Evidence base for the development of an enduring DND/CAF Operational Energy Strategy (DOES)

Expressing Canadian values through defence operational energy stewardship here and abroad

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Defence Research and Development Canada
Scientific Report
DRDC-RDDC-2014-R65
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Abstract

The intent of this document is to consolidate the information, evidences, facts and data that support and inform the first DND/CAF operational energy strategy (DOES)[1] to address the need to improve our defence operational capabilities and their sustainability by decreasing the fully burdened cost of operational energy and reducing our supply chain vulnerabilities. It captures some of the knowledge that resulted from the DOES working group discussions and workshops with selected experts and organisations. Given the complexity of the domain and potential misinterpretation of raw data available in the various records of transactions, their interpretation for the purpose of developing the strategy was addressed collectively by selected representatives from concerned DND/CAF L1s' personnel.

Such a collective view is necessary to ensure that an appropriate understanding of the energy challenges ahead permeates our DND/CAF culture and becomes part of our decision making. Then, how to address them holistically through the sustainability looking glass will open new avenues to improving our defence operational capabilities for operations here and abroad.

Analyses of historical data and simulation results were used to develop the DOES energy baseline. That energy baseline was used to develop credible DOES targets. The baseline will be used later to assess the level of success of initiatives to achieve DOES targets. An inflation methodology was used to assess the potential savings of applying the DOES targets. Moreover, using simulation techniques with scenarios informed by previous operations, the impacts of DOES targets on expeditionary operations were estimated.

In addition, the report explores the DND/CAF domain of energy, sorts it in four dimensions and proposed principles to support the selection of effective initiatives in fulfilling DOES. Selected energy technologies required to power a large variety of DND/CAF capabilities are reviewed. Then more specific examples addressing DOES targets for each environment are provided. Fuelled by DND/CAF level of ambition, DOES targets will be used in developing potential action plans and in measuring progress resulting from remediation initiatives in achieving the strategy objectives.

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[1] AKA: Defence Operational Energy Strategy (DOES).

Significance to defence and security

Contribute to ensure the sustainability of DND/CAF operations here and abroad. All our defence operational capabilities depend on the right energy availability at the time and location where it is required here and abroad, including during crisis and extreme conditions. Not considering energy as a strategic asset weakens our strategic posture[2].

Excerpt from the Deputy Minister’s letter dated Nov 13, 2012 – Defence Operational Energy Strategy:

“The Department is developing a Defence Operational Energy Strategy (DOES), as directed by the Defence Management Committee (DMC) in May 2011. The Energy Strategy aims to improve operational readiness and resilience of the Canadian Forces and potentially control costs and reduce the defence environmental footprint. Reducing energy demand and increasing energy efficiencies are key drivers that are anticipated to enhance the ability of defence to meet the Government's expectations and ensure there is continued access to adequate, reliable, affordable and sustainable energy supply to achieve the roles and missions... It is anticipated that energy related initiatives identified as having a high return on investment will be recommended for consideration in the Department of National Defence Investment Plan. L1s will develop roll-out plans intended to meet targets to reduce energy demand and increase energy efficiencies over the short, medium and long-term. Energy issues will be considered as part of the review of the Canada First Defence Strategy (CFDS), under the Readiness Pillar. Including the DOES within the CFDS would raise the visibility and stress the importance of the role of energy in defence policy and operations.”

DND/CAF operational energy targets (endorsed for the development of DOES by Defence Capability Board (DCB), Nov. 2013) are as follows:

1. Energy measurement and management: By 2030, to the maximum extent practicable, bases, platforms and expeditionary power and heating generation equipment shall employ an automated data acquisition, recording and metering system that measures the consumption of fuel from all sources;

2. Reduce demand – buildings: By 2030 all CAF Bases and Stations, as whole entities, will reduce through efficiencies their energy use intensity (EUI) by 20% from 2005-2006 levels;

3. Critical infrastructure: By 2030, all defence critical equipment, infrastructure and services will have reliable back-up power systems able to sustain independent (off-grid) operations for a minimum period of 14 days;

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[2] Boland, R. (2009), War Game Examines Energy as a Disruptive Technology, *Signal Online* (electronic journal). http://www.afcea.org/content/?q=node/2100 (Access date: 27 August 2014).

4. Military platforms and fleet: By 2025, the CAF will have reduced the class fuel consumption rate by 10% from those detailed in the Fuel Consumption Unit (FCU)[3] tool developed by ADM (Mat) and validated in 2012;

5. Commercial vehicle fleet improved efficiency: By 2025, based on a 2010 baseline, defence will double the average mileage achieved per litre of petroleum used in its commercial vehicle fleet[4];

6. Reduce demand – military camps: By 2030, per person, reduce the energy consumption required to produce main and deployed military camp services (heating, power generation, sewage treatment, water supply, etc.) during the conduct of domestic and expeditionary operations by 50%;

7. Increase energy efficiency – soldiers: By 2030, all individual dismounted soldiers will be independent from the logistics chain for energy resupply for at least 72 hours without increasing the soldier's burden;

8. Alternative energy opportunities: By 2016, the CAF will have certified the processes by which suitable advanced, 'drop-in' alternative liquid fuels, that meet Canadian military specifications, can be used in each of its tactical (non-commercial) platforms and vehicles;

9. Force planning and requirement: From 2018, tools to account for and analyse energy consumption and costs are to be incorporated into all strategic modeling and simulation (M&S) programmes that are used for force planning, options analysis and requirements development; and

10. Procurement – energy key performance criterion: From 2018, the procurement process for equipment and infrastructure (capital and O&M) will incorporate energy usage and fuel economy over the life cycle of the asset as a key performance criterion.

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[3] The North Atlantic Treaty Organisation (NATO) standardization agreement (STANAG 2115) provides a method for computing fuel requirements in military operations and a standard estimation for fuel consumption of a military unit called FCU (fuel consumption unit).

[4] This target was not submitted to the Nov. 2013 DCB.

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Résumé

Le présent document vise à regrouper l'information, les preuves, les faits et les données qui appuient et alimentent la première Stratégie d'énergie opérationnelle de la Défense (SEOD)[5] du Ministère de la Défense nationale (MDN) et des Forces armées canadiennes (FAC) afin de répondre au besoin d'améliorer nos capacités opérationnelles de défense et de les maintenir en puissance en diminuant les coûts en énergie opérationnelle imputés en totalité, de même que les vulnérabilités de la chaîne d'approvisionnement. Il présente certaines connaissances découlant de discussions et d'ateliers auxquels a participé le groupe de travail sur la SEOD, en collaboration avec des organisations et des experts sélectionnés. Étant donné la complexité du domaine et la possibilité d'une mauvaise interprétation des données brutes disponibles dans les divers relevés de transaction, l'analyse de ces connaissances aux fins d'élaboration de la stratégie a été effectuée collectivement par des représentants sélectionnés du personnel concerné des N1 du MDN et des FAC.

Une telle vue d'ensemble est nécessaire pour veiller à ce qu'une compréhension appropriée des défis à venir en matière d'énergie imprègne la culture du MDN et des FAC et qu'elle fasse partie de notre processus décisionnel. Ainsi, la façon d'y faire face de manière holistique à travers le maintien en puissance ouvrira d'autres voies pour améliorer nos capacités opérationnelles de défense en vue d'opérations nationales et internationales.

L'analyse des données historiques et des résultats de simulations a permis d'établir les données de référence de la SEOD utilisées pour définir des objectifs crédibles pour la SEOD. Ces données serviront ultérieurement à évaluer le niveau de réussite des initiatives visant à atteindre les objectifs. Une méthode de calcul de l'inflation a permis de déterminer les économies possibles en tenant compte des objectifs de la SEOD. En outre, les répercussions de ces derniers sur les opérations expéditionnaires ont été estimées à l'aide de techniques de simulations de scénarios basés sur des opérations antérieures.

Dans le rapport, on explore également le domaine de l'énergie du MDN et des FAC selon quatre dimensions et on propose des principes pour orienter la sélection d'initiatives efficaces dans la mise en œuvre de la SEOD. Les technologies énergétiques sélectionnées nécessaires pour exploiter un large éventail de capacités du MDN et des FAC sont examinées. Des exemples plus précis abordant les objectifs de la SEOD pour chaque environnement sont fournis. Alimentés par le niveau d'ambition du MDN et des FAC, ces objectifs serviront à élaborer des plans d'action éventuels et à mesurer les progrès résultant des initiatives de rétablissement par rapport à eux.

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[5] Expression utilisée lors des présentations au comité de gestion de la Défense et au comité des capacités de la Défense. L'expression suivante n'est pas recommandée: Stratégie énergétique opérationnelle de la Défense.

Importance pour la défense et la sécurité

Contribuer à assurer le maintien en puissance des opérations nationales et internationales du MDN et des FAC. Toutes nos capacités opérationnelles de défense dépendent de la disponibilité adéquate en énergie au moment et à l'endroit où elle est requise au pays et à l'étranger, y compris en cas de crise et de conditions extrêmes. Le fait de ne pas tenir compte de l'énergie dans le plan stratégique affaiblit notre position stratégique[6].

Extrait, traduit en français, de la lettre du sous-ministre du 13 novembre 2012 – Stratégie d'énergie opérationnelle de la Défense :

« Le Ministère élabore une Stratégie d'énergie opérationnelle de la Défense (SEOD) comme l'a demandé le comité de gestion de la Défense en mai 2011. Cette stratégie de l'énergie opérationnelle vise l'amélioration de la disponibilité opérationnelle et de la résilience des Forces canadiennes et possiblement le contrôle des coûts ainsi que la réduction de l'empreinte environnementale de la Défense. Réduire la demande énergétique et accroître l'efficacité énergétique sont des facteurs clés qui devraient améliorer l'aptitude de la Défense à satisfaire aux attentes du gouvernement et garantir un accès continu à des approvisionnements énergétiques appropriés, fiables, abordables et durables permettant de mener à bien les missions et les rôles confiés… Les initiatives liées à l'énergie désignées comme ayant un niveau de rentabilité élevé devraient faire l'objet de recommandations afin qu'elles soient prises en considération aux fins d'inclusion dans le Plan d'investissement du ministère de la Défense nationale. Les N1 élaboreront des plans de mise en œuvre qui devraient permettre d'atteindre les cibles visant la réduction de la demande énergétique et l'amélioration de l'efficacité énergétique à court, moyen et long termes. Les enjeux relatifs à l'énergie seront examinés pendant le renouvellement de la Stratégie de défense *Le Canada d'abord* (SDCD), dans le cadre du pilier de la disponibilité opérationnelle. Inclure la SEOD dans la SDCD ferait en sorte d'accroître la visibilité de la question énergétique et de souligner l'importance du rôle de l'énergie dans la politique et les opérations de défense. »

Les objectifs du MDN et des FAC en matière d'énergie opérationnelle (endossés pour le développement de la SEOD en novembre 2013 par le comité des capacités de la Défense, CCD) sont les suivants :

1. Mesure et gestion de l'énergie : D'ici 2030, les bases, les plateformes et le matériel expéditionnaire de production d'énergie et de chaleur devront être équipés, dans la mesure du possible, de systèmes automatisés de saisie, d'enregistrement et de mesure des données qui calculent la consommation de carburant de toutes les sources;

2. Diminution de la demande – édifices : D'ici 2030, toutes les bases et les stations des FAC, à titre d'entités à part entière, réduiront leur intensité énergétique de 20 pour cent par rapport aux chiffres de 2005-2006 grâce à des gains en efficacité;

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[6] Boland, R., « War Game Examines Energy as a Disruptive Technology », *Signal Online* (revue électronique), 2009. Sur Internet : URL:http://www.afcea.org/content/?q=node/2100 (Date d'accès: 27 August 2014).

3. Infrastructure essentielle : D'ici 2030, l'ensemble de l'équipement, des infrastructures et des services essentiels qui sont déterminants en matière de défense seront dotés de systèmes d'alimentation de soutien fiables et autonomes qui permettront de poursuivre des opérations indépendantes (hors réseaux) pour une période minimale de 14 jours;

4. Plateformes et flottes militaires : D'ici 2025, les FAC réduiront le taux de consommation de carburant de chaque classe de plateformes de 10 pour cent par rapport aux taux indiqués dans l'outil de l'unité de consommation de carburant (FCU)[7] élaborée par le SMA(Mat) et validée en 2012;

5. Efficacité améliorée du parc de véhicules commerciaux : D'ici 2025, par rapport aux données de référence de 2010, la Défense doublera le kilométrage moyen obtenu pour chaque litre de pétrole consommé par son parc de véhicules commerciaux[8];

6. Diminution de la demande – camps militaires : D'ici 2030, réduire de 50 pour cent par personne la consommation d'énergie nécessaire pour produire les services principaux et ceux dans les camps militaires déployés (chauffage, production d'électricité, traitement des eaux usées, approvisionnement en eau, etc.) pendant les opérations au pays et à l'étranger;

7. Augmentation de l'efficacité énergétique – soldats : D'ici 2030, les soldats à pied seront indépendants de la chaîne logistique en matière de réapprovisionnement énergétique pendant au moins 72 heures, sans que la charge qu'ils portent s'alourdisse;

8. Autres options énergétiques : D'ici 2016, les FAC se seront assurées que les processus — qui servent à vérifier que tous les carburants de remplacement liquides adaptés, supérieurs et utilisés librement qui répondent aux spécifications militaires canadiennes — conviennent à chaque plateforme et véhicule tactique (de nature non commerciale);

9. Planification et exigences de la Force : À partir de 2018, il faudra inclure des outils pour expliquer et analyser la consommation et les coûts énergétiques dans tous les programmes stratégiques de modélisation et de simulation qui servent à la planification de la Force, à l'analyse des options et à l'élaboration des exigences; and

10. Acquisition – principaux critères de rendement énergétique : À partir de 2018, le processus d'acquisition d'équipement et d'infrastructures (immobilisation et F&E) inclura comme critère de rendement déterminant la consommation énergétique et l'économie en carburant pour tout le cycle de vie de la ressource.

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[7] L'accord de normalisation de l'Organisation du traité de l'Atlantique Nord (OTAN) [STANAG 2115] donne une méthode pour évaluer les besoins en carburant des opérations militaires et offrir une estimation standard de la consommation en carburant d'une unité militaire appelée « unité de consommation de carburant ».

[8] La cible 5 a été exclue des cibles soumises au CCD en novembre 2013.

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The authors want to thank all the intervening personnel who contributed to the DOES WG deliberations in developing the global information and knowledge required for an enduring energy strategy.

In addition, the authors acknowledge the advice provided by a panel of experts selected to review the proposed DOES targets and the defence scientist, Mark Rempel, who designed the energy targets review process, analyzed the collected data, and supported the panel's decision-making process. Panel members: RCAF LCol PM Arsenault, ADM(S&T) LCol VD Cosman, ADM (IM) LCol J Howes, ADM(Fin CS) R Laferrière, ADM(Mat) PA Ohrt, ADM(IE) DA Paquet, VCDS LCol DA Russel, RCN Cdr S Thompson, CJOC Maj JL Carter, CANSOFCOM Maj VDM Poirier, and CA Maj CJ Young.

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1 Introduction

This report summarizes a perspective of the Canadian defence operational energy domain from historical data, trends and expected future demand, cost and availability, here and abroad. It has been prepared in support of the development of the Department of National Defence (DND) operational energy strategy lead by Assistant Deputy Minister Infrastructure and Environment, ADM (IE). It does not advocate for any specific solution or Defence Research and Development (DRDC) science and technology (S&T) activities to conduct under the leadership of ADM (S&T), but identifies state-of-the-art S&T here and abroad that support the logic of the strategy. The focus is on the impact of energy on CAF (Canadian Armed Forces) operations and capabilities, i.e., Air, Maritime, Land and Special Forces, the development of their capabilities, Chief Forces Development (CFD), as well as our domestic infrastructure under ADM (IE) across Canada including the Arctic. It also serves as an information base for DRDC, other Canadian organisations and Industry.

1.1 Purpose

Inform on the DND/CAF operational energy domain, the current state of energy technologies (at various technology readiness levels (TRLs) and use in defence and security (D&S):

- DND/CAF domestic energy demand and trend.
- Current demand per selected components.
- Current supply and potential changes due to market and technologies.
- Document the evolution of the first DND/CAF Operational Energy Strategy (DOES)[9].
- Project the potential gain of DOES targets on DND/CAF energy cost.
- Energy principles, technologies and examples of success stories for each environment.
- Potential energy strategic shocks.

1.2 Background

Although Canada economy showed some stability over the last decades, the world slower growth in Organisation for Economic Co-operation and Development (OECD)[10] countries continues to erode our economy and is driving a spectrum of budget readjustments that affect all Canadians including federal organizations and DND/CAF. In addition to the increase in cost of various CAF capability improvements planned, under such pressure, recurrent cost imposed for energy needs to be examined under the sustainability looking glass. Energy markets have proven to be more volatile than ever,

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[9] Initially DOES was Defence Operational Energy Strategy.

[10] The OECD mission is to promote policies that will improve the economic and social well-being of people around the world.

which increases our vulnerability to stock disruption and price controlled by other nations as exemplified by the oil barrel price over time. Energy is critical to all DND/CAF capabilities; it is the broadest and most essential capability enabler.

Industrial energy demands move in close step with the general state of the economy. The measure of national economic output is usually reported as gross domestic product (GDP), and refers to the total economic value of goods and services produced in Canada. Apart from the recent recession, the Canadian economy has performed remarkably well for the last 15 years. From the early 1990s until early 2008, we have seen GDP increase, low unemployment, small but steady population growth, a rise in per capita income, increased levels of trade and exports, and, predictably, rising energy demands.

Over the last decades several countries, including most of our usual allies such as UK and USA, have invested substantial efforts in developing their defence and security energy strategies in order to address concerns about energy cost and availability for sustainable military operations. This document was prepared along the development of the first DND/CAF Operational Energy Strategy (DOES) in order to provide evidences to base such a broad policy which has profound implications (Weiss and Bonvillian, 2009).

1.3 Document structure

In order to be able to inform this first energy strategy there was a need to develop a common understanding of the nature and magnitude of DND/CAF energy consumption. A search for the available data on energy and fuel used was initiated. Early results from the analysis of this data were presented to the Defence Management Committee (DMC) which supported the decision to pursue this work. Although consolidating it was difficult to track in such diverse data when considering the variety of energy and situation of use ranging from domestic to expeditionary operations, a team led by ADM(IE) and ADM(Mat) managed to produce the total picture of DND/CAF energy, including its trends as presented in Chapter 2. This is the first time such comprehensive picture of DND/CAF was produced. It includes information on the persistent energy demand increase and its cost. In addition, Chapter 2 uses examples from data centers to show the impact of advanced information technologies on electricity demand in defence and security.

Chapter 3 presents the DOES targets developed by the working group co-chaired by ADM (IE) and CFD. They were reviewed by a panel of experts and endorsed by the Defence Capabilities Board (DCB). Chapter 3 concludes by presenting potential cost savings of adopting DOES targets.

Chapter 4 provides principles for an enduring DND/CAF energy strategy. It includes four governance principles and the following four energy principles with illustrative material: 1) capacity factor, 2) energy conversion efficiency, 3) power density versus energy density, and 4) volumetric versus gravimetric energy and power density. It maps recommendations informed by the Defence Science Advisory Board (DSAB) report (DSAB, 2013) to the proposed strategy along the following four dimensions of DND/CAF energy domain: 1) defence real property and related assets, 2) military camps and compounds, 3) tactical platforms, and 4) dismounted combatants.

A forward looking at technologies that would change the energy of tomorrow is introduced in Chapter 5.

Chapter 6 provides some concluding remarks and recommendations.

Annexes document the material presented in the report as follows:

A. Fully burdened cost of energy (FBCE) methodology framework.

B. Fuel demand modelling for expeditionary operations.

C. Why critical infrastructure energy is so important?

D. Oil price, energy demand and electricity demand trends, energy forms and Earth's reserves.

E. Methodology for estimating potential cost savings from DOES targets.

F. Canadian Force Station Alert energy audit, proposed solutions and potential cost savings.

G. New energy technology trends and system views for all CAF environments.

H. Selected findings: Canadian Army (CA).

I. Selected findings: Royal Canadian Navy (RCN).

J. Selected findings: Royal Canadian (RCAF).

K. Novel low radiation nuclear technology trial results.

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2 DND/CAF energy demand

In order to appreciate the quantity (e.g., litre, kWh) and type (e.g., fuel, electricity) of energy end use (e.g., fleet, buildings) across all DND/CAF activities, this Chapter provides a summary of DND/CAF energy consumption from the data collected and analysed for this report. In addition, although there is a distinction between DOD and DND definitions of operational energy, in some instances in this document DOD proportional values for energy use and type will be cited to expand our understanding and accumulate evidences in support of our findings. Here is an example:

According to DOD, currently about 75% of DOD's energy use is operational energy and about 25% is installation energy. Operational energy is defined in law as "the energy required for training, moving, and sustaining military forces and weapons platforms for military operations." Installation energy is not defined in law, but in practice refers to energy used at installations, including non-tactical vehicles, that does not fall under the definition of operational energy (Schwartz*, et al.*, 2012, p. i).

This ratio of operational energy used (75%) over the total is useful in building confidence in the DND/CAF energy demand analysis summarized in this Chapter.

The challenge of reporting on the energy used by Canada in military expeditionary operations was documented in a parliamentary report[11], as follows: *"For DND, mission specific details are not presented to Parliament to assess the detailed yearly cost. For example, it is impossible to determine how many reservists were deployed for each year of the mission; how much fuel was consumed; or the level of expenditure on equipment reset and betterment, for all Afghanistan related operations."*

Consequently for this report the analysis will combine the available domestic data and fuel transactions with simulation data in order to estimate the proportion of energy used in expeditionary operations.

2.1 DND/CAF total domestic energy

The total DND/CAF domestic energy used for installations (buildings), excluding commercial vehicles and fuel used in domestic operations such as training has been fairly stable around 11 PJ or 11,000 TJ per year over a period of 14 years (Figure 1). Since the data were collected to fulfill DND commitment regarding GHG emissions, they also distinguish the types of energy (e.g., electricity from coal, diesel and natural gas) and their territorial or provincial origin.

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[11] http://www.parl.gc.ca/PBO-DPB/documents/Afghanistan_Fiscal_Impact_FINAL_E_WEB.pdf (Access date: 19 Nov. 2013).

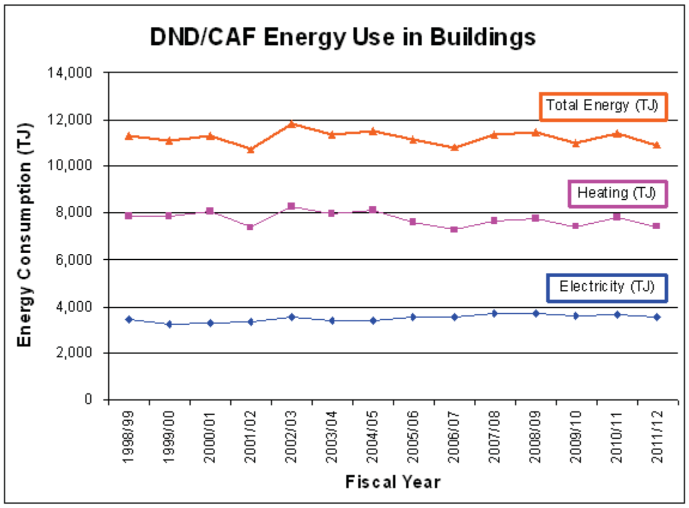

Figure 1: *DND/CAF buildings energy use trend over 14 years.*

Figure 2 provides a magnified scale of the total energy consumption versus its corresponding GHG counterpart taking in consideration the various factors affecting such estimates.

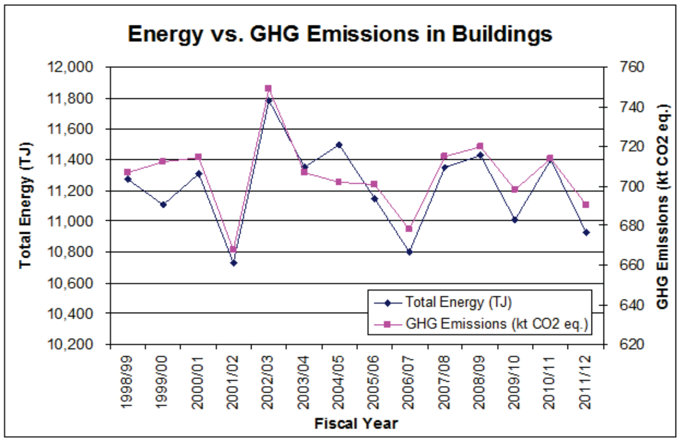

Figure 2: *GHG emissions link to DND/CAF buildings energy use.*

Figure 3 shows that although the total energy is fairly constant over that period with a small downward trend[12], with a negative slope of 1% per year according to the first order trend line with a mean square error of about 0.01. However the price or total expenditures for that energy in buildings follows a continuous increase over time at a rate of about 4.7% per year (about 65% for the 14-year period).

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[12] It seems from this small downward trend of energy used in buildings that the expected improvements from the investments made in energy building efficiency does not match the expected return on investment (ROI). It is possible that such expected ROI be observed later once more of the Federal Building Initiative (FBI) projects result in effective operational changes.

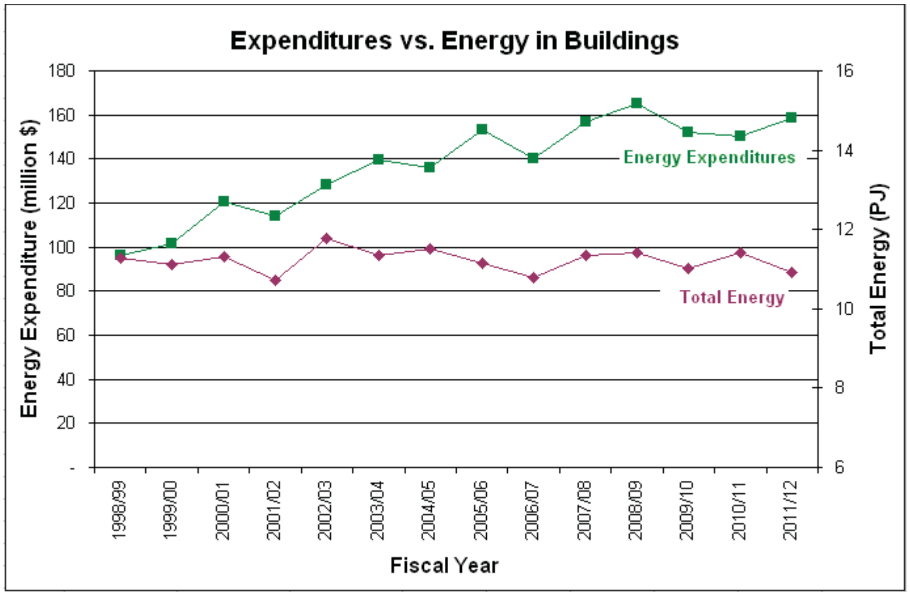

Figure 3: *Annual DND/CAF buildings energy cost trend over 14 years.*

2.2 The challenge of computing the DND/CAF total energy used

The energy consumption baseline used for DOES is established from two categories of data: energy consumed in installations and energy used for mobility purposes by the fleets. This set of data is captured over a period of three fiscal years: FY 2008/09, 2009/10, and 2010/11. The data for installations were collected for DND/CAF Sustainable Development Strategy (SDS). Fuel/Energy used in buildings includes energy from electricity, natural gas, heating fuel oils, propane, kerosene, arctic diesel, cooling water, steam and solar photovoltaic (SPV).

Aviation fuel and ship's fuel consumption data discussed in this document include both domestic and international operations. Gasoline and diesel fuel data were not available for ground fleet above 55° parallel at the time of preparing this report. This should not have a significant impact on the data presented for the overall fleet energy used. However for consistency with the subsequent charts, the simulation result for expeditionary land force of Table 1 is included. Consequently, Figure 4 provides, for the first time, DND/CAF best estimate of the proportion of energy used by the fleet of each environment[13] (air, maritime and land) out of a total of 12 PJ per year for both domestic and expeditionary operations. In reverse order of magnitude of energy used they are as follows: Canadian Army (CA) 17%, Royal Canadian Navy (RCN) 21% and Royal Canadian Air Force (RCAF) 62%.

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[13] The CAF environments are also identified as the CAF services as done for forces of other countries.

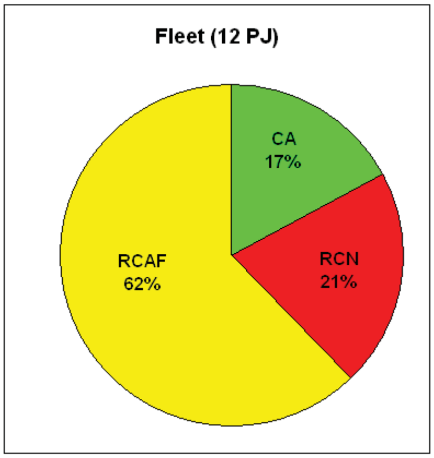

Figure 4: *Average over three years of yearly domestic and expeditionary energy per environment.*

The RCAF is the biggest user of energy among the three environments for mobility purposes. It consumes 62% of the total energy of the CAF fleets.

For the following charts (Figure 5 and Figure 6), in addition to expeditionary energy used, the total domestic energy includes the fuels used in commercial vehicles and combat equipment, i.e., the National Safety and Security (NSS) Fleet (military-patterns/manoeuvers for vehicles, ships and aircraft), the energy used in domestic operations and the total energy used for buildings. For expeditionary land energy used, the amount obtained by simulation (Ghanmi, 2013b) is included in the total reported here. The aggregated total expeditionary and domestic energy, as averaged over three fiscal years from 08/09 to 10/11, amounts to a yearly average of 23 PJ or 23,000 TJ.

The 23 PJ includes all DND/CAF energy usage, i.e., electricity, natural gas, heating oils, etc., for domestic buildings, and gasoline, diesel fuel, ship's fuel and aviation fuel for all our fleets in domestic and international operations.

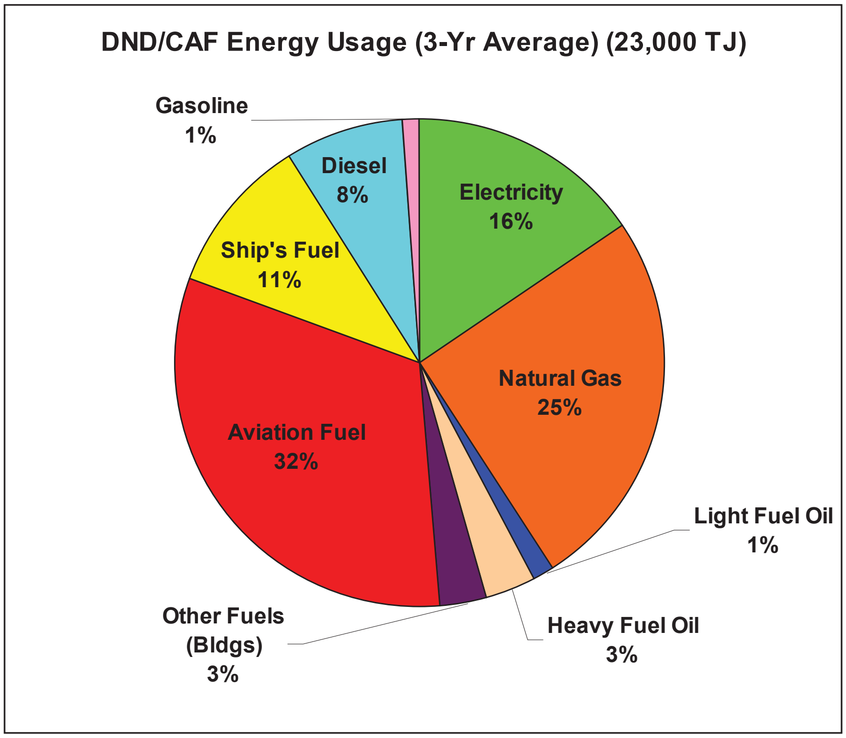

Figure 5: *Average yearly consumption over three years of domestic and expeditionary energy proportion per type.*

Out of the total domestic and expeditionary energy average of 23,000 TJ used, about 52% is for the fleets and the remainder for the buildings.

For Figure 6, the Fuel/Energy expenditures recorded under the Defence Resource Management Information System (DRMIS) for utilities (electricity, natural gas, heating oils, etc.) are most likely on the domestic front only; while gasoline, diesel, ship's and aviation fuels include invoices coming from international operations. So Figure 6 shows a three-year average of fuel/energy expenditures of the department recorded for fiscal years 2008/09, 2009/10 and 2010/11 which correspond closely to the total of 23 PJ of Figure 5.

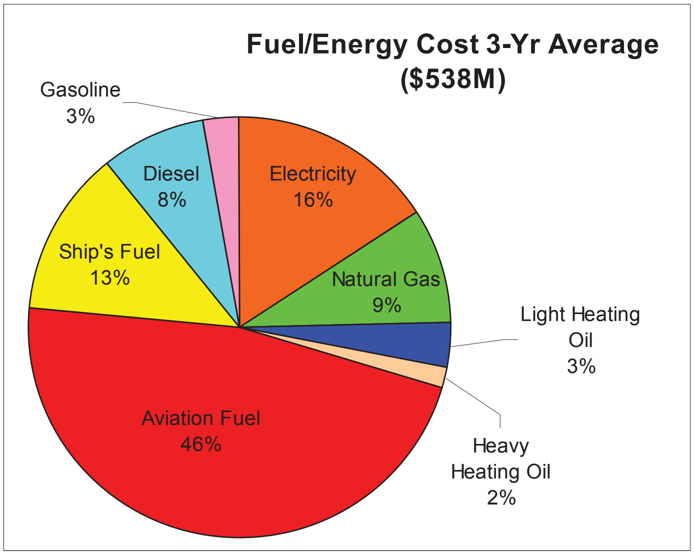

Figure 6: *Average of yearly domestic and expeditionary energy cost proportion.*

Figure 6 provides the yearly relative proportion of types of energy for DND/CAF uses as averaged over three years. From the total cost of 538 million Canadian dollars, about 70% of the cost is for the fleet and 30% for the buildings. The large difference in percentage between the energy quantities (52%-48%) and costs (70%-30%) is dominantly driven by the low cost of natural gas in Canada.

The aviation fuel represents about 66% of the total fleet fuel cost which is assumed to be the sum of the following: gasoline (3%), diesel (8%), ship's (13%) and aviation (46%), for a total of 70% for the fleet fuel cost.

2.3 Total DND/CAF energy cost trends and global perspective

The following trend of the total energy expenditures combine domestic, training and expeditionary operations with the total for buildings over the 14-year data reported for energy related GLs (general ledger accounts) in Defence Resource Management Information System (DRMIS). DRMIS reports all expenditures charged to a given GL account (domestic and foreign). Based on the information available in the financial system, we cannot clearly identify whether the payments were related to domestic or international operations.

