AMMTIAC
Advanced Materials and Manufacturing
Technology Information Analysis Center

WSTIAC
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Information Analysis Center

The "Energy-Smart" Future Force

Raising the Roof

Taking Alternative Energy "to the Edge"

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From the Editor's Desk

POWERING TOMORROW'S ARMY

"...an army without its baggage train is lost; without provisions it is lost; without bases of supply it is lost."

- Sun Tzu, *The Art of War*, ca. 5th Century, B.C.E.

It has been a maxim of every standing Army that its ability to wage war in the field is only as certain as its supply train's ability to keep pace with the Army when it is on the move, ferrying sufficient personnel and materiel to forward positions to sustain combat operations; or behind the lines to maintain the facilities that serve as the launch points for deployments, or equally important, as home for our warfighters. This is as fundamentally true today as it was when Sun Tzu wrote his famous handbook of military strategy, the earliest known, nearly 2,500 years ago. But while the criticality of logistics to combat operations may be as primary as it was in ancient times, the nature of war materiel has changed greatly. The lifeblood of a modern, mechanized, technology-based fighting force is energy, in whatever form is required to sustain the weapons, equipment, and installations of the warfighter.

The U.S. Army is in the midst of both an energy *revolution* and *evolution*. It is 'revolutionary' in the sense that in ten years' time, the Army of 2023 will look completely different in terms of how it views and utilizes energy to perform its missions. However, it is also 'evolutionary', as the path to Army future is made of many small steps; each leveraging existing technologies and practices, drawing lessons from the previous steps, and then advancing incrementally both the Army's technologies and its operating culture to thrive in the evolving military power paradigm. The President, the Secretary of Defense, and the Secretary of the Army have directed, respectively, the Nation, the DoD, and the Army to use less energy and to use it smarter. For the Armed Services, this is for reasons of economy, energy security, operational autonomy, and to meet the military's growing responsibilities in environmental stewardship. The DoD's Operational Energy Security (OES) Implementation Plan and the Army Energy Security Implementation Strategy (AESIS) have set ambitious energy goals for the short-, mid-, and long-term: Less dependence on fossil fuels, more use of alternative and renewable energy sources, partial independence from conventional power grids, reduced environmental footprint, and several other goals.

Energy security for the Army is based on five principles: a) assuring uninterrupted access to power and fuel sources; b) developing and deploying resilient power systems; c) greater use of alternative/renewable energy sources at installations CONUS and OCONUS; d) providing adequate power for critical missions; and e) promoting support for the Army's mission, its community, and the environment. Succinctly stated, these "five pillars" of Army Energy Security are Surety, Survivability, Supply, Sufficiency, and Sustainability – "The Five S's", if you will.

Thus, it was only logical that as part of developing their implementation plan, Army leaders devised five goals which not only addressed these five energy security principles, but also defined what qualities would be embodied in an energy-conscious Army of the future. These Energy Security Goals, as they have been defined in the AESIS, are:

1. Reduced Energy Consumption
2. Increased Energy Efficiency Across Platforms and Facilities
3. Increased Use of Renewable/Alternative Energy
4. Assured Access to Sufficient Energy Supply
5. Reduced Adverse Impacts on the Environment

It is absolutely critical to reduce the amount of fossil fuels consumed by the Army – both at home and in theater – to save resources, money, and lives. Power generation, distribution, and storage systems must all become more efficient. Using more renewable/alternative power sources would save fuel, provide cheap power; reduce units' logistics footprint, and facilities' dependence on civilian power grids. Army planners must make strategic energy procurement decisions to ensure continued, uninterrupted access to sufficient power and fuel supplies for future missions. Lastly, consuming less fossil fuel would be consistent with meeting the warfighters' new commitment to environmental stewardship. So, through a steady series of evolutionary steps, the Army will, in a few short years, realize revolutionary results. Meeting the challenges won't be easy, but that is usually when the Army is at its best.

Christian E. Grethlein
Editor

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The "Energy-Smart" Future Force

The Army is evolving itself into a culture of energy-conscious warfighters.

Chris Grethlein
AMMTIAC/WSTIAC

Historically, the Army and the other Services have operated on the assumption that low cost energy would always be readily available to support the mission, whatever that mission might be. In reality, reliable access to affordable, stable energy supplies is a growing challenge for the Army. Any significant disruptions of critical power and fuel supplies could harm warfighters' ability to accomplish missions.

The military has assumed, historically, that the energy they would need to perform missions would always be inexpensive and readily available. That is no longer the case.

Surety, Survivability, Supply, Sufficiency, and Sustainability: these are the core characteristics defining the energy security necessary for the full range of Army missions. Energy security for the Army means preventing loss of access to power and fuel sources (surety); ensuring resilience in energy systems (survivability); accessing alternative and renewable energy sources available on installations (supply); providing adequate power for critical missions (sufficiency); and promoting support for the Army's mission, its community, and the environment (sustainability).

In 2008, an Army Energy Security Task Force (AESTF) recommended to Army leaders that the Department's disparate energy programs be consolidated under one office to coordinate all efforts, and thus maximize efficacy. As a direct result, the Office of the Deputy Assistant Secretary of the Army for Energy & Partnerships [ODASA(E&P)] and the Army Senior Energy Council (SEC) were established. The SEC is comprised of senior leaders from the Army's key energy stakeholder organizations who oversee the Army's Energy Enterprise. The DASA(E&P) serves as the Army's Senior Energy Executive (SEE) and monitors and reports the Army's progress toward meeting its energy goals.

The "Five S's" of Energy Security: Surety, Survivability, Supply, Sufficiency, and Sustainability

AN OVERVIEW FROM THE PENTAGON

The Army's efforts to enhance energy security and foster energy independence are parts of a greater energy effort within the Department of the Defense.

In 2010, U.S. Armed Forces consumed more than five billion gallons of fuel in military operations. Twenty-first century challenges to U.S. national security are increasingly global and complex, requiring a broad range of military operations and capabilities and consequently, a large and steady supply of energy.

Military demand for energy is growing, but ready access to those supplies is coming under considerable pressure. An unstable global petroleum market causes severe price fluctuations, making long-term economic planning difficult. Moreover, emerging nations with rapidly growing economies are raising the demand for the same energy resources, further driving up prices. At the operational and tactical level, fuel logistics have proven vulnerable to attack in the recent conflicts in Iraq, Afghanistan, and potentially other locations in the Global War on Terror. In 2011, the DoD developed its new "Operational Energy Strategy" as a means to ensure that the Armed Forces will have the energy resources they need to meet Twenty-first century challenges. The strategy outlines three principal ways to a stronger force:

In 2010, the U.S. Armed Forces consumed more than *five billion gallons of fuel*

1. ***More Fight, Less Fuel:*** Reduce the demand for energy in military operations. The Department needs to reduce its overall demand for operational energy; improve the efficiency of military energy use to enhance combat effectiveness; and reduce military mission risks and costs.

2. ***More Options, Less Risk:*** Expand and secure the supply of energy to military operations. The security of the energy supply is not sufficiently robust for either infrastructure or weapons/mobility systems. This includes fuel convoys in combat zones that are subject to attack; as well as the civilian electrical grid in the United States, which powers some fixed installations that directly support military operations. The Department needs to diversify its energy sources and protect access to energy supplies to more reliably supply energy for military missions.

3. ***More Capability, Less Cost:*** Build energy security into the future force. The Department needs to integrate operational energy considerations into the full range of planning and force development activities; as energy has become a mission-critical capability, as defined in the Quadrennial Defense Review (QDR) and the National Military Strategy.

As always, the Department's top priority today is to support current operations. Becoming a more energy-smart enterprise will yield a number of benefits for the DoD, both presently and in the future. Some examples include:

- Saving lives that would be lost moving and protecting fuel on the battlefield
- Lightening the logistics load and reducing the vulnerability of fuel supply lines
- Refocusing some combat forces and capabilities from supply lines and fuel logistics to operational missions
- Strengthening the Department's resilience to energy price and supply volatility and disruption
- Posturing the future force for success in meeting Twenty-first century challenges by better aligning resources to tactical, operational, and strategic goals

THE ARMY'S ENERGY SECURITY VISION

An effective and innovative Army energy posture, which enhances and ensures mission success and quality of life for our Soldiers, their Families, and Civilians through Leadership, Partnership, and Ownership, and also serves as a model for the nation.

Figure 1 illustrates the core concepts of the vision: Leadership, Partnership, and Ownership. As main components of the Army Energy Security Vision, these elements support the logistics of expeditionary force troop mobility; the research, development, testing, and acquisition of new alternative energy sources and technologies; the training of Soldiers and Civilians; and the improvement of installation and facility infrastructure for an energy secure future.

Leadership – Changing the Army's culture to one where efficient energy utilization is automatically a part of any strategic calculus from all levels within the Army.

Partnership – The Army's energy initiative is an enterprise-wide partnership that leverages internal Army organizations, other Services, the Department of Defense (DoD), federal agencies, and the private sector to benefit Army mission accomplishment. Great advances can be made with industry to enhance energy efficiency as well as build alternative and renewable energy facilities on installations. A number of Army installations have significant potential for instituting alternative and renewable energy programs.

Ownership – The foundation of the Army Energy Vision is Ownership. This may come in part from knowledge, training, and operational awareness regarding energy in all aspects of the Army mission; but ultimately, total transformation to an energy-conscious force requires a culture change within the Army, where all personnel accept some level of accountability for sensible energy practices.

THE ARMY'S ENERGY SECURITY MISSION

Make energy a consideration in all Army activities in an effort to reduce demand, increase efficiency, seek alternative sources, and create a culture of energy accountability, while sustaining or enhancing operational capabilities.

