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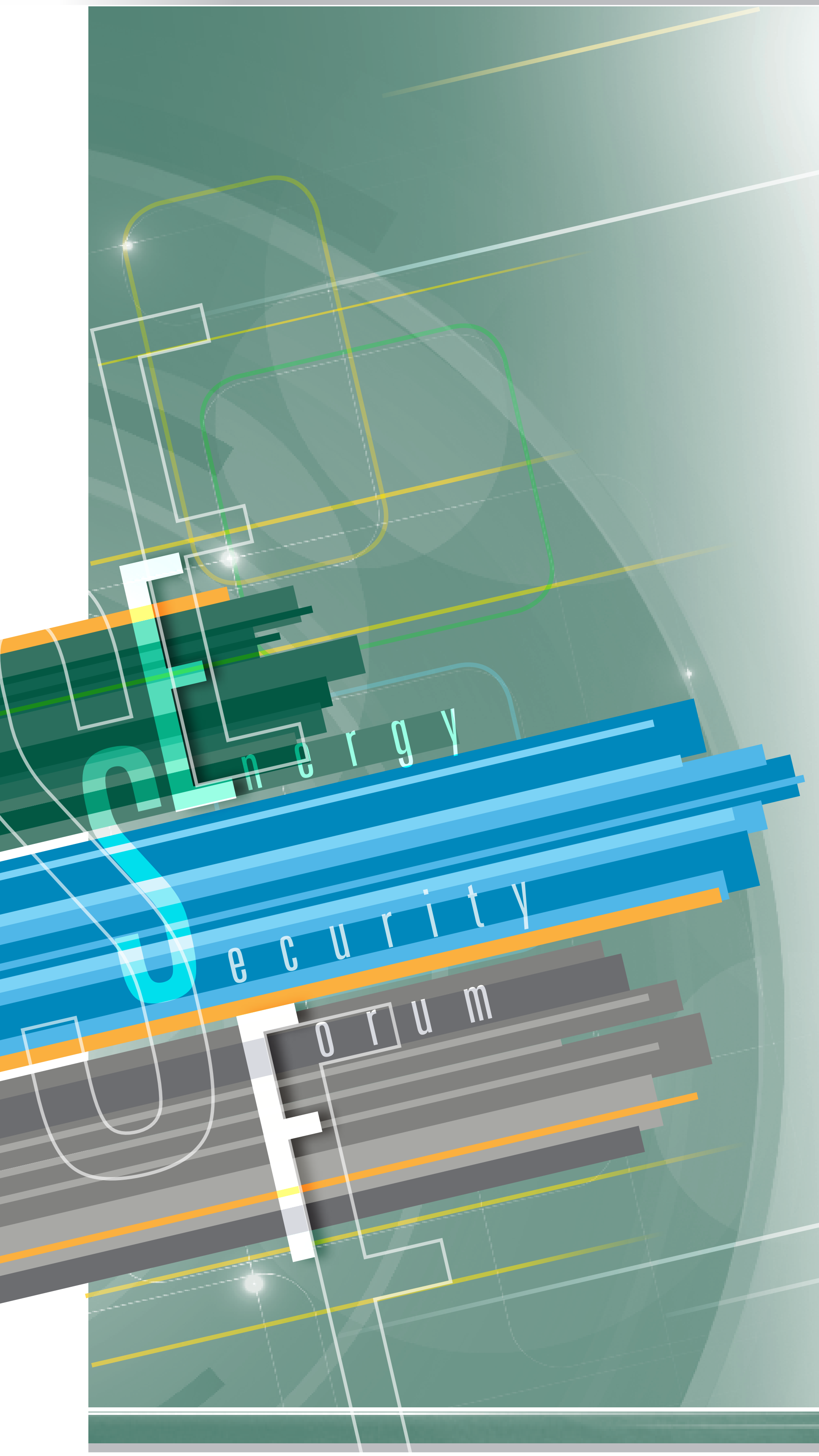

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Editorial

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The seventh volume of "Energy Security Forum" journal is the first one officially released by NATO Energy Security Center of Excellence.

Dealing with increasing fuel prices, having a reliable energy source for operations, being safe against attacks on fuel convoys are currently the main questions regarding the operational energy security. Army needs innovative and smart solutions of how they use or even produce the energy. Another thing must be kept in mind – the first army's priority will be always to complete the mission. So the energy efficiency and self-sustainability in the military should be considered from different point of view.

Currently there is a number alternative and renewable energy source technologies developed. It is worth to mention that there is no best alternative solution for replacing the conventional energy sources – it has to be a complex solution. The alternative energy sources vary from popular solar or wind power plants to small nuclear reactors and waste-to-energy plants. Each has its own advantages but must be carefully considered before implementing it for the military. The good practice was revealed at US military established "Net Zero" and UK "PowerFob" projects. Currently there is ongoing project in Taurage battalion in Lithuania called "Energy Management of Expeditionary Environment: Towards Smart Energy Base" – it will review the possibilities of military installations and deployable missions being energy efficient and self-sustainable.

The seventh edition of "Energy Security Forum" observes what challenges can arise when implementing alternative energy sources to stationary military installations and to deployable missions. This time our experts emphasize on question "Energy self-sufficient military installations: wisdom or folly?" and give their best insights to the reader.

Rene D. Kanayama (Chairman of the Board and Corporate Director, Japan Investment Advisory Council), writes about self-sufficient energy installations and its dependence on a local grid. The article aims to provide an overview of possible alternative energy sources and reminds that there must be a combination of alternative energy sources to substitute current conventional energy sources; as well nuclear reactor is presented as possible self-sufficient installation. Current costs for the fossil-fuel used by the military are still a big topic and renewable energy sources are greatly considered. By considering increasing energy efficiency and application of innovative technologies more lives can be saved and less expenditure could be generated.

Zuzana Mjartanová (Prague Security Studies Institute, Masaryk University in Brno, Czech Republic) reveals real-life options for military energy self-sufficiency, where "Net Zero" is the new name for the future military installations. For complying balance between the power output and consumption during the yearly basis smart micro-grids are proposed, but of course it has its own pros and cons. Like how to solve a problem when the micro-grid cannot be relying on renewable and conventional energy sources and during some deployable operations connection to the local power grid is impossible. Article overlooks the main problems regarding the most conventional alternative energy sources and their adaptation at specific conditions, as well the financing problems. To sum up the current renewable and alternative energy source technologies lack confident reliability and cost-effectiveness, but nevertheless by putting more effort in reaching self-sustainability and continuing including alternative energy sources to military energy mix can lead to suitable solution for national energy security model.

Col. Paul E Roege, (P.E., US Army) raises concern about the increasing threat to logistic fuel as well as to externally-supplied energy, which support important military functions on enduring installations. One of the recent reports from US Defense Science Board (DSB) recommends to "island" military grids from surrounding communities, but that actually has few flaws regarding the current practice and investments payoffs. Another concept introduced by DSB is "resilient communities", which covers the understanding how development of reliability and sustainability for military systems should look like. Such concept demands collaboration among military, local government, public, and commercial stakeholders, in order to develop a deeper understanding of important processes and relationships. It is concluded that the fortress needs to lower the bridge and update its mentality for building resilient systems and military leaders must understand that they are part of interdependent community.

Lt. Col. Ángel Gómez de Ágreda, (Spanish Air Force, J.D. Candidate, Universidad Complutense de Madrid) focuses on Military Bases' Energy independence where he estimates energy security term from more global overview and questions which stakeholders does it includes. From nowadays military perspective everyone seeks for sustainable energy models, but in final result there must be a guarantee to successfully accomplish the mission. For sustainable projects at the military bases it is necessary to have a long term plan. The future military look is combining the energy efficiency (waste management, energy savings, etc.) with new technologies for sustainable power resources. The mission accomplishment will be always the first priority, but currently the possible consequences of implementing sustainable energy sources into military operations should be overlooked with a wider focus and for longer period terms.

Kelvin Wong Programme Manager (Military Studies Programme), SAF-NTU Academy (Singapore) talks about Energy Self-Sufficient Military Installations: Assessment of the Challenges. There is a great possibility of using alternative energy sources for maintaining military energy demand during the military operations as it is currently important way of providing sustainable energy sources, but that as well can lead to significant risks. Article overlooks what is the demand and consumption of energy during peacetime and in times of conflict, as well energy self-sustaining installations possible benefits and threats. The concern is raised that the military personnel should be more informed about the alternative energy technologies capabilities and the technology itself. Every detail for installing alternative energy sources must be considered, like for example energy storage concern. Self-sustainable energy sources at the military operation or at the military installation can lead to significant advantages, but the organisational and technical challenges must be carefully considered before the full technology realisation.

Energy self-sufficient military installations: wisdom or folly?

