transporting goods and people; others spend significant time idling. A power management system budgets the available energy and optimizes its use, and can help integrate other vehicle-mounted systems. Such technologies exist today; they could be readily adapted to specific military applications.

Grid Integration

Military systems operate within power networks – on individual vehicles, within a base camp and often, connected to the local grid. A ground vehicle could be a net generator or consumer at any given time. By providing a capability to seamlessly connect and disconnect, import or export power, we would dramatically improve operating flexibility. The power and controls industries are making significant advancements in intelligent controls, monitoring and switching devices; witness the exploding interest in Microgrids. Key challenges are to sense and manage diversity and variations in parameters such as voltage and frequency, and to provide electrical protection (e.g., circuit breakers) under all possible operating scenarios. This capability should be integrated into ground vehicles likely to be connected to power grids in their operational cycles.

Alternative Fuels

In order to simplify fuel storage and distribution challenges, and, in accordance with the precedence stated in DoD Directive 4140.25, "DoD Management Policy for Energy Commodities and Related Services," the Army adopted JP-8 as its primary fuel. While the Army's goal of minimizing the number and types of fuel on the battlefield provides significant operational benefits, it does constrain opportunities to improve power and energy performance. For example, some diesel engines would operate more efficiently on a different formulation. In fact, the specification allows for a wide variation in properties, especially combustion and lubricity, which can be problematic for piston engines.

Given the established liquid fuel infrastructure, we can expect to retain JP-8, or a direct replacement, as the primary fuel for the foreseeable future. The specification should be modified to include limits for cetane rating, high-temperature viscosity, and possibly lubricity. In addition, we need to reconcile the standard with fuels from alternative sources, such as synthetically manufactured liquid fuels using coal, natural gas, or bio-mass as the feedstock. The Army should continue to work with other Services and the commercial sector to identify feasible and cost-effective alternatives to JP-8.

Waste Energy Recovery (WER)

The principle of waste heat recovery is to capture some portion of the energy being rejected by other processes – for example, engine exhaust gas. This is the basic principle behind "cogeneration" plants, which recover heat from electrical generating processes. Thermodynamically, the WER process will generally be less efficient than the primary system (e.g., the engine). WER systems deserve further development - there are manifold technology possibilities - however, power density, material cost, availability, and conversion efficiency limitations will limit applicability.

Nuclear

The working group considered and rejected nuclear energy for a vehicular application in the foreseeable future. In addition to design challenges associated with control, safety and security, nuclear fission reactors require significant radiation shielding, which would result in excessive size and weight for a military ground vehicle. Radioisotope generators (thermovoltaic or betavoltaic) used in spacecraft and small electronic devices may be quite compact, but the electrical power levels are orders of magnitude too small to power a useful vehicle.

Recommendation

While we use liquid fuels to store and distribute energy, military systems increasingly utilize electrical power networks. The Army must integrate electrical power systems and grids, including component design (e.g., controls, switching and storage). The multi-energy solution will provide a significant contribution toward increased ground force flexibility and adaptability.

Ground Vehicle Solutions

	2014	2024	2030+
Alternative Power	• Fuel cell use for low demand loads utilizing an alternative fuel source (i.e. not JP-8)	• Expansion of fuel cell use to higher demand loads	• Consider trade study of fuel cells for prime power • EM gun integration challenging due to energy source size requirements
Alternative Fuels	• Dual path focus: o Narrowing of fuel property formulation o Widening of engine acceptability	• Continuation of fuel research on independent paths	• Convergence towards a compromised fuel and engine solution
Waste Energy Recovery	• Integration into a fixed installation (i.e. generators)	• Integration in ground vehicles (aligns with current commercial system timeframes)	• Increased efficiency and more wide-spread implementation in vehicles
Alternative Propulsion	• On-board, exportable vehicle power system • Investigation of binary logic transmission	• Hybrid tactical and vocational vehicles • Integration and implementation of binary logic transmission	• Hybrid combat vehicles
Grid Integration	• Integration of technology in vehicle to exchange energy with some type of small scale grid • Creation and development of a grid control system • Conventional, wired transmission	• Integration of grid control system on a larger scope • Conventional, wired transmission	• Development and integration of wireless transmission for select applications

AERIAL VEHICLE POWER

Army aviation, manned and unmanned, is an integral member of the future Modular Force which will conduct full-spectrum operations. Lessons from OEF/OIF reinforce the prediction that future operations will involve distributed operations where aircraft and aerial delivery will become even more prevalent and important for awareness, sustainment and fires. Forces such as the Adaptive Brigade would project far inland and operate in distributed formations. In concept, this force would dramatically reduce or eliminate the need for long ground convoys – largely by reducing its fuel and water consumption and/or producing its own.