If we assume that the fleet energy price will increase at the same rate as for the last 14 years (Figure 7 upward trend in blue), approximately doubling in a decade, then the total CAF fleet energy spending would have increased from approximately 140 million dollars in fiscal year 1998/99 to 800 million dollars in 2030/31, about six times as much if no significant corrective actions are taken. The total DND/CAF energy cost (538 million in 2010-11) follows a similar trend from about 240 million to 1,100 million dollars by 2031, which is about five times as much.

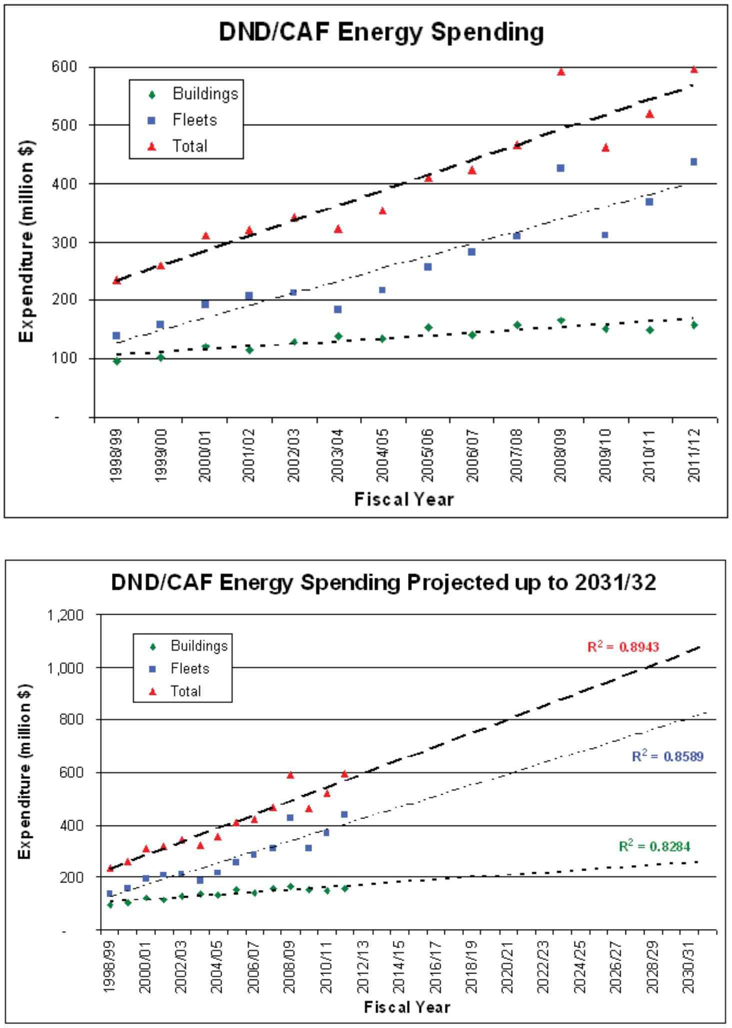

Figure 7: *Trends of DND/CAF total cost for energy according to the 14-year data and a 20-year projection based on these trends.*

Currently no additional cost is included in these figures for an eventual carbon dioxide (CO_2) tax. In the advent that Canada adds a charge or tax for the amount of CO_2 emissions, this total DND/CAF energy cost trend might be more significant in such future.

According to the US Energy Information Administration (EIA) analysis[14] based on the International Energy Outlook 2011, *IEO2011* Reference Case (DOE/EIA, 2011), the world energy consumption could increase by 53%, from 505 quadrillion Btu (~533 EJ) in 2008 to 770 quadrillion Btu (~813 exajoule (EJ)) in 2035.

This estimate of world energy use in 2008 of ~533 EJ (DOE/EIA, 2011) allows to appreciate the order of magnitude of the total energy consumption of primary energy

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[14] http://www.eia.gov/forecasts/ieo/world.cfm (Access date: 17 Sept. 2013).

used by Canada in 2008, 12,510 PJ[15] (NRCan, 2012, p. 7) or ~13 EJ, i.e., about 2.4%. According to Statistics Canada, the total energy used by all of Government of Canada (GoC) is ~60 PJ (2008, 60,134 TJ (Statistics Canada, 2012, p. 5)), which is about ~0.5%. Using the ratio of all combined floor areas (buildings and platforms), the gross floor area, we obtain a coarse estimate of ~42% or ~25 PJ for the total energy used by DND/CAF out of the ~60 PJ for the whole of GoC while remainder for other government departments (OGDs) is ~58% or ~35 PJ. Figure 8 illustrates the magnitudes of these energies used from the world perspective up to the DND/CAF total amount of energy used. This estimate of the total DND/CAF energy used will be compared in Section 2.5 with another method of estimating it that combines the values from the domestic database and from simulation results of the energy demand of CAF expeditionary operations over three years.

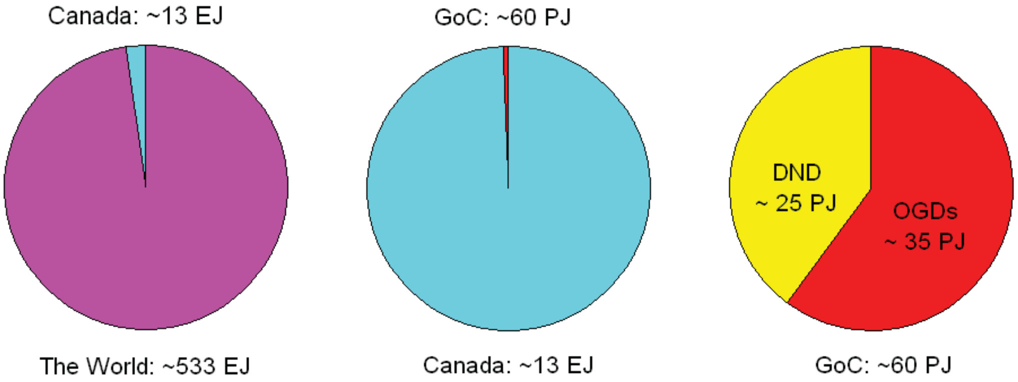

Figure 8: *Relative energy consumptions: Canada versus World, the total of all government of Canada (GoC) versus Canada and DND/CAF versus OGDs within GoC.*

2.4 CAF simulated expeditionary energy demand

In order to provide a more complete picture of the defence operational energy used by Canada, the following simulation result shows the proportion of energy used per type of fuel assuming operations and fuel hubs as described in Annex A. This result combines several thousand point estimates using specific force composition that went through all phases: deployment, force employment and redeployment.

The simulation results can be summarized as follows: The total demand was 260 million litres (ML) over three years with the following fuel type distribution, aviation fuel (54%), ship's fuel (8%) and diesel (38%) as illustrated in Figure 9.

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[15] http://oee.nrcan.gc.ca/publications/statistics/parliament10-11/chapter1.cfm?attr=0 (Access date: 17 Sept. 2013).

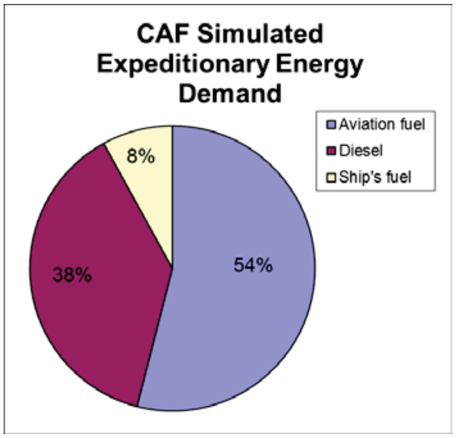

Figure 9: *Simulation results using selected scenarios of operations over three years.*

In order to use these results in the next analysis step, the following transformations were made on the total of 260 ML. Using average values of energy per litre, over three years the 54% in aviation fuel represents 5,251 TJ, the 8% in ship's fuel becomes 807 TJ and the 38% of diesel equals 3,784 TJ for a total of 9,842 TJ or 3,281 TJ per year.

2.5 DND/CAF combined energy demand

The objective of using simulated results is to be able to separate domestic operations energy from expeditionary energy in the total energy previously reported (rounded off to 23 PJ per year using available data collected). Table 1 summarizes the various information in TJ required to compute such estimates based on the three-year averaged data of fiscal years 2008/09, 2009/10 and 2010/11 provided by the Directorate of Fuels and Lubricants (DF&L), the GHG database and the simulated results.

Table 1: *DND/CAF demand of energy in TJ used for generating Figure 10.*

Type	Energy used in buildings	Fleet fuel	Simulated expeditionary
Electricity	3,620		
Natural gas	5,860		
Light heating oil	300		
Heavy heating oil	800		
Other fuels	700		
Gasoline		240	
Diesel		540	1,260
Ship's fuel		2,480	(270 included in fleet)
Aviation fuel		7,420	(1,750 included in fleet)

Total energy used = 23 PJ per year

Figure 10 expresses the total DND/CAF energy demand and shows the proportion for the various types of fuel and energy used. It includes other fuels which represent a small amount compared to aviation fuel. Other fuels included propane, kerosene, and diesel for power generation, JP-8 for power and heat generation, steam, cooling water and a small amount from SPV.

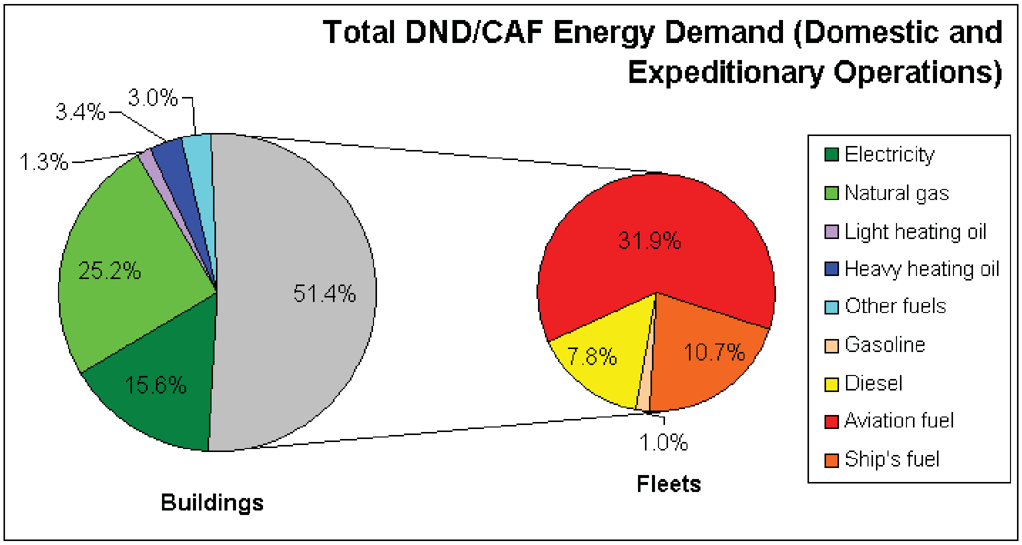

Figure 10: *Combined (23 PJ per year) domestic and expeditionary energy per type and use.*

It is important to note that this combined result does not include the energy used by contracted cargo and commercial transport used in support of operations. However Figure 10 includes the expeditionary simulated result for diesel used by land since it was not tracked otherwise.

Given the substantial amount of energy that DND/CAF used for northern facilities, such as Canadian Forces Station (CFS) Alert, this 51% (fleets) to 49% (buildings) proportion is fairly comparable to other countries. The larger proportion reported by DOD with 75% for operations and 25% for installations could be due to the large size and world distribution of their fleets. In addition from this figure we note that 62% of domestic and expeditionary fleet energy is for aviation fuel.

From Section 2.3 the estimate of total DND/CAF energy used was about 25 PJ or 42% of whole of GoC energy used. Here using a combination of accumulated DND/CAF domestic data and expeditionary operations data, including the diesel from expeditionary operations simulation results, we obtain a total energy estimate of about 23 PJ per year. The closeness of these estimates using two distinct methods increases confidence in the reported estimates.

2.6 Additional evidences

For the purpose of this report some of the material for the following evidences are presented in the report annexes or referenced to other sources.

2.6.1 High likelihood of future oil barrel price increase

According to the EIA Annual Energy Outlook 2013 (DOE/EIA, 2013a, 2013b) there is a high likelihood of an increase in the price of oil barrel in the future. If the reference projection (see Annex D) is right, that would mean a 60% increase in 2011 US dollars by

2040. If this 60% increase in oil price translates in the overall energy cost of DND/CAF, that raises an important flag to the sustainability of CAF operations here and abroad.

2.6.2 Increased electricity demand for C4ISR and new technologies

Another important trend to consider is the constant increase in data processing and exchange required in modern operations. If this is compounded with cyber warfare and intelligence over telecommunication and Internet, this may translate in substantial energy cost increases assuming this cost to follow the associated trend of GHG reported by (Janof, 2012): GHG doubled over a period of five years (see details in Annex D). From these trends it is reasonable to expect that the energy demand from information technologies used by DND/CAF to more than double over the next decade if remediation actions are not initiated soon.

According to the Environmental Protection Agency (EPA) executive summary report (EPA, 2007), essentially the best practices and state of the art scenarios assumed moving in a new facilities or major upgrades to existing ones to better match the 'ENERGY STAR®' specifications[16]. The improved operation scenario assumed no significant capital investment but offers electricity cost savings in excess of 20% according to this report.

Natural Resources Canada (NRCan) Office of Energy Efficiency (OEE)[17] reports that a "data centre is a building space filled with information technology (IT) equipment: servers, storage, networking equipment, but also cooling equipment and power supplies. Data centres consume about 1% of Canada's electricity. One square foot of data centre space can use up to 100 times more electricity than a regular office space. Servers use only around 40% of a data centre's electricity. Another 40% goes to cooling these servers; and another 10% goes to power supplies losses. Conservation measures can dramatically reduce the electricity consumed by data centres."

A good example of essential capabilities in future combat theaters is persistent surveillance with sufficient precision for mission effectiveness and force protection. These capabilities would use extended endurance UAVs and potentially underwater, surface and land unman versions[18]. Such capabilities could be classified as energy hungry because their power requirements are moderate while their extended time of operation without the need for logistic support is over a few days. In some operational theaters, users would like to extend the autonomy period to weeks without re-fueling or recharging the batteries.

2.6.3 Electricity demand for new weapon technologies

Railgun and directed energy weapon (DEW) technologies (these include technologies such as: high energy laser (HEL), radio frequency (RF) DEWs, and relativistic particle

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[16] ENERGY STAR® is the mark of high-efficiency products in Canada. The familiar symbol makes it easy to identify the best energy performers on the market.

[17] http://oee.nrcan.gc.ca/equipment/manufacturers/1875 (Access date: 17 Sept. 2013).

[18] For example Tactically Exploited Reconnaissance Node (TERN) in a DARPA program run jointly with Office of Naval Research (ONR): http://www.darpa.mil/Our_Work/TTO/Programs/Tactically_Exploited_Reconnaissance_Node_(TERN).aspx (Access date: 17 Sept. 2013).

beams (RPBs) and high power microwave (HPM)) require usually large and heavy high power sources. Such technologies have improved with higher efficiency DEWs and power sources. However, they represent a major challenge to accommodate such electricity demand on legacy platforms. Various types of DEWs are currently in deployment phases in various formats for air, land and naval platforms. Their electricity energy demands are fairly large and require very high pulse power depending on type of targets, use and range. Most of these technologies require in excess of 150 kW. So these technologies are power hungry while persistent surveillance and C4ISR ones are energy hungry.

2.6.4 Electricity end use growing faster than fuel direct use

According to Richard G. Newell and Stuart Iler as stated in "The Global Energy Outlook" (Kalicki and Goldwyn, 2013, p. 46) "Electricity is about 40% of the worldwide primary energy consumption, a role that will be increasing going forward. In terms of end-use energy consumption, electricity is growing much faster than direct use of fuels." Advance information technologies, sensors and weapons as required by future CAF missions and operations will drive similar increase in electricity demand over the life time of current and future platforms and capabilities.

2.7 Summary of DOES energy demand evidences

Although the accumulated energy demand evidences cover a large domain of data developed for DOES and documented in this Chapter, here are some of the points that need to be retained in the context of supporting strategic thinking:

1. The aggregated total expeditionary and domestic energy, as averaged over three fiscal years from 08/09 to 10/11, amounts to a yearly average of 23 PJ or 23,000 TJ.

2. The total DND/CAF energy cost (538 million dollars in 2010-11) is a yearly recurring cost constantly augmenting over the last 14 years.

3. If we assume that the fleet energy price will continue increasing at the same rate as for the last 14 years, then the total CAF fleet energy spending would increase from approximately 140 million dollars in fiscal year 1998/99 to 800 million dollars in 2030/31, about six times as much if no significant corrective actions are taken.

4. Similarly, the total DND/CAF energy cost would reach 1,100 million dollars by 2031.

5. Currently no additional cost is included in these figures for an eventual carbon dioxide (CO_2) tax. In the advent that Canada adds a charge or tax for the amount of CO_2 emissions, this total DND/CAF energy cost trend might be more significant in such future.

6. The demand of electricity from new technologies, such as C4ISR and weapon systems, will increase at a faster pace than the direct use of fuel. This is the most critical point that DND/CAF must address to insure sustainable capabilities to fulfill their mandate here and abroad.

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3 Candidate targets identified

In the development of the first DOES, the strategic imperatives were identified as the fundamental operational requirements for defence to successfully fulfill its mandate and roles. “The prime imperative is mission continuity and the capacity to deliver on enduring operational commitments. Energy considerations ensure mission continuity by enabling operations to go further, longer, or even faster on the same or reduced fuel loads and expand tactical reach. Energy must be affordable or risk grounding ships or aircraft or the inability to make trade-off decisions when faced with higher energy costs. Other strategic imperatives include the protection and compatibility of critical infrastructure, the capacity for the interoperability of platforms and energy technology, particularly with our allies. Mission success requires ensuring the sustainability, integrity and reliability of energy and the supply lines as well as reducing threats to the transportation of fuel. Moreover, to the greatest extent possible, defence aims to reduce its environmental footprint and demonstrate leadership in environmental sustainability.” Then energy targets were designed in order to meet the strategic imperatives. The identified energy targets applied across a range of defence assets and activities including information and data management, infrastructure, tactical platforms, commercial vehicles, deployed operations, use of renewable and alternative energy sources, as well as force planning and procurement. The following energy targets elaborated by the DOES working group were reviewed by an energy panel of experts and offices of primary interest (OPIs) before being endorsed by the DCB in November 2013 (Rempel, 2014).

3.1 Target 1: Energy measurement and management

By 2030, to the maximum extent practicable, bases, platforms and expeditionary power and heating generation equipment shall employ an automated data acquisition, recording and metering system that measures the consumption of fuel from all sources.

The motivation or rationale for developing this target is:

- Automated fuel data and management systems (AFDS)[19] were deployed to United States of America (USA), United Kingdom (UK) and Australia (AU) armed forces.
- In Canada trial AFDS (http://www.coencorp.com/ (Access date: 9 April 2013)) has been fielded at 10 sites. A business case was raised by DF&L for its CAF-wide deployment at a cost of 14 million dollars over three years.
- AFDS would also ensure compliance with the Auditable Financial Statement Policy (AFSP) and address concerns expressed by the Office of the Auditor General (OAG).
- Automation will improve asset visibility and evidence from trial systems indicates that AFDS could identify system losses unnoted yet which in some instances offer opportunities for significant improvements at low cost.
- Utility metering, energy audits and systematic upgrading (see CFS Alert case study: Annex F).
- High-performance building (HPB) designs and micro grids (see Annex G).

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[19] http://www.varec.com/ (Access date: 17 Sept. 2013).

3.2 Target 2: Reduce demand - Buildings

By 2030 all CAF Bases and Stations, as whole entities, will reduce through efficiencies their energy use intensity (EUI) by 20% from 2005-2006 levels.

The motivation or rationale for developing this target is:

- Within Canada, energy intensity[20] improved by 21% across the period 1990-2009.
- Global energy intensity decreased by 1.2 % per year between 1990 and 2010 (IEA).
- Possibilities within Federal Building Initiative[21] to be fully explored.
- Federal Sustainable Development Strategy (FSDS) directs the metering of buildings larger than 1000 m^2.
- Utility metering project for RCAF buildings larger than 500 m^2.
- Energy audits followed by systematic upgrading of poor performers.
- Adopt HPB designs for new buildings.
- Adoption of microgrid technologies in new buildings and in improving old ones.
- More information in Annex F, Annex G and Annex H.

3.3 Target 3: Critical infrastructure

By 2030, all defence critical equipment, infrastructure and services will have reliable back-up power systems able to sustain independent (off-grid) operations for a minimum period of 14 days.

The motivation or rationale for developing this target is:

- Microgrid study: "Energy Security for DOD Installations" (Broekhoven*, et al.*, 2012).
- Military microgrids.[22]
- Renewables or substitute sources of energy should be considered as part of the solution.
- Additional information in Annex C, Annex F and Annex G.

"Critical infrastructure refers to processes, systems, facilities, technologies, networks, assets and services essential to the health, safety, security or economic well-being of Canadians and the effective functioning of government. Critical infrastructure can be stand-alone or interconnected and interdependent within and across provinces, territories and national borders. Disruptions of critical infrastructure could result in

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[20] "Energy intensity – which measures the efficiency of energy use per unit of economic activity (gigajoules per gross domestic product [GJ/GDP]) – improved by 21% across the period. Energy use per capita, however, showed a 1% increase, reflecting lifestyle changes at home and in private transport." Ref.: http://oee.nrcan.gc.ca/publications/statistics/trends11/factsheet/factsheet.pdf (Access date: 17 Sept. 2013) "Energy Efficiency Trends in Canada 1990 to 2009".

[21] http://oee.nrcan.gc.ca/communities-government/buildings/federal/10696 (Access date: 17 Sept. 2013).

[22] Pike Research - http://www.pikeresearch.com/research/military-microgrids (Access date: 17 Sept. 2013).

catastrophic loss of life, adverse economic effects, and significant harm to public confidence." (PSC, 2009, p. 2)

3.4 Target 4: Military platforms and fleet

By 2025, the CAF will have reduced the class fuel consumption rate by 10% from those detailed in the fuel consumption unit (FCU)[23] developed by ADM (Mat) and validated in 2012.

The motivation or rationale for developing this target is:

1. **Aircraft improvements**
    - Thermoelectric generators (in 2012 improved by 6%, a trend in progress) US Air Force (USAF) S&T report "Horizons" (AF/ST, 2012, p. 16) and new highly-efficient thermoelectronic conversion (Meir*, et al.*, 2013) (more details in Annex J).
    - Lightweight materials.
    - Travis USAF saved a million $/year by moving from JP-8 to Jet A with additives.
    - Wingtip devices (3.5% more efficient - Airbus).
    - Behaviour modification, better flight planning and flight profile adjustments.
    - Full scale engine replacement, while more expensive, offers as much as a 15-25% improvement in fuel burn for fighter, bomber, attack and transport aircraft.
    - Average annual fuel efficiency improvement of 1.5% to 2020.[24]
2. **Ship improvements (compare with commercial fleets (ABB, 2012))**
    - Hull modifications, e.g., stern flap addition (3-4% more efficient - US Navy).
    - Underwater anti-fouling coating (9% more efficient - commercial shipping).
    - Thermoelectric-based waste heat recovery device.
    - More efficient hull designs.
    - Improved maintenance practices, e.g., underwater anti-fouling coating.
    - Hybrid ship drive.
    - All-electric ship (AES).
    - Engine efficiency regulations.
    - More information in Annex G and Annex I.

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[23] The North Atlantic Treaty Organization (NATO) standardization agreement (STANAG 2115) provides a method for computing fuel requirements in military operations and a standard estimation for fuel consumption of a military unit called FCU (fuel consumption unit).

[24] According to The International Air Cargo Association (TIACA), since the beginning of the jet age over 40 years ago, technology has advanced the industry to achieve 70% reduction in fuel consumption: TIACA Carbon emissions (online), TIACA, http://www.tiaca.org/tiaca/Carbon_Emissions.asp (Access date: 12 Dec. 2013). This improvement trend will continue with the newest generation of airplanes which will offer an additional 15-20% improvement.

3. **Land tactical vehicle improvements**

- Thermoelectric generators (Gibson, 2012, Smith and Thornton, 2009) and other alternatives in Annex G.
- Optimised tires (up to 8.5%[25] more efficient - US Army).
- Improved fuel injector systems.
- Reduced vehicle mass (up to 23% more efficient - US Department of Energy (DOE) estimates).
- Eliminating bad driving habits.
- Vehicle thermal insulation and IR signature reduction (Annex H.2).

For all environments, greater use of the synthetic environment for training offers both improved safety and long-term cost avoidance, i.e., simulators and procedural trainers, including deployable variants, rather than live flight hours.

3.5 Target 5: Commercial vehicle fleet improved efficiency

Target 5 has been removed from the initial list. An independent review panel recommended the removal of Target 5 because it was deemed outside the direct control of either DND or the CAF. It would be achieved naturally through federal regulations and Public Works procurement.

3.6 Target 6: Reduce demand - Military camps

By 2030, per person, reduce the energy consumption required to produce main and deployed military camp services (heating, power generation, sewage treatment, water supply, etc.) during the conduct of domestic and expeditionary operations by 50%.

The motivation or rationale for developing this target is:

- Camp improvements (several initiatives including CFS Alert: Annex F).
- Replace field space and water heaters with higher efficiency variants.
- Upgrade central power distribution systems with power management units to select and synchronise multiple power sources.
- Adjustable speed generators to match load demand (potential 20% more efficient).
- Insulation and shading of ‘soft walled shelters’ (i.e., tents).
- Portable solar panel system.
- Integrated camp energy technologies (ICE-T) TDP in partnership with NRCan at Varennes.
- NATO Sustainable Military Compounds (Smart Energy Team (SENT)).

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[25] Here we have to be careful because it is usually a function of speed and other factors, if it is 8.5% of the proportion of loss due to tire traction (say 20%) then the resulting effect is only 1.7% of the FCU. See: Bridgestone (2008), What consumes fuel?, *Real Answers Magazine*, Special Edition Four 5.

3.7 Target 7: Increase energy efficiency - Soldiers

By 2030, all individual dismounted soldiers will be independent from the logistics chain for energy resupply for at least 72 hours without increasing the soldier's burden.

The motivation or rationale for developing this target is:

- Dismounted infantry improvements (more information from ISSP and Annex H).
- Advanced Soldier Adaptive Power (ASAP): Reduce weight of power systems by a factor of three and achieve energy sources of no more than 2 kg for 72-h patrol. Currently soldiers carry 13-15 batteries with total weight of 5 kg.
- Wearable power pack / lightweight power sources (Annex G).
- Self-charging power cell - conversion of mechanical energy into stored energy (Georgia Tech).

3.8 Target 8: Alternative energy opportunities

By 2016, the CAF will have certified the processes by which suitable advanced, 'drop-in'[26] alternative liquid fuels, that meet Canadian military specifications, can be used in each of its tactical (non-commercial) platforms and vehicles.

The motivation or rationale for developing this target is:

- CF-18 and CC-130 aircraft have already had their engines certified and in collaboration with USAF and United States Navy (USN) have successfully flown utilising synthetic fuel.
- Maintains compatibility and interoperability with closest ally, i.e., US Armed Forces.
- Offers flexibility of several types of fuel to CAF during operations.
- Travis USAF savedonemillion $/year by moving from JP-8 to Jet A with additives.

3.9 Target 9: Force planning and requirement

From 2018, tools to account for and analyse energy consumption and costs are to be incorporated into all strategic modeling and simulation (M&S) programmes that are used for force planning, options analysis and requirements development.

The motivation or rationale for developing this target is:

- Decrease strategic and operational surprise due to lack of energy or its cost.
- Provide improved and more accurate critical logistic data.

Modeling and Analysis of Canadian Forces Operational Energy Demand (Ghanmi - DRDC CORA - 2012).

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[26] Drop-in fuels take many forms, but their commonality is the ability to use existing engines and infrastructure.

3.10 Target 10: Procurement – Energy key performance criterion

From 2018, the procurement process for equipment and infrastructure (capital and operations and maintenance (O&M)) will incorporate energy usage and fuel economy over the life cycle of the asset as a key performance criterion.

The motivation or rationale for developing this target is:

- Reduce uncertainties in budgeting for a capability.
- Provide necessary information required for major project auditing.

See ”Military Operational Energy - A Fully Burdened Cost Model” (Ghanmi, 2012) and “DOD Defense Acquisition Guidebook”, Chapter 3, Para 3.1.6 (https://acc.dau.mil/CommunityBrowser.aspx?id=488333#3.1.6 (Access date: 9 April 2013)).

3.11 Potential cost savings from DOES targets applied to buildings and military platforms

Details of the methodology, hypothesis, inflation scenarios and energy data used are in Annex E. The findings are summarized as follows.

Using DOES Target 2 (20% energy reduction) for real property and Target 4 (10% energy reduction) for military platforms and fleet with the domestic data for the cost of each type of energy (e.g., jet fuel and electricity) the energy savings translated into the cost savings presented in Table 2. Due to the lack of available accurate data for energy in expeditionary operations the fully burdened cost of energy (FBCE) methodology framework was not applied. Consequently the cost savings reported by Table 2 are lesser than if the FBCE had been estimated.

Table 2: *Estimated annual cost savings by 2030 and thereafter in FY 2010-2011 dollars (not adjusted for future inflation).*

	Energy type	**Estimated cost savings in million dollars, $M**
Real Property	Electricity	16.0
	Natural Gas	8.3
	Light Fuel Oil	1.2
	Heavy Fuel Oil	2.9
Fleet	Gasoline	0.4
	Diesel Fuel	2.5
	Ship's Fuel	5.5
	Jet Fuel	15.8
TOTAL		53.6
Total real property (buildings)		28.4
Total fleet		25.2

The proposed energy targets are estimated to save DND/CAF approximately $54 million, in FY 2010-11 dollars, by 2030. These savings represent approximately 9% of total energy-related expenditures in FY 2010-11.

In conclusion from this methodology, it is estimated that the selected DOES targets could translate into savings ranging from $93 million to $134 million in 2030 dollars depending on the three inflation scenarios of Table 3. Again, if the FBCE had been applied in making these estimates, much large cost savings would have been found.

Table 3: *Estimated cost savings in 2030 dollars adjusted for three possible inflation rates.*

Long-term inflation scenario	**Annual inflation rate**	**Estimated cost savings in million dollars, $M**
Most likely	2.8%	93
Low	2.0%	80
High	4.7%	134

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4 Principles for an enduring DND/CAF energy strategy

From the DND/CAF energy domain, the DND/CAF energy spectrum view point, four dimensions or views were identified as follows:

1. Defence Real Property and Related Assets (i.e., land and its permanently affixed buildings or structures connected to the grid, vehicles and other ancillary energy demanding assets).
2. Military Camps and Compounds (including forward operating bases (FOBs) and any off-grid encampments).
3. Tactical Platforms (i.e., independent, military vehicles incorporating sensor, communications and weapon systems used by nations in the conduct of operations, e.g., ship, aircraft, armoured vehicle, satellite).
4. Dismounted Combatants, e.g., infantry and combat aircraft pilot off platform.

These four dimensions of the DND/CAF energy domain relate to the DOES targets as follows:

1. Defence Real Property and Related Assets: Targets 1, 2, 3 and 10.
2. Military Camps and Compounds: Targets 1, 6, 9 and 10.
3. Tactical Platforms: Targets 1, 4, 8, 9 and 10.
4. Dismounted Combatants: Targets 1, 7, 9 and 10.

In a DRDC report (Neill, 2009) on DND/CAF alternative energy options, four strategic principles were identified to orient research and eventual adoption of energy options:

1. Operational Principle: an alternative energy option must maintain or enhance the Department's ability to carry out its fundamental operational missions.
2. Cost Principle: subject to the Operational Principle, an alternative energy option must provide power at a proportional cost equivalent to or lower than existing energy sources (taking into consideration the recovery of installation costs through lower operating and maintenance costs over the life cycle of the equipment). Business case analysis must take into account the fully-burdened costs of any proposed new technology. DND should exercise extreme caution when considering any alternative energy technology that has not proven competitive in the broader civilian economy.
3. Environmental Principle: subject to the Cost Principle, an alternative energy option should have a net environmental impact no greater than existing energy sources.
4. Political-legal Principle: an alternative energy option must conform to legal, regulatory and policy constraints. Where these would preclude exploitation of an

alternative energy option that meets the operational, cost and environmental[27] principles, DND should be willing to seek changes to legislation, regulations or policy, as appropriate.

In addition to these strategic principles some energy fundamental principles need to be given primordial precedence to ensure energy fitting to DND/CAF capabilities, especially when they drive operational effectiveness, provide CAF advantage over opposing forces and reduce risk to our combatants:

1. Capacity factor, i.e., actual energy output over a period of time against generation potential.

2. Energy conversion efficiency, i.e., the ability to convert the maximum amount of source energy toward the desired work, function or amenity.

3. Power density versus energy density (acceleration versus range), i.e., the ability to achieve varying load profiles (demands) over time (power = energy/time and vice-versa, energy = power x time).

4. Volumetric versus gravimetric energy density or power density (size versus weight), i.e., the ability to meet the physical constraints imposed by the intended application (size or form factor, and weight).

These four fundamental energy principles inform all DOES Targets and encompass the entire DND/CAF energy domain and its four dimensions.

Other considerations such as operating and shelf temperature ranges, air consumption and pollution, or reliability under operational conditions will be also discussed but since they are particular to each application they will only be mentioned when addressing a specific capability or platform.

Another great principle is that “The cheapest energy is the energy you don’t have to produce in the first place” said ACEEE Executive Director Steven Nadel[28]. It is sometimes identified as energy efficiency of a system, building, platform or piece of equipment and relates to energy wasted due to lack of isolation and energy efficient way of applying energy toward a desired work, effect or end use. For example, it costs less (requires less heat) to heat a well-designed and appropriately insulated and ventilated building (including correct use of doors, windows and openings/vents).