By Rene D. Kanayama

Chairman of the Board and Corporate Director, Japan Investment Advisory Council

Net-zero paradigm – renewables vs. hydrocarbon

Topic of energy self-sufficient military installations is rather enormous to be covered by a single generic article arguing in favor or against the idea in a fast-changing world and a climate of continuous increase in significance of military operations in most aspects of international relations. Sheer listing of all known technologies utilizing sustainable energy sources and their specific examples of installations around the world would make up for a large booklet. Most of the achievements in use of alternative resources in military installations are credited to the United States and its defense sector, while in civilian production sector, the alternative energy-based equipment and modules are equally en masse produced and applied in countries of European Union, Japan, China. There is a good reason for it – the United States military today needs to offset increasing costs of foreign operations with money-effective and energy-efficient technologies utilized in lieu of largely hydrocarbon-operated technologies and processes.

In a discourse about energy self-sufficient military installations, we often encounter a term "net-zero" energy installations, referring to those units producing exactly the amount of energy that it consumes (in overall balance of any military installation use, the "net-zero" policy refers to energy, water and waste). The reader should note that under a wide premise of "self-sufficient energy installations" we denote both installations that are fully or partially independent on a grid, or such facilities where dependence on hydrocarbon resources has significantly been reduced in favor of alternative, renewable resources. Energy self-sufficient installations, by definition, encompass all such installations that are capable of producing necessary amount of energy without dependence on a civilian grid, and the sources range from solar and wind to geothermal and wave, possibly ocean thermal energy as well as nuclear energy. The article aims to provide a brief overview of non-hydrocarbon alternatives as energy sources to operate military facilities and it should be understood that very rarely one source can substitute all known conventional sources currently used at one facility – in a typical military complex solar panels may be used to heat water, small wind farm to produce electricity to run equipment or used in assets for waste water treatment.

Solar and wind operated technologies as well as mini hydro power units are particularly high in demand for manufacture of so-called micro-grids, suitable for mobile military units or disaster management operations. Furthermore, photovoltaic panels are valued for emitting less heat signature than conventional energy sources, thus making them preferred portable energy gen-

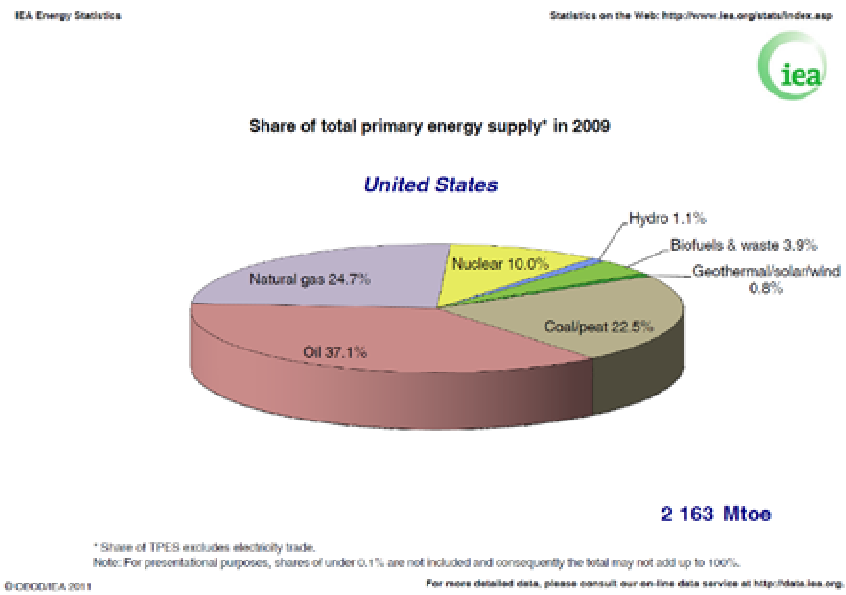


Table 1: Share of total energy supply,USA
(http://www.iea.org/stats/pdf_graphs/USTPESPI.pdf)

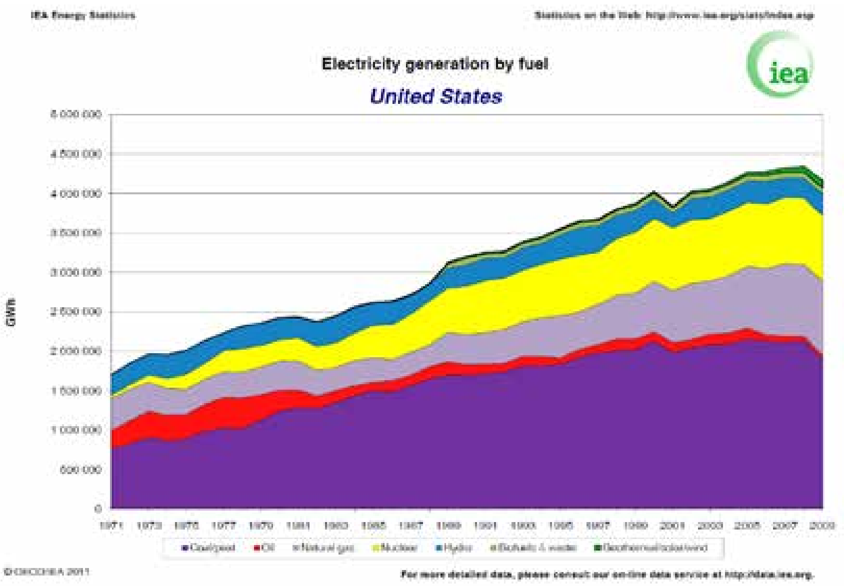


Table 2: Electricity generation by source, USA

(http://www.iea.org/stats/pdf_graphs/USELEC.pdf)

Table 3: Renewable electricity generation, North America (including hydro, geothermal, wind, solar, tide, wave, biomass and waste,

http://www.eia.gov/cfapps/ipdbproject/iedindex3.cfm)

	2007	2008	2009	2010	2011
North America	765.2325	810.986	833.7097	841.119	NA
Canada	375.444	381.464	379.474	366.416	399.131
Mexico	37.041	48.59	36.512	47.327	44.286
United States	352.7475	380.932	417.7237	427.376	520.0669

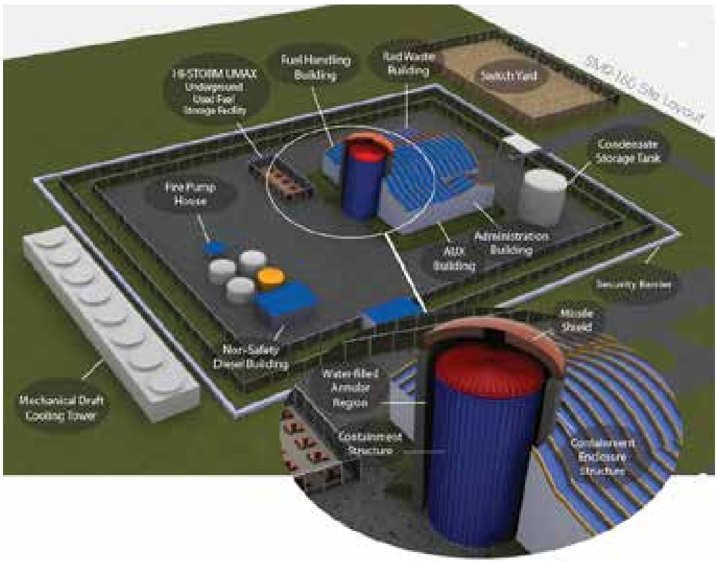
erator in operational facilities. Colonel Gordon D. Kuntz of Army National Guard of the United States even describes "biomass-operated generators utilizing coconut husks, bamboo, and wood as fuel sources to produce energy to power electrical needs of the 150-500 man force".[1]

Nuclear power – real alternative player

Independent nuclear energy generators can also be considered as sources of self-sufficient installations, as they have a significant capacity and time frame of reactor use allocated to it for energy production needed at a remote military installation. In a wake of Fukushima Nuclear Power Plant disaster, nuclear reactor manufacturers started to compete with added safety features – relatively small size and capability of being deployed in an uninhabited area is being propagated as one such feature. In March 2012, at a nuclear safety forum in Kiev, Ukraine, a US corporation Holtec International presented the audience with a concept of "unconditionally safe nuclear reactor" SMR-160 having many of the features making it an ideal candidate for remote locations, including military installations (the presenter actually mentioned the reactor being suitable for far-away desert regions with limited access by ground personnel, such as national laboratories and defense installations functioning off the grid). Refueling cycle of 3.5 years, capability to use air as a cooling medium (elimination of natural water need), no reliance of spent fuel cooling on diesel generators or off-site sources, technology allowing for waste heat rejection directly into atmosphere in case of black-out and a compact 525 MW reactor functioning deep underground are just several features that could be considered by military units for remote, independent deployment. Naturally, the missile shield over the spent fuel pool and airplane crash resistant containment are making this type of energy generator ideal for locations susceptible to possible air strike or ground attack.