A fundamental Army responsibility is to provide the Soldier with superior capabilities, weapons, and facilities to live, work, and fight. The energy required to power these assets is integral to the success of the mission and the quality of life for warfighters and their Families. Army Leadership has established specifically five enterprise-wide goals to fulfill this charge.

Figure 1. **The Army Energy Vision**

STRATEGIC ENERGY SECURITY GOALS

The Army's five Strategic Energy Security Goals (ESGs) are designed to be achieved over the long term through steady annual progress monitored through review of appropriate metrics. Success will represent a significant improvement of the Army's energy security enterprise and will place Army assets in a strong position for future energy-effective operations. Implicit within these goals is that any improvements realized shall not reduce operational capability or compromise the Army's ability to carry out missions. All prospective solutions considered must demonstrate potential towards achieving these energy goals, while effectively maintaining and improving operational capabilities, realizing long term cost savings, and enhancing mission success.

> The ultimate key to energy success in the Army is by instilling a culture of Ownership; where all soldiers and civilians consider themselves accountable in helping the Army realize its energy goals.

ESG 1. Reduced Energy Consumption

Reduce the amounts of power and fuel consumed by the Army at home and in theatre. Minimize the logistical fuel tail in tactical situations by improving fuel inventory management and focusing installation consumption on critical functions.

ESG 2. Increased Energy Efficiency Across Platforms and Facilities

Raise the energy efficiency for generation, distribution, storage, and end-use of electricity and fuel for system platforms, facilities, units and individual Soldiers and Civilians. This relates to system productivity based on energy requirements; allowing key personnel to make informed trade-offs in development, engineering, and deployment of weapon systems.

> The Army's overall Energy Strategy is embodied in five Energy Security Goals.

ESG 3. Increased Use of Renewable/Alternative Energy

Raise the share of renewable/alternative resources for power and fuel use, which can decrease dependence on conventional fuel sources while realizing significant savings in fuel expenditures. furthermore, forward units would be more independent of the supply chain, improving their mission capabilities, and would put fewer fuel convoy crews in harm's way. Army facilities would become more independent of civilian power grids, saving money, reducing their environmental footprint, and increasing their emergency power supply during times of grid failure.

ESG 4. Assured Access to Sufficient Energy Supply

Improve and maintain the Army's access to sufficient power and fuel supplies when and where needed. Energy is a critical resource in conducting Army missions. Vulnerabilities to external disruption of power and fuel sources should be minimized and the potential for industry partnerships to enhance energy security and generate net revenues for the Army should be considered.

ESG 5. Reduced Adverse Impacts on the Environment

Reduce harmful emissions and discharges from energy and fuel use. Conduct energy security activities in a manner consistent with Army environmental and sustainability policies.

Figure 2. **Strategic Implementation Overview**

STRATEGIC IMPLEMENTATION GUIDANCE

Implementing the Army's energy strategy consists of identifying, integrating, and executing specific actions to achieve the Energy Security Objectives (ESOs). Thus, it supports integrating current and future power and energy plans, programs and activities from the offices of primary responsibility to strengthen the Army's enterprise-wide energy posture and operations while facilitating management of energy costs.

> To fulfill each Energy Security Goal, the Army has defined a series of action-oriented Energy Security Objectives that must be met to satisfy goal requirements

The ESGs represent the Army's desired future energy security posture. Figure 2 illustrates the strategic approach required to achieve them. On the left side of the figure, the approach is grounded on a set of Enabling Factors that support the Implementation Activities and promote their success across the evolving Army enterprise. The activities are conducted by the OPRs throughout the Army as part of efforts to accomplish their respective missions. Execution of these activities impact the Systems and Components that produce, transmit, store or use various types and amounts of energy.

> Army organizations conduct various implementation activities, projects and initiatives, in support of individual Energy Security Objectives

ENERGY SECURITY OBJECTIVES

To achieve the ESGs, action-oriented Energy Security Objectives (ESOs) have been established to guide development and coordination of implementation activities, programs, and investments by the Army. ESOs are being developed to provide the strategic focus necessary for the Army to comply with key energy directives (laws, regulations, instructions, and policies) and to achieve the ESGs. Two examples follow:

Tactical Mobility Example	
Objective	Improve tactical fuel inventory management (This includes developing technologies, policies, and procedures that leverage automation to provide enterprise level fuel asset visibility.)
Potential Performance Target:	90% Reduction of out-of-tolerance tactical accounts
Potential Performance Metric:	Annual percent reduction of out-of-tolerance tactical fuel accounts
Energy Security Goals Addressed:	ESG 1 and ESG 4
Installation Example	
Objective	Improve the energy performance of current infrastructure (This includes facilities, equipment and energy use practices at the Army's installations.)
Potential Performance Target:	Completed electricity metering program
Potential Performance Metric:	Percent completion of electricity metering program
Energy Security Goals Addressed:	ESG 1 and ESG 2

SYSTEMS AND COMPONENTS

In general, improvements in energy security are accomplished through changing three factors: institutional actions, human behavior, and capital stock (upgrading equipment, components facilities, and technology). For the Army, institutional actions are represented by Federal laws, executive orders, DoD directives, and Army mandates regarding energy. Human behavior covers Army Soldiers, their Families, the Civilian work force, contractor support, and suppliers and includes efforts for human systems integration. *Capital stock* encompasses infrastructure, weapon systems & mobility and individual Soldier power technology; and is further described below:

- **Infrastructure** refers to permanent installations and facilities (CONUS and OCONUS) and the energy equipment to operate them, including non-tactical vehicles (NTVs). One avenue to impact installations and facilities is through military construction (MILCON).
- **Weapon systems & mobility** include the Army inventory of tactical and combat manned and unmanned ground and air platforms, weapons/logistics/C4ISR systems, and forward operating bases (FOBs) and other contingency operations base camps as well as other components and related devices that consume power or fuel.
- **Soldier power** includes the electricity or other power sources required to operate personal equipment such as weapons, communications and life support, as well as the individual Soldier know-how and commitment to use energy wisely.

PERFORMANCE TARGETS AND METRICS

The Army is measuring the progress of the many individual energy security implementation activities that are ongoing in support of the ESGs. Measuring and tracking progress will occur systematically across all major energy activities to ensure that the ESGs are being addressed and that compliance with energy directives (i.e., laws, statutes, Executive Orders and DoD and Army policies) is occurring. Progress toward directive targets and ESGs will be gauged using quantitative and qualitative metrics to permit periodic data collection, analysis, and reporting and to build an historical record of performance. Specific metrics will be derived from current mandated targets as well as for the ESGs (e.g., related to surety of energy supplies, improved asset visibility for tactical fuel use) from coordination within the SEC WGs.

> Energy Security improvements are accomplished by changing institutional actions and human behavior; or by upgrades in equipment, facilities, and technology

This analysis will include consideration of an "energy security premium", which reflects an incremental cost over and above the commodity consumption cost to provide assurance that critical activities and functions will continue to have access to the energy they need for operations.

The mandated target and metric examples in Table 1 represent only a portion of the directives for installations and operational systems to be addressed.

MEETING THE ARMY'S EVOLVING ENERGY NEEDS

Empowered with the knowledge of how critical energy is to ensuring mission success, Army energy planners must not only address the current operational paradigm, but must also take into account other evolving aspects of Army operations that could significantly affect future energy and fuel use. These developments must be considered to ensure energy supplies continue to be readily available; and are described in more detail below:

- **Future Combat Systems (FCS)** – FCS will provide superior mobility, decision making and lethality on the battlefield; requiring new technologies and an integrated energy approach to support an array of electric/hybrid manned and unmanned vehicles; deployed sensors; electric weapons and active protection systems.
- **Army Base Realignment and Closure (BRAC)** – The Army's implementation of any future BRAC actions will impact many Army installations, closing some and increasing the presence of Army staff and equipment on others. These changes would impact not only these facilities and personnel, but also influence the Army's energy use patterns and requirements.
- **Grow the Army** – In 2007, Congress authorized a 74,200 Soldier increase in end strength for the Regular Army by the end of 2012 and by 2013 for the Army National Guard (ARNG) and United States Army Reserve (USAR). The end dates for achieving the growth were later accelerated to the end of 2010 for the Regular Army and ARNG. Housing these forces and providing for their readiness, the Army is building additional infrastructure such as homes, barracks, and training ranges.
- **Redeployment and Rebasing** – About 380,000 Soldiers, Families, and Civilians are in the process of being moved in what will likely be the largest Army re-basing since World War II. This is in concert with the Army's detailed planning for significant redeployment of its overseas forces in Kuwait, Iraq, Afghanistan, and elsewhere.
- **Expeditionary Force** – The Army force structure is transforming from a forward-deployed model with units permanently stationed overseas to an expeditionary model with units stationed within the United States and deployed overseas on a rotational basis. Significant shifts in energy supply and use are only one of the consequences of this transformation. More agile energy operations will be necessary.