Requirements

- Long-range vertical lift capable of transporting unit vehicles and equipment; landing and taking off from unimproved sites;
- Aerial delivery systems for crucial resupply;
- High speed/long loiter fire support that do not require forward refueling.
- Stronger, lighter aircraft based on advanced materials and state-of-the-art design and manufacturing processes to minimize fuel consumption without compromising performance.

Efficiency goals for upgrades to current systems include:

- A 3,000 shaft horsepower (shp) turboshaft engine for Blackhawk, Apache & Future Force rotorcraft that provides a 25 percent reduction in specific fuel consumption, 65% increase in hp/weight, and 35 percent cost reduction ($/hp) relative to the T700-701D engine.
- A 6,000-7,000 shp turboshaft engine to power a future growth version of the CH-47 Chinook that provides a 35 percent reduction in specific fuel consumption and 45 percent cost reduction relative to the T55 engine.

Army requirements for manned and unmanned aviation in support of the future Modular Force:

- Increasing power capability, reducing noise and improving fuel efficiency of platforms across the range of environmental and operational extremes, while reducing size and weight.
- Reducing the Operating and Sustainment (O&S) costs while increasing availability through onboard embedded diagnostics, prognostics and improved reliability;
- Developing capability to utilize alternative fuel sources, such as biofuels and hydrogen;
- Eliminate unmanned vehicles' (Shadow) reliance on Avgas and operate on a common fuel, specifically JP-8 (near-term);
- Increase on-board electrical power capacity and provide interoperability to support both mounted (e.g., sensors) and payload systems.

Future capabilities require extended range and endurance to cover at least a 300 X 300 kilometer division area of operations (AO) and routine operations at high / hot conditions of 6000' altitude and 95° temperature. Scout/Attack, Utility, and Cargo mission capabilities for the near (2014) and mid (2024) term will likely be addressed via upgrades to current aircraft. Unmanned Aerial Vehicles are a relatively new capability area that warrants significant endurance, payload, and reliability/availability increases in the near, mid, and far term.

Proposed Solutions

Army aerial vehicles, specifically helicopters, share many characteristics with Air Force and Navy aircraft; however, Army applications pose additional technology challenges. The turbo-shaft engine is smaller and lends itself to the low altitude and slow air speeds in dirty air environments seen by rotorcraft; quite different from requirements of high altitude and high air speed turbo-fan and turbo-jet engines used in fixed wing aircraft. These engines need centrifugal compressors, power assurance sensors, miniaturized components such as small airfoils with miniature cooling features which are difficult to manufacture; power augmentation as a safety measure during takeoff; and a wide power range with fast idle-to-full power response. All of these requirements are unique to rotorcraft, limiting synergies with fixed wing aircraft development. Given the above unique challenges, there are a number of potential solutions to achieve fuel savings in future Army aerial vehicles.

Alternative engine cycles/configurations

Developers are considering a variety of engine and component alternatives in order to improve performance and efficiency; most pose integration challenges (usually additional components, such as heat exchangers for recuperation) and add weight or complexity.