4.1 Capacity factor

United States Nuclear Regulatory Commission (US NRC) defines capacity factor (net) as the ratio of the net electricity generated, for the time considered, to the energy that could

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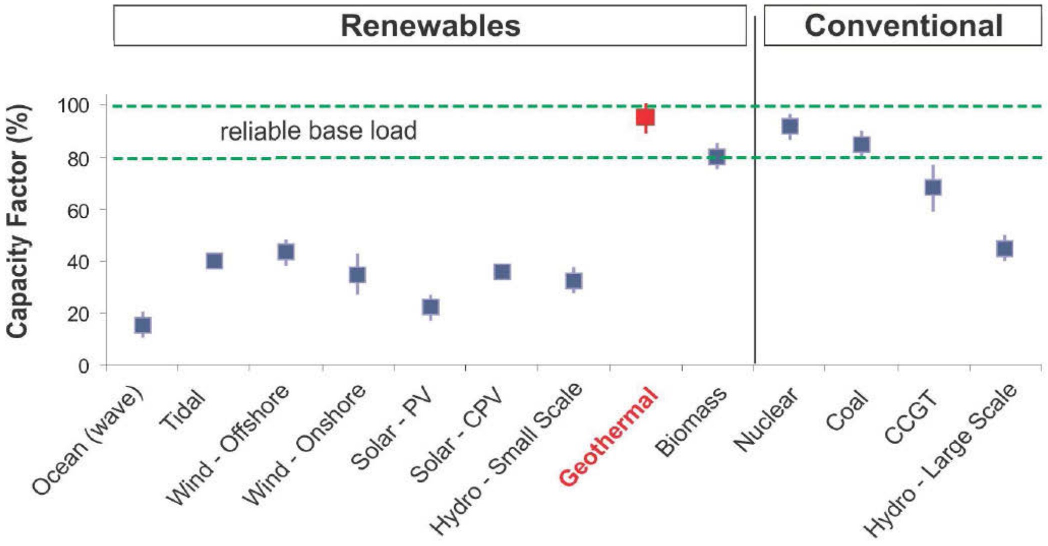
[27] The source document used the word “green” which has been replaced here by a more enduring term “environmental”.

[28] The American Council for an Energy-Efficient Economy (ACEEE), a non-profit organization, acts as a catalyst to advance energy efficiency policies, programs, technologies, investments, and behaviors. http://www.aceee.org/press/2014/03/new-report-finds-energy-efficiency-a (Access date: 17 Sept. 2014).

have been generated at continuous full-power operation during the same period[29]. A similar definition could be applied for thermal systems and electrical-thermal systems (Skowroński, 2011). Here is a simple chart of typical capacity factors that was used by NRCan (Grasby, *et al.*, 2011) to show the advantages of geothermal and enhanced geothermal technologies for electricity generation and district heating in Canada.

In addition the following chart computed with the data from two sources confirms the order of magnitude of Figure 11 average capacity factors with those for selected electric power sources in the United States.



Legend: PV = photovoltaics, CPV = concentrated photovoltaics, CCGT = combined-cycle gas turbine.

Figure 11: *Typical capacity factors of different power generation technologies.*[30]

The capacity factors given in Figure 12 represent averages for a range of recent years. For the fossil fuels and nuclear power sources, the data were from (EIA, 2009, p. 102). For the renewables the data were from DOE, National Renewable Energy Laboratory, (Aabakken, 2006, p. 201).

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[29] http://www.nrc.gov/reading-rm/basic-ref/glossary/capacity-factor-net.html (Access date: 17 Sept. 2013).

[30] Source: Emerging Energy Research (2009).

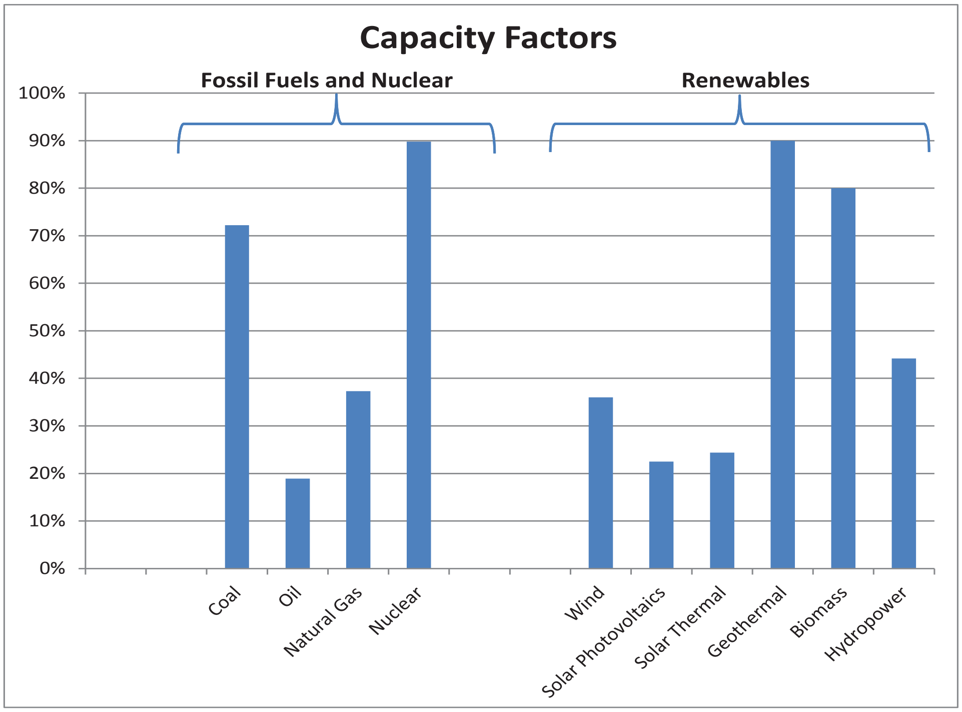

Figure 12: *Average capacity factors for selected electric power sources in the United States.*

4.2 Energy conversion efficiency

Energy conversion efficiency needs to be maximised in order to reduce undesirable loss and expenses while providing energy for a capability or a desired work. Most of the time an energy conversion or transformation is required to accomplish the desired work, e.g., using the energy of a fuel and convert it in mechanical energy to the wheels of a vehicle using an internal combustion engine. Energy transformation or energy conversion is the process of changing one form of energy into another. "In physics, the term energy describes the capacity to produce certain changes within a system, without regard to limitations in transformation imposed by entropy. Changes in total energy of systems can only be accomplished by adding or removing energy from them, as energy is a quantity which is conserved (unchanging), as stated by the first law of thermodynamics."[31]

Energy conversion efficiency (η) is the ratio between the useful output of an energy conversion device and the input, in energy terms. The useful output could be electric power, mechanical work, or heat.

$$\eta = \frac{E_{in}}{E_{out}} \tag{1}$$

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[31] http://en.wikipedia.org/wiki/Energy_transformation (Access date: 17 Sept. 2013).

For example, in (da Silva, *et al.*, 2013) the energy efficiency of fix-speed diesel and biodiesel generator sets were found to be about 10% at 25% of nominal power and 20% at nominal power. In Table 4 typical energy conversion efficiency of selected energy conversion devices captures the order of magnitude of what is currently achievable.

Table 4: *Efficiency of selected energy conversion devices.*

Energy conversion device	**Energy conversion**	**Typical efficiency**[32]
Electric heater	Electricity/thermal	~100%[33]
High-efficiency natural gas furnace	Chemical/thermal	~98%
Large electric generator	Mechanical/electricity	>95%
High-efficiency and large electric motor	Electricity/mechanical	>90%
Battery	Chemical/electricity	>90%
Water turbine	Potential-kinetic/mechanical	>90%
Permanent-magnet alternator	Mechanical/electricity	60-90%
Fuel cell	Chemical/electricity	Up to 85%
200-500 kWe[34] diesel engine generator[35]	Thermal/electricity	≥60%
Diesel engine (car/truck/ship)	Thermal/mechanical	30-50%
Gas turbine, jet engine	Thermal/mechanical	Up to 40%[36]
Low-pressure sodium lamp	Electricity/light	15-40%
Solar cell (advance)	Solar radiation/electricity	Most at 15%, (up to 40%)
Light-emitting diode (LED)	Electricity/light	Up to 35%
Thermophotovoltaic (TPV)	Heat-infrared/electricity	8-30%
Firearm (.300 Hawk ammunition)	Potential/kinetic	~30%
Gasoline engine (car/truck)	Thermal/mechanical	10-30%
4 kWe diesel & biodiesel engine generator	Thermal/electricity	~10% at 1 kW to ~20% at 4 kW
Fluorescent lamp	Electricity/light	20%
Incandescent lamp	Electricity/light	5%

It is worth noting the high efficiency of electric motors and generators compared to internal combustion (IC) engines. Also worth observing is the energy conversion

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[32] From various information sources including http://en.wikipedia.org/wiki/Energy_conversion_efficiency (Access date: 17 Sept. 2013).

[33] Using a thermo pump this could be increased by a factor of three using a ground-water loop.

[34] Kilowatt electric as opposed to kilowatt thermal (kWt).

[35] http://arpa-e.energy.gov/?q=arpa-e-events/small-scale-distributed-generation-workshop (Access date: 17 Sept. 2013).

[36] This needs to be adjusted by the propulsive efficiency η_p for specific jet parameters.

combination ($\eta \approx 63\%$) of fuel cell devices with electric motors and batteries which surpasses the traditional gasoline combustion engine ($\eta \leq 30\%$) or the more energy efficient diesel engine ($\eta \leq 50\%$). Electric car energy conversion efficiency depends on the source of electricity used but when looking at the car system itself, electric car could achieve efficiency close to the product of electric motors and battery technology used, i.e., between about 70% to 95%.

However for off-grid operations the traditional IC engine has the advantage of a transportable and storable fuel. In the case of newer technologies, fuel cell cars could offer similar advantages, with the addition of being more energy efficient than using IC engines, as long as they could be made reliable and affordable for a variety of fuels.

In general unless the end energy use is for heating, due to the nature of transforming heat from burning a fuel into useful work, the maximum energy efficiency of such transformation is limited by a thermodynamic law expressed by the Carnot equation:

$$\eta_{Carnot} = 1 - \frac{low\ temperature\ in\ Kelvin}{high\ temperature\ in\ Kelvin} \tag{2}$$

For example, this Carnot equation shows that the useful energy (e.g., electricity or mechanical work) that could be extracted from boiling water (373 K)[37] with respect to room temperature (291 K) is limited to 0.22 or 22%. However, electricity energy could be transformed into heat or mechanical work at almost 100% efficiency, but once into heat it will suffer large energy loss to transform it back to electricity as per the Carnot efficiency equation. So electricity is very useful and could be transformed into other useful energy more efficiently than heat from a fuel. Electricity is the noble energy that powers a large variety of advanced technologies and capabilities, and propels civilization into new horizons.

Figure 13 shows internal combustion engines with typical additional energy loss. The resulting energy conversion efficiency (η) between the energy of the fuel to useful output either electric power or mechanical work could be as low as 10%.

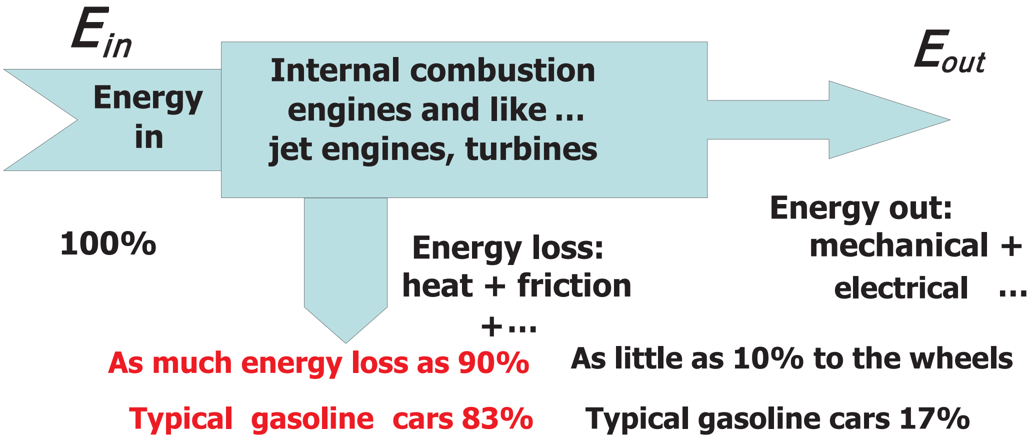

Figure 13: *Internal combustion engines energy loss.*

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[37] [°C] = [K] – 273.15.

Here is an excerpt from a report (Rissman and Kennan, 2013) on diesel motor previous and projected improvements:

"As a result of government-supported research, heavy-duty diesel trucks went from 37% efficiency in 1981 to 42% efficiency in 2007. Truck fuel economy increased almost 20%, from a low of 5.4 miles per gallon in 1981 to 6.4 miles per gallon in 2010. From 1990 to 2009, per-mile emissions of harmful nitrogen oxides (NOx), carbon monoxide (CO), and particulate matter from the US heavy truck fleet declined 67-81%, dramatically reducing adverse health impacts from diesel engines. Today, diesel engines use an array of technologies developed through the CRF[38] and ACE[39] R&D programs. Government-led diesel research is ongoing; the ACE R&D program's 2015 goals include improving overall efficiency of diesel passenger vehicles to 45% and commercial vehicles to 50%."

4.3 Power density versus energy density

To better appreciate the suitability of various energy sources and technologies to match the varying energy and power demand of an application, tools like the Ragone plots have been used. A Ragone plot helps visualizing the energy-power density of candidate sources for a specific application energy and power demand profile. For an electric power load over a period of time, Figure 14 compares selected batteries chemistry with other technologies. It shows that most batteries deliver more energy when operating at low power over longer period of time, while due to their chemistry and heat loss they deliver less energy at high power over shorter period of time. In addition, Figure 14 shows the relation of energy with vehicle range and power with vehicle acceleration compared to some electric vehicle goals.

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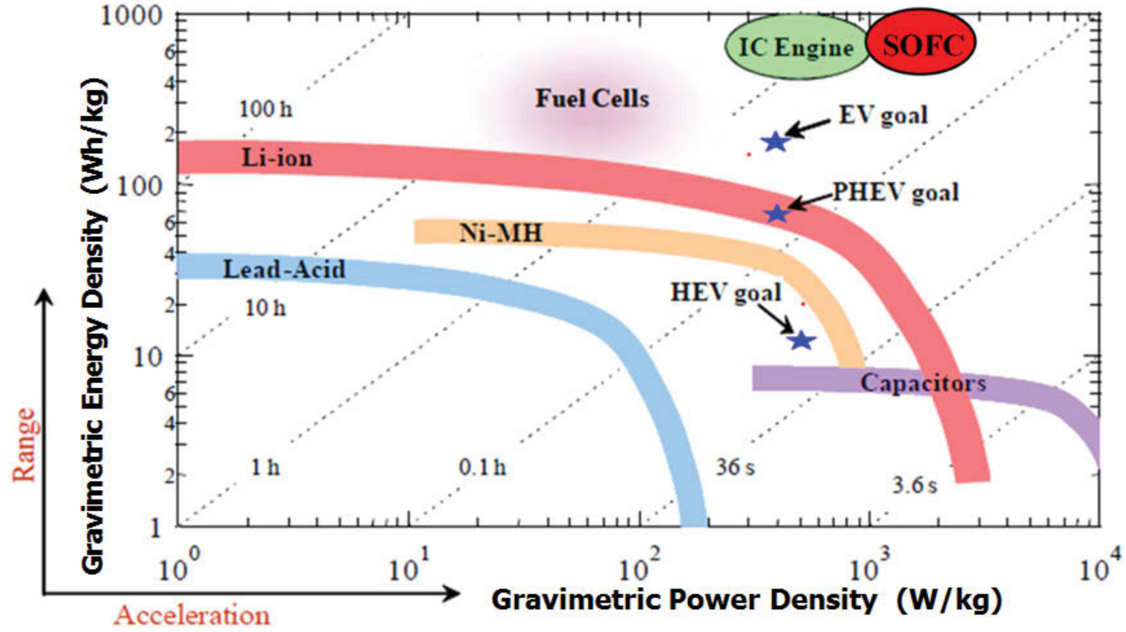
[38] Combustion Research Facility.

[39] Advanced Combustion Engine R&D program.



Legend: solid oxide fuel cell (SOFC), internal combustion (IC) engine, nickel–metal hydride battery (Ni-MH), hybrid-electric vehicles (HEV), electric vehicles (EV), and plug-in hybrid-electric vehicles (PHEV).

Figure 14: *Ragone plot of the balance between gravimetric energy and power densities (range versus acceleration).*[40]

It is worth noting that in some scientific documents the gravimetric energy density is identified as the specific energy and sometimes the gravimetric power density is labelled as the specific power. Similarly, the expression energy density is used for the volumetric energy density and so on. Consequently, in this document we adopted a less confusing language for these quantities, e.g., gravimetric energy density, volumetric energy density, gravimetric power density, and volumetric power density as for Figure 14 and Figure 15.

4.4 Volumetric versus gravimetric energy or power density

An important aspect of energy sources is their suitability to an application in terms of volume and weight. Volumetric versus gravimetric energy or power density is critical to applications such as dismounted combatant systems and air platforms where there are requirements to meet the physical constraints imposed by the intended application (size or form factor, and weight). Figure 15, adapted from (Wachsman and Lee, 2011), shows that an increase in gravimetric power density could result in a lighter device, while an increase in volumetric power density could result in a smaller device.

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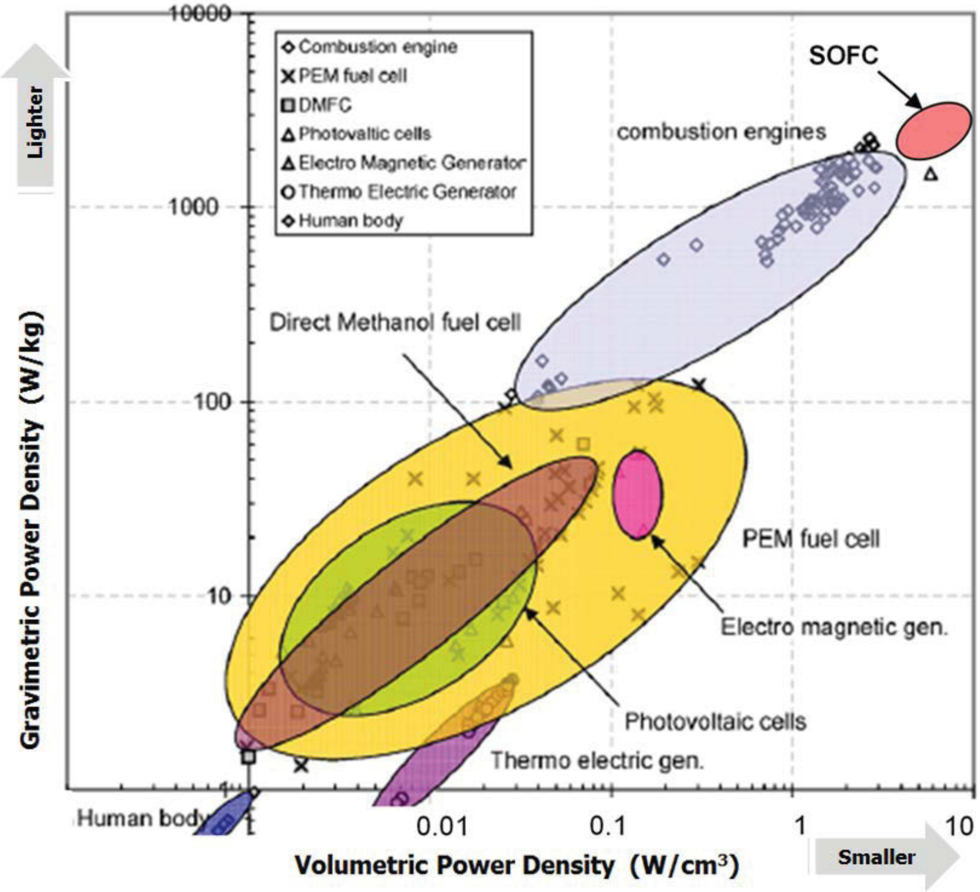
[40] This illustration is based on various sources including product data sheets as reported in http://bestar.lbl.gov/venkat/files/batteries-for-vehicles.pdf (Access date: 17 Sept. 2013) by Dr Venkat Srinivasan of the Lawrence Berkeley National Lab. It includes various electric vehicles goals and technologies compared with internal combustion (IC) engine: nickel–metal hydride battery, abbreviated NiMH or Ni-MH, hybrid-electric vehicles (HEV), electric vehicles (EV), and plug-in hybrid-electric vehicles (PHEV). Note that the diagonal lines indicate time to discharge. Then the solid oxide fuel cell (SOFC) was added in the file provided by Dr Eric Wachsman (www.energy.umd.edu). Finally it was further updated here for the purpose of this report with the selected axis labels.



Legend: proton exchange membrane (PEM) fuel cell, solid oxide fuel cell (SOFC).

Figure 15: *Selected energy sources illustrating size and weight spectrum (weight versus size).*[41]

In addition it is important to keep in mind the energy densities of a variety of energy sources, materials, storages and carriers as reported in Wikipedia.[42] Figure 16 reveals several important factors to consider when estimating the suitability of a fuel or an energy storage technology. The most obvious here is the challenge that hydrogen represents when one desires to use it to power vehicles by using hydrogen as an energy carrier to replace traditional fuels such as gasoline or diesel. The hydrogen gravimetric energy density is exceptional but its low volumetric energy density represents challenges for its commercialization at competitive life-cycle price in comparison with gasoline, diesel and liquefied petroleum gas (LPG) butane and liquid natural gas.

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[41] **Figure 15** is based on the material provided by Dr Eric Wachsman (www.energy.umd.edu) and also published in Wachsman, E.D. and Lee, K.T. (2011), Lowering the Temperature of Solid Oxide Fuel Cells, *Science*, 334, 935-939. Authorization to use the material confirmed by email: Wachsman-Labbé 18 July 2013.

[42] http://en.wikipedia.org/wiki/Energy_density (Access date: 17 Sept. 2013).

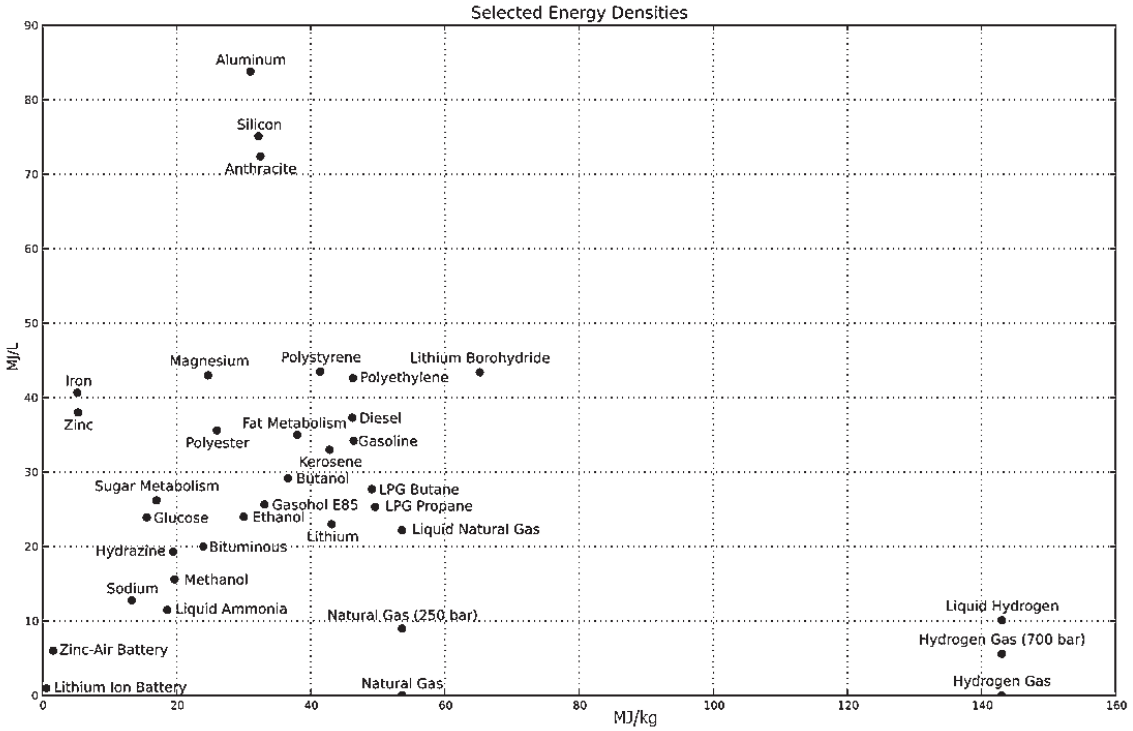

Figure 16: *Volumetric versus gravimetric energy density in energy storage and in fuel.*

4.5 Applying energy principles to DOES

Increasing dependability on technologies tailored to extend defence and security capabilities here and abroad requires assessing them from relevant aspects ranging from availability and transportability to cost sustainability over various time horizons. From the energy perspective, there are no doubts that technologies in development worldwide will try to address the threat caused by the observed trend of fuel cost increase that affects nations' capabilities to further sustain high operations tempo or ensure domestic operations in face of disasters.

In the context of the DND/CAF energy strategy, here are examples of how the energy fundamental principles (beside maturity and short-term cost) could be applied in selecting among a plethora of emerging technologies:

1. Capacity factor (actual output versus generation potential): to compare technologies and various source mixes to fulfill the energy requirement and persistence profile of a capability, for example critical infrastructures of a CAF base to ensure mission continuity requires a high capacity factor from a main source or a complex technology mix using a microgrid to meet that requirement.

2. Gravimetric power versus energy density (acceleration versus range): to assess technologies that best fit expected fast and slow load variation or profile, for example to accelerate or climb a hill, a loaded truck needs a lot of power but over time to

climb a long hill or travel long distances it needs enough energy (energy = power x time).

3. Volumetric versus gravimetric energy density (size versus weight): to match the physical constraints imposed by the intended application, for example jet fuel offers a good balance between volume and weight for the amount of energy required to fly. However, hydrogen offers higher gravimetric energy but requires large volume if not liquefied as found in some hydrogen fuel cell power packs for land equipment and transport.

4. Energy conversion efficiency: how much of the source energy is converted toward the desired work, for example the available thermal energy from gasoline using typical internal combustion engines for cars may deliver as little as only 10% energy to the wheels, the remainder being wasted in heat (about 70-75% is rejected as heat without being turned into useful work) and other functions such as powering a water pump to cool the engine. Alternatively, a hydrogen fuel cell may deliver more than 80% of the input energy through a direct current motor to the wheels.

Here are selected examples of technologies discussed in the Defence Science Advisory Board (DSAB) report (DSAB, 2013), with a few more that resonate with the DND/CAF energy strategy. For any of these technological options to effectively increase CAF capabilities and operations sustainability, sufficient training will have to be provided across military personnel at all ranks:

1. Smart grid using local energy sources such as solar and geothermal to reduce the demand on fuel. Saved fuel offers high-energy density storage.

2. Smart grid metering contributes to efficient use of energy.

3. Overall energy metering, appropriate data collection and analysis contribute to DND/CAF energy auditing and reporting to Parliament.

4. Simulation tools to anticipate energy demand and plan cost effective logistic support over the evolving realities of an operation.

5. Software tools to better design smart energy sources for off-grid applications.

6. Advanced technology batteries that offer safe, convenient and sufficient power (as from ultra-capacitors) and energy properties (as from efficient micro turbines) to cost efficiently and operationally match the expected loads and extend endurance.

7. Electrical and hybrid land vehicles for domestic, on base and expeditionary operations, integrating their storage capabilities to the local microgrid.

8. Use thermoelectric generators (TEGs) to recuperate energy of heat waste from combustion engines (all types from trucks to combat aircraft and submarines).

9. Extend operational range of operations through energy efficiency and improved sources such as hybrid energy storage power packs and frugal engines.

10. Low-voltage direct current (DC) distribution to high efficiency DC loads such as LED, electronic devices and DC motors contribute to reduce energy consumption and

extend mission endurance (savings range between 30 to 70%). Also feeding DC equipment with DC supplies reduces cost, volume and weight of systems.

11. Technologies to make domestic bases capable of sustaining self-sufficient energy resources independent of damaged civilian infrastructures.
12. Technology insertions by phase in order to timely and more cost effectively benefit from technologies in "a state of acceleration".
13. Depending on the characteristic of missions where the duration and cost of conventional energy sources such as diesel-based generators become prohibitive, dispatchable generation alternatives such as gas turbines and small nuclear generators and renewable sources (e.g., energy from waste) should be considered.
14. Small nuclear reactors like the Hyperion can be attractive for domestic bases or stations like in the Canadian Arctic.
15. Geothermal power stations are suitable if the mission is expected to last more than a year. Canada may consider giving such dependable energy source as a legacy for humanitarian aid and development of the communities during and after a mission.
16. Self-refuelling by generating fuel from nuclear and abundant sea water and CO_2. For Canada it could be done by using solar direct generation of hydrogen, and additionally in a second stage using solar energy again and H_2 to convert CO_2 to methanol using emerging nanotechnologies.

In terms of mission effectiveness the DSAB report suggests: "Development of alternative energy technologies and smart grids around military bases abroad can achieve a humanitarian mission in addition to the military objective. Many military deployments in remote areas (e.g., Afghanistan) occur in local communities with a relatively low level of energy development. The introduction of alternative energy technologies in these areas can leave a legacy of humanitarian aid for the further development of these communities during and after the military mission has been accomplished."

If we sort these 16 technologies along the four dimensions of DND/CAF energy domain identified at the beginning of this chapter, Chapter 4, the above list of 16 selected examples of technologies could be assigned to these four dimensions as follows:

1. Defence real property and related assets:
    a. 1. Using local energy sources.
    b. 2. Smart grid metering.
    c. 3. DND/CAF energy auditing.
    d. 6. Advanced safe and cost-effective batteries.
    e. 7. Electrical and hybrid land vehicles.
    f. 8. Use thermoelectric generators (TEGs) to recuperate energy of heat waste.

    g. 10. Direct current (DC) to high-efficiency DC loads such as LED and motors.
    h. 11. Domestic bases capable of sustaining self-sufficient energy.
    i. 12. Technology insertions by phases in “a state of acceleration”.
    j. 13. Depending on missions use dispatchable power generation alternatives.
    k. 14. Small-nuclear reactors.
    l. 15. Geothermal power generation.
    m. 16. Self-refuelling by generating fuel, e.g., H_2 to convert CO_2 to methanol.

2. Military camps and compounds (including FOBs and any off-grid encampments):
    a. 1. Using local energy sources.
    b. 2. Smart grid metering.
    c. 3. DND/CAF energy auditing.
    d. 4. Simulation tools for energy demand and cost of operations.
    e. 5. Software tools to design smart-energy sources for off-grid applications.
    f. 8. Use thermoelectric generators (TEGs) to recuperate energy of heat waste.
    g. 10. Direct current (DC) to high-efficiency DC loads such as LED and motors.
    h. 13. Depending on missions use dispatchable power generation alternatives.
    i. 14. Small nuclear reactors.
    j. 15. Geothermal power generation.
    k. 16. Self-refuelling by generating fuel, e.g., H_2 to convert CO_2 to methanol.
3. Tactical platforms:
    a. 1. Using local energy sources.
    b. 4. Simulation tools for energy demand and cost of operations.
    c. 6. Advanced safe and cost-effective batteries.
    d. 7. Electrical and hybrid land vehicles.
    e. 8. Use thermoelectric generators (TEGs) to recuperate energy of heat waste.
    f. 9. Extend operational range of operations through energy efficiency.

   g. 10. Direct current (DC) to high-efficiency DC loads such as LED and motors.
   h. 12. Technology insertions by phases in “a state of acceleration”.
   i. 16. Self-refuelling by generating fuel, e.g., H_2 to convert CO_2 to methanol.
4. Dismounted combatants, e.g., infantry and combat aircraft pilot off platform:
   a. 1. Using local energy sources.
   b. 5. Software tools to design smart-energy sources for off-grid applications.
   c. 6. Advanced safe and cost-effective batteries.
   d. 9. Extend operational range of operations through energy efficiency.
   e. 12. Technology insertions by phases in “a state of acceleration”.
   f. 16. Self-refuelling by generating fuel, e.g., H_2 to convert CO_2 to methanol.

4.6 Energy cannot be created or destroyed but innovative technologies allow to better exploit what is available

We cannot create new energy that is not already present in our universe. But we extract materials in which energy is stored, change their state, and harness the energy that can be captured from the state change, e.g., energy harnessed from fuels.

Energy must be captured, concentrated, transported, and converted to do useful work.

Albert Einstein and Isaac Newton both stated that energy cannot be created or destroyed but simply changed into other forms.

The largest amount of energy available on Earth is the mass of its material and from the Sun radiation. The Sun is our largest fuel source that created fossil fuels used today.

Einstein’s original statement is “If a body releases the energy L in the form of radiation, its mass is decreased by L/V^2” which is known as $E = mc^2$ (where c is the speed of light). Because the speed of light is very large, a tiny bit of mass can generate a lot of energy.

5 Technology wild cards

A 'wild card' is an unpredictable or unforeseeable factor that occurs outside of the normal rules and expectations. Examples of technology wild cards may include a) progress in technologies to produce new hydrocarbons with less GHG impacts at lower price than $50 a barrel, b) technologies to produce mechanical work and electricity with much less fuel, and c) others with substantial paradigm changes with much higher energy and power density with minimal waste and environmental impacts, such as a new nuclear technology with minimal harmful radiation, no dangerous wastes and little undesirable environmental impact.

Several classes of disruptive technologies (see references such as (Brimley*, et al.*, 2013, Closson, 2013, CSIS, 2014, Medina*, et al.*, 2014, Nathwani*, et al.*, 2014, Weiss and Bonvillian, 2014)) are not discussed here but are part of the normal evolutionary technologies as per the preceding references and most of the relevant ones to the CAF are already included in the technologies recommended in this report under the DOES targets and in the Annexes supporting the examples provided. According to (Brimley*, et al.*, 2013) "What makes a technology 'game changing', 'revolutionary', 'disruptive' or a 'killer application' is that it both offers capabilities that were not available – and were in many ways unimaginable – a generation earlier and in so doing provokes deep questions whose answers are not readily available. These kinds of institutional, organizational and even individual soul-searching questions encompass not only what is possible, but also what is proper, in everything from doctrine and staffing to law and ethics. Such technologies – be they fire, the printing press, gunpowder, the steam engine or the computer – are rare but truly consequential."

A possible wild card could be the discovery of an environment-friendly and cost-effective technology to extract methane hydrate which according to Laszlo Varro of the International Energy Agency (IEA) could be a game charger for countries such as Japan. "Potentially commercially exploitable methane hydrate (3000 billion tons of carbon) represents about three times as much of all commercially exploitable natural gas (96 billion tons of carbon), oil (160 billion tons of carbon) and coal (675 billion tons of carbon) combined[43]." However, this means emitting more GHG.

Another example is the possibility for a significant improvement in jet propulsion making an important game changing: "SABRE engine technology can enable aircraft to cruise within the atmosphere at speeds of up to five times the speed of sound with a range of as much as 20,000 km (half way around the world).[44]" This is probable since Air Force Research Laboratory's Aerospace Systems Directorate (AFRL/RQ), European Space Agency (ESA) and the UK Space Agency made major investments in such technologies. An opposing force nation with such propulsion advantage for their military platforms may create an undesirable situation.