RECENT ARMY ENERGY ACTIVITIES

The Army already has initiated a number of plans and activities that exemplify the types of implementation actions intended to help their energy strategy succeed. Their implementation does not represent the beginning of the Army's interest in energy programs, but more formally establishes energy security as an enterprise priority within the Department of the Army. The initiatives started to date were all designed to minimize the impact of possible grid failure; strengthen Expeditionary Force energy resources; and develop better fuel management systems for greater accountability of future fuel purchases and distribution. They also demonstrate the Army's new level of commitment to environmental stewardship

Army energy planners must also address trends in Army operations that could significantly affect future energy use

Table 1. Example Energy Directives and Metrics

Directive Topic	Energy Performance Target [Source]	Potential AESIS Metric	AESIS Goals
Directives and Metrics for Fixed Installations			
Installations energy use	Reduce by 30% by 2015 from 2003 [EO 13423 / EISA 2007]	% Installation energy savings relative baseline to 2003 baseline	ESG 1, ESG 2
Non-tactical vehicle (NTV) fuel consumption	Reduce 2% annually through 2015, 20% total by 2015 -2005 baseline [EO 13423]	% NTV fuel savings relative to 2005 baseline	ESG 1, ESG 2
Electricity from renewable sources	A voluntary "sense of Congress" goal – 25% by 2025 [EISA 2007 / NDAA 2007]	% of Army energy use provided by renewable/ alternative sources	ESG 3, ESG 4, ESG 5
Fossil fuel use in new/ renovated buildings	Reduce 55% by 2010; 100% by 2030 relative to 2003 level [EISA 2007]	% Fossil fuel use reduction in new/ renovated buildings relative to 2003 level	ESG 1, ESG 2, ESG 5
Hot water in new/ renovated buildings from solar power	30% by 2015 if life cycle cost-effective [EISA 2007]	% of new/renovated buildings with hot water from solar	ESG 3, ESG 4, ESG 5
Non-petroleum fueled vehicles use (ethanol, natural gas)	Increase by 10% annually [EO 13423]	% annual increase in nonpetroleum fueled vehicle use	ESG 3, ESG 4, ESG 5
Energy metering for improved energy management	Meter electricity by Oct 2012 [EPAct 2005]. Meter natural gas and steam by Oct 2016 [EISA 2007]	% completion of metering planned for electricity, natural gas and steam	ESG 1, ESG 2
Directives and Metrics for Operational Systems			
Implementation of fully burdened cost of energy (FBCE)	Use FBCE in life-cycle cost analysis for new military capabilities during analysis of alternatives and evaluation of alternatives [NDAA 2009]	Number or % of life cycle cost analyses for new systems using FBCE	ESGs 1 through 5
Implementation of energy efficiency as a key performance parameter (KPP)	Include fuel efficiency as a KPP for modifying or developing new machinery that consumes fuel, such as tanks or jets [NDAA 2009]	Number or % of equipment modifications or developments for new systems including energy efficiency as a KPP	ESG 1, ESG 2

through expanded use of renewable and alternative energy sources that minimize the warfighter's environmental footprint. What follows are a few of the many new or ongoing energy activities the implementation strategy is integrating to bolster energy security throughout the Army:

Table 2. **Selected Army Energy Projects**

Army Energy Initiative Projects
• Solar energy generation at Ft. Irwin, CA
• Private industry installation energy management, Ft. Leavenworth, KS
• Neighborhood electric vehicles (NEVs) at multiple Army installations
• Geothermal power, Hawthorne Army Depot, NV
• Biomass-to-liquid fuel technology demonstration at six Army installations
Ongoing Technology Development
• AMC-led Fuels Management Defense (FMD) Initiative
• Electric/hybrid vehicles
• Smart power grids; micro-grids
• Industrial energy optimization at Rock Island Arsenal, IL
• High efficiency lighting project at Fort Lee, VA
• Phase two barracks geothermal conversion at Fort Knox, KY Army Energy Strategy for Installations
• Energy Conservation Investment Program (ECIP)
• The AR 5-5 Future Tactical Fuel and Energy Strategy Study
Energy Programs or Organizations for Reduction of Energy Use, Efficiency Gains and Accountability
• Army Metering Program
• Chartering of the Army Mobility Fuels & Energy Council (AMFEC)
• Energy Engineering and Analysis Program (EEAP)
• The Natural Gas Risk Management Program
• Army construction compliant with Leadership in Energy and Environmental Design® (LEED) green building rating system
Development of Energy and Environmental Plans
• Army Energy & Water Campaign Plan for Installations, 2007
• Army Energy Strategy for Installations, 2005
• The Army Strategy for the Environment, 2004
• The AR 5-5 Future Tactical Fuel and Energy Strategy Study, in process
Development of Energy and Environmental Plans
• Army Energy &Water Campaign Plan for Installations
• The Army Strategy for the Environment

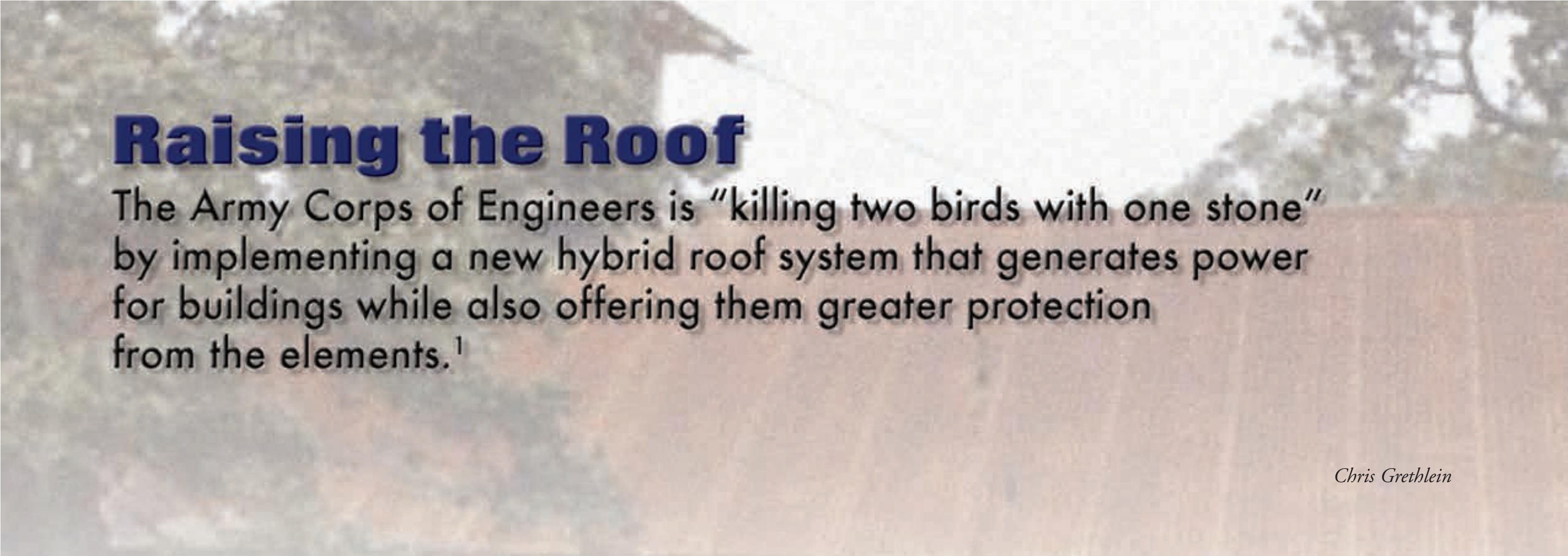
CONCLUSION

Over the past several years, the Army has undergone an 'evolution of understanding' as to the vital importance of energy security. As a critical resource, energy must be readily available to support Army missions operating tactical and non-tactical vehicles and equipment, powering Soldier-carried equipment, and providing electricity and other utilities to fixed installations and Forward Operating Bases (FOBs).

The Army has come to understand the vital importance of energy security

In recognition of this, Army leadership has raised the priority of energy security to the highest levels, with the intent of fostering a culture of energy consciousness throughout the Army. To accomplish this, the Army has taken an enterprise-wide approach to addressing the issue, which is necessary because cost-effective management of energy requires coordinated efforts across the Army. In addition to meeting Army energy mandates, Army energy initiatives must also respond to appropriate federal laws, DoD energy directives and strategies; and must ensure not only address energy goals but are consistent with relevant environmental and sustainability goals. Army energy security is now every Soldier's and Civilian's responsibility. Success depends on each individual's support and execution of solutions to their organization's energy security needs. The challenges may be great, and the road may be long; but no team has a stronger track record of rising as one to face such obstacles than the United States Army. The Army's energy future promises to be a bright one.

Army energy planners must also address trends in Army operations that could significantly affect future energy use



Raising the Roof

The Army Corps of Engineers is "killing two birds with one stone" by implementing a new hybrid roof system that generates power for buildings while also offering them greater protection from the elements.[1]

Chris Grethlein

Both the DoD's Operational Energy Security Policy and the Army's Energy Security Implementation Strategy call for increased use of alternative power sources in the future in all aspects of Army operations. In the case of combat units, this mainly pertains to reducing the warfighter's dependence on fossil fuels; but in the case of Army facilities, it directs the Army Corps of Engineers to render Army infrastructure less reliant on conventional power grids, whether in terms of consuming less power, or by generating some fraction of power from renewable sources off the grid. The Army is no stranger to solar energy, already reaping the benefits from solar panel "farms" at a number of installations around the country. These solar power facilities help to offset reliance on local power grids, and thus reduce each installation's annual energy bill. However, these panel arrays do require a substantial amount of land set aside for them. At some older, more established facilities, where land is at a premium, or terrain may not permit, it may not be practical to install such arrays. Moreover, facilities budgets are tight, and these installations must equitably address other sustainment priorities besides energy efficiency issues. Now recent innovations in solar cell technology by researchers at the U.S. Army Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL) [2,3,4,5,6] may offer a novel way to address two pressing infrastructure needs simultaneously. First is by reducing reliance on the grid, and second is making Army structures more impervious to the degrading effects intrinsic to their environment, thus lowering their total life cycle costs.

