Frontline NATO: Energy, Science and the Warfighter

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The North Atlantic Treaty Organization (NATO) acknowledged the potential impact of energy security issues in the 2010 Strategic Concept and, more recently, in the Chicago Summit Declaration, which underlined the need to integrate, as appropriate, energy security considerations in NATO's policies and activities, concentrating on areas where the Alliance can add value and make a difference. Efforts directed towards a significant improvement of the energy efficiency of NATO's military forces (and at the same time reducing their impact on the environment) were identified as areas to explore.

Several strands of work in this domain are currently being pursued by many NATO committees and organizations, one of the most active being the NATO Science & Technology Organization (STO). The STO is the main venue for NATO Defense and Security Science and Technology. Its mission is to help nations and NATO to achieve a knowledge and technology advantage for their defense and security posture. Therefore the STO promotes and conducts collaborative research in support of military capabilities development, and provides strategic advice to NATO decision-makers. The largest such collaborative body of its kind, the STO delivers S&T results using a "collaborative network" and a "lab". The collaborative network encompasses over 3000 scientists and engineers addressing the complete scope of defense and security technologies and it is supported by the Collaborative S&T Support Office (located near Paris), that facilitates the collaboration. The NATO-owned "lab", the Centre for Maritime Research and Experimentation (located in La Spezia, Italy) is a world-class scientific research and experimentation facility that organizes and conducts scientific research and technology development, centred on the maritime domain, and particularly the undersea, delivering innovative and field tested S&T solutions. The STO is governed by the S&T Board (STB), which exercises overall coordination of all NATO S&T programmes and activities. The STB is chaired by the NATO Chief Scientist, supported by his Office at NATO HQ.

The STO has been active over the last years in undertaking research activities, mainly through its collaborative network, to support the global effort on energy efficiency and environmental preservation, nowadays also referred to as "Smart Energy".
The main current activities are addressing the following areas:
- Power and Energy in NATO Operations;
- Fuel Cells and Other Emerging Man-portable Power Technologies;
- Electric Military Vehicles and Large Battery Packs: the hybrid electric technology is approaching a level of maturity which will allow fielding military hybrid electric vehicles in the near future. Use of large battery packs is currently being investigated.
- Greener Munitions: several studies focus on how to design and apply "greener" munitions, monitor their "health" during the lifetime, and adopt advanced technologies for the disposal and for the mitigation of the contamination of proving ranges.
- Environmental Noise: the current efforts are focused on aircraft noise reduction, improved modelling and management of noise, to address current trends in environmental regulations

which will make it more costly to operate military platforms without minimizing the effects of the noise they generate.
- Scarcity of Rare Earth Materials (REMs) for Electrical Power Systems: the research is addressing design issues associated with military applications of REMs.
- Reduction of fossil fuels consumption: the research is focused on opportunities and threats for vehicles (air, land, and naval), associated with the introduction of synthetic fuels. The Centre for Maritime Research and Experimentation participates in developing an electronic tool to identify the most energy efficient ship routes.

This article presents two very diverse examples of the STO activities. The first study, carried out within the System Analysis and Studies (SAS) Panel, is aimed to analyzing the impact of rising power and energy demands in military operations, as well as developing a baseline of current power and energy usage data to determine the requirements for power and energy in operations, defining common performance measures and models to conduct options analysis for power and energy consumption optimization.

The second research effort, under the aegis of the Sensors and Electronics Panel (SET), is addressing fuel cells and other emerging manportable power technologies for the NATO warfighter. The focus of this effort is on the individual soldier and unmanned platforms applications.

Military operational energy modelling and analysis

Military operational energy is defined as the energy required for training, moving, and sustaining military forces and weapons platforms in operations. It also includes the energy demand from tactical systems and generators in operational bases. The demand and cost of military operational energy have increased considerably over recent decades, creating several logistical challenges in the battlefields. Indeed, increased operational energy demands drive thicker logistics tails that can slow operations, limit maneuverability and deployability, tie up force structure in combat support, create untenable force protection requirements, expose personnel to serious and unnecessary risks, and reduce the likelihood of mission success [A. Bochman, Measure, Manage, Win – The Case for Operational Energy Metrics, Joint Force Quarterly, vol. 55, no. 4, pp. 114-119, 2009].

For example, fuel delivery convoys along vulnerable lines of communication in Afghanistan have often been prime targets for insurgent forces. Protecting these convoys imposes a high logistics burden on combat forces by diverting combat units from direct engagement to force protection missions. Reducing the need for operational energy can have significant benefits, both for force deployability and sustainability.