The third example is related to a variety of emerging energy technologies claimed by several organizations and individuals to be able to produce at very low cost, high volume, high energy density and power density with no major environmental negative impacts. Such technologies claim energy densities illustrated in Figure 17 under the label of 'new

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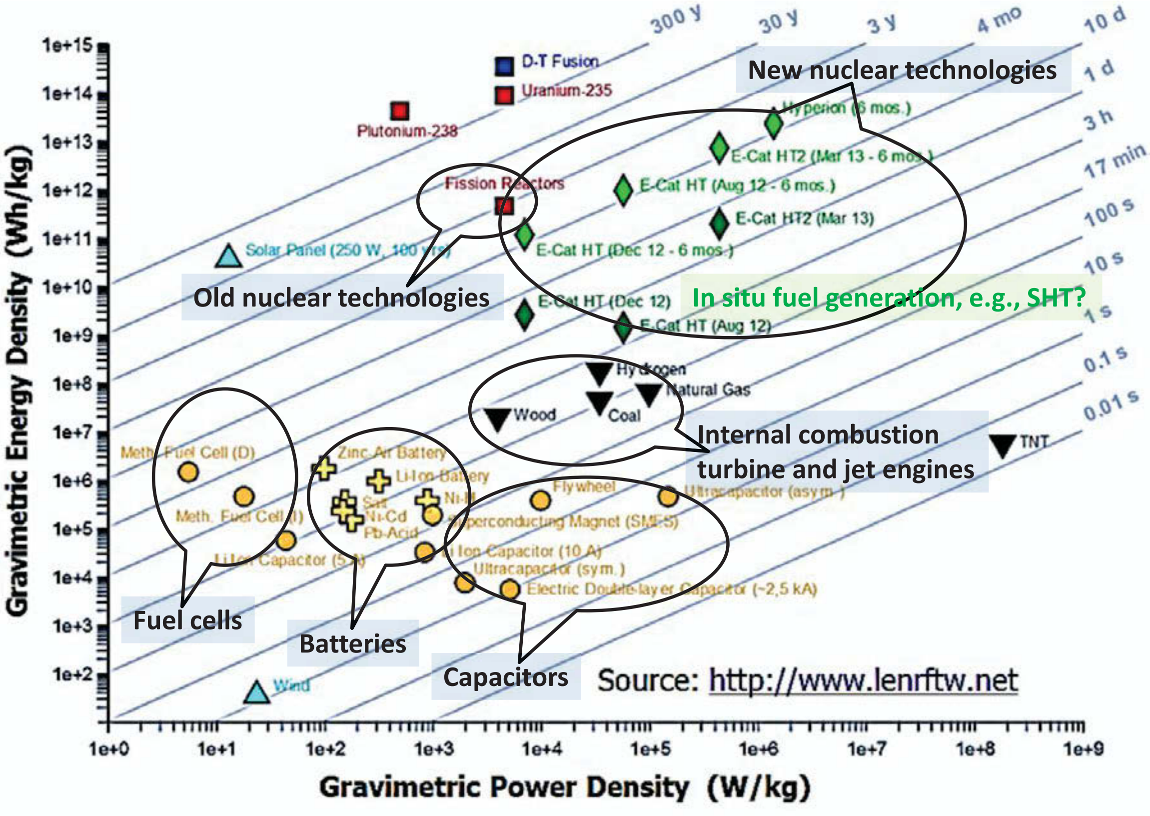
[43] https://www.wou.edu/las/physci/Energy/Gas_Hydrates.html (Access date: 17 Sept. 2013).

[44] http://www.reactionengines.co.uk/mach5cruise.html (Access date: 23 Sept. 2014).

nuclear technologies' since the energy densities claimed were much above what is currently known.



Source: http://www.lenrftw.net

Figure 17: *Ragone chart modified to show selected categories of energy sources.*[45]

Such emerging technology is considered disruptive. According to a United Kingdom MOD report, "Global Strategic Trends - Out to 2040" (MOD, 2010), not only trends drive the future situation but shocks like:

- The 2007-8 financial crisis.
- The 9/11 terrorist attacks.
- The collapse of the Berlin Wall.

"Strategic shocks have a cascade effect, leading to multiple, apparently unconnected and unforeseen changes. They transform the strategic context, changing behaviour and activity across the board. For example, the 2007 financial crisis began with US sub-prime debt… the future cannot be predicted in detail or with certainty. However, they will inevitably influence defence and security in some way, providing a strong argument for versatile and adaptable defence institutions, equipment and personnel to deal with the unexpected challenges they will present."

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[45] More details about the data and methods used in developing this Ragone chart are available at: http://www.lenrftw.net/comparing_energy_sources.html (Access date: 14 May 2014).

This MOD report selected five credible strategic shocks and the third one is about a new energy source, more efficient than anything available currently.[46]

"New Energy Source. A novel, efficient form of energy generation could be developed that rapidly lowers demand for hydrocarbons. For example, the development of commercially available cold fusion reactors could result in the rapid economic marginalisation of oil-rich states. This loss of status and income in undiversified economies could lead to state-failure and provide opportunities for extremist groups to rise in influence."

The remainder of this Chapter will be covering such new energy source which was given different names over the years from the coined label 'cold fusion' then to Low Energy Nuclear Reactions (LENR), Chemically Assisted Nuclear Reactions (CANR), Lattice Assisted Nuclear Reactions (LANR), Condensed Matter Nuclear Science (CMNS) and Lattice Enabled Nuclear Reactions. For this report the term LENR has been selected due to its support by a variety of organisations and its documentation (references such as (Storms, 2007) provide a good overview of this emerging disruptive technology). Recently LENR has been identified as one of the technology to be considered by the technology watch of TTCP MAR TP-8 Power and Energy, Materials and Systems.

Another important aspect beside the fact that the MOD recognized cold fusion (or other high-efficiency energy source technologies) as a credible strategic shock is the likelihood that China will be fast at massively producing it.

Figure 17 provides the order of magnitudes of what new nuclear technologies may bring to our spectrum of options for future energy sources. It includes LENR and another possibility reported under 'in situ fuel production' as follows: The high rates of hydrogen production as claimed by Solar Hydrogen Trends (SHT)[47] were confirmed by third party measurements (209 kL/h for 415 Wh, that generating hydrogen at an equivalent of 626 kWh, or a COP of 1500). The size and weight of tested devices were small, similar to LENR ones. So both LENR and SHT devices are in the bubble labelled 'New nuclear technologies' in Figure 17. This is enough energy to power large aircraft such as a 747 or C17 when the technology becomes commercially viable. Another contender of high energy density source is the compact fusion reactor (CFR) by Lockheed Martin which targets prototypes in five years and commercialisation in ten years[48].

NASA considers such options for their LENR aircraft.[49]

As shown in Figure 17, LENR and SHT stacks up against electrochemical devices, chemical reactions, nuclear fission plants, fusion and renewables.

Most recent results from the third party independent E-Cat trials[50] showed exceptional energy densities. When including internal plus external components the volumetric

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[46] https://www.gov.uk/government/publications/dcdc-global-strategic-trends-programme-global-strategic-trends-out-to-2040 (Access date: 14 May 2014).
[47] http://www.solarhydrogentrends.com/ (Access date: 13 May 2014).
[48] http://www.lockheedmartin.com/us/news/press-releases/2014/october/141015ae_lockheed-martin-pursuing-compact-nuclear-fusion.html (Access date: 16 Oct. 2014).
[49] http://nari.arc.nasa.gov/sites/default/files/attachments/17WELLS_ABSTRACT.pdf (Access date: 27 Jan. 2014).

energy density observed was ($3.6\ 10^4$ ± 12%) MJ/L and the gravimetric energy density was ($1.3\ 10^4$ ± 10%) MJ/kg. The energy densities of gasoline are 32.4 MJ/L and 44.4 MJ/kg respectively. So the E-Cat is thousand times more volumetric energy dense and 293 times more gravimetric energy dense than gasoline.

The conservative E-Cat gravimetric power density was ($4.7\ 10^3$ ± 10%) W/kg. Jet engines of Boeing 747 and Airbus A300 offer a power density 5.67 kw/kg. So the E-Cat is almost as gravimetric power dense as these jet engines. Wärtsilä RTA96-C 14-cylinder two-stroke turbo diesel engines display 0.03 kW/kg. So the E-Cat is 100 times more gravimetric power dense than these ship engines.

The E-Cat fuel weight of the charge was 1 g. It delivered the following thermal energy density and power density: ($1.6\ 10^6$ ± 10%) Wh/kg or ($5.8\ 10^6$ ± 10%) MJ/kg, and ($2.1\ 10^6$ ± 10%) W/kg. These results place the E-Cat beyond any conventional source of energy. It is close to the energy densities of nuclear sources, such as U235, but it is lower than the latter by at least one order of magnitude.

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[50] http://www.sifferkoll.se/sifferkoll/wp-content/uploads/2014/10/LuganoReportSubmit.pdf (Access date: 15 Oct. 2014).

6 Conclusion

Energy drives all activities of DND/CAF from those executed by a single soldier to the most complex and advanced defence and security capability which may exploit assets such as tactical platforms, forward operating bases, cyber warfare, C4ISR and directed energy weapons. Planning and strategic decisions from National Defence Headquarters (NDHQ) cannot be sustained and executed effectively without the appropriate level of power and energy. Energy is the unique enabler powering all military systems, it makes all military systems function.

Due to its pervasive impact, energy security in a defence context could be defined as follows: The condition that exists whereby defence infrastructure and tactical forces, in both domestic and expeditionary scenarios, have assured access to reliable, sufficient, affordable and safe supplies of energy necessary to conduct operations, thereby ensuring mission continuity. As stated in (Johnston, 2011) "A more fundamental problem that stems from nationalization of oil and gas operations is the ability it provides governments to disrupt energy supplies for purely political objectives — the so-called 'Energy Weapon'. Supply disruption of this type can be carried out by the producing states or by the transit states that control pipelines or transportation corridors. Their intent in doing so is to force a consumer state, or group of consumer states, to change their behaviour in a way that the antagonist desires."

Based on the findings and facts presented in this report and several of the referenced material, a review of the evidences and the identification of the most important observations will be presented here. Recommendations for addressing the targets were suggested. In addition to this, selected areas for future analyses will be identified.

6.1 Observations

Given the nature of each DND/CAF capability, infrastructure and platform, their particular energy demands and power requirements are a function of operational constraints and uncertainties at play. In order to project such energy demands in future operations and missions, logistics planning analysts used recommendations based on past experiences, agreed set of scenarios and expected operational conditions. However, analysts will add some contingency planning in order to reduce risk associated with the uncertainty about future threats.

Lack of sufficient energy at a given time and location could place units in undesirable and disadvantageous posture. On the other hand, abusive excess of energy resource at a given time and location may create a similar effect, unduly increasing the fully burden cost of energy for a mission, and depriving other units at other locations to access required energy at a critical time. So energy must be managed strategically and logistically as a function of the evolving operations and threats.

Enduring energy strategies must include an increased level of energy value awareness and understanding of energy value to mission success at all levels of decisions, from lower rank soldiers to higher command rank positions.

Evidences provided in this report are only examples of what can be done to benefit from the first DND/CAF operational energy strategy (DOES) in terms of increased capabilities for the amount of resource invested in achieving specific energy targets. It is critical to use cost-benefit analyses and life cycle cost when considering opting for a new form of operational energy and its delivery. In most cases observed, traditional methods of energy delivery use existing infrastructure and delivery asset while alternative energy means and delivery asset require some capital investments. So the immediate cost is higher than status quo energy forms and delivery. On the other hand once assessed over a sufficient period to amortize the initial capital investment, alternative energy forms and delivery methods suggested in this report and applied by Allied forces offer clear advantages such as reducing cost per year, reducing logistic tail burden while increasing platforms and force capabilities.

In addition to increase CAF capabilities, solutions aligned with DOES targets offer a substantial reduction in fossil fuel demand, GHGs and environmental impact.

To gain such advantages, each environment (CA, RCN and RCAF) and DND L1s having an impact on energy usage and projects related to the DOES Targets will have to establish how they will contribute in achieving the agreed objectives timely. That will require ensuring that energy awareness and responsibility get understood by all DND/CAF, at all levels.

For example during the process of force development and capability acquisition, decisions need to be informed by an understanding of the evolving respective energy requirements, e.g., assuming a persistently increasing FBCE of fossil fuel. Given the long life cycles of military equipment, analysts and decision makers need to realistically assess the FBCE required by a new platform to ensure its affordability over its life time.

The trend of the DND/CAF energy cost reported in Section 2.3, assuming that the fleet energy price will increase at the same rate as for the last 14 years, showed that cost approximately double in a decade. So the total CAF fleet energy spending would have increased from approximately 140 million dollars in fiscal year 1998/99 to 800 million dollars in 2030/31, about six times as much if no significant corrective actions are taken. The total DND/CAF energy cost (538 million in 2010-11) follows a similar trend from about 240 million to 1,100 million dollars by 2031, which is about five times as much.

6.2 Discussion

Over the realm of possible initiatives and technologies to curb the observed persistent cost increase of DND/CAF energy before it reaches an unsustainable level for Canada, there are strategic decisions that need to be made such as: when deploying or not forces and for how long, mission planning that includes FBCE, adoption of an energy conservative attitude, selecting more energy efficient amenities and capabilities, adopting energy source diversification and selecting improved energy conversion technologies for the desired end uses.

There are accumulated evidences that more energy technologies will move us away from fossil fuels.

6.3 Areas that require further research

In the context of ensuring a timely return of energy improvement projects in terms of defence operational capabilities delivered, the following activities were identified.

Cost-benefit analyses and operational research:

- Ensure that planned and future DND/CAF facilities and renovation programmes of existing facilities meet DOES targets: life-cycle cost for example by investing in higher efficiency devices and higher energy density sources at lower cost over the total useful life time, e.g., heat pump with ground loop, solar production of fuel to use in SOFC when energy demand is high and renewables are not suitable for the intended end use, or the use of micro-nuclear power source.
- Quantify the FBCE of energy for off-grid stations and forward operating bases for traditional energy sources and fuels to compare the operational advantages of alternative delivery such as in-situ fuel production and other locally produced energy such as solar with associate microgrid and storage.
- Examine the options, costs, feasibility and challenges of upgrading legacy surface and sub-surface platforms to electric drive using technology such as SOFC or adding heat loss recovery systems to produce electricity for C4ISR, weapon systems, amenities and hotel load.
- Estimate the increase in capabilities of legacy air platforms from the technology options presented in this report and its references for new technologies options as they reach the required level of maturity for such platform (same for CA and RCN platforms).
- Similar estimates must be developed for the acquisition of new air platforms (same for CA and RCN platforms).
- Examine the US military experience in exploiting alternative energy sources.

Strategic analyses:

- Quantify the potential impact of advanced energy technologies used by opposing forces and terrorist groups on DND/CAF vulnerability at home and abroad.
- Quantify the potential advantage of DND/CAF of adopting advanced energy technologies early, e.g., lower volume and lower weight devices with more capabilities replacing existing inefficient devices to increase legacy platform performance and capabilities.
- Estimate the net advantage of using advance energy technologies and efficient infrastructure and equipment at locations such as CFS Alert.

S&T and R&D unique to DND/CAF energy domain[51]:

- Technology demonstrations and unique basic research activities to ensure that DND/CAF exploit advanced material and intelligent devices such as the use of nanotechnologies, self-healing structures and networks.
- Exploit data and energy management made possible out of the application of Target 1 especially for expeditionary operations: "Energy measurement and management: By 2030, to the maximum extent practicable, bases, platforms and expeditionary power and heating generation equipment shall employ an automated data acquisition, recording and metering system that measures the consumption of fuel from all sources."
- Appropriate experimentation will be required in order to reduce risk of deploying CAF with new technologies (Labbé*, et al.*, 2006).

6.4 Which future technologies will be available?

As often proven in the past, it is difficult to predict what technology has in reserve for us in 5, 10 or 20 years from now in the domain of energy, its transformation and use for a variety of amenities and end uses. Advances in material driven by our abilities to produce nanomaterial never seen before with unexpected properties bring a large spectrum of possibilities. Nanotechnology findings have already changed batteries and capacitors to a point where one could replace the other, or better, deliver with the advantages of both with higher gravimetric and volumetric power and energy densities.[52] The same is observed for magnetic material and superconductors.

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[51] Here are high-level examples based on discussed DRDC S&T Outcomes: a) ideas and technologies for first generation non-conventional effectors, including maritime directed energy and non-kinetic effectors to support force application (by 2025), b) scientific advice to develop energy initiatives and technologies with the specific goal of increasing the energy efficiency while decreasing the energy use intensity of RCN platforms (specific goals and an appropriate metric defined by 2015, and initial technology enablers established by 2020), c) improved self-sufficiency (without re-supplying for the mission duration) through increased energy efficiency within acceptable added weight by demonstrating an advanced wearable power system that augments a dismounted soldier's performance, autonomy, sustainability and effectiveness in dispersed operations (by 2015), d) increased understanding of threats and opportunities from high energy lasers for defence applications as well as measure for force protection and laser safety recommendations for the employment of high powers lasers in the field (by 2016), e) improved tactical logistics through reduced demand on fossil fuel and better information management by the provision of camp power and transition to sustainable (reduction of petroleum use) and economical (no increase in cost) supplies of power and energy in support of Canada's Army (by 2015), e) ensure that the Air Agile Program also includes all the aspects of system sustainment, Human performance, Power and Energy and Expeditionary Support, f) Power and Energy – Efficiency of engines, structures, lighting, etc., will be improved, alternate sources of energy sought, and interoperability with our Allies who are also seeking and migrating to alternate power and energy sources must be maintained.

[52] This is exemplified by the following recent advances:
a) Maruyama, H., Nakano, H., Nakamoto, M. and Sekiguchi, A. (2014), High-Power Electrochemical Energy Storage System Employing Stable Radical Pseudocapacitors, *Angewandte Chemie*, 126 (5), 1348-1352.
b) http://powerjapanplus.com/news/power-japan-plus-reveals-new-dual-carbon-battery/ (Access date: 14 May 2014).

Consequently, programs must be informed of such advances in order to balance the risk of a low TRL with high value performance versus a high TRL option providing no significant advantages.

6.5 Epilogue

If fossil fuel (gasoline, diesel and jet fuel) proved to be of high strategic value since WWI, what would replace it when its fully burdened cost becomes prohibitive?

New technologies are waiting at the corners of our futures to offer higher energy density with less adverse environmental impact and at a lower fully burdened cost of energy.

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Annex A Fully Burdened Cost of Energy (FBCE) methodology framework

The NATO Fully Burdened Cost of Energy (FBCE) methodology framework[53] (NATO SAS-083, 2013) was developed in order to obtain more realistic estimates of the total fully burdened cost of delivered energy. FBCE estimates the energy related costs to operate specific pieces of equipment, including procurement of energy, the logistics needed to deliver it where and when needed, the related infrastructure, and the force protection for those logistics forces directly involved in energy delivery. FBCE can be applied in trade-off analyses for the delivery of energy in the battlespace. It is an analysis designed to identify the difference in total energy-related costs among competing options. FBCE estimates can be made and used for the appropriate apportionment of energy related costs to using countries or other entities.

The FBCE framework was developed primarily from the US FBCE (produced by the Office of the Secretary of Defense and officially published in Defense Acquisition Guidebook) and from other nations' FBCE methodologies. Canada and the UK have developed similar FBCE approaches and this report provides a common NATO framework with a common taxonomy. This NATO FBCE framework must not be construed as a change in any way to the US FBCE approved for US activities as stated in the US Defense Acquisition Guidebook. The NATO FBCE framework has been adapted here for the purpose of supporting the first DND/CAF Operational Energy Strategy.

A.1 Justification for FBCE

The cost of energy is not simply the commodity cost. Energy requires both personnel and equipment for such things as transportation, storage, handling and protection from the point and time of sale. The cost of the personnel and equipment must be added to the commodity cost to produce an equitable price of energy to the energy end user. The proper apportionment of energy and energy supply related costs to end users can be achieved through the calculation of the FBCE.

FBCE can also be used as a comparative measure in the area of operational energy related processes and equipment choices. The energy required to field and sustain forces poses significant operating costs and imposes several operational constraints on the larger force structure. Growing logistics footprints can impede force mobility, flexibility, timing and staging, especially for anti-access and irregular conflicts. Reducing the need for energy can have significant benefits for force deployability and the timeline of operations. Also, this logistics footprint presents a target for conventional, irregular, and catastrophic threats, creating demand for force protection and transportation forces. In the conflicts of the past decade, for example, adversaries have targeted fuel resupply convoys, putting forces and their missions at risk and redirecting combat power and dollars to fuel delivery.

Conversely, reducing system energy demand can make operational forces more agile and lethal by extending their range and reducing their dependence on logistics lines. These

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[53] Paul Labbé led the FBCE contribution to the NATO SAS-083 report.

reductions can be achieved through different, better informed trade space choices, design alternatives, technologies and force structure concepts.

A.2 FBCE defined

The FBCE is a scenario dependent methodology used to quantify the cost of energy. The FBCE estimate includes apportioned costs of the combined energy related logistics (personnel and equipment) needed to store, deliver and protect the energy in a scenario. Therefore, the FBCE can be used as a basis for apportioning cost among users, depending upon the scenario and the end users' demand. Also, calculating the FBCE gives decision makers a way to more accurately consider the apportioned cost of a user's energy logistics footprint for planning purposes. It has the added benefit of informing decisions on the size and focus of investments in science and technology programs that affect the energy demands of the force such as engines and propulsion, light-weight structural and armor materials, power efficiency in electronics, mobile power production and distribution, and more innovative system design approaches. Also it contributes to assess more accurately the real return on investment (ROI) of advanced energy sources and fuels.

The FBCE is the method by which costs to energy end users can be estimated. The FBCE provides a basis for determination of the appropriate price to charge end users for energy sustainment.

The FBCE includes the cost of the energy commodity itself and the apportioned cost of all of the energy logistics and related force protection required beyond the initial point of the energy commodity acquisition. Contractor logistics and protection should be considered where appropriate. The cost estimation methods are similar, though the data sources required may vary. As a decision tool, the FBCE is meant to inform technological and design choices as applied in requirements development, acquisition trades and technology investments. Successful implementation will, over time, help manage larger enterprise risks such as high and volatile fuel prices.

The FBCE can be applied in trade-off analyses conducted for all deployable systems with end items that create a demand for energy in the battlespace.

The FBCE does not include any energy related disposal considerations. Disposal of such energy related items (e.g., spent batteries) is up to the consumer and will be directly disposed of with the disposal costs paid for via the consumer's process.

Assumptions: In order to estimate operationally realistic costs, all scenarios will have to be of sufficient duration to account for demanded logistics and force protection. In addition, the calculation requires participation from force planning and analytic organizations to appropriately calculate FBCE estimates. The appropriate organizations vary by service and country.

There is no definitive, 'correct' answer for a given system's FBCE estimate, however, NATO countries should develop standard, realistic, accepted and analytically defensible scenarios and cost elements. The scenario assumptions for energy logistics must be consistent with operational plans and Concepts of Operation. Consistency enables NATO nations to evaluate their assumptions relative to strategy and doctrine, and make better informed risk decisions. All participating countries should use existing analytic tools, planning data, and costing methodologies where possible to develop FBCE values.

A.3 FBCE Price Taxonomy

Energy Commodity Price (ECP)

The first price element for consideration is the energy commodity itself. This is the rate that is charged to military customers by a vendor. The actual contracted delivery price should be used where available.

Tactical Delivery Price (TDP)

The second price element captures the burdens associated with the tactical delivery assets used by NATO countries to deliver the energy commodity from the point of acquisition (contract delivery point) to the system that will consume it. It includes: a) the Operating and Support (O&S) costs and b) the cost of depreciation of the actual delivery assets. Once NATO takes possession of the energy commodity at the point of sale, it must employ its own or contracted delivery assets. For the purposes of estimates, the ”energy commodity delivery assets” mean major items of energy delivery equipment, such as naval ships, aerial refueling aircraft for fixed-wing and rotary-wing aircraft, and tanker trucks and trailers for ground vehicles as well as transportation trucks for energy commodities other than liquid. It also includes planes that airdrop palletized energy commodities and rotary-wing aircraft carrying energy commodities for delivery.

a) The O&S cost for the energy commodity delivery assets consists of the costs of operations and maintenance (O&M) of the vehicles and equipment and the costs for military and civilian manpower dedicated to specific volumetric and gravimetric amounts of energy commodity delivered by a mission. This cost is expressed in dollars per joule ($/J) price or normalized energy price (e.g., $/L of JP-8 that could be normalized to $/J). If the planning scenarios/missions being used for this calculation require another country’s assets to deliver energy in the battlespace, involved countries are expected to share data to facilitate this estimation.

b) The cost of depreciation of the primary energy delivery assets is also part of the second price element. Depreciation provides a measure of the decline in capital value of the energy delivery assets over time from use. The standard method is to use straight line depreciation over the anticipated service life of the primary energy delivery asset. For example, for a calculation for an aerial system that requires air-to-air refueling as part of its mission profile/duty cycle, this step would require inclusion of a depreciation value for the system’s air refueling tanker.

An additional part of the cost of depreciation is the potential loss of delivery assets due to hostile attack or other attrition. Based on the scenario selected, there is a definable probability that the associated logistics platforms will be interdicted and destroyed. If destroyed, the entire remaining value of the platform is immediately amortized and this cost is added to this price element. Depending on the quantity of energy commodity being carried by the delivery asset, an adjustment to the amount of energy commodity obtained from the point of sale will be required to account for this potential loss, if appropriate.

Infrastructure Operations and Support Price (IOSP)

The third price element is infrastructure, which may include the price of O&S and recapitalization for the facilities (such as fueling facilities and energy commodity storage sites and recharging stations) and related ground system equipment (such as pumps, fuel storage bladders, hose lines, and other refueling equipment to include maintenance and parts for refueling vehicles and other related ground refueling equipment as well as energy related material handling equipment, energy commodity storage facilities and energy recharging stations). The costs to deploy the delivery assets may also be included, if the assets need to be transported to the theater of interest. This applies only to infrastructure that is operated by NATO and member countries in the theaters of interest.

Security Price (SP)

The fourth and final price element includes the costs of escort protection of the energy supply chain in hostile environments. In the case of NATO force protection assets allocated to the energy commodity delivery forces, the operational and sustainment costs, direct commodity costs and the depreciation costs will also have to be estimated and included in the overall calculation. In essence, all of the costs considered in the second 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. In some high-risk scenarios, force protection costs may be the largest factor in the FBCE estimate.

Assured Delivery Price (ADP) Computation

The Assured Delivery Price (ADP) is needed as an interim value to compute the FBCE. It is a measure of the burdened cost of the energy, in $/J, with all the tactical delivery assets and force protection needed to assure that the energy commodity is safely delivered to a given location. The price elements described in Table A.1 provide a framework for determining the ADP of energy within a given scenario.

Table A.1: *Summary of price elements to apply within each scenario to determine the assured delivery price (ADP).*

Element	Price Element	Burden Description
1	Energy Commodity Price (ECP)	Acquisition price of energy
2	Tactical Delivery Price (TDP)	
	a) 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 mission
	b) Depreciation Price of Energy Delivery Assets	Decline in value of energy delivery assets using straight-line depreciation over total service life. Combat losses due to attack or other loss (terrain, accident, etc.) should be captured as a fully depreciated vehicle (vehicle includes land, air and sea).
3	Infrastructure Operations and Support Price (IOSP) :Infrastructure, Environmental, and other miscellaneous costs over/above and distinct from the energy commodity cost	Energy unit price of energy infrastructure, regulatory compliance, tactical terminal operations and other expenses as appropriate.
4	Security Price (SP)	Potential energy unit price associated with delivering energy such as convoy escort and force protection. Includes the manpower, O&S, asset depreciation costs, and losses associated with force protection.

This is based on the NATO FBCE model.

The ADP can be expressed by the following equation:

$$\mathbf{ADP = \sum ECP + \sum TDP + \sum IOSP + \sum SP} \tag{A.1}$$

A.4 Methodology

Framework

The basic framework to calculate the FBCE extends to all forms of energy demands (e.g., liquid fuel, fuel cells, batteries, hybrid-electric engines, nuclear and solar energy sources). Figure A.1 shows the demand driven fuel/energy delivery process within a scenario. The associated costs depicted are the costs that comprise the FBCE.

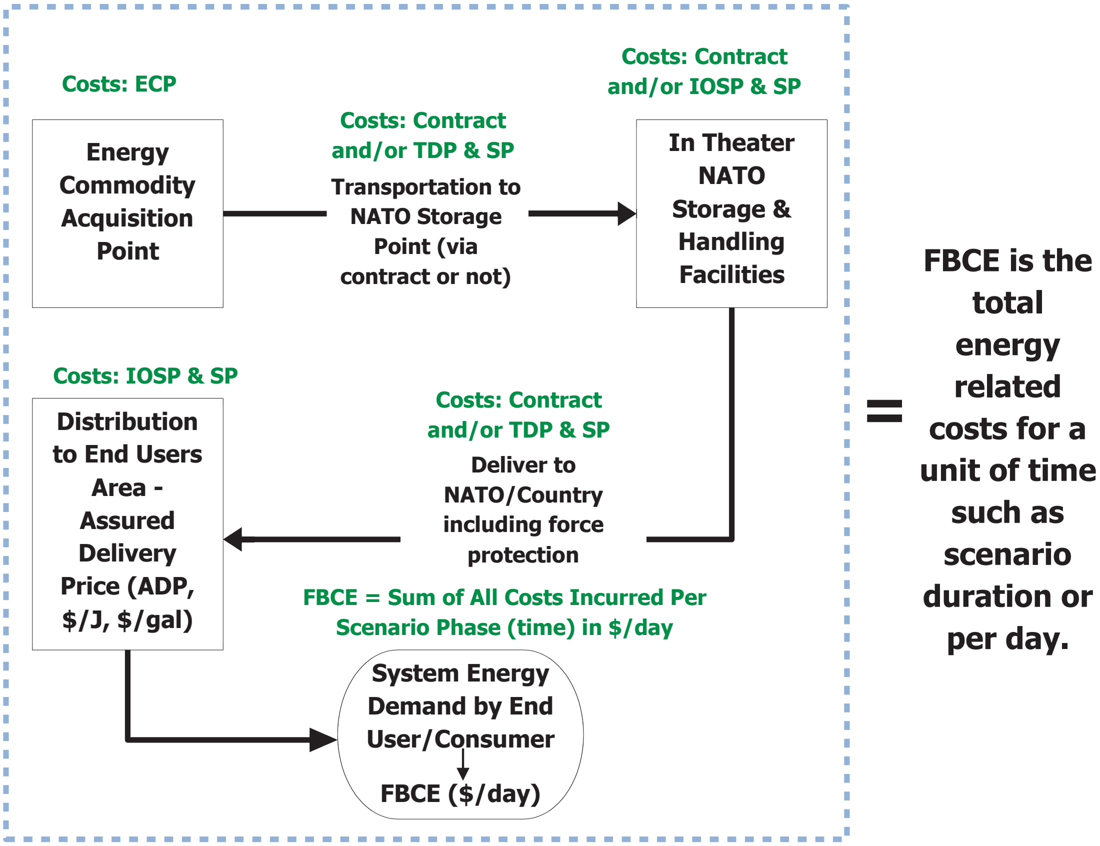

Figure A.1: *FBCE scenario fuel/energy delivery process diagram.*

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

1. **Scenarios.** Countries decide upon a representative set of future operational scenarios or vignettes. For purposes of computing the FBCE, scenarios must be of sufficient duration 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.

2. **Apportionment.** Countries determine what proportion of the energy logistics footprint identified in the selected scenarios is attributable to the forces (soldier systems), platform or system in question. Is it drawing 5% of the energy from the

energy logistics units in the scenario, or 20%, or 50%? Because no single system in any operation takes 100% of the energy, it would be inappropriate to attribute 100% of the logistics tail cost to one system when calculating FBCE. The apportioned percentage of demand should equal the total energy distributed.

Fully Burdened Cost of Energy computation

FBCE is the total energy related costs for a unit of time such as scenario duration or per day. The FBCE is computed dependent upon the scenario being considered.

In relation to this definition of FBCE, in a post-war reconstruction environment based on the Iraq and Afghanistan data, (Fiala, 2009) expands the methodology to quantify the fully burdened cost of electricity generation.

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Annex B Fuel demand modeling

This annex discusses the methodology and assumptions for modeling and analysis of fuel requirements for CAF expeditionary operations. More details are provided in the following DRDC Report (Ghanmi, 2013b).

B.1 Methodology

A Monte Carlo simulation framework was developed to study the expected fuel demand of potential future CAF expeditionary operations. The framework establishes a common set of parameters describing a typical 3-year period; within this framework, individual parameters such as locations of deployments, frequency of sustainment flights, operating hours of power generator systems, travel distances of ground vehicles, etc., are then generated stochastically. To allow for meaningful statistical evaluation, fuel consumption data are simulated and collected for a large number of randomly generated 3-year intervals.

In the simulation framework, a generic baseline scenario was constructed based on historical CAF deployment packages. The scenario considered a light mechanized task force based on Operation ATHENA–Canada's contribution to the International Security Assistance Forces in Afghanistan. Potential deployment destinations of the task force were determined through the use of 2012 Failed States Index, a combination of 12 social, economic and political/military indicators developed in Fund for Peace (2012). Within the simulation framework, probabilities of occurrence were assigned to each country based on the ranking of the failed and failing states. The mapping of the probabilities of occurrence to the indexes of failed and failing states was performed using a simple affine transformation of the index subject to a normalization constraint. To simplify the problem, only the top 60 failed and failing states are considered in the analysis. The impact of adding more failed and failing states on the expected results would be minimal.

Each randomly generated 3-year time period within the simulation framework follows a common pattern. At the beginning of the simulation, an Operation ATHENA-like task force is deployed in a country randomly selected from the set of failed and failing states. This task force will then redeploy to Canada at the end of the operation. Deployed forces will be re-supplied via sustainment flights at a rate consistent with historical experience data.

B.2 Assumptions

There are several important assumptions that underlie the analysis of the operational energy demand using the simulation framework. Foremost among these, this study was restricted to the analysis of fuel consumption and did not consider other types of energy such as electricity (which could be generated using fuel) and recharging batteries. In military operations, fuel is a critical logistics enabler for mission effectiveness and represents the most important form of energy consumed in theatre, particularly for mobility and power generation activities. While operational energy involves both domestic and international operations, this study focused on the energy demand for expeditionary operations as historical energy consumption data for domestic operations can be found in the CAF fuel and lubricants management system.