Hawaii Provides the Ideal Testbed – For the purposes of an effective demonstration, ERDC-CERL identified the Kilauea Military Camp (KMC) on the Big Island of Hawaii for the variety of buildings and the types of environmental exposure, namely, rain erosion, ultraviolet (UV) degradation, and corrosion. The aim of the project is to demonstrate and validate an integrated metal roof and photovoltaic solar cell system using an appliqué made of silicon solar cell materials. As a secondary, but equally important benefit: solar cell materials are non-metallic, primarily ceramics and polymers, and as such are also highly corrosion-resistant. This project supports not only Army energy goals, but also helps to meet initiatives set by the State of Hawaii that advocate for greater use of solar power and higher levels of sustainability in buildings. An integral photovoltaic solar cell/metal roof panel structure offers sustainable solutions that mitigate two of Army infrastructure's most pressing issues – buildings that are more energy independent and cost less to sustain – hence, "killing two birds with one stone."

Electric power costs are steadily rising and show no sign of abating in the near future. Sustainable photovoltaic powered systems would consume significantly less energy over the lifetime of the equipment within buildings at Army installations. KMC is scheduled to undergo major upgrades to its facilities within the next ten years. The results and lessons learned from this project can help guide how the Army implements these technologies to realize the full benefits power-generating, sustainable structures, at KMC and ultimately at many other military facilities.

The Need for Energy Savings Is Great – The Data Report for the FY07 Annual Energy Report that the Assistant Chief of Staff for Installation Management (ACSIM) submitted to the Office of the Secretary of Defense (OSD) shows a total commodity cost of energy of $1,099,354,300 over all Army facilities, totaling 785,176,000 square feet of floor space. This equates to approximately $1.40 per square foot7. Solar cells can offset about 25% of that cost in areas with sufficient sunlight. Even if the number of regions where solar energy could be used effectively were estimated conservatively to be as little as 10%, then the savings to the Army would still be equal to 0.25 X 0.10 X $1,099 M = $27.5 M per year.

Policy Considerations – This project addresses a number of different drivers in Army policies. Some of the major ones are laid out in Army Regulation 420-1, Facilities Engineering Army Facilities Management:

Section 22-11(f) – "Use of renewable energy systems such as solar hot water, solar electric, solar outdoor lighting, wind turbines, fuel cells, geothermal, biomass, hydroelectric, ground coupled heat pump systems, and other alternatives should be considered based on life cycle cost effectiveness."

Section 23-31 – Fuel selection – "…Energy sources will be selected with careful consideration of national reserves, local fuels availability, and LCC analysis. The use of renewable energy purchased from off-base commercial sources (waste products, solar, wind, geothermal, refuse-derived fuel (RDF), and wood) is encouraged."

Section H-18 – Renewable energy cost provisions – "Solar (active, passive, and photovoltaic) and other renewable forms of energy will be considered for all MILCON* projects. Life cycle cost effective solar or other renewable forms of energy considerations will be included in program documents and in the construction. (Cost of including renewable energy provisions in construction contracts will be shown on DD Form 1391 and in the concept design (35 percent), parametric design (5-15 percent), and later cost estimates when feasibility has been ascertained)."

The Army Energy Strategy for Installations and the Army Strategy for the Environment both support expanded use of renewable energy technologies. The Army Energy Strategy for Installations also includes the objective of enhancing energy security. Even the White House is requiring the Army to increase its use of renewable energy each year8; through Executive Order (EO) 13423 – *Strengthening Federal Environmental, Energy, and Transportation Management*. Moreover, refitting buildings with such integral PV/corrosion-resistant roofing systems would help the Army earn energy credits for the KMC facility, demonstrating their commitment as good neighbors in Hawaii. Most applicable were several different credits awardable from the U.S. Green Building Council's Leadership in Energy and Environmental Design New Construction (LEED-NC) standard. Applicable credits may include:

Energy and Atmosphere Credit 29: On-Site Renewable Energy	1 point for 2.5% 2 points for 7.5% 3 points for 12.5%
Sustainable Site Credit 7.1 Heat Island Effect (non-roof)	1 point
Sustainable Site Credit 7.2 Heat Island Effect (roof)	1 point

Working in Hawaii – The Hawaiian Islands are home to the U.S. Pacific Command (PACOM), the largest Combatant Command by geographical area, which has one of the greatest concentrations of U.S. Army, Navy, Air Force, Marine Corps, and Coast Guard assets anywhere in the world. There are more than 100 military installations covering 200,000 acres – 5% of the state's total land area.

Hawaii may be considered a "paradise" by the many tourists who visit each year, but in the eyes of facilities maintainers, it is a harsh operating environment, exacting a toll on military equipment and infrastructure alike. Hawaii's disparate terrains offer no less than eight distinct microclimates: Marine, Alpine, Temperate, Volcanic (producing acid rain), Rain Forest, Industrial, Desert, and Agricultural, making it one of the most corrosive places on Earth.

This demonstration project was jointly supported by the Office of Corrosion Policy and Oversight within the Office of the Secretary of Defense (OUSD(AT&L/CPO), the U.S. Army Office of the Assistant Chief of Staff for Installation Management (ACSIM), and the U.S. Army Installation Management Command (IMCOM). The work was performed by a team of subject matter experts from the ERDC-CERL, Champaign, IL, as well as from industry.

This project demonstrated the use of a flexible-membrane photovoltaic (PV) solar array in conjunction with a corrosion-resistant aluminum-zinc standing-seam metal roof (SSMR) with a polyvinylidene fluoride (PVDF) fluorocarbon coating. The system was installed on a building at KMC, which has a unique environment of moderate temperature, high humidity, and periodic exposure to volcanic gas. The corrosion performance of the roof and PV system components were evaluated by periodic visual examination of the completed roof, inspection of exposure coupons mounted on-site, and laboratory testing of material coupons. Sensors were also mounted on a functional PV roofing panel installed on an exposure rack at the demonstration site to record the corrosion conditions between the thin-film PV cells and the roof surface.

With most of the new DoD roofing being metal panel systems, they comprise a large portion of an installation's cumulative building surface area that is exposed to sunlight. Today's metal roofs with coatings such as PVDF and polyvinyl fluoride (PVF) can provide excellent corrosion protection in corrosive environments such as KMC.

Sustainable building integrated photovoltaic (BIPV) systems are a technology of growing interest to US military installations and the state of Hawaii. Installation electric power costs are steadily rising and show no sign of abating in the near future. Thin-film PV appliqué systems which can be incorporated into metal roofing potentially provide a major source of alternative energy. However, to become a viable technology, integration of the PV products must not compromise the corrosion resistance and performance of a roofing system throughout its design service life. The effect of these PV systems and their components on the corrosion resistance of coated metal roofing systems during exposure is not known.

Choosing the Right Building – Building 84, located in a service-utility section at KMC, was selected for the demonstration. The building, which was constructed in 1946, is used primarily as a warehouse and for vehicle storage with some office and other storage space on the east and west ends. It has one level with about 5,500 square feet of flooring. The main section of the building, which has a gable roof, has open bays along the north

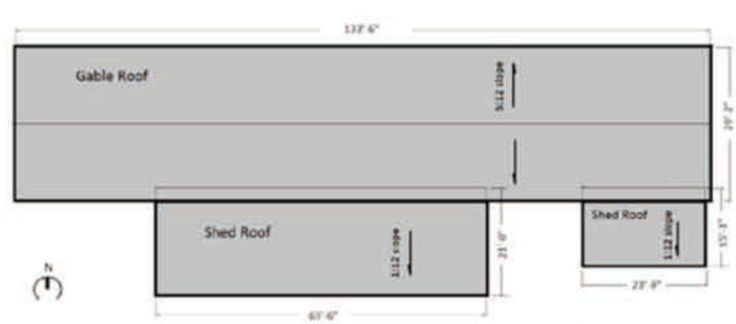


Figure 1. Building 84 – The Open Bays on the North Wall and the Layout of the Roof

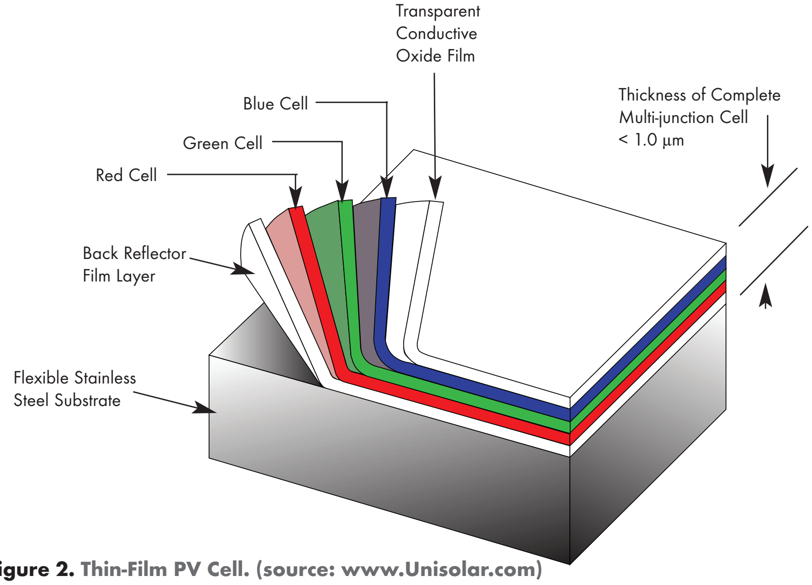


Figure 2. Thin-Film PV Cell. (source: www.Unisolar.com)

wall for vehicle access and parking. Figure 1 shows a layout of the building roofs. There are two building additions on the south side of the building's main section that have "shed" roofs. The roofs on all three sections of the building are a metal panel system and all are severely corroded.