- *Turbine Engines* are the best solution for large rotorcraft *(>500 hp)* applications for the foreseeable future. Promising areas of improvement include: aerodynamics, material, and manufacturing improvements and increased use of electric accessories. Additionally, investment should continue in rotors, airframes and transmissions as key enablers to achieve the WFO.
- *Alternate Engine Cycles/Configurations (>500 hp)* should be *re-evalu*ated in light of recent advances in related manufacturing and materials technologies. These concepts should be researched in parallel with advancements in core turbine engine technologies. Implementation of some alternative engine cycles/configurations, such as the recuperated cycle, will be driven by mission-specific user requirements (recuperated engines are advantageous for ultra long range/endurance cases due to fuel efficiency attributes).
- Alternate Engine Cycles/Configurations (<500 hp) are under development, but require further investigation. Several novel concepts show promise in the near to midterm, such as the Nutating engine, Bonner engine, Advanced Rotary (Wankel) diesel engine, and the Very Small Heavy Fuel Engine (VSHFE*).*

"More Electric"

More electric technologies promise reduced engine parasitic losses including power-on-demand, increased capability for self-diagnostics/prognostics, freedom from traditional packaging constraints, and will enable new opportunities in advanced controls for manned and unmanned systems. Advances in Silicon-Carbide (SiC) power electronics promise smaller and more heat tolerant controllers with higher operating voltages. All-electrical components such as starters and generators must become lighter, smaller and more efficient in order to meet form factor, power demand and heat rejection constraints. Component, system, and vehicle qualification remains a challenge for electrical components and electric propulsion systems, especially in manned systems. As an example, the on-engine fuel pump must be 100% prime reliable. With the current state-of-the-art, this would require redundancy, posing weight and cost penalties over the mechanical pump it would replace.

Hybrid Propulsion

Integration of the engine with a powerful and efficient energy storage device is a promising far-term technology for new platforms, given future improvements in energy storage. However, hybrid electric drive technologies are currently too heavy and bulky to compete with internal combustion aircraft engines. Even with improvements in battery and/or fuel cell power and energy densities, adding components (batteries, motors and controllers) to the fueled engine would add critical weight that will be only partly offset by reduced engine size. Similarly, waste heat rejection systems would add weight and create significant integration issues with little efficiency payback. Finally, the qualification of hybrid propulsion systems would further complicate the aircraft testing and evaluation process. There is potential for earlier application of the hybrid propulsion concept to unmanned aerial vehicles.

Alternative Fuels

Current fuels offer very few constraints or challenges; however, implementation and certification of alternative fuels would require careful analysis and specification development with respect to chemical composition and physical properties, such as lubricity, to avoid damaging components such as seals and injector nozzles. Finally, aircraft emission standards become a constraint in the near to mid-term; first in Europe, then potentially within the U.S.

Recommendation

Continued investment in turbine engine technology per current demonstration plans will meet the near and mid-term needs for manned Army rotorcraft. Long-term Army needs warrant basic research and benefit studies on alternative engine cycles/configurations, leading to demonstrations of the most promising technologies. We need further research on hybrid and electric propulsion systems at the basic (6.1) and component (6.2) level.

The Tri-Services and industry are developing a number of novel engine cycles/configurations for unmanned Army aircraft, at all levels of maturity, which promise significant payoffs in terms of fuel efficiency, horsepower to weight ratio, and reliability. Unmanned systems require further analysis to down-select designs and components.

Aerial Vehicle Solutions

	2014	2024	2030+
Hybrid Propulsion Systems			• Turbine engine integrated with advanced energy storage device such as advanced battery system or fuel cell
More Electric Engine	One or two electric accessories	• A few electric accessories • Certain functions/components become "distributed". Voltages >270 V	• Majority or all accessories are electric • Majority of components become distributed. Fully integrated electric starter generator • Exhaust to produce electricity (Thermionic) • SOFC running combined cycle with gas turbine Voltages >600 V