Historically, the CAF used a combination of chartered and native assets for deployment, sustainment and redeployment lift operations. This includes strategic airlift and sealift as well as ground movement. For the purpose of this study, only fuel consumption by native airlift assets (the CAF has no native sealift strategic assets) was simulated and calculated. A ratio of native to chartered airlift sorties consistent with historical experience was used in the analysis. Airlift flying times were determined using the great circle distance method, neglecting diplomatic over-flight clearances or weather conditions.

Different types of fuels and lubricants are used in military operations, notably aviation fuel for aircraft and helicopters, diesel for ground vehicles, marine fuel for ships, gasoline, etc., For simplicity, it is assumed that operational fuel requirements are grouped into three main categories, namely aviation fuel, diesel for ground systems, and ship's fuel. Note that the North Atlantic Treaty Organization (NATO) has been developing standards of a single fuel concept for air and ground assets. Lubricant requirements were not considered in the analysis.

Finally, in order to avoid issues with classified information, the conditional probabilities that Canada would respond to crises in a given failed or failing state were deliberately neglected. Inclusion of these effects would tend to place greater weight on areas of strategic importance to Canada while reducing the importance of being capable of rapid deployment to other areas.

B.3 Operational scenario

The initial deployment of vehicles and equipment during Operation ATHENA was conducted by sealift from Montréal, Canada to Derince, Turkey and then by airlift into Kabul, Afghanistan using a fleet of chartered lift assets. Another set of vehicles was later moved to the theatre of operations using contracted lift and the CAF strategic air lift aircraft (CC-177). The total number of vehicles deployed to Afghanistan was about 800.

To maintain a close parallel with historical movements, a two-phase deployment consisting of an initial sealift from Montréal to an intermediate Seaport of Disembarkation (SPOD) followed by an airlift to the final Airport of Disembarkation (APOD) at a given failed and failing state was considered in the framework. However, for the purpose of this analysis the airlift was conducted using both chartered aircraft and CC-177. Note that the CC-177 aircraft was not available at the time of the initial deployment of Operation ATHENA but was later used for the sustainment and redeployment lift operations. A number of CC-177 sorties, consistent with the historical Operation ATHENA redeployment lift, were assumed for the deployment. Six SPODs located at different strategic regions, known as Operational Support Hubs (OSH), are considered for the deployment: Spangdahlem, Germany; Dakar, Senegal; Mombasa, Kenya; Kuwait, Kuwait; Singapore, Singapore; and Kingston, Jamaica.

The Operation ATHENA redeployment was conducted in three phases. High priority items, representing about 25 to 35 CC-177 sorties, were redeployed directly from Afghanistan to Trenton, Canada. Some equipment (e.g., high value items) were moved to an OSH using chartered airlift and CC-177 (about 150 to 200 sorties) and then by chartered sealift to Canada. The remaining equipment and cargo were moved by land to

Karachi, Pakistan and then by sea to Montréal. In the simulation framework, it is assumed that the task force redeployed by sea for failed and failing states in the littorals and used the same lines of communication as the Operation ATHENA redeployment for failed and failing states in land-locked countries.

Operation ATHENA personnel were deployed from Trenton to an intermediate staging base (e.g., operational support hub) using the CC-150 strategic lift aircraft, and then to the theatre of operations using the CC-130 tactical lift aircraft. Troop rotations were conducted every six months using the same transportation approach. At the end of the mission, troop redeployed through an intermediate staging base (for decompression) using CC-150 aircraft. During the employment phase, the task force was supported with sustainment flights from Trenton at the historical rate.

For the purpose of this analysis, the baseline scenario also considered the deployment of an Air Force component and a naval task force. For the Air Force component, in addition to the strategic and tactical lift assets (CC-177, CC-150, CC-130) that were used for the deployment, sustainment and redeployment of the task force, a number of tactical helicopters (6 CH-147 Chinook and 8 CH-146 Griffon) and Unmanned Aerial Vehicles (UAVs) were also deployed with Operation ATHENA. The helicopters played several operational roles such as tactical logistics transport, medical evacuation, and rescue operations whereas UAVs were used to support surveillance and reconnaissance missions. For the naval task force, it is assumed that a number of CAF frigates were deployed at various locations in support of international activities (e.g., anti-piracy missions). For planning purposes, each ship deploys for a six-month period. Historical CAF ship deployments were used as proxies upon which simulated deployments were based.

B.4 Fuel consumption prediction model

In the framework, fuel requirements are modeled and simulated for land, air, and maritime operations independently. For land operations, fuel requirements are mainly determined by the daily consumption of ground vehicles and power generation systems of the task forces. NATO has developed a standardization agreement (STANAG) for computing fuel requirements for an operational base, STANAG 2115. The STANAG determines a standard estimation for fuel consumption of a military unit called Fuel Consumption Unit (FCU). The FCU represents the quantity of fuel (in litre) required per day for the operation of a given unit under assumed average operating conditions for a given standard performance. The FCU can be calculated using the average consumption rates of all equipment of the unit as follows (assuming a single fuel):

$$FCU = \sum_{v=1}^{V} c_v \, d_v + \sum_{g=1}^{G} r_g h_g \qquad \text{(B.1)}$$

where:

V	number of vehicles in the unit;
G	number of power generators in the unit;
v	index of vehicles;
g	index of generators;

c_v	average fuel consumption rate of vehicle v (L/km);
r_g	average fuel consumption rate of generator g (L/h);
d_v	average daily distance traveled by vehicle v (km/day);
h_g	average daily operating hours of generator g (h/day).

For units involved in combat operations or for special terrains or weather conditions other than normal, a series of operational factors affecting the fuel consumption are derived in the STANAG for use in modifying the standard day to fit the combat day. These operational factors are grouped into three categories, namely: combat intensity, terrain and weather factors. To calculate the fuel requirement per day of land systems, all FCUs are multiplied by the appropriate operational factors. The total fuel demand of the land task force (F_{Land}) is calculated by multiplying the daily fuel requirements by the mission duration D (in days):

$$F_{Land} = D\sum_{m=1}^{U} B_m \, T_m \, W_m \, FCU_m \qquad \text{(B.2)}$$

where:

U	number of units in the operation;
m	index of units;
B_m	combat intensity factor for unit m;
T_m	terrain factor for unit m;
W_m	weather factor for unit m.

For the Air Force component, fuel requirements are mainly determined by the consumption of assets during the deployment, sustainment and redeployment airlift operations as well as the tactical helicopter and UAV operations in theatre. Currently, the CAF would use three types of aircraft (CC-177, CC-150, and CC-130) for airlift operations, in addition to chartered assets. The lines of communication between Trenton and the APOD in failed or failing states would have various nodes and airlift legs, depending on the type of lift (tactical, strategic) and the kind of move (cargo, personnel). An airlift leg is a distance between two nodes in the lines of communication. For example, the airlift leg between a given OSH and the APOD at destination would be used for tactical lift. For the 3-year scenario, the total fuel demand of the airlift operations ($F_{Airlift}$) can be calculated as follows:

$$F_{Airlift} = \sum_{i=1}^{N}\sum_{j=1}^{M} 2\, n_{ij}\, c_i \,\frac{d_j}{v_i} \qquad \text{(B.3)}$$

where:

N	number of aircraft types;
M	number of airlift legs;
i	index of aircraft types;
j	index of airlift legs;
c_i	average fuel consumption rate of aircraft type i (L/h);
v_i	average speed of aircraft type i (km/h);
d_j	distance of leg j (km);

n_{ij}	number of sorties of aircraft i on leg j.

For tactical air operations using helicopters and UAVs, the fuel consumption ($F_{Tactical}$) is calculated as follows:

$$F_{Tactical} = D \sum_{p=1}^{P} n_p \, x_p \, t_p \tag{B.4}$$

where:

P	number of asset types (Griffon, Chinook, UAV);
p	index of asset types;
n_p	number of asset of type p;
x_p	average fuel consumption rate of asset type p (L/h);
t_p	average flying hours per day for asset type p (h/day).

For maritime operations, fuel consumptions for a 3-year scenario (F_{Marine}) can be calculated as follows (there are six periods of six months each in the scenario):

$$F_{Marine} = 6 \sum_{k=1}^{S} y_k \, q_k \tag{B.5}$$

where:

S	number of ships;
k	index of ships;
y_k	average fuel consumption rate of ship k (L/day);
q_k	average number of days per period for ship k (days/period).

The fuel consumption rate per day (y_k) depends on the ship class and its cruising speed (in-harbour, in-transit, and high intensity). In the model, the percentage of time spent by a ship at a given speed in operations is represented by a probability distribution function.

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Annex C Motivation of mission continuity depending on critical infrastructure

Under identified circumstances DND has the mandate to coordinate efforts with Canadian civilian organizations, departments and agencies. In order to project the Canadian government influence here and abroad, DND command centers, CAF bases and stations must be able to respond timely and proportionally to the level of effort requested. With the request to deploy CAF abroad comes an incremental budget that could be revised as the situation dealt with evolves. So the flow of incremental budget is proportional to the DND effort at stake. In case of expeditionary operations, it is more obvious in terms of involved force asset and personnel deployed but the same is required for operations within Canada. With any of these operations here and abroad, there is a flow of asset and personnel to be sustained. The incremental budget must include all the supplementary cost such as "additional cost to deploy troops and equipment and to provide ongoing maintenance and support during the applicable operation". In addition to all the personnel and equipment required for any of these operations, energy due to its market volatility evolved into a difficult to predict budget line item, one that constantly increased over the last decades. For deployed forces, we developed an agreed FBCE model to be applied among nations participating jointly in such international missions.

To deliver the required D&S capabilities here and abroad, DND command centers, bases and stations must maintain a state of readiness and being able to sustain the expected tempo of operations as per its mandate. So support to CAF personnel placed in harm's way depends on the supply essential to ensure the desired operational effectiveness which includes best training, equipment and resources. In some circumstances, as for deployment within Canada, the sustainability logical path is less understood but still necessary. For deployed forces it is obvious that all the required resources flow through the incremental budget. It starts from Canada command centers and bases and it reaches the operational deployed forces. Operational asset and personnel include all involved and that includes the energy required. When our forces are deployed abroad, we assumed that our command centers and bases are fully operational. As observed during major electricity black out here and in other countries, since most of our command centers and bases depend on regional and provincial utilities and services, these critical operational components become too rapidly vulnerable and unsuited to deliver the expected command and services at the level and persistence required under their mandates. Fuel reserves for such operational Canadian defence facilities and their fleets are limited. In case of energy (fuel and electricity) disruption in a geographical area of Canada, DND current energy emergency reserves are quite limited. In order to reduce this vulnerability, ADM (Mat) DF&L is working on an analysis for the department Strategic Fuel Reserve that will provide suggestions for stocks of refined ready to use fuel by DND/CAF. OCDE nations including our neighbour, the USA, have devised plans for extended operations independently from the civilian utility services for fuel and electricity. They plan for command centers and bases to be able to operate over much longer period than our current sustainable capabilities. Given the increase of uncertainties driven by climate change, rate and magnitude of disasters, and market volatility of energy (both fuel and electricity), Canada must be prepared to respond to such events here as well as to be able to deploy sustainably abroad.

Excerpts from http://www.vcds.forces.gc.ca/sites/internet-eng.aspx?page=14661 (Access date: 9 April 2013):

1. "Full DND Cost" is the sum of incremental cost plus the salaries of Regular Force personnel, equipment depreciation, command and support cost, as well as the operating cost of some major equipment, such as aircraft, that are within normal planned activity rates and, therefore, had not been included in incremental cost.

2. "Incremental DND Cost" is the additional costs for personnel and equipment that are directly attributable to the Canadian Forces operation. More specifically, incremental costs include the additional cost to deploy troops and equipment and to provide ongoing maintenance and support during the applicable operation, in addition to any specialized training required for the operation. DND does not include the full capital acquisition cost of major equipment in incremental cost, unless procured specifically for the mission with no life expectancy post operation, as this equipment will not be used in other CAF operations. However, the full cost includes depreciation of major equipment.

Annex D Crude oil price, energy consumption trends, energy forms and Earth's reserves

D.1 Crude oil price trend

Models developed for forecasting crude oil price rely on a variety of facts and other expected trends such as: past data, expected future demands, level of available sources of petrol, economic stability of the countries providing the main sources of crude, expected demand from emerging economies, availability of alternate energy sources and policies. In addition to such factors if the price of jet fuel is of interest, other factors include refinery capacity and availability as function of time, import and export constraints, and distribution and transport to hubs that serve specific services. As for most products, price is affected by offer and demand.

For the purpose of this report, Brent Crude was selected given it is applied to price two thirds of the world's international trading of crude oil. "The other well-known classifications (also called references or benchmarks) are the Organization of the Petroleum Exporting Countries (OPEC), Reference Basket, Dubai Crude, Oman Crude, and West Texas Intermediate. Brent is the leading global price benchmark for Atlantic basin crude oils. It is used to price two thirds of the world's internationally traded crude oil supplies."[54]

The following chart, Figure D.1, is derived from the data provided in the US Energy Information Administration (EIA) | Annual Energy Outlook 2013 (DOE/EIA, 2013a, 2013b). It shows the high likelihood of an increase in the price of oil barrel in the future. If the reference projection is right that would mean a 60% increase in 2011 US dollars by 2040.

Figure D.1: *Historical and projected price of oil barrel in 2011 $US: Annual average spot price for Brent crude oil in three cases, 1990-2040, data from (DOE/EIA, 2013a, Fig. 21).*

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[54] Source: http://en.wikipedia.org/wiki/Brent_Crude (Access date: 18 Feb. 2014)

If this 60% increase in oil price translates in the overall energy cost of DND/CAF that raises an important flag to the sustainability of CAF operations here and abroad.

D.2 World energy consumption trend

Figure D.2 illustrates the expected world total primary energy consumption trend to 2035, (DOE/EIA, 2011). This figure shows that much of the growth in energy consumption occurs in countries outside the Organization for Economic Cooperation and Development (non-OECD). This certainly expresses a significant pressure point for future conflicts if not taken into account in our strategic plans.

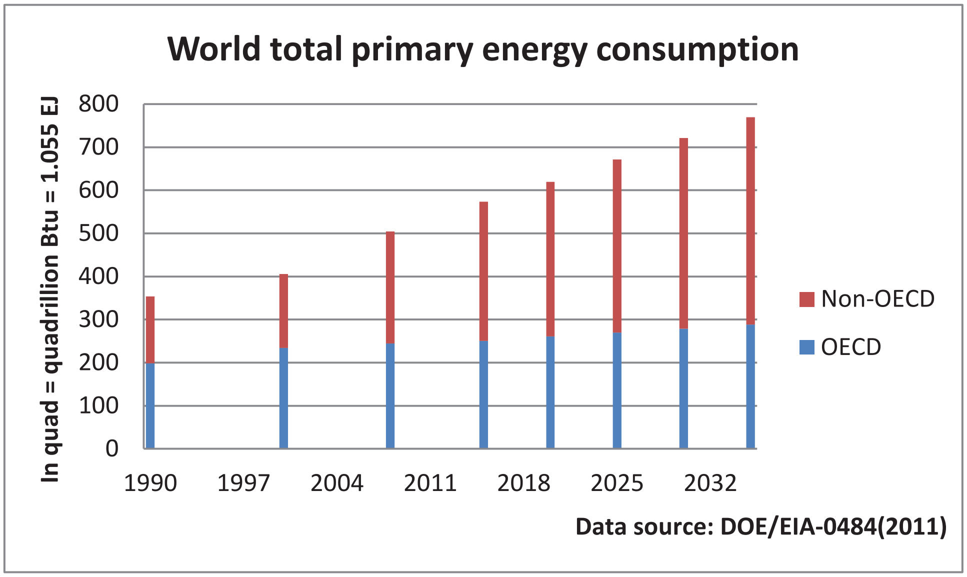

Figure D.2: *Expected energy consumption increase dominated by non-OECD countries future demands.*

D.3 Information technology and electricity demand trend

Also another important trend to consider is the constant increase in data processing and exchange required in modern operations. If this is compounded with cyber warfare and intelligence over telecommunication and Internet, this may translate in substantial energy cost increases illustrated by Figure D.3 where the GHG doubled over a period of five years (Janof, 2012). From these trends it is reasonable to expect that the energy demand from information technologies used by DND/CAF to more than double over the next decade if remediation actions are not initiated soon.

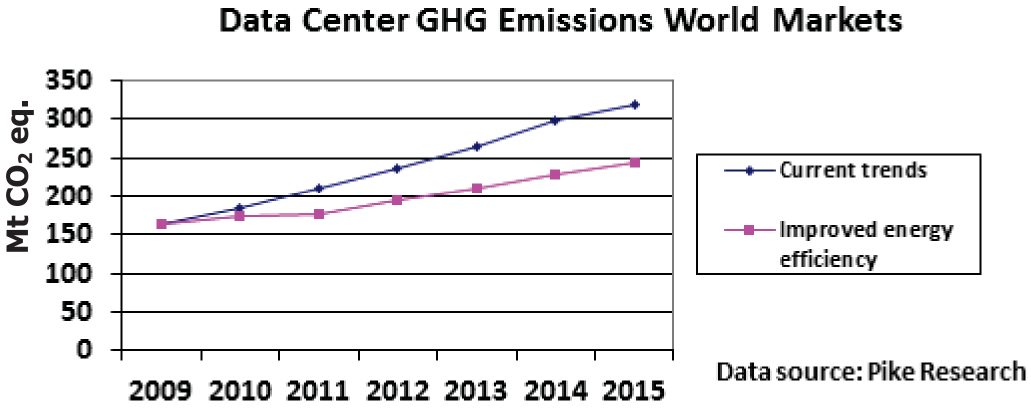

Figure D.3: *Historical and 2011 projected GHG of data centers*[55].

The chart of Figure D.4 provides an example of the energy breakdown of a server where only 37% of the energy is for the server itself (Rasmussen, 2010). It is important to observe that a large part of the energy directed to information technologies is essentially for cooling.

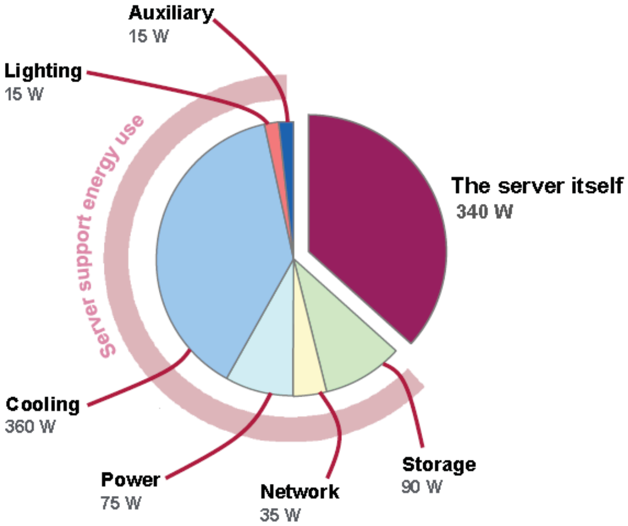

Figure D.4: *Energy breakdown of a server with an energy allocation of 930 W.*

The scenarios for Figure D.5 are described in the Environmental Protection Agency (EPA) executive summary report (EPA, 2007). Essentially the best practices and state of the art scenarios assumed moving in a new facilities or major upgrades to existing ones to better match the 'ENERGY STAR®' specifications. The improved operation scenario assumed no significant capital investment but offers electricity cost savings in excess of 20% according to this report. The current efficiency trends scenario represents the effect

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[55] http://www.djc.com/news/en/12038213.html (Access date: 14 May 2014) "High costs are spurring companies like Amazon and Microsoft to make their data centers more energy efficient…ultra-high-efficiency mode…increases a UPS's efficiency to up to 99 percent."

of updating the server technologies compared to the status quo which is labelled as 'historical trends scenario'. Then the report concluded that improving beyond the 'current efficiency trends' could reduce the US annual electricity cost in 2011 by $1.6 billion to $5.1 billion.

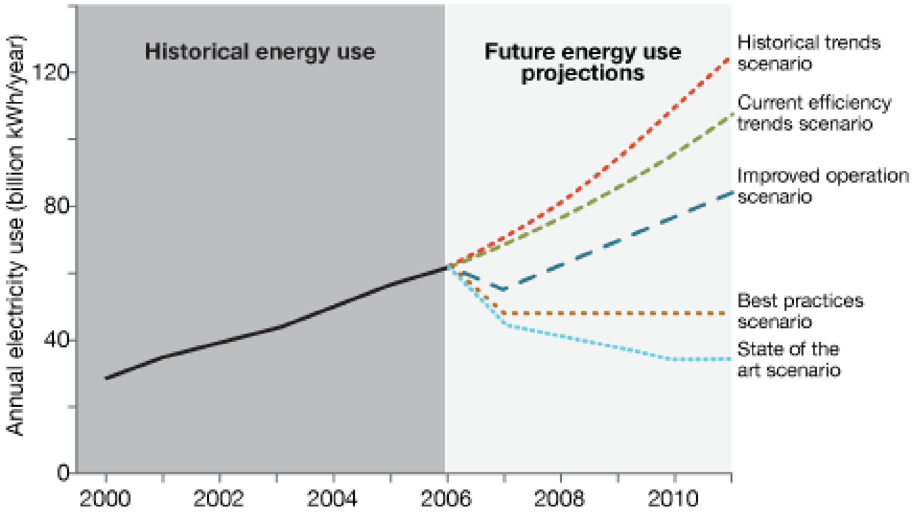

Figure D.5: *EPA comparison of projected electricity use, all scenarios, 2007 to 2011.*

According to Natural Resources Canada (NRCan) Office of Energy Efficiency (OEE)[56] a "data centre is a building space filled with information technology (IT) equipment: servers, storage, networking equipment, but also cooling equipment and power supplies. Data centres consume about 1% of Canada's electricity. One square foot of data centre space can use up to a hundred (100) times more electricity than a regular office space. Servers use only around 40% of a data centre's electricity. Another 40% goes to cooling these servers; and another 10% goes to power supplies losses. Conservation measures can dramatically reduce the electricity consumed by data centres."

D.4 Energy forms, transformation processes and reserves

When it comes to taxonomy of energy types, forms and transformation processes numerous essays have been published (Falk*, et al.*, 1983). For its easy access and clarity of its explanations a Wikibook[57] was selected. It defines energy as "a measure of the amount of change taking place within a system, or the potential for change to take place within the system". Energy can be divided in two forms, kinetic and potential. In a closed system a falling book has kinetic energy because its position in the closed system changes. A book resting on shelf has no potential energy relative to the shelf given its relative height to the shelf is zero. But if the book is at some height over the shelf it has potential energy proportional to the height and local gravity. In this example the book potential energy decreases as it falls toward the shelf while its kinetic energy increases proportionally, following the energy conservation law. Work is another concept which is defined as "a measure of the amount of change brought about in a system, by the

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[56] http://oee.nrcan.gc.ca/equipment/manufacturers/1875 (Access date: 20 Sept. 2013).

[57] http://en.wikibooks.org/wiki/Physics_with_Calculus/Mechanics/Energy_and_Conservation_of_Energy (Access date: 20 Sept. 2013).

application of energy". Then the following could be stated: "In all physical processes taking place in closed systems, the amount of change in kinetic energy is equal to the amount of change in potential energy. If the kinetic energy increases, the potential energy decreases, and vice-versa". "The total energy of a system (kinetic plus potential) increases by the amount of work done on the system, and decreases by the amount of work the system does."

In physics[58], the law of conservation of energy states that the total energy of an isolated system cannot change—it is said to be conserved over time. Energy can be neither created nor destroyed, but can change form; for instance, chemical energy can be converted to kinetic energy. A consequence of the law of conservation of energy is that a perpetual motion machine of the first kind cannot exist. That is to say, no system without an external energy supply can deliver an unlimited amount of energy to its surroundings.

Here are some energy sources, storage devices and conversion processes (Aricò, *et al.*, 2005) that need to be considered for efficiency and cost considerations (Geidl and Andersson, 2007) in developing an enduring DND/CAF operational energy strategy. Figure D.6 captures the main energy sources and conversion processes that need to be considered in exploring potential candidates for powering legacy and future DND/CAF amenities, functions, services and capabilities.

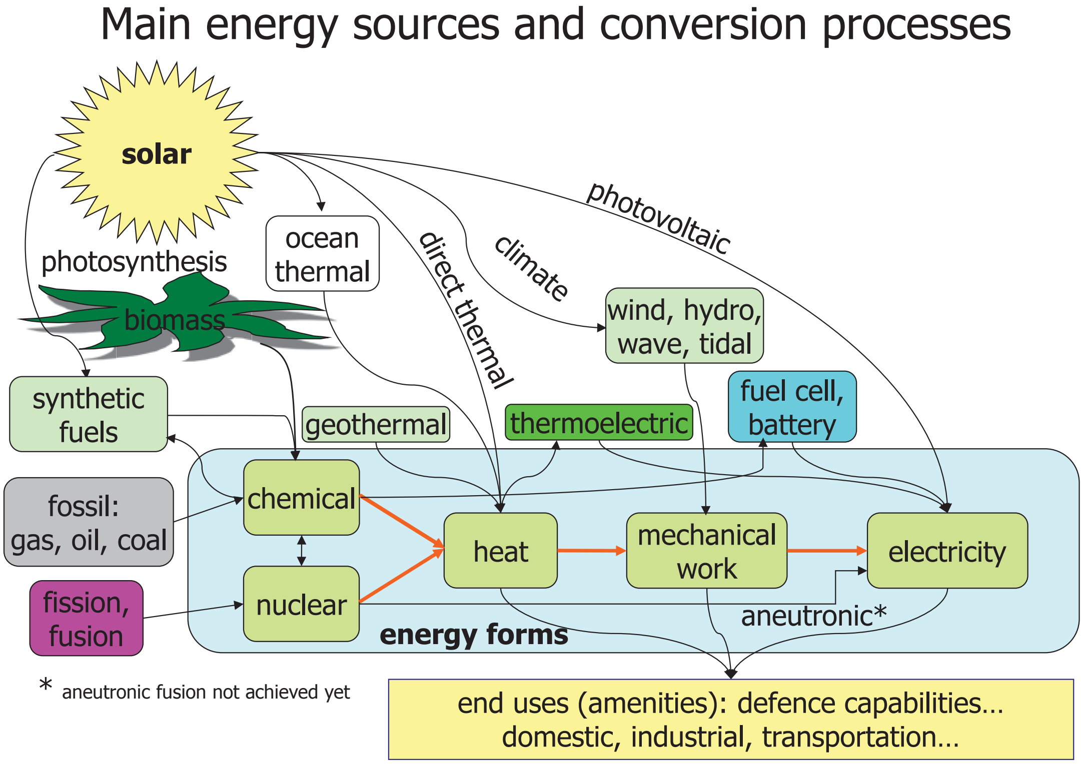

Figure D.6: *Mapping energy sources and conversion processes.*

Furthermore, in considering the availability, suitability and sustainability of energy from a strategic view point, Figure D.7 compares the finite and renewable planetary energy reserves in terawatt-years. Figure D.7 sizes of spheres express the relative amount of

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[58] http://en.wikipedia.org/wiki/Conservation_of_energy (Access date: 20 Sept. 2013).

energy as follows: for the finite resources the sizes express the total recoverable reserves, for renewables the size is proportional to early potential amounts, and for the world consumption the sphere sizes express yearly total consumption for 2009 and its projected value for 2050 (Perez and Perez, 2009, Perez*, et al.*, 2011). The authorization for using this material was provided by the author Dr Richard R. Perez, University at Albany-SUNY who pointed out that the addition of thorium and advanced nuclear power generation may increase the nuclear sphere in the 1000's, i.e., much larger than the total coal reserve (emails Perez-Labbé 17/11/2012 to 04/02/2013).

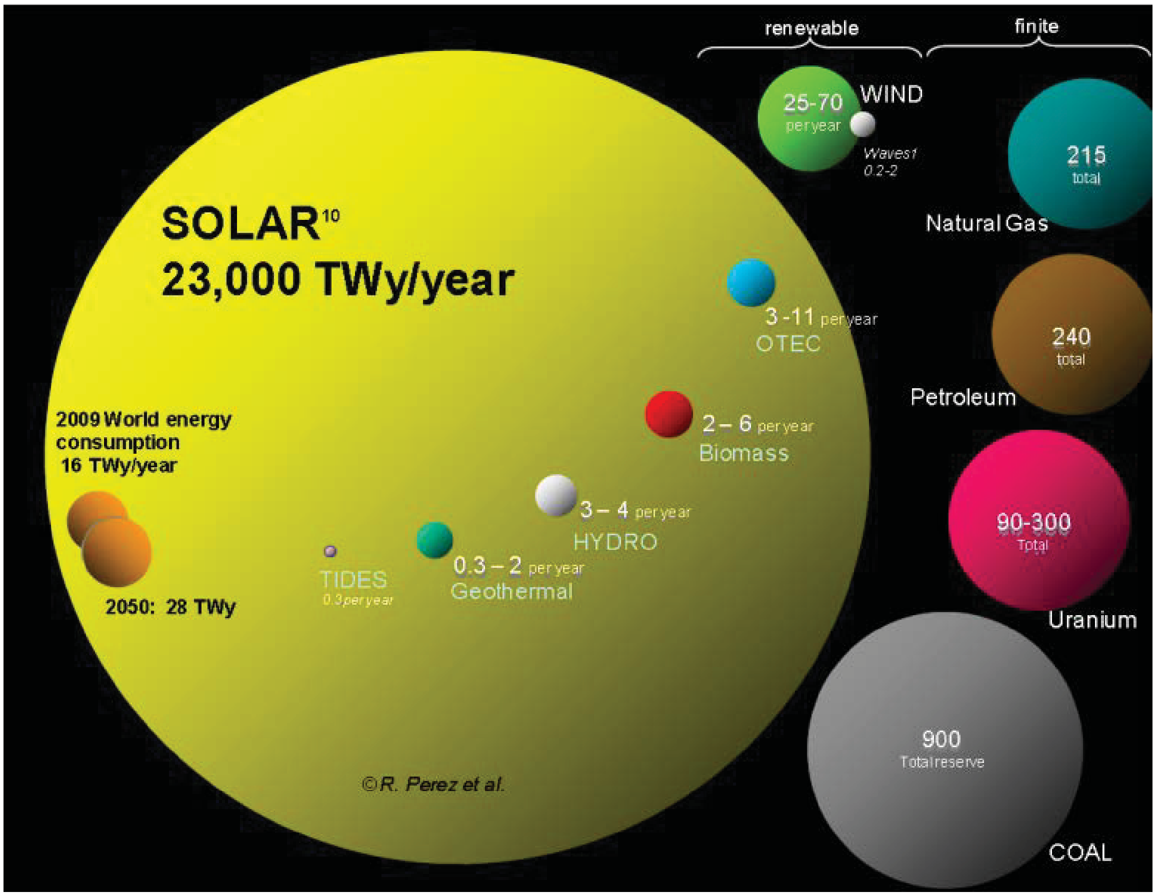

Figure D.7: *Annual world energy consumption, annual renewables and total finite Earth resources.*[59]

As reported under the capacity factor some renewable such as geothermal or ocean thermal energy conversion (OTEC) technologies could produce energy reliably with no interruptions for years. On the other hand renewables such as wind and solar require special attention due to their low capacity factors driven by daily and seasonal variations.

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[59] SOLAR^{10}: Solar energy received by emerged continents only, assuming 65% losses by atmosphere and clouds. More indications on the source of data for Figure D.7 are available at Perez, R. and Perez, M. (2009), A fundamental look at energy reserves for the planet, *The IEA SHC Solar Update* (electronic journal) 50. http://www.iea-shc.org/data/sites/1/publications/2009-04-SolarUpdate.pdf (Access date: 18 Sept. 2013)

In Annex F on CFS Alert, Figure F.1 illustrates the effects of northern seasonal variation and associated energy demand for that station.

Transport depends mainly on petroleum but is expected to be curbed over the next decades. According to Richard G. Newell and Stuart Iler as stated in “The Global Energy Outlook” (Kalicki and Goldwyn, 2013, p. 46) “Electricity is about 40% of the worldwide primary energy consumption, a role that will be increasing going forward. In terms of end-use energy consumption, electricity is growing much faster than direct use of fuels.” Advance information technologies and sensors as required by future CAF missions and operations will drive similar increase in electricity demand over the life time of current and future platforms and capabilities.

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Annex E Estimated potential energy cost savings

The aim of this Annex is to estimate the annual cost savings likely to be realized by 2030 and thereafter as a result of the proposed energy consumption targets outlined in the DOES for military operations. It should be noted that the energy reductions associated with deployed operations are included this analysis but without considering the fully burdened cost of energy (FBCE) methodology framework because accurate data separating expeditionary energy from domestic energy and types (i.e., jet fuel, diesel, electricity, etc.) were not available at the time of this calculation. The cost savings are based on domestic prices and consequently the estimated cost savings would have been much larger if the FBCE methodology could have been used (see CFS Alert case study, Annex F).

E.1 Methodology

The savings were estimated in two stages. In the first stage, the estimated savings were calculated in FY 2010-11 dollars. FY 2010-11 is the latest fiscal year for which energy consumption data were available. In the second stage, the estimated savings are brought to 2030 dollars. The impact of energy inflation since FY 2010-11 on estimated savings is assessed using three long-term inflation scenarios.

It should be noted that this analysis only examines the cost impact of the reduction in DND/CAF energy consumption levels as presented in Section 2.2 Figure 5, Table E.1 and as outlined in Section 2.5 Table 1.

Stage 1: Estimated savings in FY 2010-11 Dollars.

Seven types of energy were included in this analysis: electricity, natural gas, heating fuel (light and heavy heating fuels being combined as one), gasoline, diesel, ship's fuel and jet fuel. The estimated savings (in Canadian currency) for each type was calculated by multiplying the target energy saving, expected to be realized by 2030, by its average unit price in FY 2010-11. The aggregate estimated savings are calculated by summing across energy types. This approach is summarized below:

$$\sum ES_i = \sum (TCS_i * AUP_i) \tag{E.1}$$

where:

ES_i is the estimated saving for each energy type (i.e., Electricity, Natural Gas, Gasoline, etc.),

TCS_i is the target consumption saving (in volume) for energy type *i,*

AUP_i is the average unit price in FY 2010-11 for energy type *i,*

i is the index for the seven energy types included in this estimate, *i.e.*, electricity, natural gas, heating fuel (light and heavy combined), gasoline, diesel, ship's fuel (F-76), and jet fuel.