Scholars Andres and Breetz, however, define today's potential in small nuclear reactors for military use in those having power output capacity of 300 MW and less (as a power unit the specialists refer to scalable design reactors with power output between 25 and 125 MW), arguing

[1] Kuntz, Gordon D., Use of Renewable Energy in Contingency Operations,2007 (http://www.aepi.army.mil/publications/sustainability/docs/use-of-renew-en-conting-ops.pdf)



Picture 1: Holtec SMR-160 nuclear reactor and site layout
(http://www.smrllc.com/news/hh_27_11.pdf)

that the prime incentive behind installation of grid-independent nuclear mini-plants is to reduce opponent's impetus to attack the civilian grid in an effort to induce a power outage. Again, the argument for the installation of such nuclear mini-plants lies in its replacement capability of conventional fuel logistical chain, so prone to enemy attacks in forward operational locations such as Afghanistan or Iraq. In a post-Fukushima nuclear safety-conscious world, it may serve the cause for these types of self-sufficient installations to mention that U.S. Navy has deployed over 500 nuclear reactors since 1948 and experienced no reactor accident.[2]

Leaving oil and gas behind

In argumentation in favor of energy self-sufficient installations, we could employ several basic sets of criteria – one in relations to decrease of hydrocarbon use, one in relation to general security issues, and one related to overall economy of implementation of alternative sources:

a) Hydrocarbon vs. renewable source

In an era where all government and industry sectors are still dominated by hydrocarbon sources, including military operations and maintenance of installations of the U.S. Army and its NATO allies, let us have a look at basic cost saving factors associated with use of energy self-sufficient installations:

1. Cost of conventional fuel as such – we still depend largely on oil and its products and as major current military conflicts have shown, we operate either in areas with abundance of crude oil but limited refining capabilities (Iraq) or in areas where both the source and products are lacking (Afghanistan).
2. Cost of oil needed to produce the fuel is multiplied by a fact that crude oil is often purchased from countries hostile in nature to NATO operations (Middle East as a whole, Venezuela, Russian Federation).
3. Cost of fuel transport to its needed points of operations is significant given the logistics expenses over territories which are themselves in potential conflict zones (e.g. transporting fuel from Pakistan to Afghanistan, use of refining capacities in Kyrgyzstan and Uzbekistan to supply Afghanistan).

In a discussion what should come after depletion of known hydrocarbon resources or should we aim for emission-free energy source, Freed, Horwitz and Ershow argue that namely nuclear power in form of small modular reactors (SMRs) may be the answer to covering current base-load power needs in the U.S., where 50% of the electricity still comes from coal.[3] (Given that

2 Andres and Breetz, Small Nuclear Reactors for Military Installations: Capabilities, Costs, and Technological Implications, Strategic Forum, 2011 (http://www.ndu.edu/inss/docuploaded/SF%20262%20Andres.pdf)

3 Freed, Horwitz and Ershow, Thinking Small On Nuclear Power, The Clean Energy Program, 2010 (http://content.thirdway.org/publications/340/Third_Way_Idea_Brief_-_Thinking_Small_On_Nuclear_Power.pdf)

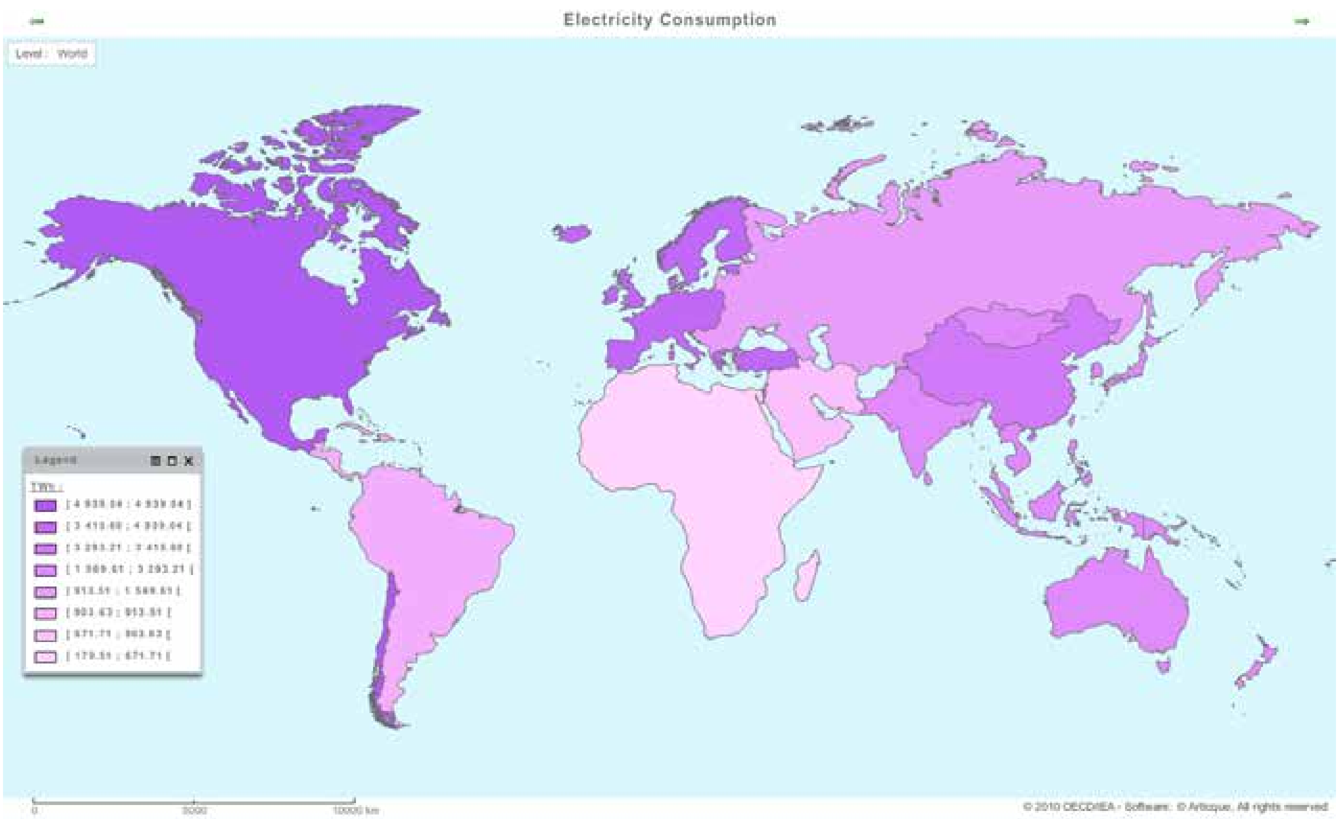
99% of electricity needs today for military is sourced from civilian grids, the predicament of how to achieve carbon-free electricity source burdens civilian and military sectors alike.)

b) Increasing security by deployment of localized renewable sources

At times when cataclysmic events impact our lives more often, it is desirable to localize individual energy sources and separate military installations from civilian grids – this helps effective managing of disasters and gradual restoration of lost power capacities while military units can continue their functionalities unhindered by recovery works in non-military parts of an affected area. Paradoxically, long-term power outages in areas affected by a nuclear power plant accident, such was the case in Fukushima, could be well solved by deploying temporary scalable nuclear power reactors developed for military units, for their compact size and relative power output. The design of such mini-reactors demand their installation be deep underground, making them less exposed to radiation leaks from the accident – in case of deployment of portable solar or hydro devices we will not be able to re-use these later due to their contamination. As the case is with many natural disaster contingencies, the prime role in disaster management is often passed onto military (regardless of a country or region) and thus

Table 4: Fuel imports (% of merchandise imports) in Afghanistan

(http://www.indexmundi.com/facts/afghanistan/fuel-imports)



Picture 2: World electricitay consumption in TWh, 2010

(http://www.iea.org/country/maps.asp)

advanced know-how regarding energy self-sufficient installations possessed by a military proves to be useful during these events.

c) Economy of alternative source implementation

As with any endeavor to change the current status quo, implementation of new renewable sources at military installations, ranging from temporary operational units to permanent housing for military personnel, the process generates jobs and revenues in related industries. While for instance a unit cost of solar panel manufacturing steadily decreases, we attain an economy of scale effect in applying the relevant technology to our everyday use - and the military operations are of no exception.