Adv Turbine	• Small Heavy Fuel Engine (SHFE) demo provides TRL 6 technology demo for application to small manned and large unmanned Army rotorcraft o Advanced aero o Dual alloy turbine rotors o Variable cooling flow • Compact, high effectiveness combustion	• AATE and FATE demos provide TRL 6 tech demo for application to medium/large manned Army rotorcraft • Materials (more CMCs); Manufacturing; Integration; Cooling; Water injection • Two-level maintenance • System-level integration • NOX/CO_2 emission addressed in design	• Materials; Manufacturing; Integration; Cooling for small airfoils; Water injection; New seals; New bearings • Condition based diagnostics/prognostics
Alt Fuels	•	• Run on up to 50% blend (synthetic and petroleum based fuel)	• Able to run on 100% synthetic or 100% petroleum based fuel
Alt Cycle/ Alt Config (>500 hp)	Gov funded concept design studies (6.1) of advanced turbine cycles/configurations such as Recuperators; Pulse-detonation; Compound-cycle-diesel; Inter-turbine burner; and others	• Launch applied research (6.2), technology advanced development (6.3) as appropriate	• Continue applied research (6.2), technology advanced development (6.3) as appropriate
Alt Cycle/ Alt Config (<500hp)	• Expand demonstration of and leverage new cycles/ configurations such as Demo of Nutating Engine; various rotary diesel concepts; Bonner Engine; Army VSHFE (Very Small Heavy Fuel Engine)	Expand demonstrations of and leverage new cycles/configurations such as Migrating Combustion Chamber Engine	• Develop demonstration/ implementation plans as technologies/UAV systems mature

SOLDIER POWER

Soldiers are the most important component of our operational capability, and the greatest challenge to support. They patrol cities and mountains on foot; search buildings and engage locals; build bridges and base camps; operate manned and unmanned vehicles and weapons systems; and man supply points. In the expeditionary environment, the greatest Soldier energy challenge is to power a dismounted Soldier's equipment on an extended mission. US equipment is the best in the world, providing protection, lethality, sensing, situational awareness, navigation, communications, heating and cooling.

Today's Soldiers carry inordinately large numbers of batteries to power the range of individual equipment during a mission. Furthermore, there has been a proliferation of unique battery types, sizes and shapes. This is not simply a logistics problem; added weight and volume diminish Soldier performance. The Soldier power challenge has become so keen that the Army has identified it as a "grand challenge", and has instituted a number of technology competition events to encourage and evaluate innovative solutions.

Although the energy supply burden is receiving significant attention, Soldiers and their leaders still lack the capability to effectively monitor and manage their energy use. At best, individual devices may have fuel level gauges or battery charge indicators, but this information is not aggregated, trended or projected, nor do operational procedures or training take energy management into account.

Requirements

- Increase specific power and energy for Soldier-carried storage devices (Warfighter Outcome: 2 x power at ½ the weight);
- Reduce energy consumption by 50% by making end items more efficient and introducing power management algorithms;
- Reduce the quantity and variety of batteries (from typical 7-8) carried by the Soldier ;
- Identify locally available energy sources and Soldier power technologies;
- Provide interoperable interfaces between Soldier systems and infrastructure and vehicle-mounted energy systems.

Assessment

Dismounted Soldiers represent only a part of the challenge. When they are not walking, Soldiers ride in ground and air vehicles, share information and operate weapons systems or other equipment. Many Soldiers perform their operational mission on an enduring installation or an expeditionary base; especially those performing functions such as command and control or force protection. These Soldier-system system interfaces offer opportunities for combined functionality, such as ad-hoc networking of Soldier communications, using a vehicle or ground-based “hotspot” as a node; or, recharging Soldier batteries wirelessly and without intervention, from a similar energy “hotspot”.

Proposed Solutions

There are a variety of technology opportunities to address Soldier power and energy needs. Power and Energy Innovation Workshop participants evaluated the following key opportunities:

Energy Storage

Battery energy densities and service life are continuously improving, although many Soldiers are still ordering older battery chemistries. We can expect continued improvement, not only in specific power and energy and service life, but also in terms of safety. For example, Li-ion batteries provide outstanding performance for systems ranging from laptop computers to hybrid vehicles; however, they may burn violently when damaged. Advancements in Lithium polymer and other chemistries may provide safer alternatives with comparable performance.

Rechargeable batteries would mitigate a significant logistics issue, addressing both the proliferation of battery sizes and the volume of material currently in the supply chain. Unfortunately, rechargeable batteries are not popular in the field, largely due to convenience, time constraints and durability issues. We need high power, long-life rechargeable batteries and reliable compact, universal charging stations that are inherently safe and which produce little electro-magnetic interference (EMI). A wireless recharging “hotspot” capability would dramatically boost the convenience of rechargeables.