Stage 2: Estimated savings in 2030 Dollars

The calculation to bring aggregate estimated savings from FY 2010-11 dollars to 2030 dollars is done by using appropriate historical and forecasted energy inflation rates. In FY 2011-12, energy inflation was 19.1%.[60] For the time frame beyond FY 2011-12, three long-term inflation scenarios were considered:

a. The most likely inflation scenario in which a rate of 2.8% per year was used. This is the forecasted inflation rate for Standard Object 7 - Fuel and Electricity in the most current DND Economic Model.[61]

b. The low-inflation scenario in which a rate of 2% per year was used. This corresponds to the target consumer price index (CPI) inflation rate used by the Bank of Canada.

c. The high-inflation scenario in which a rate of 4.7% per year was used. This is based on average annual inflation for Standard Object 7 - Fuel and Electricity over the past 25 years.[62]

E.1.1 Data Sources

Target consumption savings: The DOES Baseline Working Group proposed target domestic consumption savings on a volume basis (except when otherwise specified). So our assumptions are based on the volumetric energy targets contained in DOES that are projected to be achieved by 2030. For real property (buildings), it was based on 20% reduction in energy consumption (DOES Target 2). For fleet, it was based on 10% reduction in fuel consumption (DOES Target 4). They were transformed into energy unit, terajoule (TJ). The projected savings in TJ are presented in Table E.1.

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[60] *DND Historical Economic Model FY 2012-13* (Directorate of Costing Services/ADM(Fin CS), http://admfincs.mil.ca/Publications_e.asp (Access date: 9 April 2013).

[61] Based on forecasted long-term inflation rate of the Standard object - Fuel and Electricity according to *DND Economic Model FY 2012-13*, http://admfincs.mil.ca/Publications_e.asp (Access date: 9 April 2013).

[62] Based on last 25-year historical average inflation rate of the Standard object - Fuel and Electricity according to *DND Historical Economic Model 2012-13*, http://admfincs.mil.ca/Publications_e.asp (Access date: 9 April 2013).

Table E.1: *Projected energy consumption savings by 2030.*

Category	Energy type	Energy quantity per year in TJ (3-yr average)◊	Projected reduction percentage	Projected energy reduction by 2030 in TJ
Real property	Electricity	3,600	20%	720
	Natural gas	5,900		1,180
	Light fuel oil	300		60
	Heavy fuel oil	800		160
	Other fuels	700	-	-
Fleet	Gasoline	200	10%	20
	Diesel fuel	1,800		180
	Ship's fuel	2,500		250
	Aviation fuel	7,400		740
TOTAL		23,200		3,310
Real property				2,120
Fleet				1,190

◊ Data from the Energy Consumption baseline: Chapter 2.

Average Unit Price: The historical energy unit prices paid by DND in various regions, and the quantity of energy procured at various prices, are not readily available. Departmental financial systems track total payments/expenditures associated with energy but do not report information on unit prices and consumption levels. As such, a research was conducted to obtain historical unit price data from various sources. The average unit price for each energy type was calculated using these price data.

Currently there is no clear way to separate energy expenses between expeditionary and domestic operations. The FBCE method was not applicable because of lack of accurate data on energy used during expeditionary operations. Table E.2 summarizes the data sources and methodologies used to calculate average unit energy prices. Given that the prices are obtained from various sources, the estimated average unit prices are only an approximation of the actual unit prices and may not be directly comparable among various fuel types. Consequently, the resulting energy saving estimates dependent of the average domestic unit energy prices used and could not account for the more expensive cost of energy observed in several expeditionary theaters. Savings are expected to be much larger for most expeditionary operations. The estimated cost savings are based on the domestic unit price of each fuel/energy type and the estimated savings of each fuel/energy type.

Table E.2: *Data sources and methodologies used in calculating average unit price.*

Energy type	**Average unit price FY 2010-11 (excluding taxes)**	**Data sources**	**Estimation methodology**
Electricity	$0.08 per kWh	• Implied Unit Price FY 2010-2011 • Comparison of Electricity Rates in Major North American Cities, April 2011, Hydro Quebec	• Calculation implied unit price by dividing expenditures by consumption volume. • This implied unit price was then compared to the Hydro Quebec electricity rates to assess the reasonableness of the implied unit price. The average price for Canadian cities ranges from $0.07/KWh (large power users) to $0.12/KWh (residential users). The implied unit price falls within this range.
Natural gas	$0.27 per m^3	• Implied Unit Price FY 2010-2011 • Energy Facts: Canadian Energy Pricing Trends 2000-2010, National Energy Board (NEB), October 2011	• Calculation implied unit price by dividing expenditures by consumption volume. • Implied unit price was then compared to prices contained in NEB report to assess the reasonableness of the implied unit price. The Canadian average natural gas price in 2010 was approximately $0.38 per m^3 (including taxes) so the implied unit price appears reasonable.
Heating fuel	$0.77 per L	• Standing Offer Agreement (SOA) weekly prices for first quarter of calendar year 2011 from Public Works and Government Services Canada (PWGSC) (previous quarters were not readily available) • Bi-weekly prices for diesel, gasoline and heating fuel for FY 2010-2011 (cents/L) NRCan website[63].	• Average price was calculated based on SOA rates. • Applied the price trend as per Nirvana data for FY 2010-2011 to first quarter 2011 SOA rate to estimate the DND average annual price for FY 2010-2011.
Gasoline fuel	$0.69 per L		
Diesel fuel	$0.74 per L		
Ship's fuel	$0.83 per L	• FY 2010-2011 ship's fuel price data provided by MARLANT and MARPAC	• Calculated the average ship's fuel price FY 2010-2011 based on the data provided by MARLANT and MARPAC
Jet fuel	$0.82 per L	• SOA weekly prices for first quarter of calendar year 2011 from PWGSC (previous quarters were not readily available). • Statistics Canada Industry Price Index for Canada Aviation Fuel Price[64]	• Average price was calculated based on SOA rates. • Applied the price trend in FY 2010-2011 as per Statistics Canada price index to first quarter 2011 SOA rate to estimate the DND average annual price for FY 2010-11.

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[63] http://www.nrcan.gc.ca/energy/1374 (Access date: 9 April 2013).

[64] v53434389 - 329-0065 Industry price indexes for electrical and communication products, non-metallic mineral products, petroleum and coal products; Canada; Aviation, turbo fuel and gasoline.

E.2 Results from applying the methodology to the available data

The results of stages one and two are presented in Table E.3 and Table E.4 respectively.

Table E.3: *Estimated annual cost savings by 2030 and thereafter in FY 2010-2011 dollars (not adjusted for future inflation).*

	Energy type	**Estimated cost savings in million dollars, $M**
Real property	Electricity	16.0
	Natural gas	8.3
	Light fuel oil	1.2
	Heavy fuel oil	2.9
Fleet	Gasoline	0.4
	Diesel fuel	2.5
	Ship's fuel	5.5
	Jet fuel	15.8
TOTAL		53.6
Total real property (buildings)		28.4
Total fleet		25.2

The proposed energy targets are estimated to save DND/CAF approximately $54 million, in FY 2010-11 dollars, by 2030. These savings represent approximately 9% of total energy-related expenditures in FY 2010-11.

Table E.4: *Estimated cost savings in 2030 dollars adjusted for three possible inflation rates.*

Long-term inflation scenario	**Annual inflation rate**	**Estimated cost savings in million dollars, $M**
Most likely	2.8%	93
Low	2.0%	80
High	4.7%	134

In conclusion from this methodology, it is estimated that the selected DOES targets could translate into savings ranging from $93 million to $134 million in 2030 dollars depending on the three inflation scenarios of Table E.4.

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Annex F Case study: Canadian Forces Station Alert

Established in the 1950's as a signals intelligence unit and weather station, CFS Alert is now a unit of the RCAF, and it supports many tasks as a sovereign Canadian outpost in the high Arctic. Located on the north-eastern tip of Ellesmere Island (82°28'N, 62°30'W), extremely cold temperatures are experienced throughout the majority of the year. Consequently, a significant energy budget is required to sustain this community and operational activities this far north, which is largely driven by electrical and thermal demands. Four 850-kW nominally-rated cogeneration generator setups (gensets) at the main power plant are used primarily to provide electricity and thermal energy to many buildings of the core complex via an electrical and thermal grid. Secondary boilers and furnaces are also used to provide additional heating where needed or to buildings that are not on the thermal grid. In addition to the main power plant, there are also two backup 1.2-MW nominally-rated gensets in an adjacent auxiliary power plant. JP-8 fuel is used in all of the generators onsite, which is delivered by airlift out of Thule, Greenland via Operation BOXTOP.

CFS Alert is one of the two most energy-intensive infrastructure assets across all of DND; the other being the North Warning System. For example, in 2010, the energy use intensity (EUI) of CFS Alert has been reported as 4,301 MJ/m^2 in FY2010/11 (Kan, 2012). By comparison, the energy-use intensity of Canadian Forces Base (CFB) Winnipeg, which is much larger in size, was reported as 1,371 MJ/m2 in the same fiscal year. Figure F.1 shows the seasonal variation of the amount of electricity generated in hundreds of MWh being used monthly compared with the inverse seasonal variation of the average external temperature per month over a year.

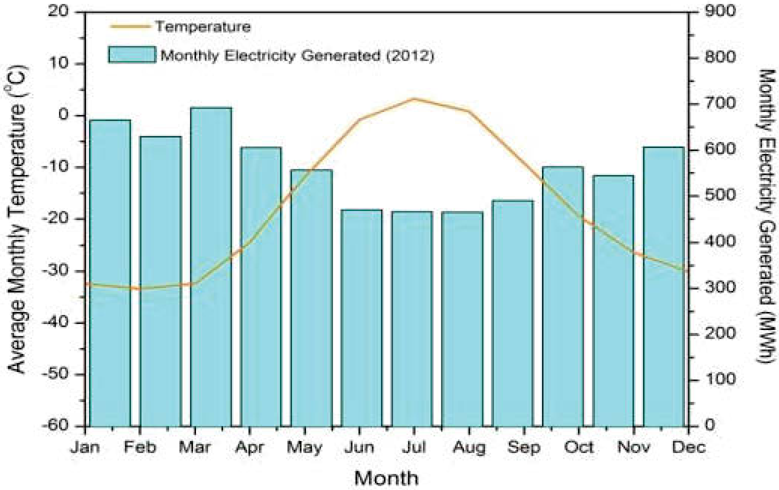

Figure F.1: *Inverse relationship of the electrical energy generated at the main power plant (2012) and the average external temperatures at Alert, Nunavut (Source: CFS Alert power plant logs and Environment Canada).*

On average, from 2007 to 2010, approximately 1.8 million litres of JP-8 fuel have been reported to be consumed at the main and auxiliary power plants. With an average annual cost[65] during this period of $5.45/L, it is highly desirable to identify alternative power and energy options. Energy options should include alternative technologies and strategies based on a comprehensive energy audit to understand baseline energy usage and the identification of energy saving measures that could be performed readily (Kegel, Wilkens, *et al.*, 2012).

The 2012 energy audit is the most comprehensive done to date, for the first time, as it relies on sufficient collected empirical data on CFS Alert to capture its particular energy related characteristics. They were obtained from the installation of electrical sub-meters for demand side electrical load monitoring, blower door tests, measured lighting and occupancy schedules, existing fuel records, interviews with onsite personnel as well as the development of extensive and detailed building energy models to provide further refinement of energy consumption at the station. In total, 73 buildings, all of which are on the electrical grid of the main power plant, were investigated. Of the 73 buildings, 50 buildings were identified as being heated either through the district heating system, fuel-fired boilers/furnaces or electric heaters. The electrical load breakdown of each of the seven building clusters fed by the main power plant has been obtained for the very first time with Station Centre, operations (OPS) building and Station East accounting for approximately 65% of total station energy used as shown by Figure F.2.

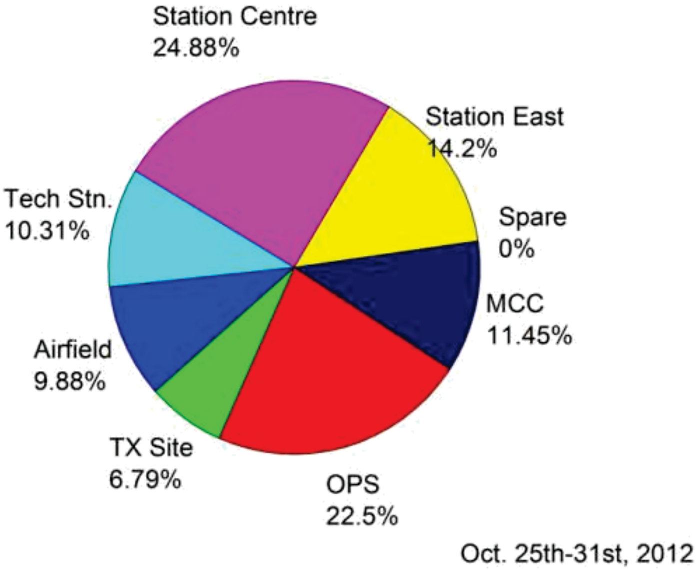

Figure F.2: *Energy used by building clusters fed by the main power plant at CFS Alert.*

With the validated energy models developed in this study, further analyses were carried out to identify short-term simple energy savings measures and their impact on fuel and cost savings. In addition, an analysis of more long-term capital-intensive improvements is also provided. The results of implementing these short and long-term measures are summarized in Table F.1, Table F.2 and Table F.3 below.

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[65] This cost includes the raw fuel cost, the cost of delivery and logistics (Source: G. Stewart, 8 Wing Alert Management Office). Fully-burdened costs of energy are estimated to be higher (Source: Ghanmi, A. (2013a), Fully Burdened Cost of Energy in Military Operations, *Journal of Energy and Power Engineering*, 7 (4), 501-513).

The short-term measures include:

a) Repairing and sealing holes in the building envelope.

b) Adding or replacing weather-stripping garage doors and man doors.

c) Replacing incandescent light fixtures with compact fluorescent fixtures.

d) Controlling light fixtures with occupancy control sensors.

e) Incorporating a boiler control strategy to prevent overheating.

f) Replacing the secondary heat recovery loop pump motors with correctly sized units.

Longer-term efficiency measures include:

a) Upgrading building envelopes to increase thermal resistance and lower air leakage.

b) Replacing high-bay light fixtures with induction lights offering lower power consumption, longer service life and improved control.

Table F.1: *Anticipated annual electricity and fuel savings implementing proposed short-term and long-term efficiency measures.*

Efficiency measure[a]	**Electricity savings (kWh)**	**Heating fuel savings[66] (L)**	**Cost savings[67] (thousand $)**
Short-term measure	650,000	93,000	540
Longer-term building envelope upgrade	1,000,000	274,000	1,100
Longer-term high-bay light fixture upgrade	1,150,000	76,000	770
All measures	1,500,000	257,000	1,330

[a] Long-term measures assume short-term measures have been implemented.

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[66] The reported savings for the 'Long-Term' measures take into account initial savings attained by implementing the 'Short-Term' measures. It is important to recognize that compensatory heating from the respective installed space heating equipment for buildings used in the analysis (e.g., furnaces, boilers, cogeneration thermal grid) has been accounted for on the implementation of high-bay lighting fixture upgrades. Thus, when more efficient lighting is implemented into the long-term envelope (i.e. 'All Measures'), the impact on the additional heating load will be different than implementation on its own.

[67] The cost analyses of the measures are based on real costs and not fully burdened costs. The cost to implement any measure is only an estimate for budgetary purposes and should be verified prior to implementation.

Table F.2: *Anticipated equivalent fuel load savings delivered by Hercules aircraft; implementing proposed short-term and long-term efficiency measures.*

Efficiency measure[a]	Global fuel savings[b] (L)	Equivalent fuel loads[c]
Short-term measure	268,000	15
Longer-term building envelope upgrade	544,000	30
Longer-term high-bay light fixture upgrade	386,000	21
All measures	662,000	37

[a] Long-term measures assume short-term measures have been implemented
[b] Global fuel savings also include the fuel required to produce electricity assuming a constant generator efficiency
[c] Based on an ~18,000 L fuel load carrying capacity of a Hercules aircraft in the fuel bladders

Table F.3: *Anticipated real costs to implement energy efficiency measures.*

Efficiency measure[a]	Real cost ($, CDN)	Payback period (Month)
Short-term measure	77,500	2
Longer-term building envelope upgrade	7,065,000	78
Longer-term high-bay light fixture upgrade	240,000	4
All measures	7,382,500	66

[a] Long-term measures assume short-term measures have been implemented

Table F.1, Table F.2 and Table F.3 show that the short-term measures result in an 11.2% and 19.3% reduction in electricity and fuel savings respectively with a relatively short payback period of less than two months. In addition, the long-term measures result in a 25.3% and 53.3% reduction in electricity and fuel savings with a longer-payback period of 5.5 years.

This energy audit lays the foundation for an energy strategy to reduce the fuel consumption and fuel logistical delivery burden to meet electrical and thermal energy demands at CFS Alert. Based on this energy audit, significant reductions in fuel consumption, and therefore fuel delivery, can be realized with low technology options that are readily available today. Human behaviour and culture will have a role to play in reducing fuel consumption and further study to quantify the impact of changing behaviours should be investigated, as it is not addressed in this study. Reducing the energy demand through the implementation of the proposed energy saving measures can then lead the way to the potential use of alternative power and energy options (i.e., renewable energy). The use of renewable energy and alternative options is the focus of an ongoing in-depth study "Alternative Power and Energy Options for Reduced-Diesel Arctic Infrastructure" underway since 2010 (see the scoping report for more information (Amow, 2010)).

Additional remediation measures like adding seawater to air heat pump may add additional fuel saving if the required capital investment is made. The potential coefficient of performance (COP) at CFS Alert was found to be in excess of three all year around for indoor temperature between 15 to 21 °C (Kegel, *et al.*, 2012).

Annex G New technology trends and system approach

For most practical applications, especially when low capacity factor sources such as wind and solar energies are part of the mix, the trend is to use a smart grid system or some microgrid approaches. The energy is locally transported and stored in order to obtain a system capacity factor approaching 100% most of the time, i.e., offering continuous energy at the designed power level reliably for the extent of time specified by the application requirements. This requires special attention to the microgrid design, including components and connectivity redundancy to make it more failure resilient with plenty of energy storage geographically distributed for a military base or distributed across a military platform. Such systems require a variety of technologies, design techniques and analyses but only the battery and solar aspects will be discussed here given their relevance to military operational energy. The smart grid or microgrid detailed system aspects are beyond the scope of this report but the essential is as follows.

Several ongoing studies[68] and projects (Mitra and Vallem, 2012, Romankiewicz*, et al.*, 2013, Skowronska-Kurec*, et al.*, 2012, Van Broekhoven*, et al.*, 2013) already demonstrate that although these microgrid and hybrid energy systems increase system complexity, if done appropriately, they drastically improve the overall system performance and reduce the overall capability life cost. Usually an energy management system (EMS) offers to a local microgrid (Olivares*, et al.*, 2011) the opportunity to optimize the energy as function of the policy selected providing fair priority to specified functions based on real-time user demands (thermal, mechanical or electrical).

Microgrid value proposition (Dohn, 2011):

- Efficiency: Lower energy intensity and distribution system loss.
- Reliability: Near 100% uptime for critical loads.
- Security: Enable cyber security and physical security.
- Quality: Stable power to meet exact consumer energy requirements.
- Sustainability: Expand generation to renewables and cleaner fuel sources.

G.1 Nanotechnologies applied to power and energy challenges

There are several references (Aricò*, et al.*, 2005, Engström and Bergman, 2013b, Luther and Hessen-Agentur, 2008, Wen*, et al.*, 2013, Zhang*, et al.*, 2013) in the energy domain which reports the positive impact of nanotechnologies on energy saving, storing and generation. Insulations, improved conductors, batteries, fuel cells, desalination systems and synthetic fuel production technologies have already benefited from

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[68] http://w3.usa.siemens.com/smartgrid/us/en/microgrid/Documents/The%20business%20case%20for%20microgrids_Siemens%20white%20paper.pdf (Access date: 17 Sept. 2013).

nanotechnologies as exemplified by direct use of solar energy to split water into hydrogen and oxygen.[69]

Another interesting impact is on the design and low-cost mass production of silicon capacitors with 10 times the previous energy density which may allow to use them as batteries in some applications (Oakes*, et al.*, 2013).

G.2 Batteries

Lead acid and alkaline batteries have a long history of use and have proven their predictability for a variety of applications. However their power densities are not comparable to advanced batteries as required for new applications such as in the era of smart phones and information age military operations. In addition, although lead acid batteries have proven their usefulness for a variety of applications over decades, their use in military operations cause a serious environmental challenge in terms of recycling them.

Here is an example of battery requirements for a specific CAF application. The updated key findings from DRDC reports in support of DND/CAF on battery requirements for dismounted infantry (Dobias, 2013, Dobias and Po, 2009) where two alternatives to alkaline batteries are considered, rechargeable nickel-metal-hydride (NiMH) and disposable lithium iron sulphide – LiFeS (LFS) are as follows.

- The alkaline batteries remain the cheapest option for a single mission under normal temperatures; in cases of operations in extremely cold temperatures the disposable LFS or rechargeable NiMH batteries outperform alkaline batteries.
- For repeated missions and extended deployments the rechargeable NiMH batteries are a viable alternative to the currently used alkaline AA batteries.
- The key requirement to make the NiMH batteries a best option is an ability to recharge them during missions (e.g., during rest periods), or at the minimum at the end of every mission.
- Further research focused on the recharging mechanism could possibly improve the feasibility and acceptability of rechargeable batteries. Some focus areas that could be considered include the ability to recharge batteries without removing them from respective systems, and the use of alternative power sources (such as solar cells or harnessing motion) to recharge the batteries.

Currently a dominant battery technology for energy grumpy phones is the Li-ion[70] batteries. However, although they have evolved to reduce the risk of fire and explosion (high temperature fire and toxic fume), they are still more prone to explode or burn than

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[69] http://en.wikipedia.org/wiki/Photoelectrochemical_cell (Access date: 14 May 2014).

[70] From Wikipedia: A lithium-ion battery (sometimes Li-ion battery or LIB) is a member of a family of rechargeable battery types in which lithium ions move from the negative electrode to the positive electrode during discharge and back when charging. Li-ion batteries use an intercalated lithium compound as the electrode material, compared to the metallic lithium used in non-rechargeable lithium battery...Handheld electronics mostly use LIBs based on lithium cobalt oxide ($LiCoO_2$), which offers high energy density, but presents safety risks, especially when damaged. Lithium iron phosphate (LFP), lithium manganese oxide (LMO) and lithium nickel manganese cobalt oxide (NMC) offer lower energy density, but longer lives and inherent safety.

the older technologies but offer about twice as much gravimetric and volumetric energy density. Battery energy density improvement trend used to be about doubling energy density every 10 years. As technology advances over time other alternatives to current batteries will be made available with the desired safety and capacity sought for a variety of CAF applications and operational theater conditions. As illustrated in Figure G.1 (a courtesy of Panasonic) in maximum ampere hour (Ah) for a small 18650-size Li-ion rechargeable battery, the use of silicon-alloy anode material changes the established trend line of 11% improvement annually to 18% (Frank, 2012).

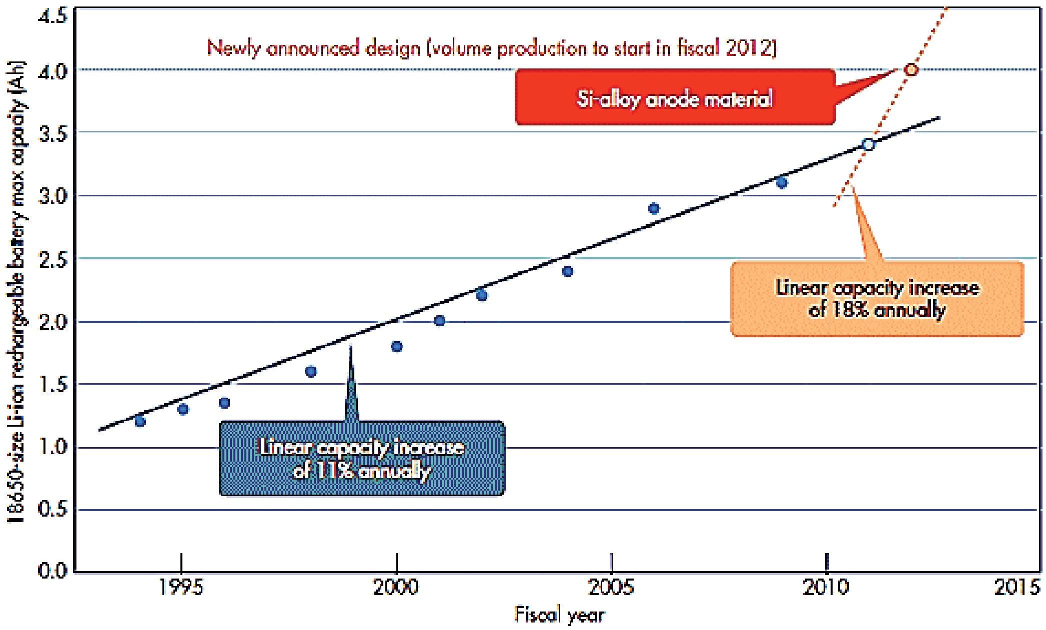

Figure G.1: *Using silicon-alloy anode material increases the gravimetric energy density trend over the previous Li-ion technology gravimetric energy density trend.*[71]

Experimental advanced batteries, such as Li-Air, are reported with energy density in the order of 3,000 Wh/kg (more energy dense by one order of magnitude than Li-ion) but they are not commercialized yet. As reported (Silberglitt, *et al.*, 2014) they may exhibit dangerous reaction and thermal run unacceptable for dismounted combatant and currently too fragile for most military applications.

In order to better appreciate the characteristics of batteries for transport applications, which are relevant to CAF mobility, Table G.1 compares six battery chemistries across a dozen properties.

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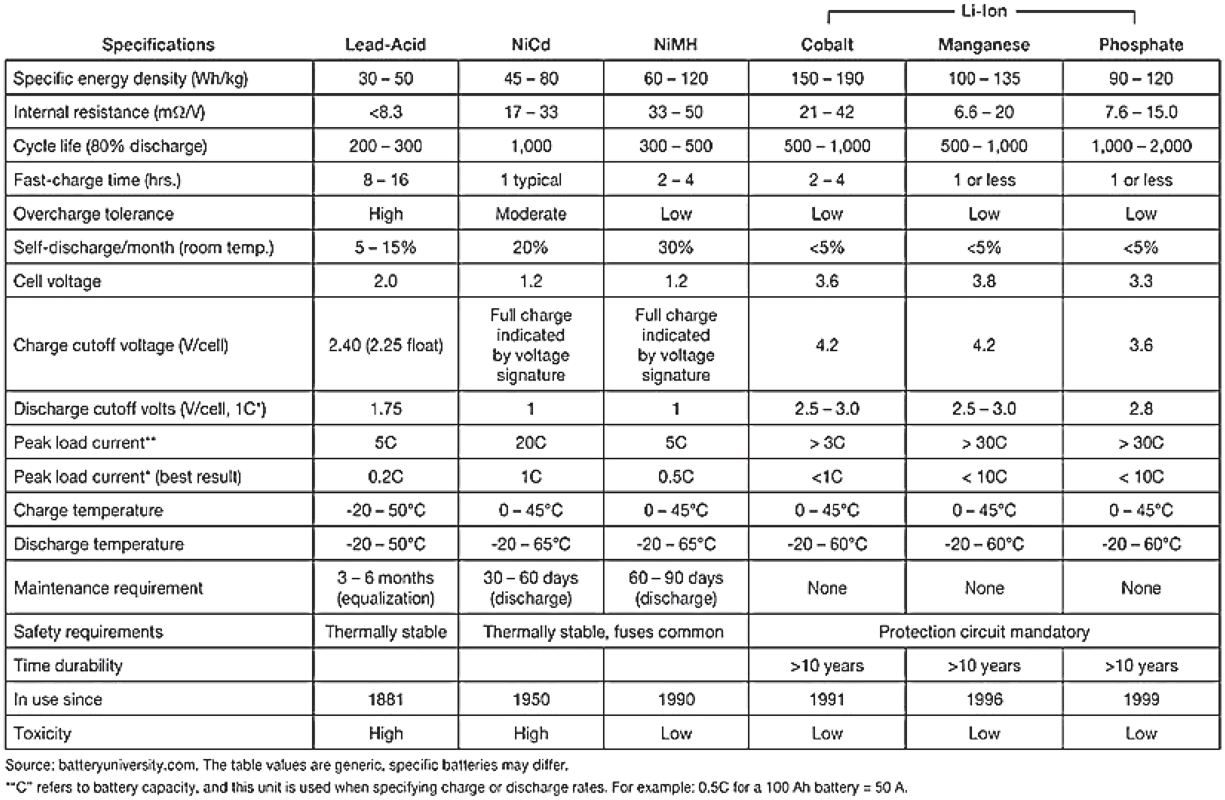
[71] http://electronicdesign.com/power/here-comes-electric-propulsion (Access date: 17 Sept. 2013).

***Table G.1:** Key properties of batteries for land platforms.*[72]



				Li-Ion		
Specifications	Lead-Acid	NiCd	NiMH	Cobalt	Manganese	Phosphate
Specific energy density (Wh/kg)	30 – 50	45 – 80	60 – 120	150 – 190	100 – 135	90 – 120
Internal resistance (mΩ/V)	<8.3	17 – 33	33 – 50	21 – 42	6.6 – 20	7.6 – 15.0
Cycle life (80% discharge)	200 – 300	1,000	300 – 500	500 – 1,000	500 – 1,000	1,000 – 2,000
Fast-charge time (hrs.)	8 – 16	1 typical	2 – 4	2 – 4	1 or less	1 or less
Overcharge tolerance	High	Moderate	Low	Low	Low	Low
Self-discharge/month (room temp.)	5 – 15%	20%	30%	<5%	<5%	<5%
Cell voltage	2.0	1.2	1.2	3.6	3.8	3.3
Charge cutoff voltage (V/cell)	2.40 (2.25 float)	Full charge indicated by voltage signature	Full charge indicated by voltage signature	4.2	4.2	3.6
Discharge cutoff volts (V/cell, 1C*)	1.75	1	1	2.5 – 3.0	2.5 – 3.0	2.8
Peak load current**	5C	20C	5C	> 3C	> 30C	> 30C
Peak load current* (best result)	0.2C	1C	0.5C	<1C	< 10C	< 10C
Charge temperature	-20 – 50°C	0 – 45°C	0 – 45°C	0 – 45°C	0 – 45°C	0 – 45°C
Discharge temperature	-20 – 50°C	-20 – 65°C	-20 – 65°C	-20 – 60°C	-20 – 60°C	-20 – 60°C
Maintenance requirement	3 – 6 months (equalization)	30 – 60 days (discharge)	60 – 90 days (discharge)	None	None	None
Safety requirements	Thermally stable	Thermally stable, fuses common		Protection circuit mandatory		
Time durability				>10 years	>10 years	>10 years
In use since	1881	1950	1990	1991	1996	1999
Toxicity	High	High	Low	Low	Low	Low

Source: batteryuniversity.com. The table values are generic, specific batteries may differ.

*"C" refers to battery capacity, and this unit is used when specifying charge or discharge rates. For example: 0.5C for a 100 Ah battery = 50 A.

In selecting battery chemistries for an application, special attention must be given to safety and toxicity. It is worth noting that lithium-ion batteries are especially prone to thermal runaway. However, advances in their design, chemistry and system integration have proven to reduce such risk to a point that high energy density batteries could be used safely even in extreme environments.[73]

G.3 Photovoltaics

The advent of cheaper and higher efficiency solar photovoltaic cells and kits that could be adapted to various military operational theaters makes then the most suitable renewable energy source for several DND/CAF capabilities. Some kits are designed with flexible panels that can be rolled for transport and storage. The basic kits come with appropriate connections, microgrid controllers and batteries for applications such as dismounted soldiers in a reconnaissance operation. The soldiers could use that energy to maintain their battery-operated equipment fully charged without having to use a noisy generator or using the energy from a motorized vehicle. Other kits are designed for adding capacity

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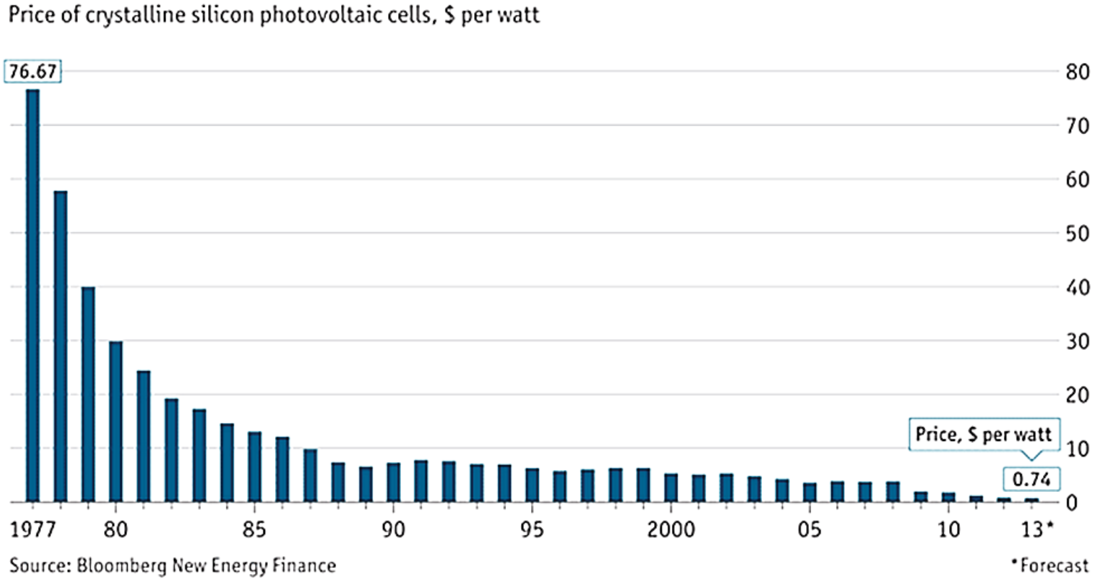
[72] Alternate link for this table: http://www.homepower.com/articles/solar-electricity/equipment-products/lithium-ion-batteries-grid-systems (Access date: 17 Sept. 2013).

[73] See Brecher, A. (2010), Assessment of Needs and Research Roadmaps for Rechargeable Energy Storage System Onboard Electric Drive Buses, 115. and Lithium Ion Phosphate Batteries for improved safety and thermal stability in http://www.fta.dot.gov/documents/FTA_Report_No._0024.pdf (Access date: 3 Oct. 2013).

to camps or forward operating bases while contributing to reduce the noise from generators and reducing the diesel fuel demand.

Figure G.2 shows the plummeting price trend of solar energy in US$/watt over the last decades. It is worth noting that this trend indicates that the price is not decreasing fast anymore but as the efficiency increases for the same price the size of the photovoltaic per watt will continue to decrease somewhat.



Source: Bloomberg New Energy Finance

Figure G.2: *Example of technology cost decrease for photovoltaics.*[74]

The National Center for Photovoltaics (NCPV)[75] at National Renewable Energy Laboratory (NREL) of US DOE provides continuous updated data on the progress in photovoltaic cell efficiency over a similar time frame. Currently average commercial cell efficiency is about 17% (10% to 22%). Some advanced photovoltaic[76] could almost reach 50% of efficiency in transforming the input solar energy into electricity, but the cost for such advanced technology was prohibitive when this report was prepared.