Going high-tech ensures sustainability

An article in online Forbes Magazine in November 2012 put the dilemma of using conventional fuel in military operations more narrowly in a following description of need to move to "clean energy" by Senator Mark Udall of Colorado:

- The military is 25 percent of government's energy burden
- The Pentagon is biggest consumer of fossil fuels in the world, burning 300,000 barrels of oil per day at a cost of more than $30 million in fuel per day
- A $1 increase in the price of oil increases Department of Defense's energy cost by $100 million per year
- Convoy and security costs $100 per gallon for combat zones.[4]

Udall added: "Saving energy saves lives," and that "adopting clean energy technologies is one of the most patriotic things we can do."

Needless to say, United States is today at forefront of implementation of "green" energy policies across its military – by some accounts the Army, Navy, and Air Force have each established targets of 1 GW of installed renewable energy capacity by 2025.

Table 5: World alternative and nuclear energy (non-hydrocarbon) 2003-2010, in % of total energy use

(http://data.worldbank.org/indicator/EG.USE.COMM.CL.ZS/countries/1W?display=graph)

Ecological concerns, fashionable use of renewable, increasing energy efficiency and application of innovative technologies may all be valid drives behind deployment of energy self-sufficient military installations – the main drive today, however, seems to be cost-related incentives (many argue that live-saving factor plays the main role here - in cases related to replacing conventional fuel logistical chain with advanced energy self-sufficient installations for instance, but that in turn is a quantifiable facet on its own – more lives we save, less expenditure we generate). With the relatively fast dissemination of information and spread of technology use to our adversaries, national defense budgets need to plan for re-allocation of financial sources for research & development programs and advancement in military technologies and hardware and thus significant cost savings attained with use of energy self-sufficient installations do justify raised focus for their utilization. Wider use of energy self-sufficient installations, in whatever form or energy source, will therefore lead to ensuring integrity and sustainability of military objects, having an acceptable burden on national budgets and gaining popular recognition as a „must have" technology in peace and conflict times alike.

[4] http://www.forbes.com/sites/pikeresearch/2012/05/11/u-s-military-not-retreating-on-clean-energy/

Real-life options for military energy self-sufficiency

Zuzana Mjartanová

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Energy security and sustainability are operationally necessary, financially prudent and essential to a military mission's successful completion. Vulnerability of civilian power grids, logistic issues with transporting large quantities of conventional liquid fuel via convoys through hostile territory or the possibility of cyber-attacks on critical infrastructure all pose threats to the daily operation of military facilities. The question today is not whether military installations should be turned into "islands" of energy self-sufficiency not, but rather how to achieve this change and to what extent is this transformation feasible. This article hopes to provide a critical assessment of the feasibility and impact of the introduction of new power generating technologies on the day-to-day operations and efficiency of military facilities.

Today military installations typically rely on large-scale commercial power grids. Potential outages are covered for by diesel-powered generators. Power production by diesel fuel suffers from low efficiency, high costs and has a negative impact on the environment. These generators can provide power only for periods of few hours or days at maximum. In addition diesel generators are fully dependent on a continual and timely supply of fuel. The transportation of fuel is a high risk operation as fuel convoys are a vulnerable target in war zones, risking the lives of convoy personnel. In 2009 US President Obama signed Executive Order 13514 ordering the Department of Defense (DoD) to increase the share of renewable energy in military installations´ energy mix to 20% by 2020. The concept of net zero energy was also introduced, according to which all new military installations built after 2020 must be in accordance with the "net zero" concept by 2030.[1] This concept requires all military installations to produce as much energy on-site from renewable energy generation or through the on-site use of renewable fuels, as they consume altogether (including building, technical facilities and equipment, vehicles etc.). It is important to note that the net zero concept is not a strategy for self-sufficiency, as it requires the output and the consumption of energy to be balanced on a yearly basis. Still it clearly shows that the world´s most sophisticated army is turning to more energy efficiency, independence and environmental sustainability.

One way of complying with the net zero energy concept is the proposed installation of so-called smart micro-grids, which could help in attaining self-sufficiency for some installations. Micro-grids are islanded power grids connected to the conventional civilian grid. The prerequisite is the existence of renewable and/or alternative technologies generating power on-site, and existing demand outside the micro-grid. During energy surplus periods power flows from the military site to the utility grid. When there is an energy deficit on-site, the power flows in the opposite direction. With this, one can achieve the goal of having net zero energy consumption. In the case of hostile attacks or any other threat, installations and the whole micro-grids can be disconnected from the civilian grid.[2] As well as being independent when needed, micro-grids have the advantages of being relatively resistant to cyber-attacks. But the question of total self-sufficiency remains. The installation naturally could not be dependent only on renewable and alternative sources or conventional diesel-powered generators. Also, it is questionable whether the concept can even be applied in deployed operations where in some cases connection to a local power grid will not be possible.

High-tech renewable sources installed on-site could contribute to self-sufficiency in the future. One of the reasons why we cannot achieve energy independence with current technologies lies in the intermittent nature of renewable energy technologies and their vulnerability to attacks due to their visibility on the site. Renewable energy technologies need specific geographic con-

[1] http://www.armyeitf.com/downloads/ASA(IEE)%20energy%20goal%20attainment%20policy%20(24%20Aug%202012).pdf, last accessed March 28, 2013.

[2] Samuel Booth, John Barnett, et al. *Net Zero Energy Military Installations: A Guide to Assessment and Planning.* Technical Report from National Renewable Energy Laboratory (August 2010), p. 5-6.

ditions in order to be reliable. Pumped storage hydro plants could balance demand during peaks or troughs, but they need to be placed on elevated sites, which are not always available. Geothermal energy is relatively reliable, but again specific natural conditions for this kind of power plant / heating facility are required. Photovoltaic, despite the continuing decline in average prices, is an expensive source for power generation and therefore not so attractive an investment. Still it could significantly lower dependence on outside supplies of energy when used for water heating. Wind power plants are too dependent on airflow conditions, prone to attacks due to their visibility, and radar interference from turbine blades makes their use at air facilities even more problematic. This is one example of technology having a negative effect on day-to day operations.

An additional problem with renewable sources is the storage of electricity, as it is technologically impossible to balance production and consumption. Smart micro-grids are a solution, but as stated above, connection to the civilian grid may still be challenging, and even during outages when the micro-grid is operating independently, it needs to use the surplus of power somewhere. Battery technology is not sufficiently developed at present to serve as a backup for critical facilities, and significant progress in this area is essential if military installations are to be energy self-sufficient utilizing renewable sources. This, however, is a long-term objective – after all, humanity has been trying to solve the problem of energy storage since well before the invention of electricity over a century ago.

Among the more promising alternative sources is waste-to-energy (WtE) and waste-to-power technology. Each installation produces significant amounts of waste, which if used to generate energy could both improve waste management and increase energy security. Most of the current WtE technologies use combustion to produce electricity or heat. Other technologies can convert waste to combustible gas that can be further used (for example in gas cogeneration plants). Advantage of the WtE technology is the zero cost of input (garbage) and the possibility of immediate regulation of output. Disadvantages lie in possible environmental impacts. Not only does the burning of solid waste produce notable amounts of carbon dioxide and toxic fly ash, but also dumping sites may be a potential health hazard and therefore need to be placed at an adequate distance from the installation. Nevertheless, waste-to-energy could considerably contribute to the energy independence of military facilities.

Small nuclear reactors / modular reactors are another option for achieving self-sufficiency. Under small reactors we understand reactors with installed capacity of less than 300 MWe.[3] They can decrease or absolutely remove dependence on civilian electric grids and could also ensure the safety and reliability of energy supplies to troops during overseas operations. Total energy independence eliminates incentives for hostile forces for targeting local utility grids as such attacks would not inflict any damage on military installations. Another advantage of small, portable reactors is that they could potentially be used in the field to power hydrogen electrolysis units to generate hydrogen for vehicles.[4] This could lessen the reliance on liquid fuel and associated logistics support during operations. One disadvantage of small reactors is the nuclear energy itself – it is not safe to build them in the immediate vicinity of the installation as possible breakdown or attack would inevitably lead to a catastrophe. Other concerns point to the problem of nuclear waste. Even if some smaller devices have a lower footprint, there is a widespread unwillingness to deal with nuclear waste because of the perception of putting the lives of personnel in danger. One more obstacle for the use of small nuclear reactors is water availability. Reactors need substantial amounts of water for electricity generating turbines and for cooling. This poses obvious problems in regions with high water scarcity. The cost-effectiveness of small reactors is limited by their small scale of production, as conventional large reactors achieve their feasibility through economies of scale. Still, they could be more reliable and effective than diesel generators.

The last problem which affects all these technologies (renewable, alternative, nuclear reactors) is the requirement for extensive investments. The incentive of clean or energetically secure military installations has to be balanced against a stringent financial environment where any form

[3] Richard B. Andres and Hanna L. Breetz. *Small Nuclear Reactors for Military Installations: Capabilities, Costs, and Technological Implications*. National Defense University: Centre for Strategic Research, February 2011, 1.