“Nuclear batteries” or power supplies driven by radioactive decay are available and being improved for high endurance, low power operations, but they would be too heavy and bulky in sufficient quantities to provide useful energy for most Soldier applications.

Energy Harvesting

Energy harvesting technologies such as photovoltaic (solar), thermoelectric (body heat or other temperature differential), piezoelectric or induction (motion and vibration) could provide energy to support extended missions and reduce the logistics tail. Current state of the art for these technologies generally offer low electrical conversion efficiencies; incur an inordinate weight penalty; require excessive space or are otherwise inconvenient for Soldiers in the field. To date, these technologies have only been suited for low power applications. Most are relatively expensive on a *per watt* basis, if electrical power or fueled sources are available.

Advances are being made in materials to make the technologies smaller, lighter, and more flexible, but most of these technologies require significant technology improvements and manufacturing cost reductions in order to become feasible for widespread use. These technologies would be most useful in conjunction with rechargeable batteries or other efficient means to store energy for later use.

Fueled Systems

Fuel cells are the leading candidate technology to reduce the Soldier battery load, particularly for extended duration missions (72 hours or more). Liquid fuels generally offer an order of magnitude or greater advantage in specific energy compared to battery electrolyte. In addition to safety issues and operating constraints (e.g., operating temperature and fuel requirements) addressed under “Ground Platforms”, above, small fuel cells tend to be less efficient than larger systems. Where these constraints are manageable, methanol and solid oxide fuel cell technologies could be useful as an efficient power source to recharge batteries, at the cost of proliferating liquid fuels in theaters of operation. Given material advances to reduce the size and weight, and availability of suitable fuels, fuel cells eventually could be integrated directly onto the load bearing vest; refueling would be simple and quick. Compared to battery technology, there is significantly less incentive among the commercial market to invest in development; therefore, continued military investment is critical to achieve significant progress.

Hybrid systems

Hybrid systems integrate multiple power and energy technologies to optimize their performance. A simple example would match an energy storage device (battery) to a power source (e.g., solar cell) to accommodate the application. Power and energy technologies should incorporate a modular approach to facilitate “mix and match” of applicable technologies.

Power Integration

Every new electrical or electronic soldier device increases their battery load. This trend in capability growth, and consequent battery demand growth, is likely to continue into the future. When viewed as a system, it may be possible to aggregate various individual batteries into larger ones, reducing complexity, logistics, and cost. However, the resulting large format batteries must ultimately be fightable, driving designs toward non-standard, conformal shapes.

Considering the need to simplify Soldier support and to provide system interoperability, we need a “system of systems” design approach to integrate Soldier equipment with platforms and other systems. Energy status and power monitors would enable Soldiers and their leaders to manage this critical resource. Interface standards could enable a “plug and play” capability to reconfigure systems for specific missions. An integrated power and energy architecture would enable significantly greater availability and reliability by enabling mobile, scalable, modular, and mission tailor-able distributed power generation to support the entire system.

Recommendation

The first and most important step is to educate and train the Soldiers and leaders about power and energy technologies, operational implications and ways to select and adapt technologies for different situations. As a supporting activity, the Army should continue to invest in technology advancement related to power and energy monitoring and management.

In the near and mid-term, Soldiers will continue to rely upon batteries for most electrical applications. Priorities should include:

- Integrating power management technologies into electronic devices to minimize drain (similar to cell phone and laptop computer approaches);
- Continuing to develop lighter, safer batteries with higher specific energy and power;
- Continuing to develop small efficient high power density fuel cells;
- Continuing the application of systems engineering to the Soldier;
- Standardizing battery selection in system designs;
- Providing for convenient recharging capability.

Continue to integrate Soldier equipment with other military systems, and combine technologies - not only to optimize functionality, but also to sustain power and energy requirements.