G.4 Advances in heat to electricity conversions

Piezoelectric and thermoelectric devices and generators are well documented in the following report: Technology Trends, Threats, Requirements, and Opportunities (T^3R&O) Study on Advanced Power Sources for the Canadian Forces in 2020 (Andrukaitis, *et al.*, 2001). Thermoelectric generators (also called Seebeck generators)

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[74] Graphics from http://www.thegreenage.co.uk/solar-prices-crashing-great-for-consumers/ (Access date: 14 May 2014). The rule of thumb for this decrease is that the cost to generate the photovoltaic cells falls by 20% with each doubling of global manufacturing capability. It has been often called the Swanson's law or effect for photovoltaics (named after Richard Swanson, the founder of SunPower Corporation, a solar panel manufacturer) in relation to More's law for the number of transistors on integrated circuits that doubles approximately every two years.

[75] http://www.nrel.gov/ncpv/ (Access date: 14 May 2014).

[76] http://www.nrel.gov/ncpv/images/efficiency_chart.jpg (Access date: 14 May 2014).

are devices that convert heat (temperature differences) directly into electrical energy, using a phenomenon called the Seebeck effect (a form of thermoelectric effect)[77]. Their typical efficiencies are around 5–8%. Thermophotovoltaic (TPV) devices are semiconductor diodes that directly convert photons from a black body radiating source at temperatures typically below ~2000ºC into electricity. In this they are similar to solar photovoltaic (SPV) devices. At the time of the T^3R&O report, the highest overall efficiency that was achieved in a TPV system was 7.2% and expected potential improvement rising to 15-20% in the long term.

New technologies that could benefit from solid-state manufacturing advances includes thermionic or thermoelectronic and pyroelectric, others exploit alternative means to convert low heat difference into electricity.

G.4.1 Thermionic converter

A thermionic converter consists of a hot electrode which thermionically emits electrons over a potential energy barrier to a cooler electrode, producing a useful electric power output[78]. "Practical thermionic generators have reached efficiencies of about 10%. The theoretical predictions for our thermoelectronic generators reach about 40%, although this is theory only," noted Mannhart.[79]

G.4.2 Pyroelectric converter

A new type of microelectromechanical systems (MEMS) high-efficiency heat energy converter, or scavenger, has been developed by Oak Ridge National Laboratory (ORNL) inventors[80]. The device is based on temperature-cycled cantilever pyroelectric capacitors. The device converts thermal waste heat to electricity while simultaneously reducing cooling requirements[81]. "Unlike thermoelectric devices, which use a constant temperature difference to generate a constant voltage, pyroelectrics only generate that voltage for a short amount of time, for as long as the electrons in the crystalline material leak from one end to the other." Until this advance, pyroelectrics efficiency was limited to about 5%. The new technology, MEMS pyroelectrics, can generate electrical energy from thermal waste streams with temperature gradients of just a few degrees up to several hundred degrees. "Scott Hunter, working at the ORNL hopes his new heat-recovering invention will scavenge lost heat with an efficiency of up to 30%".[82]

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[77] http://en.wikipedia.org/wiki/Thermoelectric_generator (Access date: 24 Sept. 2013).

[78] http://en.wikipedia.org/wiki/Thermionic_converter (Access date: 24 Sept. 2013).

[79] http://phys.org/news/2013-12-highly-efficient-thermoelectronic.html#jCp (Access date: 24 Sept. 2013).

[80] http://www.techconnectworld.com/Cleantech2013/a.html?i=4540 (Access date: 24 Sept. 2013).

[81] https://techportal.eere.energy.gov/techpdfs/2285%20Final%20Fact%20Sheet.pdf (Access date: 24 Sept. 2013). MEMS-based Pyroelectric Thermal Energy Scavenger by D. Sims, Oak Ridge National Laboratory, US.

[82] http://www.greenoptimistic.com/2011/05/17/scott-hunter-pyroelectri/ (Access date: 24 Sept. 2013).

G.4.3 Thermoacoustic converter

Thermoacoustic converters use heat to stimulate a resonating mode of a cavity or similar component. The oscillating part of the resonating cavity is attached to an electrical transducer to generate electricity.

One such device is the NASA's thermoacoustic Stirling heat engines (TASHE) which converts heat into acoustic power with very high efficiencies (up to 49% of Carnot's limit). It has moving parts that require no bearings and lubrication of components. It is claimed to exhibit low manufacturing and maintenance costs. The generated acoustic power is typically directed towards a resonator where it can be harvested with an appropriate acoustic load. It was designed for radioisotope/nuclear-fission power systems for deep-space travel but more recent applications for TASHE include household energy systems and industrial refrigeration (achieved by reversing the thermo-acoustic cycle). One example is a cogeneration of heating and electricity with a claimed system efficiency of 90%[83]. From a system view it is known as thermoacoustic-magnetohydrodynamic (TA-MHD) converter of heat to electricity.

Another example, the Thermal Acoustic Converter (TAC)[84], was designed by Etalim Inc. to convert any fuel or heat source to electricity using thermoacoustic physics. This device has virtually no moving parts and is inherently simple and reliable. It is straightforward to manufacture using inexpensive traditional materials and processes. They consider it as a next-generation piston-less Stirling engine. The thermoacoustic design employs heat to control the intensity of sound waves within a sealed cavity. They claimed to have achieved a high efficiency (~40%) of almost twice the efficiency of other small engines, but with zero mechanical friction, wear, lubricants, valves or dynamic seals, and extreme reliability and zero maintenance over an operating life of many decades. Their objective is to reach markets in 2015.

"Encased within the core of Etalim's engine is a plate of metal that replaces the function of a piston in a conventional Stirling engine. When pressurized helium on the top side of the metal plate is heated, sound waves traveling through the gas are amplified, causing the plate to vibrate, and a metal diaphragm below (separated by a cooler layer of helium) to push down on a shaft. All mechanical friction is eliminated. The shaft is attached to an alternator that produces electricity."[85]

G.4.4 Thermogalvanic effect

As reported by Stanford, MIT scientists developed a new way to harness waste heat energy, the low grade heat, i.e., cases where temperature differences are less than 100 degrees Celsius. Their method allows converting this heat into electricity stored in a battery. They exploit the well-known thermogalvanic effect inherent to battery technology. It is a four-stage process that uses waste heat to charge a battery. "First, an uncharged battery is heated by waste heat. Then, while the battery is still warm, a voltage is applied. When fully charged, the battery is allowed to cool, which increases the voltage.

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[83] http://www.nirvana-es.com/news_pr120913.html (Access date: 24 Sept. 2013).
[84] http://www.etalim.com/solutions.html (Access date: 24 Sept. 2013).
[85] http://www.technologyreview.com/news/422611/an-engine-that-harnesses-sound-waves/ (Access date: 24 Sept. 2013).

Once the battery has cooled, it actually delivers more electricity than was used to charge it."[86]

G.5 Electrical versus thermal energy storage

In some circumstances it could be advantageous to use thermal-energy storage due to its high efficiency especially when the end-use energy is thermal such as heating and cooling. To ensure high efficiency in thermal energy storage several considerations need to be accounted for: how the energy will be transported, distance, amount and shelf storage time. Usually by selecting an appropriate phase-change material (PCM) one could outperform the average transformation efficiency of photovoltaic in generating electricity, i.e., $\eta \approx 15\%$. The conversion of solar energy to heat could be as efficient as $\eta \approx 70\%$ to 80%. Then this heat could be transformed to electricity with efficiency around 30%. Figure G.3 provides an example of a high energy density thermal storage compared with batteries and other technologies (Vancompernolle*, et al*., 2012). However when low-cost photovoltaics reach an average transformation efficiency in generating electricity above 25%, the advantage of thermal-energy storage may become less attractive depending on related technology advances and target applications.

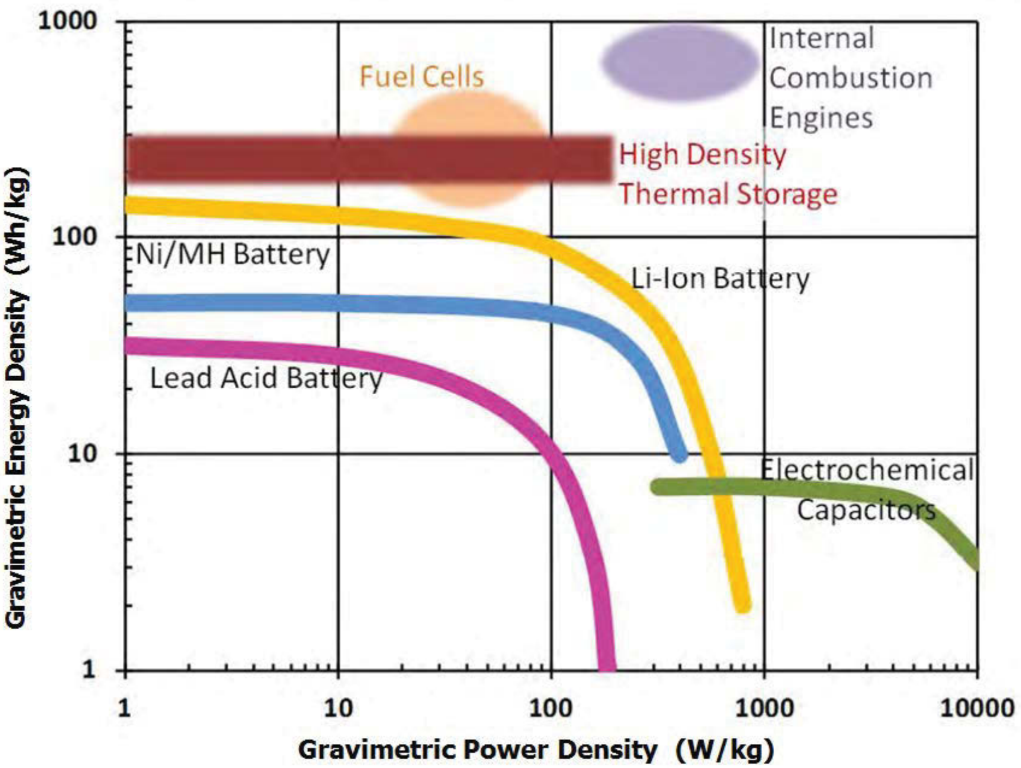

Figure G.3: *Ragone plot showing the relative performance of thermal storage.*

According to the 2013 McKinsey Global Institute report on disruptive technologies "Advances that will transform life, business, and the global economy" (Manyika*, et al*., 2013), the potential economic impact of improved energy storage could be 90 to 635

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[86] http://news.stanford.edu/pr/2014/pr-waste-heat-battery-052114.html (Access date: 24 Sept. 2013).

billion dollars per year by 2025 for all applications which includes 20 to 415 billion dollars per year by 2025 for electric and hybrid vehicles alone.

G.6 Material considerations in adopting alternate energy technologies

When considering alternate or advance energy solutions, it is critical to consider what such emerging technologies require in terms of material to manufacture them. Table G.2 uses the data from a study conducted under the chairmanship of the European Union (EU) on critical raw materials (EU Ad-hoc WG, 2010) (see also (Angerer, *et al.*, 2009)) required for selected emerging technologies.[87]

Table G.2: *Emerging technologies global demand on raw material.*

Raw material	**Production 2006 (t)**	**ETRD 2006 (t)**	**Indicator 2006**	**ETRD 2030 (t)**	**Indicator 2030**	**Selected emerging technologies**
Gallium	152	28	0.18	603	3.97	Thin layer photovoltaic, ic, LED
Indium	581	234	0.40	1,911	3.29	Thin layer photovoltaic, display
Scandium (RE)	1.3	2	0	0 3	2.31	Solid oxide fuel cell
Germanium	100	28	0.28	220	2.20	Fiber optic cable, infrared optic
Neodymium (RE)	16,800	4,000	0.23	27,900	1.66	Permanent magnets, laser technology
Platinum (PGM)	255	Very small	0	345	1.35	Fuel cell, catalyst
Tantalum	1,384	551	0.40	1,410	1.02	Microcapacitor medical technology
Silver	19,051	5,342	0.28	15,823	0.83	RFID tag, lead free soft solder

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[87] http://oilprice.com/Alternative-Energy/Renewable-Energy/Nine-Challenges-Facing-The-Alternative-Energy-Industry.html (Access date: 17 Sept. 2013).

Raw material	Production 2006 (t)	ETRD 2006 (t)	Indicator 2006	ETRD 2030 (t)	Indicator 2030	Selected emerging technologies
Cobalt	62,279	12,820	0.21	26,860	0.43	Lithium-ion battery, synthetic fuel
Palladium (PGM)	267	23	0.09	77	0.29	Catalyst, sea water desalination
Titanium	7,211,000	15,397	0.08	58,148	0.29	Implant, sea water desalination
Copper	15,093,000	1,410,000	0.09	3,696,070	0.24	Efficient electric motor, RFID tag
Niobium	44,531	288	< 0.01	1,410	0.03	Microcapacitor ferroalloy

t = metric tonne (1,000 kilograms or 2,204.6 pounds)
ETRD = emerging technologies raw material demand
RE = rare earth
PGM = platinum group metals
ic = integrated circuit
LED = light-emitting diode
RFID = radio-frequency identification

The indicator column is simply the ratio of the demand over the reference production. The larger is the 2030 projected ratio, the more critical a material is expected to become in the future. This is important to DND/CAF since some of these critical materials, especially the rare earths, are mainly produced by a single country, China. Currently Natural Resources Canada through the Canadian Rare Earth Elements Network is publishing a series of progress reports to better understand the situation and potential risk to the Canadian economy. There are other related initiatives such one led by the UK Natural Environment Research Council's (NERC) Security of Supply of Mineral Resources.

G.7 Geothermal energy

Although geothermal energy exhibits a very high capacity factor (see Figure 11 and Figure 12) and low GHG emissions, it is worth noting that geothermal may induce minor tremors (NRC, 2013, p. 169), findings include:

1. The induced seismic responses to injection differ in cause and magnitude with each of the three different forms of geothermal resources. At the vapor-dominated Geysers field hundreds of earthquakes of M 2 or greater are produced annually with one or two of M 4, all apparently caused principally by cooling and contraction of the reservoir rocks. The liquid-dominated field developments generally cause little if any induced seismicity because the water injection typically replaces similar quantities of fluid extracted at similar pressures and temperatures. The high-pressure hydraulic fracturing into generally impermeable rock associated with the stimulation operations at enhanced geothermal systems (EGS) projects can cause hundreds of small microseismic events and an occasional earthquake of up to M 3 due mainly to the imposed increased fluid pressures.

2. The mitigation of the effects of induced seismicity is, in some instances, clearly necessary to maintain or to restore public acceptance of the geothermal power generation activities. The early use of a 'best practices' protocol and a 'traffic light' control system indicates that such measures can provide an effective means to control operations so that the intensity of the induced seismicity is within acceptable levels (recommended protocol).

G.8 Atomic batteries

Here we use the term 'atomic battery' to include a variety of technologies[88] known by the source of heat, radioisotope, and the energy conversion technology used either thermal to electricity or direct conversion via a diode. Atomic batteries are well known for their space applications and remote sensors installed in difficult to access locations such as the Arctic. For these applications expensive radioisotope thermoelectric generators (RTGs, RITEGs) and Stirling radioisotope generators (SRGs) have been designed. RTGs have been successfully deployed and proved to be highly reliable except that the power measured over time showed to be slightly lower than specified, forcing operators to redo power budgets of missions.

Depending on their design, selected fuel and energy conversion technology efficiency, atomic batteries are still the most attractive option for long missions that require no maintenance as in space projects and difficult to access locations underwater or under extreme temperature and environment. In such environments, a thermoacoustic-magnetohydrodynamic (TA-MHD) converter that uses thermoacoustic coupled with magnetohydrodynamic (MHD) offers a system free of moving parts[89] that could run unattended for decades.

Note that Plutonium-238, the isotope that fuels Curiosity, is expensive. Less expensive isotopes have disadvantages. Strontium-90 produces gamma radiation which requires more shielding, it delivers lower heat temperature which affects the conversion efficiency but with its 28.8 year half-life Sr-90 offers more gravimetric power density as illustrated in Figure G.4[90]. Americium-241 has a half-life of 432 years but only 1/4 of energy density

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[88] http://en.wikipedia.org/wiki/Atomic_battery (Access date: 17 Sept. 2013).

[89] http://www.stfc.ac.uk/resources/pdf/esapb-hme(2008)43rev1progproposalcorecomponen.pdf (Access date: 17 Sept. 2013).

[90] This figure was reproduced with permission from Kumar, S. (2011), Energy from radioactivity. http://large.stanford.edu/courses/2011/ph240/kumar2/, personal communication Kumar-Labbé 31 October 2013.

of Pu-238 and requires at least 18 mm lead shielding to screen the penetrating radiation it produces. More radiation shielding reduces the gravimetric energy density advantage of an atomic battery.

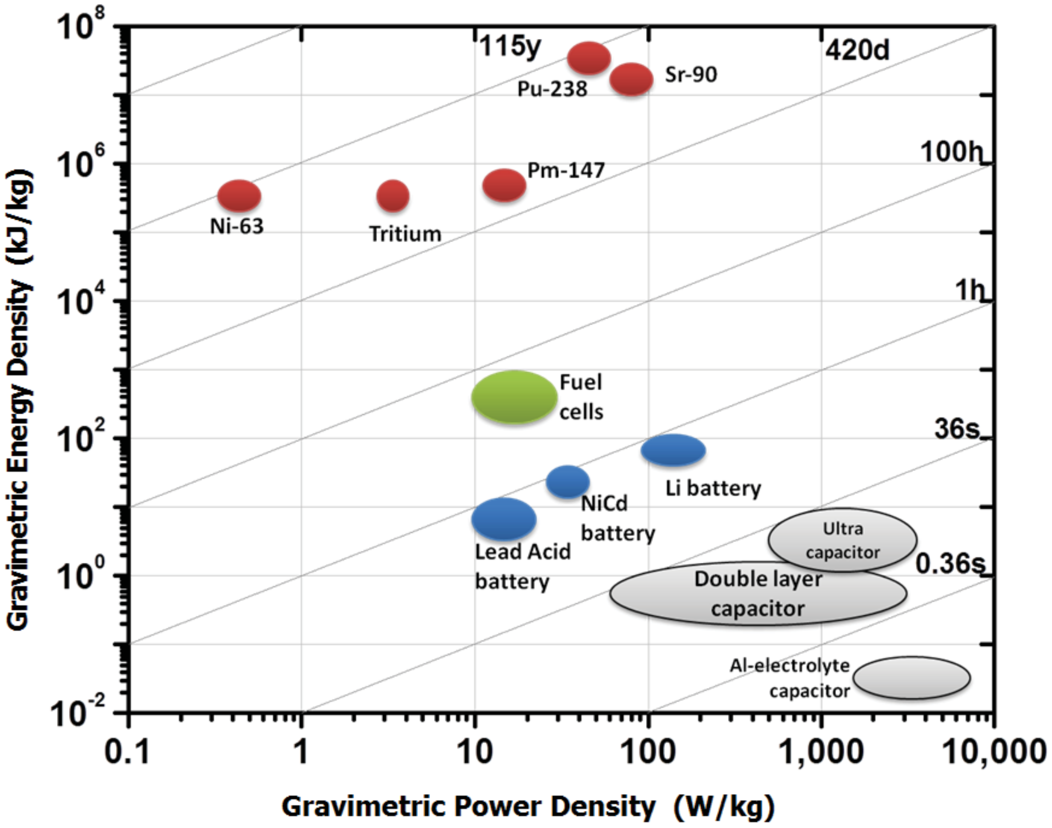

Figure G.4: *Ragone plot for various batteries including atomic batteries (or RTGs).*

Figure G.5 shows that although the cost of atomic battery fuel is high and represents a large part of the total cost of such battery, once considered in terms of the cost per unit energy ($/kJ) it becomes more competitive. It is worth noting that some of the atomic batteries, especially those of Sr-90 and Cesium-137 (Cs-137) are comparable in power density to chemical batteries, but atomic batteries are lower in cost per kilojoule ($/kJ) due to their very-high gravimetric energy density. So when considering such alternatives, one must look at the total life cycle cost using the FBCE paradigm.

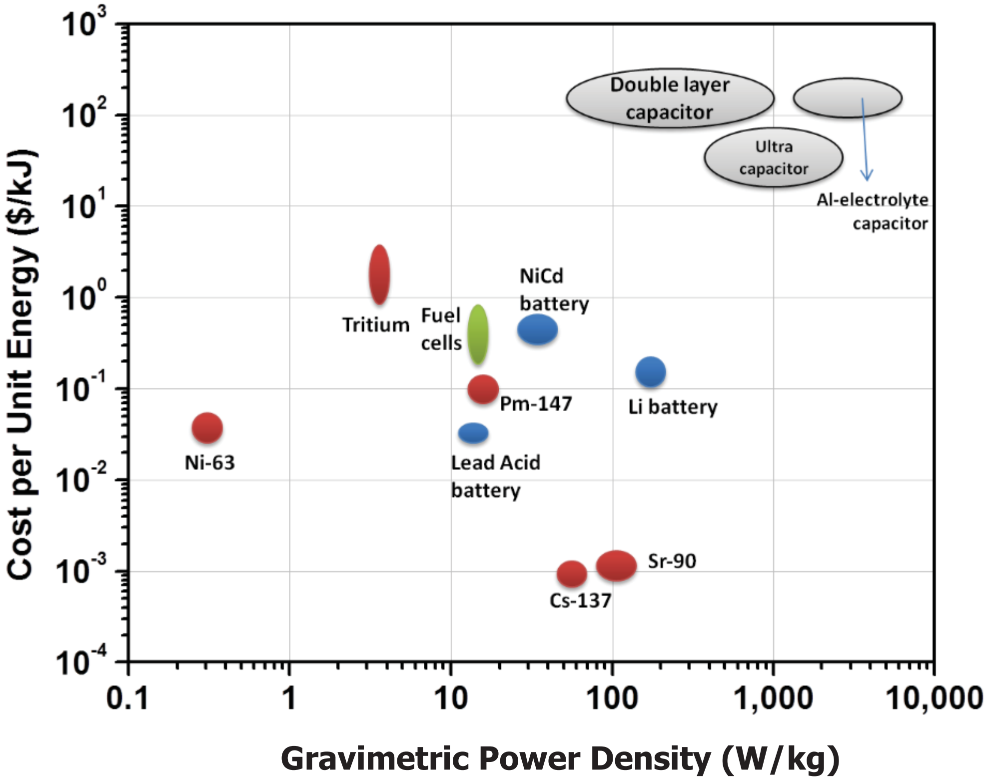

Figure G.5: *Cost comparison of various energy sources provided by (Kumar, 2011).*

G.9 Value of electric drives and turbo-hybrid transmissions to CAF

Turbo-electric transmission has been used in ships and trains in hybrid versions for almost a century, e.g., the battleship USS New Mexico, launched in 1917, was the world's first turbo-electric steamship. Numerous hybrids today use this technology with different electric energy generation systems using diesel, gas and nuclear fuel. The efficacy of this technology relies mainly on the high efficiency of electric motors to convert electricity to mechanical work at varying loads. This allows the energy generation component of the hybrid to work closer to their respective optimal operating points by storing energy in batteries and other storage means. This avoids using generators that match the maximum power demand but only the maximum steady state expected over a period of time beyond the energy stored.

Alternatively, NASA turbo-electric aircraft propulsion (Masson, *et al.*, 2013) explores turbo-electric distributed propulsion using super conductors in order to increase energy efficiency. Another approach is to power the electric motors by fuel cells and batteries according to a NASA study (Bradley and Droney, 2012, p. 91) on ultra-green aircraft. This later approach offers higher maximum energy efficiency and reduces noise level.

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Annex H Selected findings for the Canadian Army (CA)

Several aspects of interest to the CA energy were discussed in Chapter 3. Here are some specific aspects regarding bases, especially the forward operating bases, then the platforms and the dismounted soldiers.

H.1 Forward operating bases (FOBs)

During peacetime the fuel consumption of the US Army is dominated by its air platforms while during wartime the FOB generators become the largest single fuel consumers of the battlefield (DOD, 2008). Similar fuel consumption could be observed for the Canadian Army (CA).

When considering the FBCE for batteries, one can conclude that dismounted combatants need higher energy efficiency of their electronics which would reduce the demand of fuel for batteries transport or for batteries recharging on the FOB power grid which mostly depends on generators that use fuel in a combustion engine. But adding demand for fuel when it's fully burden cost is significant creates serious challenges in several operational theaters abroad.

On the other hand using alternate energy sources, such as solar, curbs the FOB fuel demand. For FOBs expected to be operated more than a year at a given place, water-ground loop cooling is advantageous and is cost efficiently available at most sites within less than 30 meters underground. A large percentage of FOB energy consumption is for heating, ventilation, and air conditioning (HVAC). Heat pumps with a ground loop represent a net cost advantage in face of FBCE at a FOB and could contribute to noise reduction and FOB security.

Another value of on-site resources is for fresh-water supply which could represent a substantial portion of a FOB energy cost. Purifying water from municipal supplies at some distance from the FOB and transporting it requires additional military protection and fuel. Checking the availability of subsurface water at each FOB location, and if confirmed, could represent a substantial advantage in autonomy, evaporative cooling, security and fuel cost demand reduction.

As more reliable and higher efficiency generators are made available, such as those with variable speed, the replacement of less efficient and noisy ones could be paid off in a shorter period of time when considering the FBCE in most expeditionary theaters.

"Theater infrastructure and sustainment operations involve tremendous amounts of material and personnel. The vast majority of supplies travel by sea and land, which require establishment of ports and other intermodal nodes and staging areas. Lines of communication must be protected as supplies spend days or weeks in transit. In theater, base camps provide space and security for maintenance, resupply, housing and a life support functions – each of which is energy-intensive." Quoted from (ARCIC, 2010).

H.1.1 Water generation and waste energy generation

Bringing drinkable water to isolated military bases could be very energy intense and represents a high risk on personnel in most operational theaters. Instead of transporting all the drinkable water to forward operating bases, alternatives were sought to make it more cost effective and less demanding on personnel by using some recycling and water purifying techniques.

For example DARPA[91] developed a Lightweight Water Purifier (LWP) that offers desalination and could produce approximately 75 gallons of potable water per hour (gph) from seawater. "This capacity, however, comes at a cost in energy, weight and size. A three-kilowatt generator supplies energy, and the entire 2,000-pound (907 kg) LWP system must be transported on the back of a Humvee."

Bioenergy is a renewable energy that plays an indispensable role in meeting today's ever increasing energy needs. Unlike biofuels, microbial fuel cells (MFCs) convert energy harvested from redox reactions directly into bioelectricity. MFCs can utilize low-grade organic carbons (fuels) in waste streams. The oxidation of the fuel molecules requires biofilm catalysis. In recent years, MFCs have also been used in the electrolysis mode to produce bioproducts in laboratory tests. MFCs research has intensified in the past decade and the maximum MFCs power density output has been increased greatly and many types of waste streams have been tested. However, new breakthroughs are needed for MFCs to be practical in wastewater treatment and power generation beyond powering small sensor devices. To reduce capital and operational costs, simple and robust membrane-less MFCs reactors are desired, but these reactors require highly efficient biofilms. This review is an update on the recent advances on MFCs designs and operations (Huggins*, et al.*, 2013).

However for deployed forces such systems need to be improved in order to provide an advantage over current techniques to reduce sewage treatment cost in terms of burden and total energy used.

H.2 Land tactical platforms

In Chapter 0 on the energy principles Figure 14 and Figure 15 provided several examples of the relation between power and energy to acceleration and range which are associated to the platform manoeuvrability and autonomy of a tactical land vehicle in an operational theater.

Advanced military land platforms are likely to take advantage of direct electric drive distributed to tractions components, avoiding the extra weight of transmissions and complex differential components. It circumvents several single point of failures observed during recent operations. Such platforms will have the advantage of larger electrical capacity to power sensors and weapons of tomorrow.

The following is a success story about energy efficiency for an armour vehicle deployed in Afghanistan which needs to be presented separately here.

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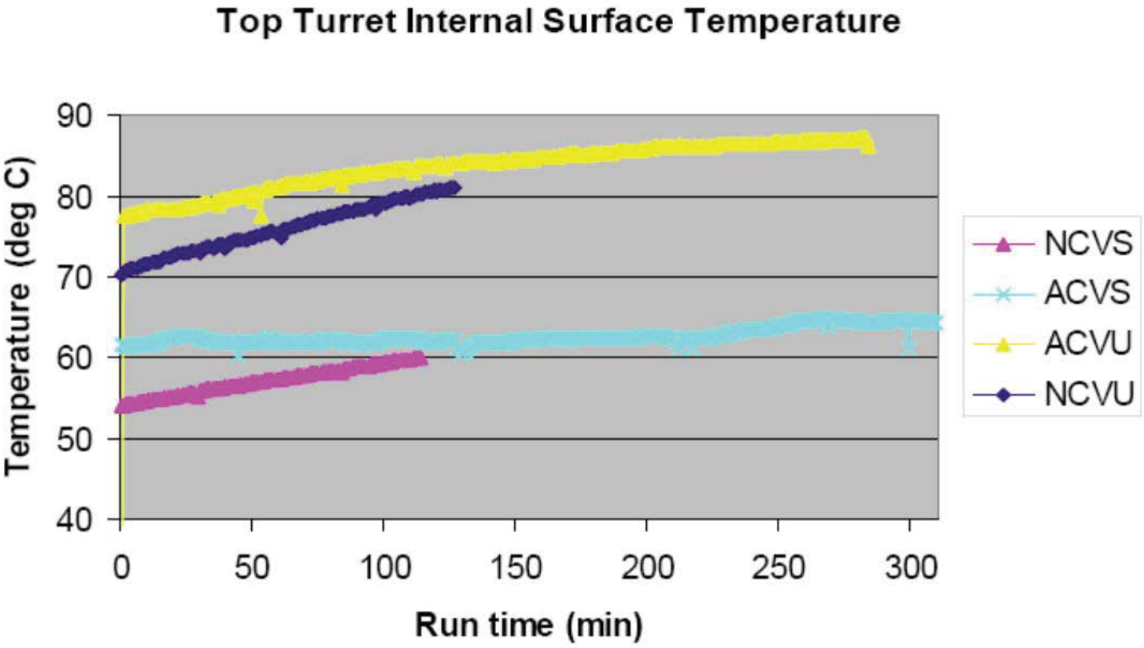
[91] http://www.darpa.mil/NewsEvents/Releases/2013/06/25.aspx (Access date: 24 Sept. 2013).

H.2.1 Reducing thermal load to increase fuel efficiency (Leopard)

Most of the military legacy platforms when exposed under sunny conditions exhibit a substantial thermal signature due to solar absorption and energy loss in the form of heat loss associated with the internal combustion engine. Most of these platforms use some form of air conditioning and air cooling (A/C) system to ensure operability of onboard systems and acceptable operator health conditions and alertness. For example studies (Hendricks, 2001, Rugh, 2002) showed that the "impact of the A/C system over a range of light-duty vehicles was to increase 1) fuel consumption by 28%, 2) carbon monoxide emissions by 71%, 3) nitrogen oxide emissions by 81%, and 4) non-methane hydrocarbons by 30%." Due to overall environmental impacts and significant increase in operating cost (fuel cost to generate cooling), nations are developing strategies and technologies to reduce these extraneous and undesirable life cycle cost in times of budget pressure to reduce government expenses.

In the following example (Figure H.1), instead of increasing the A/C system cooling capacity to cool an armoured vehicle, a more cost-effective approach was used to address the problem at its sources. By doing so the alternate technology reduces the demand on the A/C cooling capacity by using a novel heat shield that prevents the sun radiation to build up heat on the tank surface which transfers easily inside the tank turret and other operators' areas.



NCVU = No Cooling Vehicle Unshielded
ACVU = Active Cooling Vehicle Unshielded

NCVS = No Cooling Vehicle Shielded
ACVS = Active Cooling Vehicle Shielded 35°C

Figure H.1: *Effect of solar shield on surface temperature on top of turret inside of tank.*

The solar heat shield was developed for three Leopard versions and deployed in Afghanistan. Tests showed a 25°C temperature decrease for the patented advance heat shield. More information could be found in the patents of the heat shield for Leopard tanks (Dumas, 2010, 2011). So based on the example studies (Hendricks, 2001, Rugh, 2002) mentioned, using a heat shield for decreasing the temperature of a military vehicle offers a substantial reduction of additional fuel demand that would have been required if the tank cooling system capacity had been increased to get the turret temperature decreased by 25°C. This may represent a potential fuel consumption saving of up to 28%. In addition the heat shield was designed to act as a camouflage which provides a substantial decrease of the thermal signature.

H.3 Dismounted soldiers' energy challenges

The increase reliance in recent deployments on tactical small units (TSUs) imposed expanding responsibilities of ground forces beyond traditional combat which add to dismounted soldiers capability requirements such as more Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance (C4ISR), blue-forces tracking and controlled robotic capabilities that add to other energy hungry electronics of modern battlefields, see (NAP, 2013). In this report the shortcoming of current batteries were identified as follows (similar to those identified by the CAF):

1. Too many battery types;

2. Not energetic enough;

3. Too many batteries needed for long missions;

4. Too heavy and bulky; and

5. Evolution of capabilities adds to energy requirements.

The ISSP Soldier System Roadmap (DND, 2013, p. 48) identifies nine technical domain drivers including 'reduced weight' which is a common driver across all ISSP's technical domains:

- reduced weight;
- energy density, power density;
- safety (human and of information);
- voltage, current;
- wide temperature performance;
- wearability;
- mobility/transportability;
- usability; and
- ruggedness.

As stated in the SSTRM, in addition to essential soldier's combat supplies such as food, water and ammunition, power and energy became a fundamental element driven by the recent digitization effort. Electrical power must be provided to all involved electronic equipment in order to function synergistically. In face of operations diversities, soldier systems evolved to include new capabilities and increased the dependence on electrical power. The introduction of enhanced C4I and sensing capabilities at the soldier level allows the soldier to be more aware of his or her surroundings and to collaborate effectively with other soldiers. This generates more data that need to be processed and shared, requiring even more electrical power. As stated in the SSTRM, the generation, storage, distribution, management and use of greater electrical power must be provided and integrated in such a way as to minimize the overall weight and bulk of the soldier's equipment. These aspects of power provide the foundation for the four power and energy technical domain themes identified below (DND, 2013, p. 47) with their associated technical domain deficiencies.