[4] Ibid, 4.

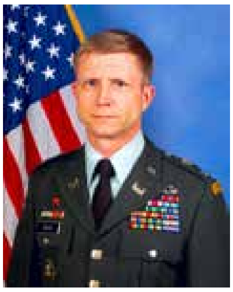
of large-scale long-term investment is deeply troublesome – augmented by the image problem of the military itself in many nations. One solution to the financial issue could lie in collaboration with utility companies through power-purchase agreements and long-term utility energy service contracts.[5] These companies could fund energy projects whose financing from traditional sources (from the state budget) would be problematic. The contract would give the private sector confidence that they will recoup their initial investment within a fixed period of time, and at the same time, military installations would gain confidence in an uninterrupted supply of energy. One potential problem is a lack of expertise among utility companies in dealing with the entirely different risk management culture which applies in the military. In addition, the companies themselves identify perceived risk deriving from cooperation with the army (and with government bureaucracy).

In summary, it is not possible to achieve the goal of 100% energy independent military installations with current technologies in a cost-effective manner. It is feasible with the use of diesel-power generators, but this is not environmentally friendly and provides risk factors in the form of flammable liquids which need to be transported through and stored in a potentially hostile environment. Furthermore, reliance on oil products carries geopolitical vulnerabilities. Renewable energy sources cannot be considered as a basis for self-sufficiency of military installations due to their intermittency and vulnerability. Small nuclear reactors are very promising;. but require substantial investment both financially and in image management to transition from concept to marketplace.

Nevertheless, the military should continue in further efforts to reach self-sufficiency. First, it should include renewable sources in energy mixes (as the US DoD does today) in order to achieve a greater variety of sources. Second, defence departments and ministries should support the development of new technologies, such as small modular reactors. As in so many other areas, a defence incentive can accelerate research and development in this area, which carries clear economic benefit as well as significantly increasing national energy security, overall.

5 *Collaboration between Army Installations and Utility Companies.* Research Brief: Rand Arroyo Center, 2011.

Making Installations Stand-alone – Wisdom or Folly?



Col. Paul E Roege

P.E., Colonel, US Army

Evolving Threat

People have organized and protected their communities from physical threats for thousands of years, building all forms of fortresses and walled cities. Over the past century, social, political and economic structures, enabled by technologies, have significantly reduced the perceived need for turrets and moats in developed areas of the world. While terrorists and criminals still pose physical threats, it would seem that marauding tribes with clubs and spears have been replaced by cyber warriors and other asymmetric threats. In this new domain, increasingly efficient information, energy, water and transportation networks have become the basis for private and public well-being. These extensive networks, by nature, transcend traditional geographic and even political boundaries; the functions themselves are becoming highly interdependent. Energy networks power transportation and communication systems, but themselves depend upon reliable and efficient information flow and analysis. Unfortunately, these rapidly advancing social and financial infrastructures face increasingly frequent disruption due to both natural and hostile events. Consequences can be extensive and the impacts severe; traditional fortress defense concepts are proving inadequate to protect us.

Energy Islands Proposed

In 2008, the US Defense Science Board (DSB) issued its report, "More Fight - Less Fuel,"[1] highlighting not only the operational and security challenges associated with the logistic fuel-based energy approach in expeditionary operations; it also recognized the substantial vulnerability and increasing frequency of disruptions to externally-supplied energy supporting important military functions on enduring installations. This finding amplified concern within the US national security community over energy vulnerabilities, and helped to motivate such mitigating steps as the establishment of the Office of the Assistant Secretary of Defense for Operational Energy Plans and Programs. Among other recommendations, the report asserted the need for military installations to develop capabilities to "island" their electrical power grids from surrounding communities, thus enabling them to continue their missions, especially in the face of extended disruption to the civilian electrical power grid. This principle of self-reliance is a natural extension from current "mission assurance" concepts, which focus on assuring isolated reliability and continuity of service to critical functions, generally through dedicated generators and stockpiled fuel.

The "islanding" concept recognizes the importance of military missions, but in its simplicity, suffers from three fundamental flaws. First, most installations share important functions with their surrounding communities; aligning energy priorities with installation boundaries rather than operational functions would be counterproductive in terms of readiness and response. Nearly every military base relies upon external sources of energy, water, food, communications and transportation and other services, and many have agreements in place for mutual assistance such as medical, law enforcement and emergency response capabilities. By viewing our fence line as the "shore," military installations forfeit the potential to support important "offshore" functions in favor of some possibly less critical activities that happen to be situated on the installation proper. Second, the US military *exists* to support national security - which includes essential support to our civilian population during emergencies. A strategy to simply isolate and sustain those functions located on an installation would arbitrarily cede the opportunity to mitigate consequences and accelerate broader recovery by considering community-wide functions during planning and design. Finally, large-scale alternative energy projects are being sited on military installations to displace less desirable fossil fuels. Most of these projects rely upon the larger electrical power grid to buffer their inherent variations in generation rate, and to provide power

[1] US Department of Defense, Defense Science Board Report, More Fight – Less Fuel, Washington , DC, February 2008.

on demand - especially in the case of popular wind and solar sources. If installation commanders hope to leverage these alternative sources to support stand-alone operation, it would require substantial additional investment in dedicated energy storage, distribution and control systems. Such investments are difficult to justify because they do not directly reduce the energy bill.

Resilience to Face of Dynamic Threats

An alternative concept that would more fully address the DSB's underlying concern is one of "resilient communities." In this context a useful definition of resilience is: the capacity of a system, enterprise or a person to maintain its core purpose and integrity in the face of dramatically changed circumstances.[2] Community resilience recognizes mutual dependencies between and among today's military and civilian communities, and introduces the importance of enhancing the ability of the system of systems to respond to natural events or hostile attack. Rather than focusing on a few critical design features and supplementing them with redundant capabilities for contingency use, resilient design suggests that we avoid creating single points of failure in the first place. The idea is to start with fundamentally robust principles – stable and sustainable – then incorporate such attributes as diversity and flexibility into system designs, ultimately to deliver capabilities that are by nature less critically dependent upon specific conditions.

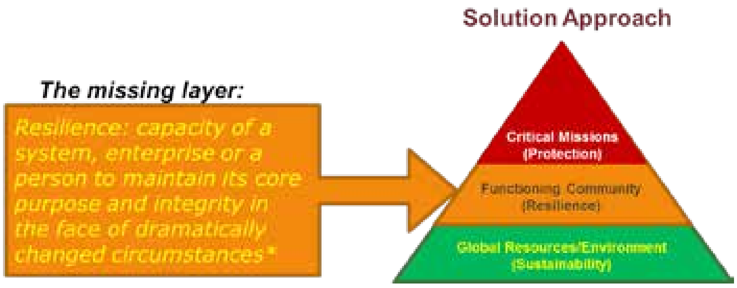


Figure 1 - Resilience Supports Entire System

Resilience itself has been a fading concept in post-industrial society, but interest has recently begun to resurge. In fact, several civilian organizations have established research efforts and advocacies, such as the Community and Regional Resilience Institute (www.resilientus.org) and the Infrastructure Partnership (www.tisp.org). Within the military community, the concept suffers from an apparent dissonance with two deeply embedded principles: structure and control. Western military leaders generally learn, lead and succeed by analyzing and planning missions, obtaining resources and authority, then firmly controlling execution. Military planning is highly structured, and command relationships and expectations are clear. In apparent contrast, resilience thinking requires consideration of broader, more ambiguous situations, and a more complex risk calculus. Solutions are neither obvious nor discrete, and military leaders may lack the full authority or resources to execute them. While these ideas may be uncomfortable, the new approach could be important to sustain overall security though both frequent, minor disturbances and the occasional but disruptive "black swan" event.

Resilient design would not necessarily displace existing approaches for reliability or sustainability; rather, it offers an organizing context for existing efforts while providing a practical and affordable means to address a broader range of important capabilities. Existing mission assurance programs provide reliability for systems whose failure, even over relatively short durations, could have high consequences. Sustainability programs have largely focused upon global issues such as resource depletion or environmental impacts, with relatively weak ties between program goals and the capabilities of the system at hand. Resilient design respects both reliability and sustainability, integrating and relating them to broader operational needs and system behaviors over short and long time frames. A resilient design could, for example, integrate renewable sources, energy storage and intelligent control systems in a manner that reduces environmental impacts and dependence upon external energy logistics, yet increases both system reliability and responsiveness to real-time demands during normal operation or emergencies.