One of the fastest ways of reducing the operational energy demand, especially fuel demand, would be to optimize current energy usage patterns. This could be achieved through cultural changes and operational efficiency initiatives. From a culture change perspective, it is important to increase the awareness of energy issues in operations and to understand the human factor aspects of decision-making pertaining to avoid wasting energy. From an operational efficiency perspective, it is important to take initiatives to optimize the energy usage in operations. This includes the installation of energy efficient structures in camps, the use of tactical intelligent power management systems tapping on local energy sources, as well as the increased use of simulators for training [Defense Science Board, Department of Defense Energy Security Initiatives, The AMMTIAC Quarterly, vol. 9, no. 1, pp. 3-10, 2009].

In the longer term, operational energy demands and costs could be reduced through various technology insertion programs. These could include the development of energy efficient platforms, the use of mature and emerging renewable energy sources for deployed camps, and alternative fuels for mobility systems. In addition, it is important to factor properly energy logistics in the acquisition-decision trade space to reduce life-cycle operations and sustainment costs. This could be achieved through the establishment of energy efficiency Key Performance Parameters (KPPs) for consideration in system requirements development and trade-off analyses. One of the energy efficiency KPPs that could be included in the acquisition trade space is the Fully Burdened Cost of Energy (FBCE). The FBCE concept considers all operational factors in the energy supply chain, including transportation, infrastructure, manpower, maintenance, security protection, and storage of energy [Corley, R. M., Evaluating the Impact of the Fully Burdened Cost of Fuel, Master’s Thesis in Business Administration, Naval Postgraduate School, Monterey, California, 2009]. The FBCE concept allows a proper evaluation of the energy costs when assessing different alternatives in military operations and acquisitions.

As part of the NATO Science and Technology Organisation (STO) collaborative program of work, a task group under the title “Power and Energy in NATO Operations” (SAS 083) was established to research these concepts and to develop a final report that presents two decision support tools for analyzing operational energy issues [Ghanmi, A., Power and Energy in Military Operations, Technical Report, NATO Science and Technology Organization, System Analysis and Studies Panel, Task Group SAS-083, 2013]. The group, which consisted of experts from six NATO nations, was stood up in May 2010 and delivered its final report in June 2013. A FBCE framework was developed to examine the life cycle cost of energy delivered to military operations. A Fuel Consumption Prediction Model (FCPM) was also developed to determine fuel requirements for expeditionary operations.

The FBCE is a scenario dependent methodology used to quantify the total cost of energy, including apportioned costs of the combined energy related logistics needed to store, deliver and protect the energy in a scenario. The FBCE estimate involves the following price elements [ibid]:

- Energy Commodity Price: represents the acquisition price of energy. The actual contracted delivery price should be used where available.
- Tactical Delivery Price: captures the burdens associated with the tactical delivery assets and includes:
    - Energy Delivery Operation and Support Price: energy unit price of operating energy delivery assets including the cost of military and civilian personnel dedicated to the energy delivery and support mission.
    - Depreciation Price of Energy Delivery Assets: decline in value of energy delivery assets over total service life. Combat losses due to attack or other loss should be captured as a fully depreciated vehicle.
- Infrastructure Operations and Support Price: includes the price of operations, support, and recapitalization for the facilities and related ground system equipment. The costs to deploy the related ground system assets should also be included in this price element, if the assets need to be transported to the theatre of operations.
- Security Price: involves the costs of escort protection of the energy supply chain in hostile environments. In essence, all of the costs considered in the tactical delivery price element should also be considered for security assets. This includes the possibility that some security assets will be destroyed due to hostile activity while protecting the energy supply chain.

The sum of the different energy price elements is called the Assured Delivery Price (ADP). To calculate the FBCE, the ADP should be multiplied by the apportioned amount of energy demanded by each end user. The basic framework to calculate the FBCE extends to all forms of energy demands.

There are two key analytical components essential to developing a FBCE value:

- Scenarios. A number of operational scenarios need to be identified. The scenarios should have sufficient durations to require logistical re-supply of energy. Once the FBCE is calculated for the selected scenarios, a simple mean average of the results can be computed if desired.
- Apportionment. The energy delivered out to the battlespace is not used exclusively by the system under investigation, but rather is used by a number of other systems. Defining how much energy is used by a system versus how much is demanded by other systems is termed apportionment. The apportionment should be factored in the FBCE calculation to reflect the exact energy demand of a system.