Soldier Power Solutions

	2014	2024	2030+
Energy Storage (Disposable)	• Replace Li/SO2 (1X) with Li/MnO2 (1.5X) • Introduce Li/CFx (2X) • Charge indicators – "fuel gauge on each battery"	• Replace Li/MnO2 (1.5X) with Li/CFx (2X) • Introduce Li/Air (4X) • Improved battery chemistries: Li/CFx, Li/MnO2, Zn/Air, Li/FeS2 and Li/Air • Integrated Hybrid battery/ultra-capacitors	• Replace Li/CFx with high performance Li/fluorocarbon • Replace Zn/Air with Li/Air • Bio-inspired materials • Carbon nanotubes • Mini and micro batteries
Energy Storage (Rechargeable)	• Nano-Li-Ion • Li-Ion Polymers • Vehicle based large scale recharging stations • Smart batteries • Battery health and energy management displays • Conformal shaped batteries (140wh/kg)	• Improvements in nano-technologies (e.g. Nano-Li-Ion and LiTitanate) • High voltage cathode materials • Wide window electrolytes • Integrated Hybrid battery / ultra-caps • Wireless recharging • LiMetalF chemistries	• "True" Li-Polymers (flexible, conformal solids) • Bio-inspired materials • High temperature electrodes • Integration into body armor • Molten salt electrolytes
Energy Harvesting	• Thin film photovoltaics (backpacks, foldable tail/wing) • Motion capture, e.g. hand cranks, knee braces, backpacks, Micro-inverters	• Photovoltaic textiles • Motion and vibration devices • Thermoelectrics from body heat • Inductive charging	• Thermoelectrics, combining heating and cooling • Backpack swing generators
Fueled Systems	• Fuel cells (25-75 watts in rucksacks, 150-300 watt and 25-35 lbs man-transportable); packaged fuels (1300 wh/kg) • Engines (portable, multi-	• Fuel cells (25 watts on Soldier, 500 watt 20 lbs man-portable); desulfurized JP8 • Thermoelectric/thermo-photovoltaics (50-150 watts, 25 lbs, 15% conversion efficiency,	• Fuel cells (standard JP8) • Carbon nanotubes • Thermoelectric and heat scavenging • Thermophotovoltaics • Multifuel, cheap, reliable

	fuel burning Stirling 45 lbs) • Small diesel engine 35 lbs	<70dba)	engines
Nuclear		• Beta-decay for low wattage applications	• Isomers • Tritium illumination

V. CONCLUSIONS

Power and energy enable decisive Army capabilities; they also represent an exploitable vulnerability. We must build operational concepts with full consideration of energy and power, tipping the balance in our favor and maintaining energy as an operational advantage.

The most significant, crosscutting challenge is to build capabilities and processes to monitor and manage power and energy. This comprehensive challenge requires analysis, planning and well-placed sensors and controllers – not only to promote awareness, but to actually influence behaviors in concert with our everyday mission. This also requires operational analysis in much greater detail than presented here, to define energy-related performance requirements and measures. Awareness and control are fundamental enablers for performance improvement, regardless of the DOTMLPF solutions we choose to apply.

Second, we must integrate power and energy solutions, in order to achieve efficiency, availability, reliability and other important parameters, consistent with the mission. We need to experiment, develop and deploy combinations of technologies to foster innovation and learning. This imperative is not only important to validate durability of off-the-shelf systems, but to help develop the best integrated DOTMLPF approaches to support required operational capabilities.

Finally, a comprehensive systems engineering approach would provide the structure to link these crosscutting goals with the respective requirements and technologies for both enduring activities and expeditionary operations. The Army should implement a flexible approach that accommodates the dynamic nature of operational requirements and technologies, but provides for systematic analyses and logic-based tools to support design, selection, prioritization and sequencing and integration of important technologies within the overall DOTMLPF model.

Figure 2 illustrates a “layered” architecture to facilitate the analysis process. The bottom layer addresses the most fundamental element, the energy source. Progressing up the hierarchy, each layer represents a component requiring greater insight, but which can impact system performance to a respectively greater degree. Ultimately, the concept of energy-informed operations suggests that operational decisions fully integrate energy and power implications - analogous to a NASCAR crew choosing to slow their driver to avoid needing to refuel.