2 Andrew Zilli, Resilience: Why Things Bounce Back (New York: Simon & Schuster, Inc., 2012), 7.

Reaching Beyond the Fenceline

Disruptive design approach is not the only challenge inherent in pursuing community resilience. In the structured military environment, leaders are accustomed to managing the resources they are allocated through the budget system. Commanders reasonably focus their attention toward decisions and investments defined by installation boundaries. Under normal circumstances, they have neither the resources nor authority to manage or improve off-base capabilities. However, a resilient community approach demands collaboration among military, local government, public, and commercial stakeholders, in order to develop a deeper understanding of important processes and relationships. This cross-community dialogue is important to synthesize an understanding of system dynamics and needs and, in turn, inform decisions that may lie in the respective domains of various stakeholders. Better understanding of community needs and interactions would also provide important insights for operational modes, contingency planning, and designs for such projects as smart grids and energy storage – regardless of ownership.

Figure 2 – Installations as Part of a Community

Meanwhile, military budgets are already strained to satisfy operational demands, maintenance needs and sustainability mandates. Appropriated funds are limited and expected to decline even further in the coming years. In response to this long-term trend, the Department of Defense has developed innovative business processes that leverage private investment to provide for reimbursable services such as electrical power, water and housing on installations. While these mechanisms may seem to reduce military autonomy, they have incidentally increased collaboration and teaming. Resilient community efforts could further leverage other relationships, analyses and planning capabilities developed over the past several decades in areas such as health care, law enforcement and emergency management.

Maturing our Understanding of Energy

Ultimately, a substantive system transformation would require a conceptual maturation from the common perception of energy as a simple commodity - to be produced and delivered at the lowest possible price - to one that recognizes and values other energy attributes such as reliability, stability, timing and management capability. People intuitively understand that such factors have tangible impacts, not only to military operations, but to industrial processes and even entertainment. Millions were forced to extend their Superbowl parties on February 4th, 2013 by more than a half hour due to a power failure in the Superdome. In some other circumstances, reliability or availability shortcomings carry more serious consequences. More comprehensive analyses will yield new insights about energy and its relationship to operational processes, in turn providing the basis for design and even more challenging reform to energy policies and business processes. For example, energy pricing eventually could be restructured to factor in attributes of importance, such as reliability and stability, in real time. Deployed with requisite technical and sociological advances, "smarter" pricing could spur innovation and create investment opportunities to improve respective performance, without the need for direct Government subsidies.

Figure 3 - Example Energy Attributes of Importance

Energy Value Depends upon Application		
Reliability	Stability	Environmental Impact
Capacity	Flexibility	Quality
Delivery rate	Energy density	Responsiveness

The time has come to update our fortress mentality with a more modern networked perspective. In energy, as in other domains, we should not try to build a moat at the fence line. Instead, military leaders must accept their positions as members of an interdependent community. We must work together to build resilient systems that function efficiently and sustainably under normal conditions, and respond gracefully in the face of contingencies. Building community resilience will require new analytical tools and culture change, but the effort can evolve in the larger context of national and international resilience efforts. The change may be uncomfortable, but the alternative of "business as usual" leaves our efforts disjointed and our communities unnecessarily vulnerable. Rather than digging new moats, we may need to lower the bridge.

Military Bases' Energy independence

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Energy security does not, by any means, equal energy self-sufficiency. Not necessarily, at least. In a globalised world there are little chances that a nation will be energy self sufficient regardless how much energy it produces. It also goes far beyond purely being able to fill the tank every time we need to. Assured access to energy resources needs to be guaranteed in the short, medium and long term. That implies that our providers need to be able to address our demand, but also that the model itself is sustainable from the economic, social and political points of view.

Security is not an absolute term itself. You "feel" secure, you "believe" you are safe, but there is no such thing as a foolproof system that will provide certainty that you will get what you need, when you need it and at a price that will meet your possibilities.

More and more, we are designing our organizations in such a fashion that they will be able to withstand unforeseen events, learn from them and evolve accordingly. Resilience, more than security, will be the watchword of tomorrow's world, if not today's. The amount of change taking place in our societies, the tempo at which technology pours new factors into the equation and the ever more complex number of intertwined relationships that exist make it almost impossible to strive for perfection. Not to mention lasting perfection.

And yet, given the huge investments that betting on a specific model imply, we need to make sure that whatever we design is going to be valid until, at least, it repays itself. Flexibility and sustainability are linked to modularity and diversification. Industry and science no longer use trial and error, we shouldn't either. The path to perfection does not always go in a straight line and the closest that we may be able to get to a perfect model might be very different from the ideal.

When it comes to thinking about the design of energy models for military bases, we will need to have all these factors in mind since a purely commercial approach will not suffice. Our model will have to be:

- Sustainable in terms of supply, affordability, maintainability and the effects on the environment and public opinion
- Efficient, as it will need to minimize the logistic footprint
- Adapted to local circumstances and, therefore, able to take advantage of the possibilities available both in terms of supply and reduction of demand. It will also need to take into account the vulnerabilities of the base, so that
- It is able to guarantee the accomplishment of the mission. This one being of paramount importance and key to the acceptability of the model.

Sustainability of energy models

A sustainable model is one that will be able to cover, for the foreseeable future, all the energy demands for a system. It is also a model which is and will continue to be affordable even in modern ever-changing market conditions. It will need to be acceptable both in social, legal and political terms. While, say, a nuclear power plant could very well provide electricity to most military bases worldwide, it is very unlikely that such a solution would be palatable for public audiences. Neither would it be the preferred way out because of the consequences its potential destruction would entail.

When it comes to designing an energy model for our military facilities at home and abroad, does it make sense to make them autonomous? Should we design our bases so that they are able to operate in isolation? Do we need to build base-generated renewable energy sources? What are the advantages and the drawbacks of such an approach?

Efficiency

Arguably, a global market usually is a more efficient one. That is the reason why a high degree of connectivity in pipelines or electric grids allows not only for benefits of scale but it also opens the possibility to adopt the most favorable mix for any given period of time. Wind turbines and solar panels combined provide a much better chance of energy being available at any time than either of them separately.

One recent example of these two sources being used jointly can be found in the Spanish Army's base of Viator, in southeastern Spain. A careful study of wind and sun conditions led to the deployment of a few solar panels combined with one wind turbine to provide energy to a remote outpost inside the base. Neither technology could have offered a viable solution by itself.

Defense is a critical service for our societies. As such, it is a service that needs to be provided 24/7. Neither critical services nor critical infrastructures can determine their energy mix on economic considerations alone. A number of criteria need to be met so that a solution is eligible to provide power for our military.

When it comes to critical infrastructures and services, survival is paramount. When you are dealing with defense, accomplishing the mission is a prerequisite to establishing desirable criteria. Once mission completion is assured you can -and have to- look for ways to do it in such fashion that you minimize harm and cost. Anyhow, efficiency can only be sought when efficacy is guaranteed.

On the other hand, society and common sense demand that Armed Forces make the best possible use of the resources provided by tax payers. Every dollar or euro saved in the process of supplying energy to the military can be used to improve other areas and enhance the readiness of the services. Furthermore, the mere fact that something is a critical infrastructure or service does not exempt it from contributing to the mitigation of climate change through the reduction of emissions. Sustainability, being a long term concept, needs to be considered not only for the expenses that we will incur today, but for those that will arise tomorrow based on the actions -or inactions- of the present.

Not one size fits all

During the Industrial Era we were prone to providing answers that would solve all problems. Mass production and mechanization ruled and we tried to develop something which size would fit all. Presently, we are full into the Knowledge Age (not the Information Age any more as there is plenty of information available and real value lies in understanding and making sense of the information and not in data itself) and we have moved from chain production to customized solutions, very specific for the problem at hand.

Even if I believe that we should avoid classifying everything around us (for that oversimplifies the problem), it is pretty obvious that, when addressing the subject of energy independence for military bases, we need to consider, at the very least, four different types:

- Large operational bases,
- Headquarters and administrative sites,
- Remote fixed outposts located in the homeland and
- Forward operating bases.

Each of these merits a different approach based on common characteristics notwithstanding individual consideration depending on unique features.

Large bases at home are roughly equivalent to neighborhoods or entire cities. As with those, they include critical facilities which need to be guaranteed permanent access to energy. Much like in the case of Headquarters and administrative sites, applying the criteria exposed above will demand that we apply the same principles that are already being used in the smart city concept. Whenever legally, technically and economically feasible, we need to create our own built-in energy generation station so that we are able to contribute to the sustainability of the general grid.

It could be argued that the energy produced by these military facilities ought to be, at least, enough to power the critical services within. Anything beyond that line should be regarded as an added value, should it exist, to the economic sustainability of the military. Location and physical characteristics of the base will determine which is the source -or combination of sources- that best suit each facility.