THIN-FILM PV APPLIQUÉ TECHNOLOGY

The innovative PV technology consists of thin-film appliqués that are bonded to the metal roofing panels. These PV cells are made by depositing a thin film of amorphous silicon on a substrate material. The triple junction solar cell appliqué is composed of 3 layers of semiconducting material stacked one on top of another (Figure 2) for maximum absorption of the solar energy spectrum and conversion into electric power. The bottom, middle, and top layers absorb red, green, and blue light, respectively. A back reflector film layer is placed below the amorphous layers. The top surface of the appliqué is a transparent conductive oxide film and the bottom surface is a flexible stainless steel substrate. The panels have an ethylene propylene copolymer adhesive backing with a microbial inhibitor.

The efficiency of amorphous silicon used in the thin-film PV modules is between 5 to 8 percent, much less than the 15 percent produced from traditional PV panels that use crystalline silicon and are mounted in aluminum frames above the roof surface. When used in conjunction with a metal roofing system, the thin-film PV modules do not add significant weight to the roof's support structure or create any wind resistance issues due to their flat profile.

Installation of the PV appliqués to metal roof panels is straightforward. The release sheet is peeled away from the appliqué, exposing a layer of the adhesive. The appliqué is then rolled onto the metallic substrate in such a manner as to not entrap air between the two surfaces. A rubber roller is applied to the top of the appliqué to obtain optimal contact between the adhesive and the roofing panel.

To provide suitable power for various applications, these PV appliqués can be joined together to form larger units. Modules connected in series produce a higher voltage and modules connected in parallel produce more current.

Roof System Design – Prior to upgrading the roof, it was necessary to determine whether Building 84's gable roof framing system – still the original installed in 1946 – had sufficient structural integrity to support the new roof system. Thus, an engineering study was performed to establish the design wind forces for the new standing seam metal roofing (SSMR) system using American Society of Civil Engineers (ASCE) Standard 7, Minimum Design Loads for Buildings and Other Structures. The design wind load was a 3-second, 105-mph gust at a 50-year mean recurrence interval. The subsequent wind uplift resistance of the system was designed to meet International Building Code (IBC) requirements for the KMC location. Based on a site survey, documentation of the existing construction and a structural analysis, the existing roof framing system for Building 84 was determined to be inadequate for supporting the new roofing system and required live load. Therefore, the decision was made to replace the existing roof framing system with a more structurally suitable configuration that would more than adequately support the SSMR system.

Metal Roofing System – The selected SSMR has 16-inch-wide, 24-gauge, 50-ksi aluminum-zinc coated roof panels. The standing seam is 1-½ inches high and has a snap-lock configuration. The profile of the roofing panels can be seen in Figure 3. The panels are coated with a PVDF organic coating on the external facing surface and polyester enamel on the interior-facing surface. The high-performance coating provides greater scratch and mar resistance than previous generation PVDF coatings. The inclusion of Teflon within the coating provides improved stain resistance and cleanability. The coating complies with Cool Roof Energy Council, Energy Star, and LEED 2009 standards.

The PV modules are electrically connected to an inverter, which converts the direct current (DC) produced from the solar array into the standard alternating current (AC) suitable for powering the building or for supply back to the electrical grid. There is no means of energy storage within the system, so when the PV power output is greater than that needed for building usage, the excess is transferred to the grid for use by other buildings at KMC. It is noteworthy that this power system could allow building 84 to continue to operate independently when there is a partial or total grid failure. The power system features a web-accessible remote monitoring module, which allows remote monitoring and recording of system performance.

PV System – The modules were applied to the roof panels prior to them being installed on the gable roof. The surfaces of the roof panels were wiped with a solvent. The next step was to peel off the backing paper from the PV appliqué (Figure 4) and

Figure 3. Eave end of new standing seam metal roof

Figure 4. Removal of Release Paper from Back of PV Module

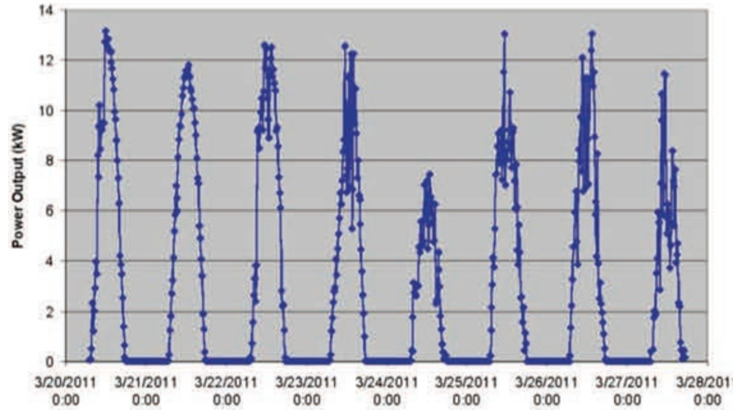


Figure 6. PV System Power Output Over One Week

Figure 5. PV modules Installed On Gable Roof Section of Building 84

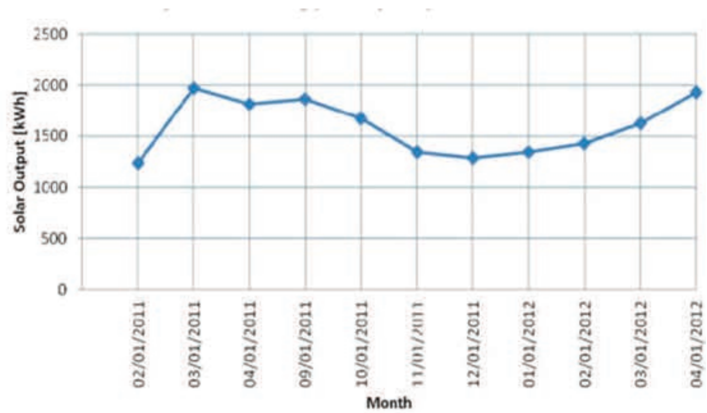


Figure 7. System Energy Output

to press the modules in place against the panels. The metal panels were then placed on the roof with the ends of the modules having the electrical connectors located upslope. Figure 5 shows the PV modules installed on the gable roof section.

Technology operation and monitoring – The inverter reports energy and power production information to the Fat Spaniel monitoring system. However, the power production data does not distinguish between that which is consumed by Building 84 and that which is distributed to the other buildings at KMC. The data is downloaded to an external server, which records the information and (on request) provides data and graphs describing the system's performance. The information is accessed via the internet.

The corrosion performance of the SSMR with the integrated PV power system was assessed by 1) visual observation and evaluation of the completed roof 2) evaluation of coupons that have been subjected to natural exposure and accelerated corrosion testing and 3) evaluation of recorded environ-mental conditions at the PV module-metal roof panel interface. The energy and power output of the inverter are also being monitored to assess the energy performance of the PV modules.

Visual inspection – Technicians visited the project site at 6 and 12 months after installation and inspected the SSMR and PV system components. Both systems were determined to be performing exceptionally well in the KMC environment. The metal panel coating and PV modules exhibited no visible deterioration and the wiring and connections displayed no signs of corrosion.

Coupon evaluation – A series of coupons emulating the roof configurations were tested on exposure racks under various conditions to establish performance benchmarks. The set of coupons placed on the exposure rack at KMC were visually inspected after 6 months. Examination showed that the coupons displayed no evidence of corrosion, with the exception of the uncoated metal panel coupons, which began to show corrosion in the scribes and also spots of corrosion elsewhere.

PV Energy Performance – A plot of one week's worth of power output data can be seen in Figure 6. Each point in the graph represents the average power output over a 15-minute period. The energy output from the solar panel system was measured by the data logger on an hourly basis. The weekly outputs ranged from 224 kWh to a maximum of 530 kWh. The wide range of energy output is primarily due to inconsistent weather blocking the sun's exposure to the solar panels. Based on the first 12 months of data (Figure 7), the monthly average energy output from the solar panels was about 1594 kWh. According to local electric utility company's filings to the public utilities commission, the cost per kWh for general service during that time was approximately $0.3518. Based on this, the total energy cost savings generated from the solar panels during a 12 month period of service is about $6,729.

Conclusions – Thin-film PV technology is an effective means of generating electrical power in climates where direct solar radiation is available during most of the year. However, if system procurement costs were lower than those incurred for this demonstration project, this technology could become an economical option, particularly in areas with high electrical costs or grid-capacity constraints.

Standing seam metal roofing with high-performance coatings and cool pigments are already widely used at Army facilities. This technology has been validated and accepted by industry and the market place. The metal panel coating and PV module and components have not exhibited corrosion or other visible deterioration. These finding are supported by coupon evaluations and the sensor readings at the PV module/metal panel interface located on the exposure rack erected at the site.

Excluding costs, thin-film PV systems can provide benefits relative to systems that use traditional crystalline and silicon cell technology. Thin-film PV modules can be adhered to the metal panel surface, reducing or eliminating penetrations and metal flashings which are often used with conventional rack-mounted PV systems. As a result, the potential for moisture intrusion and subsequent water damage can be greatly reduced.

Recommendations – The technology operates as designed, and has not had any negative effects. In places where energy conservation or the use of alternative energy is desired or mandated, or where power infrastructure is deficient, this technology could be considered as a possible option.

If a PV system is specified for a project, first consideration should be any regulatory requirements set by the local utility (if the system is to be grid-tied). As experienced in this project, obtaining necessary approvals and permits for grid-tied operation may need to be initiated several months before the start of construction.