Operational energy demand is a key parameter for the evaluation of the FBCE. In military operations, energy demand data can be used to develop realistic sustainment plans and to allocate appropriate fuel delivery resources in theatre. From a process perspective, energy demand data is essential not only for budget planning and reporting expenditures, but also for strategic level analysis and decision-making related to the defense operational role, such as force development, strengthening operational readiness, and building a more efficient and resilient force. While energy usage data for domestic infrastructure and operations would be easily collected, little information about energy data for expeditionary operations is available. To address the data availability issues, modelling and simulation methodologies could be used to determine the expected energy consumption in expeditionary operations. A methodological framework for forecasting fuel consumption in military operations has been developed by the study group [Ghanmi, A., Modeling and Analysis of Canadian Forces Operational Energy Demand, Proceedings of the International Conference on Operations Research, Istanbul, Turkey, June 2013].

Fuel requirements in military expeditionary operations could be simulated using the Monte Carlo simulation methodology. This methodology establishes a common set of parameters describing a set of deployment scenarios; within each scenario, individual parameters such as composition of the task force, locations and duration of deployments, frequency of sustainment flights, fuel consumption rates, etc., are then generated stochastically. To allow for meaningful statistical evaluation, fuel consumption data should be simulated and collected for a large number of randomly generated deployment scenarios. Each operational scenario would involve land, air and maritime operations and fuel consumptions are calculated for the three operations.

For land operations, fuel requirements in a given scenario are mainly determined by the daily consumption of ground vehicles and power generation systems of the task force. Key input data into an energy demand simulation model would include distances travelled by ground vehicles, number of vehicles, number of generators, operating hours of generators, and consumption rates. The fuel consumed by each vehicle is calculated by multiplying the distance travelled by the fuel consumption rate of the vehicle. The fuel consumed by a generator is calculated by multiplying the operating hours by the fuel consumption rate of the generator.

Air force operations would involve airlift activities as well as tactical air operations. For lift activities, fuel requirements are mainly determined by the consumption of the lift assets during the deployment, sustainment and redeployment operations. For tactical air operations, fuel consumptions are driven by the tactical asset activities. Key input parameters into an energy demand simulation model would include number of aircraft sorties, average sortie length, aircraft speed, aircraft consumption rate, helicopter consumption rate, etc.

For naval operations, key input data would be the number of days that each platform spends in each of a set of activities including: pre-deployment, transition, deployment, and post deployment. For each activity the minimum and maximum speeds are defined. The input data will be used to determine the total scenario consumption based on activity per day.

Fuel cells and other emerging manportable power technologies for the individual soldier

The NATO warfighter of today has become increasingly dependent on electronic devices to achieve battle superiority. The use of these devices requires the production of electricity which can range from the utilization of small batteries to large diesel generators. However, reliance on these forms of power generation is becoming increasingly problematic. The use of diesel or gasoline internal combustion engines to power a generator or for propulsion generates noise, is maintenance intensive, and consumes large amounts of fossil fuels. Non-rechargeable batteries create a large logistical footprint, are expensive, and create environmental disposal issues. The use of rechargeable batteries is somewhat less costly with a smaller overall logistics footprint – but requires an energy source for recharging.

Recent advances in fuel cell technology have been able to demonstrate that fuel cells can be a source of electricity generation on the battlefield and can minimize or totally eliminate some of the problems associated with traditional sources of energy. When compared to fossil fuelled generators, fuel cells are virtually silent with minimal thermal signatures, thus providing a tactical advantage in some scenarios. They also require less maintenance and because of the low emissions, can conceivable be used indoors. In general, they are more efficient over a wider output range than a standard generator, resulting in less fuel being required for operation. In certain battery operated devices that have a constant drain, a fuel cell can actually replace a battery and most certainly be used as an onboard battery charger. This decreases the logistics burden of constantly transporting non-rechargeable batteries to forward positions (and back for disposal of the toxic materials) or movement of rechargeable batteries to and from charging stations.

The NATO STO Task Group “Fuel Cells and other Emerging Manportable Technologies for the NATO Warfighter” (SET-173), established in 2011 and comprising experts from twelve NATO and Partners Nations, is focusing its efforts on the applicability of using fuel cells in manwearable/manportable and unmanned applications. The group of experts is also assessing and forecasting advances coming both from industry and governmental agencies in this field. The objectives of the study are multiple: Identifying and recommending the optimum applications for use of fuel cells; studying and making recommendations as to specific actions required to fuel cells to actually replace the existing power source, whether it be a battery, internal combustion engine or generator; identifying the issues and make recommendations related to gaining wider acceptance of fuel cells by the NATO warfighter; conducting an assessment for emerging technologies and recommend leveraging of resources; and serving as subject matter experts and act as a liaison to other NATO technical teams. The study group is expected to deliver a final report including recommendations by the end of 2013.