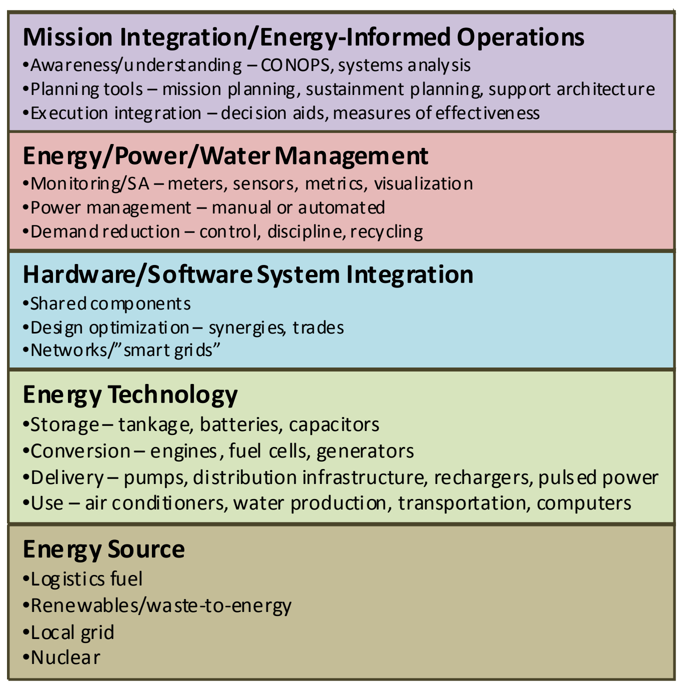

Figure 2- Energy Systems Architecture

VI. PATH FORWARD

Several Army organizations have already undertaken proactive initiatives, such as initial enterprise metrics being established by the SEC; the Tactical Fuel and Energy Implementation Plan (TFEIP) sponsored by Army G-4; and TARDEC's new Ground Systems Power and Energy Laboratory. ARCIC will proceed to establish an Integrated Capabilities Development Team, with its initial assignment to document operational energy and power requirements, gaps and DOTMLPF recommendations in an Initial Capabilities Document (target: summer 2010).

Meanwhile, DoD is negotiating a Memorandum of Understanding (MOU) with the Department of Energy (DOE) to address military energy challenges. This document will provide the basis for a governance structure to organize and manage joint efforts, such as renewable energy projects, which have been conducted for many years on an ad hoc basis.

This strategy sets the stage for an aggressive Operational Energy Campaign, informed by Warfighter Outcomes, Operational Needs Statements and other known gaps, as well as emergent operational analysis and learning. The campaign would coordinate concepts, requirements, capabilities, procurement, performance and sustainment in a comprehensive, Army effort, reduce vulnerabilities and cost in today's fight, and transition the requisite capabilities to prevail in future operations. ARCIC, G-4 and RDECOM will coordinate with the Army Energy Executive (DASA (E&P)) and others to develop the campaign plan; the figure below depicts a notional overall structure.

Early campaign tasks would include a comprehensive baseline assessment, establishment of a system of systems architecture, and development of information tools, training and a cross-functional operational energy community of practice. Over time, the effort would mature as performance measures and processes are institutionalized.

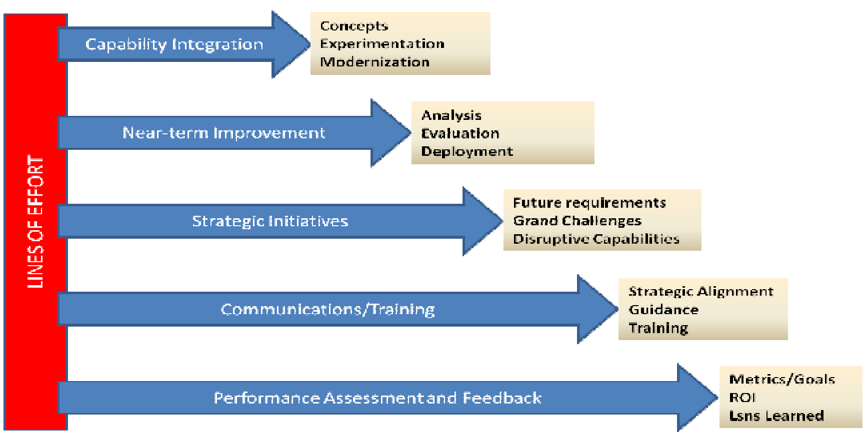

Figure 3- Operational Energy Campaign Lines of Effort (notional)