ACKNOWLEDGEMENTS

The author gratefully acknowledges the support of Mr. David Bailey and Mr. Tarek Abdallah of the Construction Engineering Research Laboratory, U.S. Army Engineer Research and Development Center (ERDC-CERL); who led this installation project at KMC and provided invaluable materials for this publication.

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New Technical Resource for Scientists and Engineers:

Analysis of Alternatives to Hexavalent Chromium

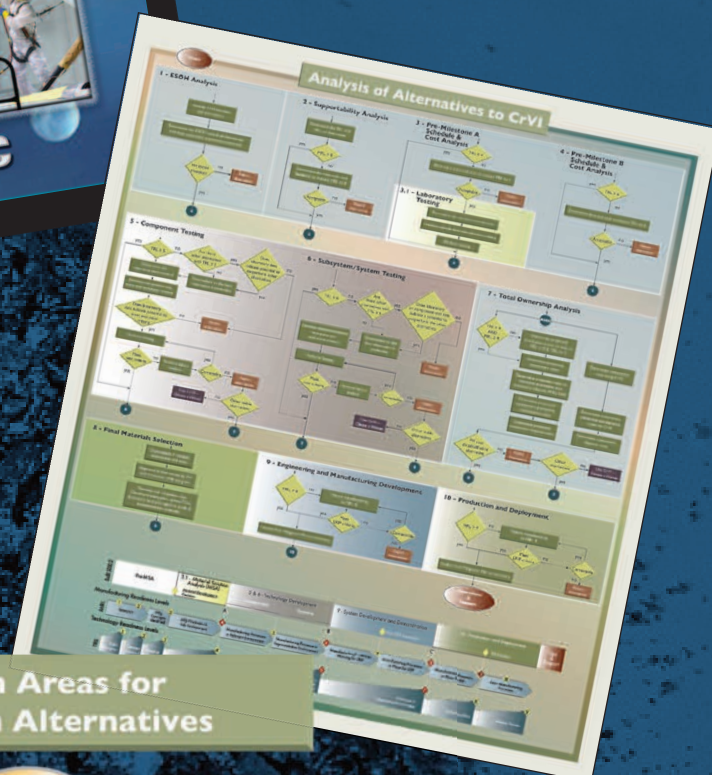
One of AMMTIAC's newest technical products, Analysis of Alternatives to Hexavalent Chromium: A Program Management Guide to Minimize the Use of CrVI in Military Systems, is a first-of-its-kind guide on minimizing the use of hexavalent chromium-bearing (CrVI) compounds in corrosion prevention applications for new acquisition programs. The Guide is a compendium of information resources; providing an extensive summary of the policy, programmatic, technical, safety, and regulatory issues pertaining to the restricted use of CrVI. This publication was created as a resource to aid those in the acquisition community who must navigate through a sea of conflicting requirements to arrive at technical solutions that meet National Defense, environmental, safety, and occupational health (ESOH) gorals.

Guidebook Highlights Include:

- Challenges and strategies associated with the use or omission of CrVI.
- Policies, regulations, and DoD memoranda regarding the use of CrVI.
- ESOH problems associated with using CrVI in defense systems
- The impact using alternatives to CrVI may have on military systems
- Procedures/strategies for evaluating/validating CrVI alternatives
- How to obtain a CrVI waiver when no suitable alternatives are available.

Qualification/Selection Process Flowchart for CrVI Alternatives: Designed to serve as an engineering reference for technical personnel, the process, illustrates the recommended material selection process to evaluate and assess the suitability of alternative materials for various systems. As part of the process, it also specifies when using CrVI would be the best option, typically when there is no acceptable alternative.

Written with the Program Manager in mind, this Guide addresses the myriad issues that PMs and their engineering staffs will need to address when considering potential applications of CrVI in an increasingly complex acquisition environment.



Taking Alternative Energy "to the Edge"

The U.S. Army's Rapid Equipping Force is bringing energy independence straight to the warfighters' doorstep.

Meeting the ambitious goals set out in the Army Energy Security Implementation Strategy (AESIS) is challenge enough for anyone who wears an Army uniform. However, in the case of Army combat troops that challenge is multiplied several fold, and with much more at stake.

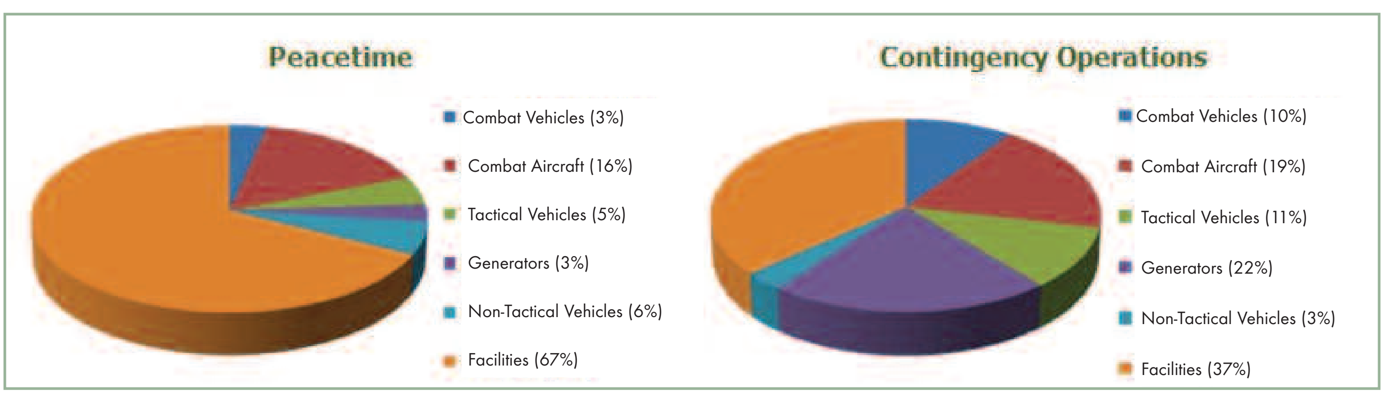
The Secretary of the Army has a series of energy-saving initiatives; among them are lessening the Army's dependence on fossil fuels and more fully utilizing alternative energy sources. As it turns out, the greater degree to which combat units can comply with these directives is entirely to their advantage. While detailed later in this article, it is sufficient to say at this point that using conventional fuels in forward operating positions only promotes reliance on the highly stretched supply chain, which is not only expensive, but could prove hazardous to combat troops should that chain be disrupted for an extended period. Conversely, most alternative energy systems considered for field use are mobile, with most requiring no supply chain at all. With the myriad different commercial off-the-shelf (COTS) alternative power systems available today, it is important to evaluate a variety of these systems in the field in a limited number before incorporating any of them into standard Army doctrine.

The U.S. Army's Rapid Equipping Force (REF) equips operational commanders with Commercial-off-the-Shelf (COTS) and Government-off-the-Shelf (GOTS) solutions to increase effectiveness and reduce risk. The REF serves as a solutions catalyst, canvassing the military, industry, academia, and the science community for existing and emerging technologies. Thus, the REF and its partners are charged with developing expedited solutions to meet current and projected operational requirements by identifying and inserting "game-changing" technologies (such as alternative power systems) into the operational environment. By exploiting the benefits of accelerated product evolution (i.e. product "revolution") methodologies, the REF speeds new capabilities to the Warfighter in significantly shorter cycle times than conventional RDT&E approaches.

HOW THE WARFIGHTER CONSUMES ENERGY

In Fiscal Year (FY) 2008, the Army estimated it consumed over 180 trillion British thermal units (BTUs) of total energy at a cost of more than $4 B. Included in that sum was the purchase of approximately *880 million gallons of fuel for mobility operations*[1]. Army energy consumption in wartime differs dramatically than that of consumption during peacetime – not only in total energy consumed, but in where it is consumed. Figure 1 illustrates estimated Army consumption patterns during scenarios for peace (total of 112 trillion BTU) and wartime contingency operation (total of 208 trillion BTU) based on realistic system energy consumption performance in the FY 2006-7 time period.

The major Army energy consumer for both scenarios is Facilities, but during time of war (denoted in Figure 1 as 'Contingency Operations), Facilities, and Non-Tactical Vehicles' share of the total drops substantially in relation to other components. Most noteworthy is the relative increase in energy consumption by *generators*. Nearly insignificant in their peacetime energy consumption (3% of total), generators' usage multiplies many fold to represent 22% of the Army's total energy consumption profile, *the second largest energy demographic in wartime*. This statistic alone supports the initiative to reduce the Army's overall consumption of fossil fuel and to consider alternatives to conventional generators. However, the unique challenges of transporting fuel to forward operating bases (FOBs) and similar installations exact added costs that only serve to highlight the importance of reducing their dependence on fossil fuels more rather than less; and sooner rather than later.



Sources: Defense Science Board, More Fight – Less Fuel (February 2008); Department of the Army, FY07 Annual Energy Management Report (December 2007)

Figure 1. Army Energy Consumption Scenarios

Forward Operating Base (FOB) **Combat Operations Post (COP)** **Observation Post (OP)**

Figure 2. Types of Forward-Deployed Installations

THE RELIANCE ON FOSSILS FUEL IS COSTLY – IN MANY WAYS

Forward Installations are Remote – The road to the front is long and tortuous, figuratively and literally; and in some cases, no road exists at all. These installations can range greatly in size, from Forward Operating Bases (FOBs), which may house upwards of several hundred troops, to very small Observation Posts (OPs) comprised of a dozen or fewer soldiers (Figure 2).