Introduction of the concept of energy security in the design of our bases and of its sustainability should lead to the identification of the best approach in each individual case. The expanse of most military facilities allow for large surfaces devoted to generation and to waste management. Anyhow, special attention should also be devoted to the design of the grid, the efficiency of buildings, tools and appliances, and to increasing the awareness of the end users.

Many nations may find the idea of armies producing and selling energy as against the law as it would make them competitors to private owned companies whose business is energy generation, storage and distribution. Should these problems occur, commercial agreements with these corporations could be reached so that they own and operate the system inside the bases.

That would hardly be a problem in remote outposts where no private company provides service. Energy self-sufficiency is a must in these cases. Betting for renewable energies is almost mandatory as reliance on outer supply would amount to adding vulnerabilities to the outpost.

The Spanish MoD is currently designing and building power generation stations in several remote outposts located on islands off the coast of Africa. Physical conditions (such as geology, meteorology,...) will determine which type of energy source is more appropriate in each individual case.

It could be tempting to adopt the same approach for forward operating bases than for remote, isolated outposts at home. Nonetheless, since the former are both more prone to attack by enemy forces and more offense-oriented (and, therefore, more likely to use more energy and other resources), operational concerns need to take precedence when dealing with them.

Military facilities as critical assets

Efficiency can only be sought for after a minimum efficacy has been achieved. Remote outposts at one will benefit most from autonomous solutions which take advantage of local weather or geological circumstances while reducing the environmental fingerprint and allowing savings in infrastructure.

Front-line bases should also try to minimize the logistic burden by means of self-sustainability as long as it does not imperil fulfilling the mission's goals. Ad-hoc studies will be needed as to determine which is the acceptable degree of dependence each particular base can have on in-house generated energy. As a general rule, most non-mission critical supplies could be eligible as long as there is enough redundancy in the systems.

We do not need to rush into current technology and try to apply it across the board. A cautious approach would first identify which are the facilities where there is more potential for the use of indigenous energy, which ones need to be self sustained and which ones would provide most savings.

A review of the facilities implementing these types of initiatives in the US military shows that is the approach the Pentagon has taken so far. The US is probably one of the most advanced nations regarding specific legislation towards energy use and greenhouse gases emissions. Executive Orders 13423 and 13514 address both these issues together with the Energy Independence and Security Act of 2007 and the National Defense Authorization Act of 2010.

Recent studies show that putting the focus on efficiency and waste management can bring savings comparable to the implementation of new technologies. Attractive as buying off the shelf solutions may be for decision-makers, wisely devised changes in the procedures followed on everyday routines may achieve similar results at a much lower cost. This behavioral approach will eventually have to be adopted however.

Mission first, but with a wider focus

In a nutshell, the best approach for each specific facility will be determined by the criticality of the mission performed, the location of the base, the resilience of outside providers and the economic sense that the implementation of a separate system makes. All of this compounded with legal considerations and approached with an open mind which avoids standardization when conditions are different.

As to what kind of energy should we use, if our Armed Forces are supposed to do whatever it takes to keep our citizens out of harms' way and to provide them with an environment in which they can prosper, they need to do that in such a fashion that this goal is achieved today and is sustainable in the future. Sustainable both in economic, social and physical terms. Overlooking the long term consequences of saving today can imply a heavy burden for the next decades. It can also lead to social disaffection in the short term and to poor environmental conditions for the Nation.

Accomplishment of the mission does not simply mean to timely deliver effects to a certain point. Consideration for the longer term effects in both the target area and in our own social environment is also of critical importance and Commanders will need to be able to include that factor into their planning process.

Energy Self-Sufficient Military Installations: Assessment of the Challenges

By Kelvin Wong

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Introduction

The provision of energy to sustain operations has been an enduring concern for military planners since the dawn of organised warfare. Major energy challenges today include risks associated with transporting adequate fuel to and on the battlefield in order support tactical operations. However, military installations are also significant consumers of energy, and are also affected by the consequences of high operational energy requirements just like tactical units. This paper explores the energy challenges for military installations by identifying some of these issues through the lens of recent operations in the Middle East. New and emerging technologies are often touted as potential solutions to the military's installation energy challenges, but the pursuit of alternative methods to power these facilities may also face significant risks. Moreover, military adaptation to these new technologies may also encounter implementation difficulties from both the hardware (the technological) and the 'heartware' (the people) perspectives.

Energy concerns in contemporary military operations – forward and fixed installations

Challenges with supplying remote expeditionary bases have been starkly illustrated in recent conflicts in the Middle East. Military forces engaged in operations were frequently deployed across vast stretches of austere terrain, and have had to set up support facilities significant distances away from principal supply depots. These deployed forces are thus particularly vulnerable to fuel supply disruptions because of the uncertainties and dangers inherent on the battlefield, and ensuring a steady supply of fuel and power to sustain these widely-distributed combat units can pose significant challenges.

As a consequence, the majority of forward-based military installations are powered by generators which produce electricity for essential functions such as air-conditioning, heating, lighting, and communications. Some military installations have required more extensive air conditioning systems to in order to reduce physiological stress for personnel, while others play host to more extensive command and control equipment. These additional burdens have naturally correlated with even larger fuel and power demand. US Army engineers note that Camp Leatherneck in Afghanistan, a 10,000-strong garrison, consumes approximately 36,000 gallons of fuel every day. At least 15,431 gallons of the average daily base consumption (42 per cent) is expended to operate generators. Similarly, military installation consumption at Camp Arifjan accounted for at least 930,472 gallons of fuel in June 2008, which accounted for 78 per cent of fuel consumption for the installation (see Fig.1).

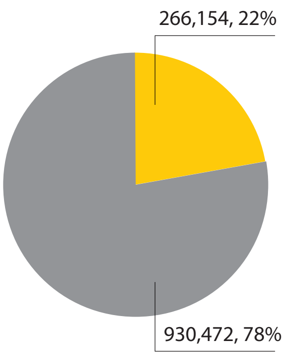


Fig.1 Camp Arifjan, Afghanistan consumed 930,472 gallons of fuel (78%) for installation functions (e.g. for cooling and heating, and powering mission-critical equipment) in the month of June 2008, as compared to 266,154 gallons of fuel for air and ground operations in the same month. (Source: GAO)

Domestic or homeland military installations also constitute an important segment of this study. The energy consumption patterns of military installations during peacetime and conflict can vary greatly. For example, the US Defence Science Board (DSB) noted in 2008 that US Army installations were estimated to have accounted for at least 67 per cent of the estimated annual energy consumption during routine operations in peacetime, while depending on generators for 3 per cent for its needs (Fig. 2b). In times of conflict, it was found that the estimated demand for energy for installations was around 37 per cent, while the estimated demand generators rose to 22 per cent (Fig.2b).

Fixed military installations typically rely on power from the commercial power grid and depend on generators during power outages. As a consequence, military installations can be just as vulnerable to power supply disruptions from events such as natural disasters and power grid failure as civilian infrastructure. The problem is particularly acute given that military installations have a near-total dependency on the commercial power grid for operational energy – it has been reported that 99 per cent of US domestic military installations are serviced by the commercial power grid.

This vulnerability has been clearly illustrated during recent disasters in the US and Japan. Hurricane Katrina brought widespread devastation to the US in 2005, inflicting critical damage to infrastructure across the Gulf Coast. Military installations were not spared from the resultant power outage and had to rely on backup generators to restore partial functionality. Even so, the severity and duration of the disaster exposed the limitations of backup generator systems, and some installations had to be sent aid. After the Fukushima nuclear disaster in Japan in March 2011, the US-controlled Misawa Air Force Base required an airlift of extra generators to the base so that it could continue to sustain critical functions as well as act as a hub for search and rescue missions. The power outage had left communication and fuelling equipment inoperable, leaving the base isolated and hampered air-transportation of search and rescue teams to the disaster site.

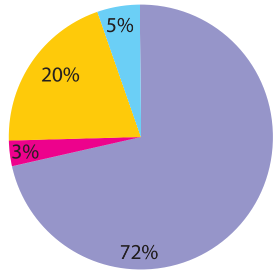
Finally, recent reports have highlighted the vulnerability of commercial power grids to cyber-based attacks which could disable portions of the network for extended periods. Information-technology experts note that concerted software attacks on key parts of the power grid, such as transformers, can trigger a nationwide collapse of the network that could endure for up to 18 months. Such a catastrophic event will have severe consequences for defence readiness, although there is little the military can do to prevent such attacks from occurring. The onus is on the utilities firms to invest in adequate protection against cyber-attacks, and it seems that the level of precautionary measures taken thus far have left security analysts concerned. For example, a 2012 Bloomberg survey of 21 energy firms in the US found that they are currently protected against only 69 per cent of known cyber-attacks, and it would be fiscally unsustainable for these firms to develop a greater degree of protection against known cyber threats. The survey noted that it would cost an average of US$344.6 million per annum to be safeguarded against 95 per cent of cyber threats, but such spending would be unsustainable for even the largest utility firms.