A manwearable application is defined as a piece of equipment that the warfighter wears or carries in his rucksack, such as a radio, whereas a manportable application is something that can be moved without a vehicle, usually limited to what can be lifted by two persons, such as a small generator or battery charger. The investigation of unmanned applications includes ground, air and undersea systems.

Fuel cells offer some significant advantages when compared to other forms of energy generation for the applications mentioned above. A manwearable fuel cell combined with a rechargeable battery into a hybrid configuration can perform as a central power source to all manwearable equipment. Another option is to eliminate the battery portion and have the fuel cell act as a small battery charger, allowing for batteries to be charged while being worn by the warfighter. In either instance the advantages are a reduction in the number of batteries required to complete a mission with the associated reduction in weight carried by the warfighter. Furthermore since the technology is easily scalable, fuel cells are becoming available at power levels below most generators. The smallest generator currently being fielded by the United States Army is 2 kW: fuel cells would ideally fill the energy generation requirements between a battery and this generator size. This is an important feature for forwardly deployed units in areas where it is not practical or feasible to position and provide the logistics support for a standard generator.

When used in unmanned applications fuel cells can replace the battery pack or internal combustion engines. By reducing the weight of the power plant, it results in longer mission times or increased payload capability. This translates into longer loiter times, increased weapon packages or reduced exposure of the operator due to the need to replace a battery pack.

Fuel cells have already been tested and used in tactical environments. Fuel cells of various output levels that are fuelled by bottled hydrogen, direct or reformed methanol and propane have been used to a limited extent in military exercises and deployed by various NATO militaries. These have proven to be valuable in providing information for optimizing the design of a given system and providing lessons learned to the developing agencies. However, before fuel cells can be widely utilized in military weapon systems and support activities, there are several challenges that must be overcome. One of the major obstacles is the ability to operate using standard logistics fuels (e.g. the JP-8, the kerosene-based jet fuel for military aircrafts), which would have a strong logistic advantage. Considerable research and development resources are being applied to reform JP-8 in fuel cell systems and several prototypes of larger systems (in the kilowatt range) have been demonstrated to operate on JP-8 in laboratory type environments. With smaller fuel cells (such as for manwearable applications), the use of JP-8 is not seen as a viable alternative, at least in the near future. It appears in the near term fuel cells smaller than 250 watts will most likely be powered by methanol, propane or a chemical hydride formulation.

The other major obstacles are related to the initial investment and reliability of the systems. Currently even the smallest fuel cells costs tens of thousands of US dollars. This represents a significant investment when compared to the use of batteries or generators, especially in a time of decreasing budgets. This is further complicated by the fact that none of the technologies have been able to demonstrate consistent, long term failure free performance (measured in thousands of hours) in a true tactical environment. In times of restricted budgets, it is difficult for a government to make an investment in an expensive fuel cell technology compared to much less expensive batteries. Nevertheless the multiple logistic, efficiency and tactical advantages that manportable/manweareable fuel cells are able to ensure, would suggest to pursue the research efforts in this field.

Conclusions

Despite their diversity, the two examples presented in this article, show how relevant energy efficiency is becoming to military forces and in demonstrating the impact energy efficiency may have in operations. They also show that a change of culture is required to implement the notion of “operational energy”, because one has to analyze and balance potentially competing courses of action pertaining to energy considerations and to mission requirements. The true importance of energy availability and efficiency is most likely underappreciated, as for certain military platforms it may become a limiting factor during combat. This is particularly relevant for high-tech soldier systems, as they gradually begin to be fielded by NATO nations, which are more and more reliant on electronics requiring lightweight energy supply devices. The study conducted within the SET Panel shows that technical solutions, such as fuel cells, may be available, but they need significant funding to reduce the upfront costs, limiting their affordability to NATO nations.

Energy related considerations, including their cost, are a real issue to Armed Forces during peacetime. During combat operations it has to be addressed as well, for example, because of the resources needed to move and protect energy supplies, as experienced in the Afghan operational theatre. This requires a new mindset in which scientific evidence-based methods should be used to inform decision makers. The study conducted within the SAS Panel proposes a model (FBCE) to capture the complete life cycle of fuel in operations, complemented by a methodological framework (FCPM) to determine energy requirements for expeditionary operations. These are two important decision-support tools: the first could be used to assess alternate forms of energy and to inform decisions on the size and focus of investment in S&T programs, whereas the second could be used to determine a baseline of current energy consumption and to assess the impact of different energy targets.

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