Ferrying Fuel To The Front Is Difficult And Expensive – Originally, U.S. Forces in Afghanistan relied upon an overland supply line, ferrying fuel from Europe through Central Asia before it finally reached Afghanistan. More recently, this supply train has been augmented by contracting to local fuel suppliers in country. This has reduced the overland transportation costs somewhat, but the most arduous portions of the supply route remain, as the Afghan landscape is one of the most rugged and untamed anywhere on the globe. The roads, where available, tightly conform to the contours of the mountains and ravines they pass through en route to FOBs and Combat Operations Posts (COPs). They are narrow, winding, steep, frequently unpaved, poorly graded, and ill-maintained. As a result, fuel convoys must frequently drive highly treacherous routes at slow speeds to lessen the chance of accidents, lengthening the trip's duration (increasing danger to convoy personnel) and elevating the cost of each convoy. Where roads become too narrow or substandard for Heavy Expanded Mobility Tactical Trucks (HEMTTs) or other fuel trucks, fuel may need to be transferred to 55-gallon drums and transported the final distance via Humvees or other appropriate vehicles. Some COPs and OPs are not accessible by existing roads, and must have their fuel ferried in on a sling load (typically 55-gallon drums on a pallet, or a collapsible fuel bladder) underneath a helicopter.

Ferrying Fuel To The Front Costs Lives – The harsh terrains that convoys must negotiate pose many natural and potentially fatal hazards to soldiers and equipment – dangerous road conditions, winter weather, landslides, vehicular brake failures on the steep grades, and vehicular accidents, to name several. However, these risks are minor by comparison to the constant threats posed against convoy crews by attacks from insurgents along their routes. The steep terrain gives any attacking force the natural advantage of the high ground, while convoys lie exposed below them, with no room to maneuver through the narrow passes and deep valleys. Even on relatively open ground, convoys are vulnerable to a second threat – improvised explosive devices (IEDs). These may be buried in the roadbed itself, functioning similar to a landmine, or they may be hidden by the side of the road, triggered by a remote detonator, such as a modified cell phone.

Fuel convoys must frequently take very treacherous mountain roadways to reach FOBs

For outposts beyond the reach of the convoys, fuel must be brought in by individual barrels

A helicopter prepares to ferry a collapsible fuel tank in a sling load

Figure 3. Fuel Convoys Are Expensive and Difficult

Alternative Energy Systems Will Save More Than Fuel And Money: They Will Save Lives – Implementing alternative and renewable energy power systems will help meet several of the Energy Security Goals set forth in the Army Energy Security Implementation Strategy; but more importantly, they will keep more soldiers out of harm's way. The potential reduction in the casualty rate would not be insignificant. Army casualty statistics report that from 2003 through 2007 in Iraq, *1 in 8 soldiers wounded or killed were protecting fuel convoys*[ii]. While attending a field demonstration of several hybrid solar generator systems at the Army's Network Integration Event in May 2012 (NIE 12.2) at Ft. Bliss, TX, Vice-Chief of Staff of the Army (VCSA) Lloyd J. Austin III remarked about the criticality of reducing the number of fuel convoys in combat areas for the express purpose of saving soldiers' lives. Moreover, General Austin stated to soldiers and civilians present at the demonstration that he viewed viable alternative hybrid power systems as 'win-win' propositions for the Army, as they would save lives, expend fewer dollars on fuel, and make forward deployed forces more energy independent.

MEETING THE WARFIGHTER'S ENERGY NEEDS

As part of its 'Net-Zero' Initiative, the REF inaugurated its 'Energy to the Edge', or E2E program in FY11. The effort was a response to the growing energy demands among troops in theater, often posted in distant, hard-to-reach locations; referred to as the "tactical edge." The initiative seeks to decrease reliance on JP-8 and diesel fuel for military vehicles and equipment. E2E focuses on meeting energy and water requirements at locations that are hard to reach with logistical aid, while simultaneously reducing dependence on ground and aerial resupply operations. To do this, the REF and its partners are evaluating alternative power generation systems with the potential to make the greatest impact in reducing fossil fuel consumption. Thus, these new systems are aimed at supplanting or replacing the Army's #2 wartime consumer of fossil fuels – the conventional generator.

UNDERSTANDING THE ARMY'S CURRENT ENERGY PARADIGM

FOBs and COPs are served by a series of fossil fuel generators of varying sizes, which deliver constant power output, between 5 kW and 100 kW, when running. Most installations are furnished with generators in excess of what is required to power the various facilities within the installation, and thus most of them run seriously under-utilized[1] which hikes up both fuel and generator maintenance costs. Conventional generators provide what can be characterized as "dumb power" (Figure 4). That is, generators only have two settings – on and off. They run at full output, regardless of the power load placed on them by the equipment they serve. A properly functioning 10 kW generator, for example, will nominally generate 10 kW, whether it's servicing a variety of equipment pulling a 9 kW load, a 5 kW load, a 2 kW load, or even if nothing is plugged into the microgrid at all! Conventional generators waste tremendous amounts of fuel, as they are almost always under-utilized, which results in "wet-stacking"[2] of generators, increasing their maintenance costs and shortening their service lives.

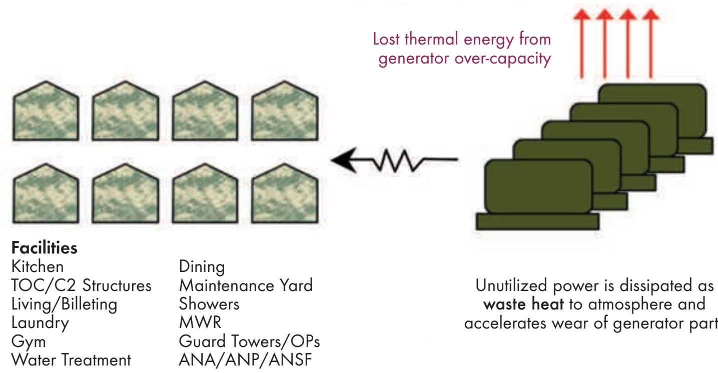


Figure 4. The Original Energy Paradigm – "Dumb" Power

What is required to meet fully the warfighter's energy needs while minimizing waste is a power delivery system that will provide precisely the amount of power needed to meet the real-time load at exactly the time it is needed, with no wasted output?

THE ARMY'S NEW ENERGY PARADIGM: "SMART" POWER

Meeting the total power needs of the warfighter in the field will require a "hybrid approach" – a combination of energy sources and generation technologies – from the leading edge in renewable, alternative energy systems, at one end of the spectrum, to the judicious reapplication of more "low-tech," traditional power sources at the other. Each hybrid system possesses the same basic traits, but is configured uniquely to meet the special circumstances of its set of peculiar load requirements. While the specific components may vary by system, all hybrid systems are comprised minimally of a bank of batteries, a power management system (PMM), and one power source. Figure 5 illustrates a notional example of a hybrid power system, comprised of multiple power sources, providing AC and DC power separately. Most real systems are far less complex. The simplest smart

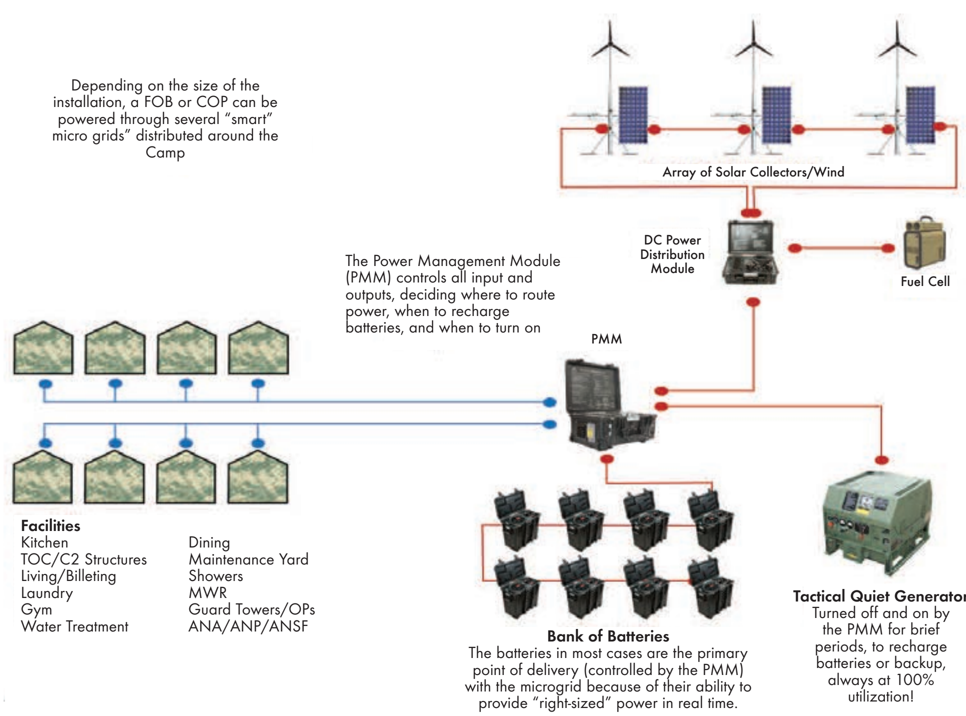


Figure 5. The New Energy Paradigm: "Smart" Power

system possible, and there are several fielded in Afghanistan, consists of a Power Management Module, a battery, and a solar collector.