Appendix A – Acronyms and Terms

AATE	Advanced Affordable Turbine Engine
AC	Alternating Current
AF	Air Force
AH 64D	A four-blade, twin-engine attack helicopter with reverse-tricycle landing gear, and tandem cockpit for a crew of two
AKO	Army Knowledge Online
APU	Auxiliary Power Unit
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
AVGAS	High Octane Aviation Fuel
Bonner Engine	Ultra-efficient, two-stroke heavy fuel engine
CAFE	Corporate Average Fuel Economy
CFx	Carbon Monofluoride
CH 47	A versatile, twin-engine, tandem rotor heavy-lift helicopter
CMC	Ceramic Matrix Composite
CO2	Carbon Dioxide
Corona Effect	When voltage is high enough, electrons are attracted to ground (at lower potential) with sufficient energy to ionize air. It is the breakdown that produces the corona (plasma field).
dBA	Decibels in acoustics
DC	Direct Current
DOE	Department of Energy
DoD	Department of Defense
ECU	Environmental Control Unit
EISA	Energy Independence Security Act

EM	Electromagnetic
EMI	Electromagnetic interference
EO	Executive Order
EPA	Environmental Protection Agency
EPAct	Energy Policy Act
FATE	Future Affordable Turbine Engine Program
FOB	Forward Operating Base
FY	Fiscal year
G-3	Operations, including staff duties, exercise planning, training, operational requirements, combat development & tactical doctrine.
G-4	Logistics and Quartering
GV	Ground vehicle
hp	Horsepower
HVAC	Heating, ventilation and air conditioning
Hybrid	Dual power source energy resource
Jet A-1	A kerosene based fuel suitable for most turbine engine aircraft
JP5	A jet fuel in use by the U.S. Navy
JP-8	A kerosene based jet fuel
KPP	Key performance parameter
kW	Kilowatt
lbs	Pounds, as a unit of weight
LEED	Leadership in Energy and Environmental Design
LiFeS2	Lithium Iron Disulfide
LiMetalF	Lithium Metal Fluoride
LiMnO2	Lithium Manganese Dioxide

LiIon	Lithium Ion
LiSO2	Lithium Sulfur Dioxide
LiTitanate	Lithium Titanate
LPC	Low Pressure Compressor
MEMS	Micro-electromechanical Systems
MIL	Military Standard
MILCON	Marine Corps Military Construction
More Electric	Aviation industry term for the increased electrification of both airframe and engine accessories (i.e. fuel pumps), actuators (i.e. flight controls). Does not include electric propulsion
MOU	Memorandum of Understanding
NIST	National Institute of Technology and Standards
NOx	Nitrous Oxide
Nutating Engine	Highly efficient heavy fuel engine with a disc on an eccentric shaft
O & S	Operating and Sustainment
P & E	Power and Energy
PAIV	Power as an Independent Variable
PMs	Program Managers
PV	Photovoltaic
R & D	Research and Development
RDECOM	Research Development Engineering Command
Recuperator	A heat transfer device that uses exhaust gas heat to increase the heat of incoming air
Rotary Engine	Also known as a Wankel engine
S & T	Science and Technology
SBIR	Small Business Innovation Research

SFC	Specific Fuel Consumption
Shadow	A rail-launch UAV with a 14ft wingspan.
SiC	Silicon Carbide
SOFC	Solid Oxide Fuel Cell
STTR	Small Business Technology Transfer Program
TARDEC	Tank Automotive Research, Development and Engineering Center
TRADOC	Training and Doctrine Command
UAV	Unmanned Aerial Vehicle
UGS	Underground Gas Storage
UGV	Unmanned Ground Vehicle
UH 60	A four-bladed, twin-engine, medium-lift utility helicopters manufactured by Sikorsky Aircraft
U.S.	United States
VSHFE	Very Small Heavy Fuel Engine
WER	Waste Energy Recovery
WFO	Warfighter Outcomes
WTE	Waste to Energy
Zn/Air	Zinc Air

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