Energy self-sustaining installations: potential benefits

Cognisant of the challenges of energy supply to military installations, a range of technologies are being explored by military forces and defence science organisations. These technological options include acquiring more efficient versions of current equipment such as the ubiquitous diesel-generators that are commonplace in any military installation, to alternative means of power generation by harnessing renewable energy sources such as geothermal, wind, and solar energy. Moreover, military organisations are keen to achieve even greater energy autonomy for their installations by setting up "micro-grids", which are self-contained on-site power generation and distribution systems that may also incorporate some of the aforementioned renewable energy sources.

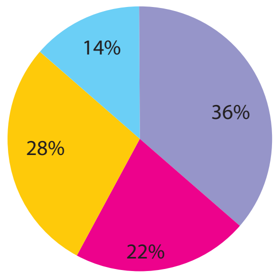
The key thrusts of these new technologies are to: (1) reduce the need for costly and dangerous fuel-resupply missions to forward operating bases on the battlefield, and (2) to reduce the dependency of fixed military installations on centralised and potentially vulnerable commercial power grids. For some military forces, a particularly ambitious and longer-term goal is to achieve near or total energy self-sufficiency capabilities for their installations by exploiting these technologies. These energy self-sufficient installations would, in theory, be able to generate most if not all of the necessary power for operational needs – a capability which would offer a number of operational and strategic advantages upon successful implementation.

Energy self-sufficient forward installations will directly enhance military performance on the operational level by reducing the need for fuel can account for up to 70% of the logistical needs for contemporary military operations, a key advantage which will have higher order positive effects on the supply chain, a virtuous cycle which reduces logistical vulnerabilities on the battlefield. On the strategic level, reduced overall demand for fossil-based fuels by military forces – which often constitute the single largest consumers in many developed nations – will ease national energy security vulnerabilities from a near-total dependency of supply from the volatile Middle East and the oil-price uncertainties inherent in the global energy market.



Installations
Generators
Combat platforms (aircraft and vehicles)
Non-combat vehicles

Fig.2a US Army installations in peacetime. Total estimated consumption was 112 trillion British Thermal Units (BTU) (Source: DSB)



Installations
Generators
Combat platforms (aircraft and vehicles)
Non-combat vehicles

Fig.2b US Army installations in conflict. Total estimated consumption was 208 trillion British Thermal Units (BTU) (Source: DSB)

Energy self-sustaining installations: potential pitfalls

The need to reduce energy supply vulnerabilities on both the operational and strategic spectrum certainly makes a strong case to for the military and defence science community to expend the effort and resources in pursuit of relevant technologies, and a number of these organisations have already embarked on ambitious long-term programmes to deploy such technologies at military installations. However, some critics have raised the spectre of potential issues that have to be appreciated and managed carefully to reduce the prospect of risks and even costly failure.

As military organisations look to expand investment in the necessary technologies to enable energy self-sufficient installations, access to funding will be a particular challenge. A deteriorating macroeconomic climate in Europe and the United States have raised questions over national commitments to tackling military energy dependency and have cast doubt on the availability of financing for relevant energy projects, which can be capital-intensive endeavours. The importance of policy support in making renewable power economically viable and sustainable for industry cannot be understated. For example, credit-rating agency Standard & Poor's has noted that subsidies to solar power projects can account for up to 85% of initial revenue for commercial enterprises.

As a result of competing imperatives, national interest in these programmes can be vulnerable to uncertainties, even if the military is consistently championing the cause. The uncertainty is particularly acute at the early phases when planners are grappling with issues such as permits and approvals, gathering scientific data, land acquisition, and even public-private partnerships. The bankruptcy of the US government-funded solar panel maker Solyndra in 2012 raised accusations of political favouritism and mismanagement of taxpayers' money by government officials. Such incidences impact on the confidence of stakeholders and the public.

Adaptation, economic, and technical challenges

Moreover, large organisations often encounter difficulties during the process of implementing concepts and adopting emerging technologies, and it is no different for military forces in this instance. Considerable organisational and technical challenges need to be addressed before energy self-sustaining technologies can be fully exploited to their greatest effect.

First, it is important to examine organisational and cultural issues that may inhibit the military's energy transition to self-sustaining installations. Organisation and cultural change is essential to effect a successful energy transformation, because warfare is inherently a human enterprise. But what exactly constitutes organisational or cultural change? Military organisations will have affected a culture change when senior leaders instinctively recognise that they are directly accountable for energy consumption, when they understand that efficiency and energy self-sustainment produces its own "effect" in increasing combat capability, and they can appreciate the fact that energy is a consideration in all military activities and operations. Only then will energy self-sustainment be a defining characteristic of military operations and facilities.

However, the lack of knowledge and awareness among military personnel on alternative energy generation concepts and technologies is another major stumbling block in efforts to achieve energy self-sufficiency. Alternative energy generation systems have yet to be widely appreciated, and conventional notions of installation power generation entrenched in their psyche. Some military leaders have noted that there is little reference in existing doctrine and policy regarding operational use of alternative technologies. Limited, if any, information is found in key military publications such as regulations, policies and procedures, technical manuals, supply and re-supply procedures, and operations papers which relate to alternative technologies. It is thus vital that doctrinal instruction be updated to reflect changes in new energy generation and management systems.

Second, new energy generation and management technologies are still not fully mature. For example, integrating micro-grids into the wider commercial network pose considerable challenges, particularly by commercial utilities firms. These firms are particularly wary that the use of alternative energy generation in military installations during a power outage may jeopardise worker safety by maintaining electricity in the grid whilst they are performing repairs or maintenance. Indeed, a US Government Accountability Office (GAO) report noted that four out of five military installations it surveyed were not allowed to engage their alternative energy generation systems during a power outage due to utility worker safety concerns. Therefore, to enable military installations to be connected effectively to the civilian grid, on-site power generated by military installations must conform to acceptable commercial standards. New power interconnection standards need to be developed to ensure consistency and achieve synchronisation between military installations and the wider commercial grid.

Another technical challenge is electricity production and storage in military installations that produce power from inconsistent sources such as wind or solar energy (although it would be logical to assume that such locations would have already been thoroughly investigated before the infrastructure is set up). The challenge then, is to determine the most accessible energy sources that are available in the geographical climate and location of the military installation. Some installations are situated in areas that are not conducive, or downright detrimental, for certain equipment. For example, solar panels set up in warm and humid climates may lose power output if mould is allowed to grow and propagate on the panels.

The greatest weakness in current micro-grid systems seems to be power-storage. To fully utilise the power generated through alternative sources, electricity generated via on-site needs to be stored and then distributed effectively when needed. Power storage facilities such as battery banks adds complexity to micro-grid systems, requiring military installations to devote additional space to install these batteries, as well as requiring regular maintenance for reliable operation. The conventional lead-acid batteries that are most commonly-used to assemble these storage banks have a relatively short lifespan. According to the World Bank, typical lead-acid battery banks in micro-grids can last between three to seven years before requiring replacement depending on the environmental conditions. More advanced batteries such as lithium-based cells have much longer lifespans, but are still relatively expensive at this juncture. However, while current battery capacity cost effectiveness remains relatively low, analysts have noted that cost-effectiveness of storage systems are expected to improve as maturing battery technologies and growing economies of scale for advanced batteries in the commercial sphere become apparent downstream in the future.

Conclusion

It is imperative that military installations remain functional in both conflict and peacetime. Other than the obvious requirement to contribute to the country's defence during times of conflict, military installations are vital centres of support for the civilian populace when disaster strikes. The experience of the US military during Hurricane Katrina already offers a strong testimony to the utility of military infrastructure in providing critical aid to affected civilians. Such large-scale disasters are expected to increase in frequency in the future, and the importance of these military installations in humanitarian assistance operations will only increase. On the battlefield, forward-based military installations require assured energy in order to support tactical units pursuing operational objectives. However, these installations are frequently located in austere and contested territory, which makes resupply operations a costly and potentially hazardous prospect.

Military forces that successfully implement energy self-sustainment capabilities are offered significant advantages. With the ability to isolate itself from the commercial power grid, fixed military installations can continue to remain functional for extended periods of time and maintain mission-critical facilities. Self-sustainable military installations can also reduce the strain on commercial grids by relying on on-site generation of power and only tapping on commercial power when necessary. On the battlefield, self-sustaining military installations diminish the frequency and scale of resupply operations, alleviating logistical burdens and risk of attack on vulnerable supply lines. However, significant organisational and technical challenges remain before these installations can be fully realised.

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