THE ELEMENTS OF A HYBRID, SMART POWER SYSTEM

A *"real-time" point of delivery* – In most cases, this would be a bank of batteries, with chemistries ranging from traditional lead-acid to advanced, lightweight Lithium ion technologies. Batteries, traditionally thought of only as energy storage units, provide power to its service load in exactly the amount required, and only when needed. This is because batteries are repositories of energy, and not generators of it. The devices they power actually "pull" the power they require from them, as opposed to generators, which "push" energy, regardless of the demand of the devices on the receiving end.

A variety of power generation sources – Many of these alternative energy microgrid power systems may be termed as 'hybrid' power systems, as they rely upon more than one power generation source. The number and variety of sources employed is largely dependent on the required service loads of that microgrid, as well as the criticality of ensuring uninterrupted power supply around the clock, regardless of weather conditions or time of day.

An intelligent power management module – Having a variety of power generation sources as part of a hybrid, "smart" power system greatly enhances energy surety because each type of generator serves as a "backup" to the others. But equally important, each generation source – alternative, renewable, and conventional – has individual strengths and weaknesses with the strength of one overcoming the weakness of another. Smart power systems have one other critical capability beyond generators and storage units. They can monitor the state of the total power system, analyze the real-time power load, monitor its own power reserves, select which generators to activate, and identify where to direct the energy they produce. This capability is provided through an intelligent module, or *power management module*, which serves as the system's brain controlling all inputs and outputs. It also serves as a traffic cop directing energy flow from generators to devices directly, or alternately, to recharge batteries, as needed.

Conventional Backup Power (Optional) – For applications with higher loads or more stringent power surety requirements, a conventional diesel tactical quiet generator (TQG) wired for automation is part of the system, and is directly controlled by the PMM, being turned on only when needed to augment current power supply, or more likely to recharge the batteries. In the hybrid system setting, TQGs only run when called upon to do so, and run at 100% utilization.

THE LOW TECH PART OF THE SOLUTION: REDUCING THE NUMBER OF GENERATORS

The most visible parts of E2E's purpose are to promulgate the use of alternative energy systems in combat areas, saving fuel, money, and lives by limiting the number of fuel convoys that are required annually. However, E2E's overall purpose is to reduce troops' reliance on fossil fuels by any means. The other major way to accomplish this is by instituting efficiencies among the conventional power equipment. Most camps are supplied with a surplus of generators, and as mentioned previously, too many generators are run to power too little equipment at extremely low utilization rates (<20% in many cases).

Even as many camps wait to receive alternative power systems, REF has already been affecting efficiency measures at these very camps by consolidating generators. E2E processes enhance energy efficiency by "right-sizing" generator loads. E2E operators tie together several microgrid, previously powered by severely underutilized generators, and instead power them by a single generator running at a high rate of utilization (≥80%).

E2E'S IMPACT AT FOBS AND COPS WAS IMMEDIATE

The first E2E units were deployed in Afghanistan in early 2012; and already, these systems have made some significant contributions to power surety for facilities at remote locations while minimizing, and in some cases, eliminating altogether their dependence on fossil fuels.

What follows are "real-world" examples of E2E-introduced alternative power systems inserted into operational environments with minimal disruption to operations and immediate benefits for the users:

EXAMPLE #1: POWERING RAID TOWERS

There are two Rapid Aerostat Initial Deployment (RAID) towers on top of an OP just outside a major COP. One is used for the camera and the other is used for communications. Prior to E2E, the towers were being powered by a 60 kW generator (the units' 5-kW generators were no longer working), with a peak load of only 1.5 kW.

The REF team replaced the oversized (and underutilized) generator with a hybrid power system comprised of three solar collector units, a PMM, and a bank of batteries. The solar cells were capable of fully powering the two towers during daytime, and the batteries provided sufficient power overnight, eliminating the need for a generator to be part of the system. This hybrid now runs completely renewable with a 100% operational reliability. Retiring the generator resulted in *a savings of 35 gallons of fuel per day* for just one observation post. Imagine how that would translate if applied to all OPs in theater.

Figure 6. **Three Solar Generation Units Provide 100% of Power for an Observation Post**

EXAMPLE #2: POWERING COP AID STATION

A COP's Aid Station would lose power at various times. The issue was most critical when such outages occurred while treating casualties. The REF team installed a mobile, solar hybrid power system, which now *provides all the Aid Station's power with 100% reliability*. By having batteries as the primary power source, power is delivered to meet the real-time load instantly with no wasted energy. The batteries are recharged primarily through the solar panels, with a Tactical Quiet Generator (TQG) as an emergency back-up.

EXAMPLE #3: CONSOLIDATING GENERATORS AT A COP

As mentioned already, most camps possess and operate a surplus

Table 1. **Power Generation and Fuel Data for COP– taken April–May 2012**

Power Distribution:	Distributed power on Force Provider equipment, spot power otherwise
Total kilowatts from generators targeted by E2E: Initial assessment (4/26/12): Completion of fixes (5/11/12):	 300 kW (5 60-kW generators) 123 kW (2 60-kW &1 3-kW generators)
Kilowatt usage of generators targeted by E2E: Initial assessment (4/26/12): Completion of fixes (5/11/12):	 41 kW (13% utilization) 41 kW (33% utilization)
JP–8 fuel usage For generators targeted by E2E: Initial assessment (4/26/12): Completion of fixes (5/11/12):	 218 gallons per day 111 gallons per day
Fuel Savings due to "Fixes" and Placement of E2E Equipment:	107 gallons per day (measured) 3,210 gallons per month (projected) 38,520 gallons per year (projected)*

* This equates to over fifteen fully loaded HEMTTs' worth of fuel, which could constitute five or more convoys (keeping upwards of 200 soldiers out of harm's way in avoided convoys!

Figure 7. **Hybrid System Provides All of Aid Station's Power**

of generators in highly underutilized states. For one particular COP the REF team visited, the various facilities of the COP were being serviced by 5 operating 60 kW generators, producing a total output of 300kW. However, upon some careful measurements, it was found that the total electric load pulled by all equipment in the camp was only 41 kW. This strongly indicated that many of the micro power grids could be tied together, and several generators could be taken out of service. The ability to consolidate generators was somewhat limited by the physical location of the individual units (i.e. it would not be practical to tie together grids from opposite ends of the camp. They needed to be proximal). Based on placement of units and load distribution, the team took three of the 60 kW generators out of service, and added one 3 kW generator to the ensemble. The entirety of the camp's grids could be adequately serviced in this configuration. Table 1 summarizes the nature of the improvements.

INCORPORATING LESSONS LEARNED FROM YEAR 1

Introducing hybrid power systems in-theater had its own unique set of challenges. Since most of these systems had never seen active duty prior to E2E, this first year was very much a 'proof of principle' phase. The REF team was faced with the issues inherent to a major system startup – the logistical challenges of positioning equipment and spares at forward locations, system assembly, test, optimization, and lastly, personnel training. Moreover, it was critical that soldiers not only be competent in the workings of these systems, but that they accepted them as operational equipment, otherwise they would have had no chance for success, as they would have been discontinued when SMEs departed. However, the immediate and substantial impact of the E2E systems fostered rapid 'buy-in' from FOB and COP personnel.

Besides the challenges of start-up, another challenge facing REF SMEs in Phase 1 was that no one was entirely sure what the real power requirements of any of the equipment or facilities were. This was partly because few efforts had been made in the past to ascertain them, but was made even more difficult because the real demand loads were masked within the waste of the conventional generators, which were producing power well in excess of what was needed. By switching to hybrid systems with load-driven delivery (i.e. batteries), it was now possible to accurately measure usage and demand.

While the deployed system performance was admirable, a number of applications suggested potential avenues for improved performance. For example, many of the solar generation systems provided a maximum of 3 kW of power under ideal conditions. This served a number of applications very well (such as the two aforementioned examples), but as demands became better understood, it was clear there were other applications at the various COPs and FOBs that required an incremental amount of power more than what the solar equipment in Phase 1 could provide. In Phase 2, the REF will deploy upgraded solar collectors that close the capability gap, which will serve to further diminish the roles of even more fossil fuel generators.

CONCLUSIONS

Year 1 of the E2E project yielded some very encouraging results, but as of now, only a very small fraction of forward installations have been equipped with some degree of alternative power systems. Year 2 will see a larger amount of equipment, with enhanced capabilities in some cases, distributed to many more locations in-theater. As more comprehensive and conclusive data continue to be collected in the coming years, it will become apparent to all that E2E has more than fulfilled its share of meeting the Army's strategic energy goals.

GENERAL REFERENCES

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CITED REFERENCES

[1] 'Utilization' refers to the percent of a generator's total output that is being used to power something. Example: a 10 kW generator that is powering equipment drawing a total load of 5 kW is 50% utilized. What happened to the other 50%? It is wasted energy, dissipated as heat. A generator's degree of utilization is a direct measure of how much energy it is wasting. The closer generators can run to 100%, the better.

[2] 'Wet-stacking' is a condition in diesel engines in which not all the fuel is burned in the engine, and passes on into the exhaust system, and occasionally into the pump machinery. Some of the uncombusted fuel can carbonize around injection tips, decreasing the engine's overall performance. The word "stacking" comes from the term "stack" for exhaust pipe or chimney stack. The oily exhaust pipe is therefore a "wet stack." In diesel generators, wet-stacking usually occurs when they run for prolonged periods at only a small percentage of their capacity (rule of thumb: never run generators for extended periods at less than 40% utilization).

[i] *Army Energy Security Implementation Strategy*; January 13, 2009; The Army Senior Energy Council and the Office of the Deputy Assistant Secretary of the Army for Energy and Partnerships

[ii] *www.CNNMoney.com* (statistic on casualty rate among convoy personnel).

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