Theme 1: Power Generation (Fuel Cells and Energy Harvesting)

Theme 2: Power Sources (Storage)

Theme 3: Power and Data Distribution

Theme 4: Distributed Power Management

So the challenge is to provide enough energy and power to the dismounted combatant while trying to reduce the volume and weight for an extended period of time. In order to illustrate this challenge, an example with missions extending up to 72 hours without adding burden on the combatant and associated logistic was developed as follows. In Figure H.2 a comparison of four energy options used three lines representing the thresholds of energy requirements for 72-hour missions with average power demands of 12, 20 and 30 watts, that is 0.86, 1.44 and 2.16 kWh of energy respectively.

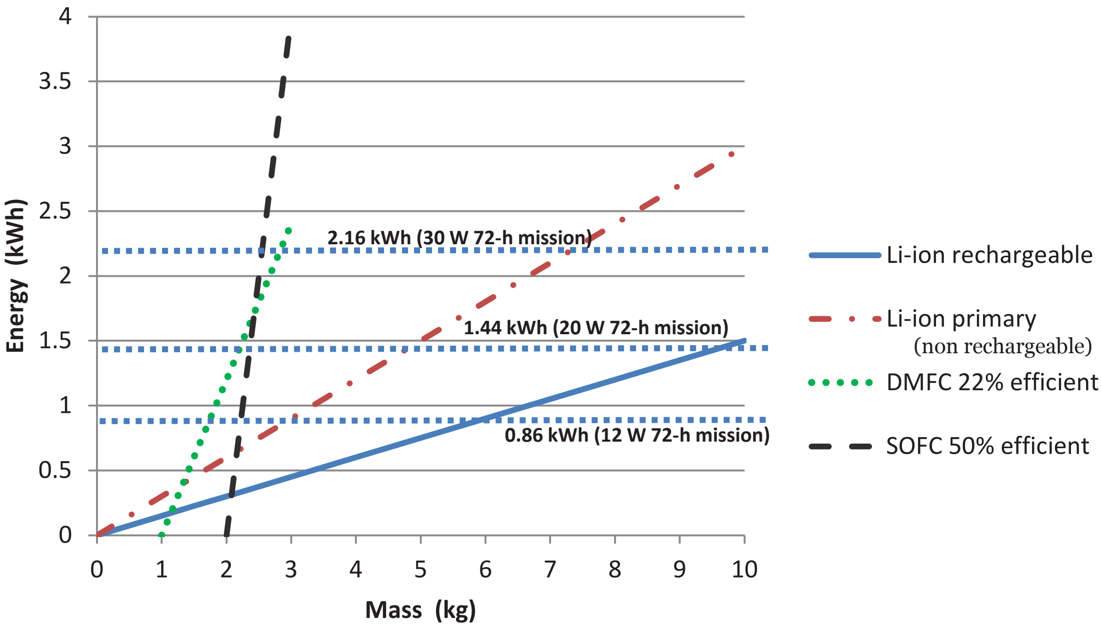


Figure H.2: *Example of energy options for three dismounted combatant 72-hour missions.*[92]

For shorter missions and lower nominal power demands, batteries can support the operations with minimal additional burden on the combatants and the logistic support. For longer missions and higher nominal power demands, the fuel cells offer a net advantage over the selected batteries.

With the advance in technologies that makes microgrids and hybrid-power systems more cost effective, the optimal options will include appropriate energy management in various hybrid forms in order to increase mission capabilities and reduce overall burden on the soldier and required logistic support. Such future microgrids or hybrid power systems will include energy management software and hardware, high energy sources such as fuel cells, high-performance batteries and supercapacitors to shave the peak power demands.

However one needs to consider other aspects such as the additional cost of advanced energy sources and training required for the best use in deployed theater. Consequently a mission planning aid to assist in balancing manoeuvrability, military effects and survivability of small units must be developed and used in training (either simulated or training field exercises), and subsequently used during operations by the soldiers, their leaders and higher echelons.

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[92] The direct methanol fuel cell (DMFC) and solid oxide fuel cell (SOFC) selected are based on the data provided for Figure 4-3, page 124 of NAP (2013), Making the Soldier Decisive on Future Battlefields, The National Academies Press. It refers to data adapted from Energy-Efficient Technologies for the Dismounted Soldier (NRC, 1997). Currently the Communications-Electronics Research Development and Engineering Center (CERDEC) considers hybrid-power systems which integrate high-power rechargeable battery with a fuel cell and packaged fuel to enable longer runtimes with less overall mission weight (https://www.rusi.org/downloads/assets/Bui_Part_1.pdf) (Access date: 24 Sept. 2013).

H.4 Dismounted combatants

The energy demand for dismounted combatants is highly dependent on the function, type of operations and environmental conditions (e.g., from very cold to very hot weather, from very humid to extremely dry conditions). During our recent operations, the dismounted combatant relied essentially on batteries for most of the energy requirements for equipment ranging from laser aiming devices to personal radios. The current autonomy for one day needs to be extended to three days. The following information has been extracted and modified from the draft of the Soldier Systems Technology Roadmap (SSTRM) 2011-2025 Capstone Report and Action Plan (DRDC Draft Version March 2012) and from the DND published report (DND, 2013), Soldier Systems Technology Roadmap; Capstone Report and Action Plan.

The Soldier Systems Technology Roadmap Capstone Report and Action Plan captures and summarizes the findings of the Development Phase of the SSTRM initiative. The SSTRM is a groundbreaking industry-government collaboration focused on enhancing the operational effectiveness of the future Canadian soldier and the competitiveness of Canadian industry through open innovation. Led by the Department of National Defence (DND)—with participation from Army and Materiel branches and DRDC—and Industry Canada, the initiative enjoys the strong support of the Canadian Association of Defence and Security Industries (CADSI) and of Technopôle Defence and Security (TDS). Applying roadmapping principles and processes to Canadian Forces soldier modernization efforts, the initiative involves industry and academia collaboratively in a comprehensive knowledge-sharing platform to articulate future needs and identify capability gaps, related challenges and potential technology solutions for the Canadian soldier of the future. The report includes an Action Plan that highlights the key R&D priorities identified by the soldier systems community of interest and makes recommendations for next steps in the initiative to encourage industry, academia and government collaboration in bringing innovative solutions forward for use by the future Canadian soldier. Figure H.3 illustrates some of the technologies requiring energy that are considered in Cycle I and II of the Integrated Soldier Systems Program (ISSP), such as combat computer, tactical display, local communication, Global Positioning System (GPS), Battlefield Combat Identification (BCID), digital magnetic compass, and night vision/target acquisition.

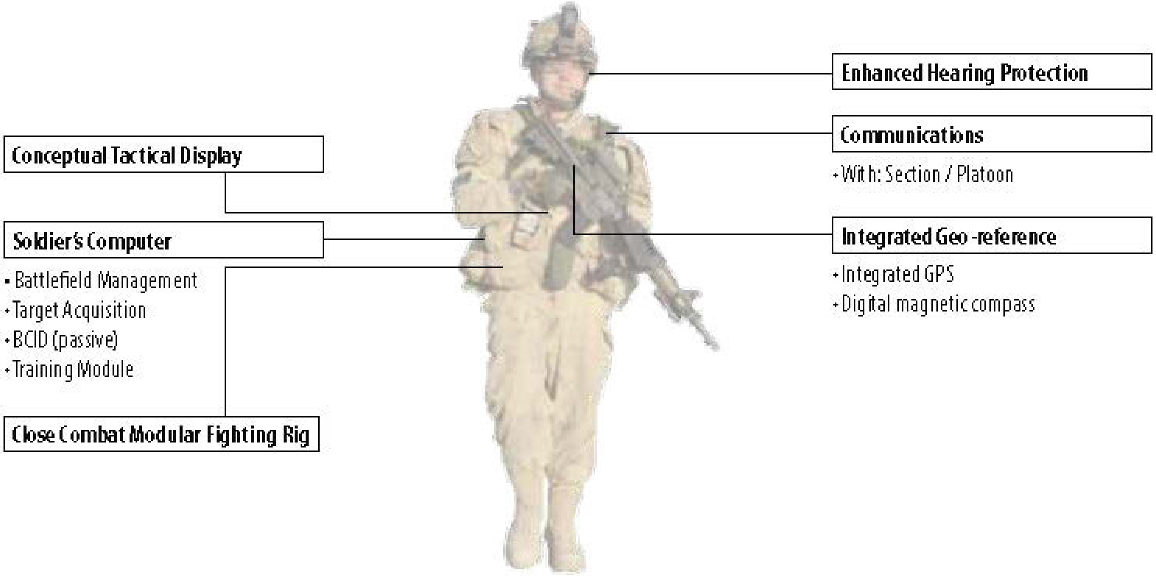

Figure H.3: *Concept of capability delivery for ISSP Cycle 1 and Cycle 2.*

Power and energy on the dismounted soldier is a key technical domain with many associated challenges. It is a fundamental element of the recent digitization effort, which has become as essential as traditional soldier commodities such as food, water and ammunition. Electrical power must be provided for any of the electronic equipment to function. As soldier systems evolve to include new capabilities, the dependence on electricity will continue to grow. The SSTRM vision for the Power and Energy technical domain in 2025 is to provide the future networked soldier with self-sufficiency—without re-supplying for the mission duration—through increased energy efficiency, with the lowest acceptable added weight.

Overall system goals for:

1. 2015–2020—soldier systems with sufficient energy storage capacity to operate through a 24-hour mission, and with the recharging or fuel re-supply to operate through a 72-hour mission.

2. 2020–2025—soldier systems capable of energy autonomy.

Here are some updates (Dobias, 2013, Dobias and Po, 2009), the key findings, on rechargeable nickel-metal-hydride (NiMH) and primary (i.e., disposable) lithium/iron sulphide (LFS) as evaluated for their current suitability to the dismounted soldier:

1. The alkaline batteries remain the cheapest option for a single mission under normal temperatures; in cases of operations in extremely cold temperatures the disposable LFS or rechargeable NiMH batteries outperform alkaline batteries.

2. For repeated missions and extended deployments, the rechargeable NiMH batteries are a viable alternative to the currently used alkaline AA batteries.

3. The key requirement to make the NiMH batteries a best option is an ability to recharge them during missions (e.g., during rest periods), or at the minimum at the end of every mission.

4. Further research focused on the recharging mechanism could possibly improve the feasibility and acceptability of rechargeable batteries. Some focus areas that could be considered include the ability to recharge batteries without removing them from respective systems, and the use of alternative power sources (such as solar cells or harnessing motion) to recharge the batteries (Andrukaitis*, et al.*, 2001, Dobias, 2013, Dobias and Po, 2009).

However, when considering the trends of batteries (as presented later in this report) one can expect that safe Li-ion or other new batteries technologies will be available by the time some procurement actions will be initiated with requirements based on capabilities to fulfill the energy density, form factor and safety requirements.

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Annex I Selected findings of interest to RCN energy

According to (Doerry, *et al.*, 2010) the US Navy is pursuing a number of energy efficiency initiatives to reduce fossil fuel consumption across its non-nuclear powered fleet. These efforts are grouped into the following categories:

1. Improved prime mover efficiency.
2. Reduced propulsion power demand.
3. Reduced mission systems and ship systems power demand.
4. Modifying the concept of operations (CONOPS) to achieve mission objectives with less fuel consumption.

Findings reported include the facts that most of the energy losses occur in internal combustion engines (either diesel or gas turbine), i.e., in converting fossil fuel energy into mechanical work for propulsion or electricity. The second most significant loss is due to the inefficiency of turning mechanical power input to the propellers into ship movement. Studies are related to DDG51 class modernization program (FLT III) with direct contribution from Carderock. Several factors need to be considered in projecting the potential cost effectiveness of a proposed ship energy improvement. One such factor is to develop a speed-time profile based on current and projected operational data for a given ship (ship class) instead of lock-in speed-time profiles based on obsolete assumptions (Anderson, 2013).

To better visualise the overall energy picture of typical war ships, two diagrams are presented in Figures I.1 and I.2 (Doerry, *et al.*, 2010). One shows the losses for a mechanical drive ship and another one for an electrical drive or integrated electric ship. These diagrams are similar to a Sankey diagram[93] of a ship energy flow but without the modulation of the arrows' widths as function of the percentage of energy at play, i.e., the losses and uses or outputs.

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[93] From Wikipedia: Sankey diagrams are a specific type of flow diagram, in which the width of the arrows is shown proportionally to the flow quantity. They are typically used to visualize energy or material or cost transfers between processes.

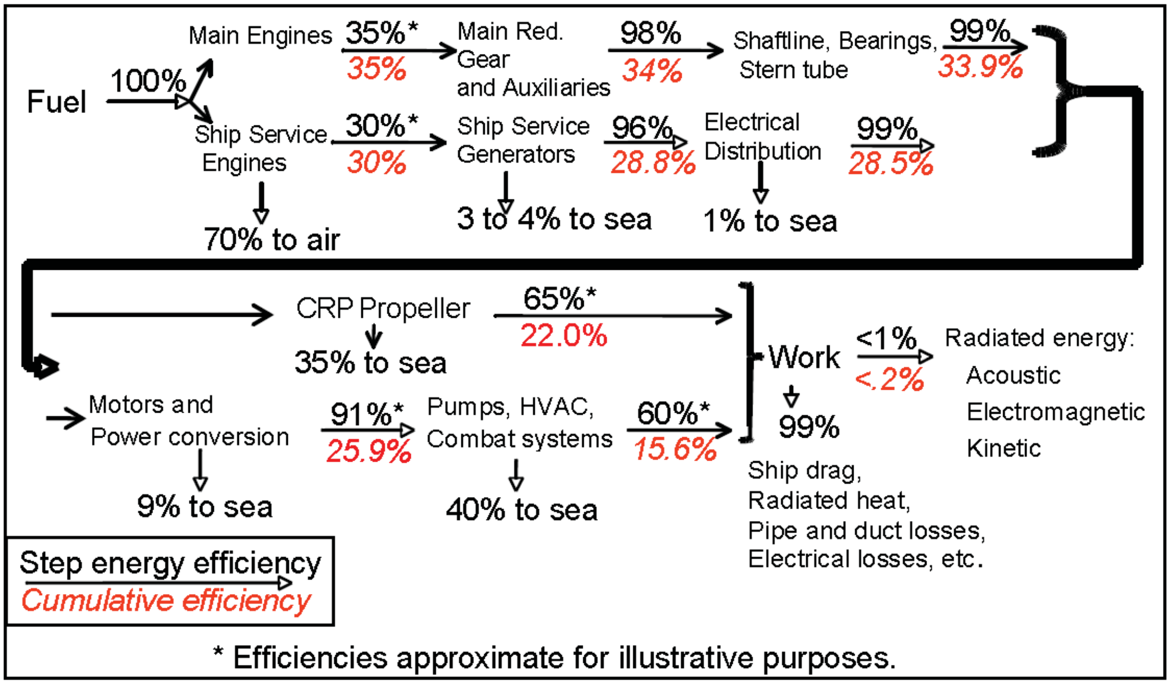

***Figure I.1:** Example of energy flow for a mechanical drive ship from (Doerry, et al., 2010).*

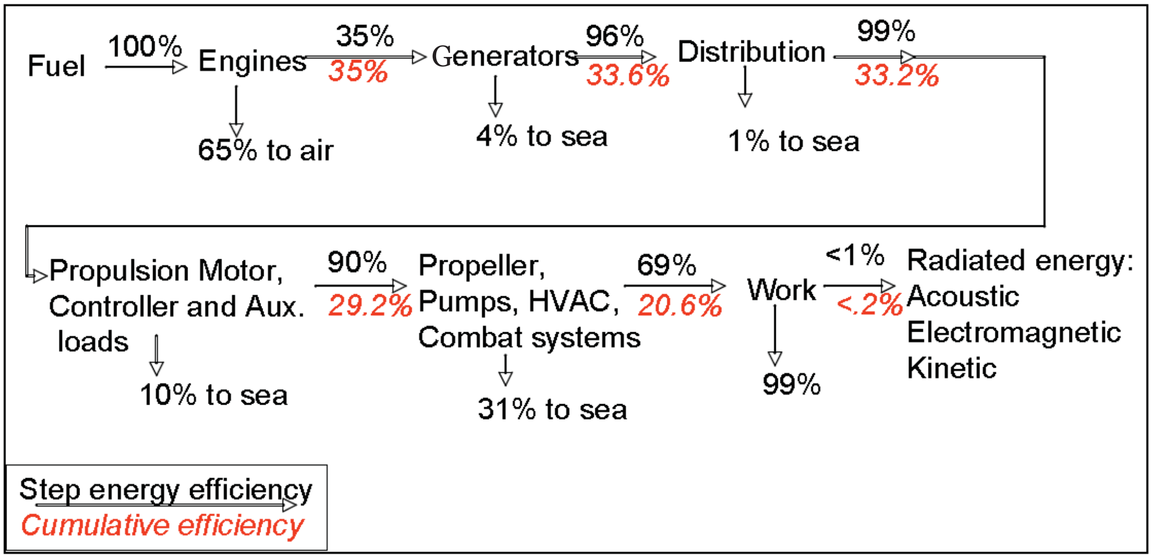

***Figure I.2:** Example of energy flow for an integrated electric ship from (Doerry, et al., 2010).*

I.1 Improved prime mover efficiency

Maintenance to the main engine and potential engine improvements can make a big difference. For legacy platforms significant changes to the main engines could be expensive. Appropriate payoff time studies must be conducted in order to secure meaningful return on investment.

For new platforms considering high efficiency engines and hybrid electric drive has already shown considerable advantages in terms of total life-cycle-cost. For example, Figure I.3 displays a detailed Sankey diagram of new generation of cruise ships which was reported in the Generations magazine (ABB, 2012) by ABB Marine and Cranes. It shows the net advantage of using a high-efficiency engine as the first step in converting the fuel energy to mechanical power. It also shows that some of the heat could be recuperated to increase the overall energy efficiency of the ship. In addition the early conversion of the prime mover mechanical energy into electricity offers a range of capabilities that could easily be upgraded as technologies evolved or become available allowing low cost modifications to keep a ship up to date. Changes to the hull or mechanical drive of a ship could be very expensive compared to changes to electrical and combat systems, communications, sensors and other ship amenities electrically powered.

As shown in Figure 14 and Figure 15, solid oxide fuel cells (SOFCs)[94] outperform the energy transformation efficiency of best internal combustion engines[95] proposed for most advanced ships and submarines (when excluding nuclear power). In addition they are silent and require less maintenance. The Office of Naval Research (ONR) is currently using fuel cell technologies in some pilot tests such as for UAVs[96] (Aguiar, *et al.*, 2008) and planned UUVs[97]. SOFCs have been used for several years currently and have proven to be highly reliable and capable of high power capacities.[98]

In addition the current efficiency of SOFCs could be increased when processing the excess heat with thermoelectric generators (TEGs) or using it for heating water, desalinisation or fuel generation.

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[94] http://energy.gov/fe/why-sofc-technology (Access date: 24 Sept. 2013). They are not subject to Carnot cycle limitations because they are not heat engines. SOFCs are fuel-flexible – they can reform methane internally, use carbon monoxide as a fuel, and tolerate some degree of common fossil fuel impurities, such as ammonia and chlorides. Planar SOFCs using a thin ceramic (yttria-stabilized zirconia, or YSZ) electrolyte could operate at lower temperatures (<800°C) than predecessor SOFC topologies, allowing the use of lower-cost stainless steel interconnects, rather than a costly and difficult-to-process ceramic interconnects required of higher-temperature SOFCs.

[95] From Wikipedia: The energy efficiency of a fuel cell is generally between 40–60%, or up to 85% efficient in cogeneration if waste heat is captured for use. The largest internal combustion engines in the world are two-stroke diesels, used in some locomotives and large ships. … an example of this type of motor is the Wärtsilä-Sulzer turbocharged two-stroke diesel as used in large container ships. It is the most efficient and powerful internal combustion engine in the world with over 50% thermal efficiency. For comparison, the most efficient small four-stroke motors are around 43% thermal efficiency (SAE 900648); size is an advantage for efficiency due to the increase in the ratio of volume to surface area.

[96] ONR Ion Tiger 26hr flight Nov 2009, low cost UAVs for long endurance missions, http://www.onr.navy.mil/Media-Center/Fact-Sheets/Ion-Tiger.aspx (Access date: 24 Sept. 2013).

[97] Unman underwater vehicles: ONR Long Endurance Undersea Vehicle Propulsion.

[98] http://www.onr.navy.mil/Media-Center/Press-Releases/2013/Solid-Oxide-Fuel-Cell-Generator.aspx (Access date: 24 Sept. 2013).

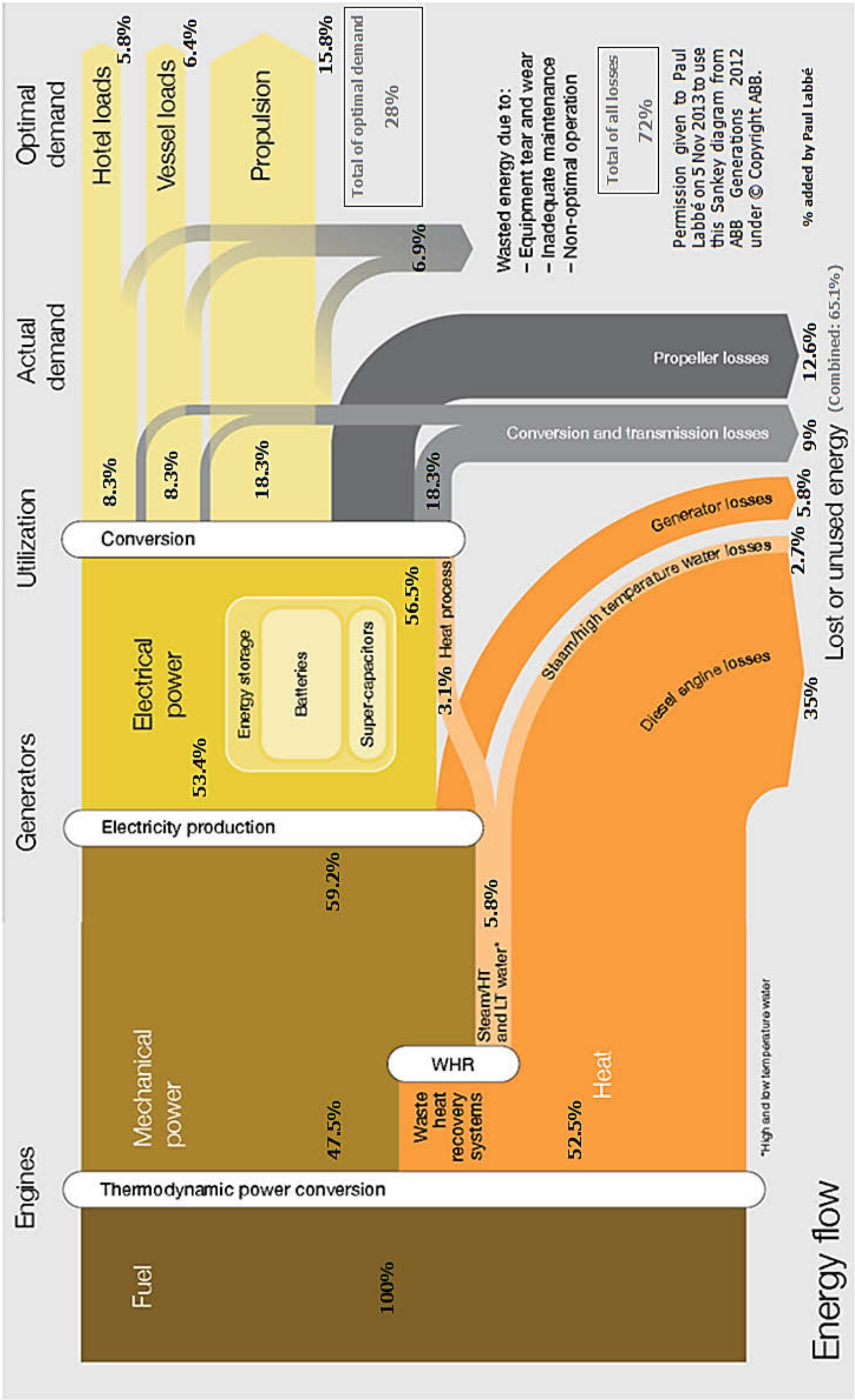

Figure I.3: *Sankey diagram of the energy flow of a state-of-the-art cruise ship (ABB, 2012, pp. 20-21).*

I.2 Reduced propulsion power demand

Years of experience in designing ships and measuring their performance in various sea conditions provides a rich source of trustable information about what could be a cost effective technique to transfer more power to effectively propel a ship. Tests conducted at the Naval Warfare Center, Carderock Division (Cusanelli and Karafiath, 2012, Karafiath and Cusanelli, 2006) and implementations done by the US Navy (Naval Sea Systems Command, NAVSEA) (Doerry*, et al*., 2010) are good examples from which one can draw practical design improvements.

Some of these studies and trial results could be summarized[99] and expanded as suggested by Dr Barkyoumb, Director of Strategic Relations, at Naval Surface Warfare Center Carderock Division, NSWC:

1. Stern flap additions and optimizations for a given ship configuration have proven to be cost effective and easy to do, and work well at most speed and sea conditions. Computational fluid dynamics calculations need to be done right to get the benefit as full-scale results may not be seen in scale-model testing due to Reynolds number effects.

2. Stern bulb modifications (Karafiath, 2012, Karafiath and Cusanelli, 2006) seem to work for some ships but it is hard to overcome the drag induced by the added surface. This is a potential modification on ships where a stern flap cannot be installed. Stern bulbs may make ship track better and that can be some gain.

3. Contra-rotating propeller installations are the most efficient as demonstrated for a high-speed sea lift study and numerous other studies. There are novel ways to attach counter-rotating props and keep the mechanical complexity down. In (Doerry, *et al*., 2010) they report an example of what a contra-rotating pod hull mounted drive can offer for two ferries built by the Nagasaki Shipyard of Mitsubishi Heavy Industries (MHI) in 2004. “When placed into service, they consumed 17% less fuel than the twin shaft mechanical drive ships they replaced.”

4. Hull and propeller cleaning / anti-fouling coatings — Carderock lab has been in the lead for these coatings. There is a version of silicone coating, of which a commercial off-the-shelf (COTS) trade name is ‘Intersleek’. Industry had good data that this coating kept barnacles off the hull. The US Navy found that ships spent too much time in port for this to have a big effect. The commercial ships transit most of the time and get better results. It seems that applying this coating to the propellers may prove to be a more cost-effective approach for war ships. One has to do the operational analyses for naval vessels to know if there is any benefit. Assuming that the results from Commercial vessels will apply to Navy ships is insufficient.

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[99] Private communications Barkyoumb-Labbé 11-14 March 2014.

Another option mentioned in (DOD, 2008, p. 49) is the use of biomimetic propellers which are believed to reduce energy consumption on the order of 25% while reducing noise. Biomimetic design mimics natural design characteristics that minimize energy usage through reduced friction and drag.

I.3 Reduced mission systems and ship systems power demand

In the areas of ship systems power demand, also known as the hotel loads, replacing the following by high efficiency versions could represent a substantial energy saving that could be turned into combat power capabilities: light, electric motors (e.g., variable speed drive for HVAC, chilled water pump, and fire pumps, see (Doerry, 2013) for details on improvement and payback periods from immediate to a few years). In order to estimate the return on investment for specific ship load system energy improvement initiative or modification, appropriate measures of the demand (power load) for the under evaluation function or amenity need to be done at the necessary level of spatial and temporal granularity to be meaningful (Doerry, 2013). For example it could be the following factors: the cost of the fuel used by a ship during a given event, the efficiency of transforming this fuel in electricity and the amount of electricity used by a function or amenity over the monitored period of time over which that function or amenity was used (its duty cycle should also be recorded). Then, the aggregation of such data could be used to project the amount of energy saved and its cost saving advantage. In addition other costs such as the total cost of inserting a new technology or modification becomes part of the procedure to evaluate the return on investment and the time to pay it off (the breakeven point, BEP).

The cost of generating electricity on ships that used diesel engines to power generators is about three times as much as our domestic average price of electricity in Canada which is about 10¢/kWh[100]. For domestic price of electricity of 10¢/kWh, LED lighting has a BEP of abouttwoyears now (lower price of LED and high price of electricity could reduce this BEP). Depending on RCN fuel price paid and generator efficiency, the electricity cost on a ship could be around 30¢/kWh (excluding the equipment depreciation) which may result in a BEP of less than eight months.

An appropriate auditing of platform energy with sufficient granularity is highly recommended in order to identify the best opportunities for energy improvements that would be cost effective and make a good return on investment over the remaining platform life cycle. All forms of energy at play must be considered including the expected fully burdened cost of energy at play such as the ship’s fuel.

However future operations are likely to require even more advanced sensors, electronics, combat systems and eventually directed energy weapons. A special attention must be

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[100] According to http://www.hydroquebec.com/publications/en/comparison_prices/pdf/comp_2013_en.pdf (Access date: 24 Sept. 2013) (page 20) the average electricity prices for major cities in Canada on 1 April 2013 was between 6.9¢/kWh and 15.5¢/kWh. In Table E.2 for 2011 the estimated average value used was 8¢/kWh.

given to such eventuality in designing ship upgrades and future ship designs. Designing with in mind a much higher capacity in electricity generations and storage, including an appropriate microgrid to match both the energy and power demands of modern warfare, is essential.

I.4 Modifying CONOPS

Another cost-effective means of optimizing ship's fuel consumption is by modifying the CONOPS while achieving the same mission objectives with less fuel consumption. Fuel consumption decreases up to 6% were reported by some vendors. Examples of ship's fuel optimization software for the US Navy listed by (Doerry, 2013) include: "The US Navy is investigating the use of a Smart Voyage Planning (SVP) capability software module that would extend the vessel's Electronic Chart Display and Information System – Navy (ECDIS-N). This module will use available capabilities from the Naval Meteorology and Oceanography Command (METOC) and also include the abilities to include training excursions within the planned voyage and to optimize the transit of battle groups. With this capability the US Navy hopes to take advantage of optimized route planning whenever mission allows."

Another approach is via incentives: "…Incentivized Energy Conservation (i-ENCON) program that routinely travels to US Naval Bases around the world to meet with ship operators to review operational / procedural modifications strategies and techniques for reducing energy consumption. The i-ENCON program offers monetary and several prestigious recognition awards to those ships with the most fuel-efficient operations."

Here is a summary of operational changes that likely provides significant fuel consumption avoidance that could be translated at opportune times in combat capabilities advantages:

1. Drift Operations (Ops) or Anchoring at Sea. When ships are not required to maintain station keeping, they can realize up to a 70 percent fuel savings by merely drifting while at sea.

2. Trail Shaft Ops at Sea. Like Drift Ops at Sea, when the mission allows, substantial fuel savings can be achieved by trailing a shaft. Up to a 50 percent savings can be obtained through this procedure.

3. Clean Hull/Propeller. Marine growth that accumulates on a ship's hull which increases drag or resistance through the water. Keeping the hull clean can realize up to a 12 percent fuel savings, depending on the time between hull cleanings. Likewise, a clean propeller can reap an additional six percent in savings.

4. Smart Navigation. While the mission always comes first, there are times when ships can take advantage of local currents or avoiding bad weather to save fuel.

5. Planned Maintenance System. Judiciously following prescribed preventative maintenance enables systems and equipment to operate efficiently and save fuel.

Annex J Selected findings of interest to RCAF energy

There are several ongoing US programs worth mentioning when addressing technologies that could improve energy efficacy of air platforms. For example the "Versatile Affordable Advanced Turbine Engine" (VAATE) is to deliver aircraft fuel efficiency technologies applicable to legacy platforms such as the C-17 and to new platforms that could improve specific fuel consumption by as much as 25% (DOD, 2008) compared to a 2000 state-of-the-art (STOA) engine. This is related to the Highly Efficient Embedded Turbine Engine (HEETE) program which expects to reduce substantially the engine weight and increase its thrust-to-weight ratio by 60% compared to a STOA design. They expect a 25% in fuel efficiency which represents doubling loiter time and recuperates from 100-400 kW to power onboard additional advanced electronics.

For air platform propulsion system there are two main components: the engine and some means to generate thrust, such as a propeller or a propulsive nozzle. The thrust from the propulsion system must balance the drag of the platform when it is cruising. In order to accelerate the thrust must exceed the drag of the platform. So for large platforms such as C-17 the propulsion system efficiency is critical. For a jet fighter aircraft acceleration is critical.

According to the US Air Force Chief Scientist "Energy Horizons" report (AF/ST, 2012), a unifying method to simultaneously measure energy efficiency progress, related energy use, and aircraft capabilities is the well-established Breguet range equation:

$$Range = \frac{V}{SFC}\frac{L}{D}\ln\left(1 + \frac{W_{fuel}}{W_{pl} + W_0}\right) \qquad \text{(J.1)}$$

This equation shows that improvements to airframe efficiency can be measured as an increase to the lift to drag (L/D) ratio and a decrease of the total weight, i.e., the addition of W_{pl} (weight of the payload) plus W_0 (total weight of the aircraft without the payload). W_{fuel} is the fuel weight. Equation J.1 expresses propulsion efficiency gains as the ratio of the airframe speed (V) over the specific fuel consumption (SFC). "Linking energy to range across these factors establishes a relationship between war-fighter capability and energy efficiency attributes." [101]

J.1 Examples of energy efficiencies and improved capabilities

For legacy air platforms, as well as for new air platforms, the Breguet range equation means that replacing low gravimetric energy density batteries by much better ones could result in reaching a BEP within a short time or over a small number of sorties compared

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[101] This concept was identified in the 2006 Air Force Scientific Advisory Report *Technology Options for Improved Air Vehicle Fuel Efficiency* (SAB-TR-06-04) critically linking energy and warfighter capability.

to the available life span left of a given air platform. Similarly transforming the engine energy heat loss into useful energy such as electricity can result in substantial range extension or fuel consumption reduction. As for other environments, software to optimize flight route and manoeuvers could significantly increase air operations cost effectiveness.

For new airframes more technology options are available including improved aerodynamic technologies and designs, the use of new advanced composite materials (DOD, 2008) (most important single factor in achieving fuel savings of 20% in Boeing 787 compared to STOA), manufacturing methods and airframe optimisations for the targeted applications.

Newer engines have shown improved performance and fuel efficiency over the last decades for applications where it makes a big difference in life-cycle-cost.

Efficacy of onboard power sources such as generators could offer dramatic advantage by curbing their weight and increasing their gravimetric power density (DOD, 2008). For example, the Multi-megawatt Electric Power System (MEPS) trims 100 lbs (45 kg) and thermal load while offering four to eight times the kW/lb compared to STOA by using cryogenic cooling and high RPM generator technology in view of driving more powerful weaponry.

An interesting view of the ensemble of possibilities is the map presented in the "Energy Horizons" report (AF/ST, 2012) which is displayed in Figure J.1. In addition to these possibilities it is worth mentioning the cost effectiveness of using flight simulator to increase readiness and decrease fuel usage.

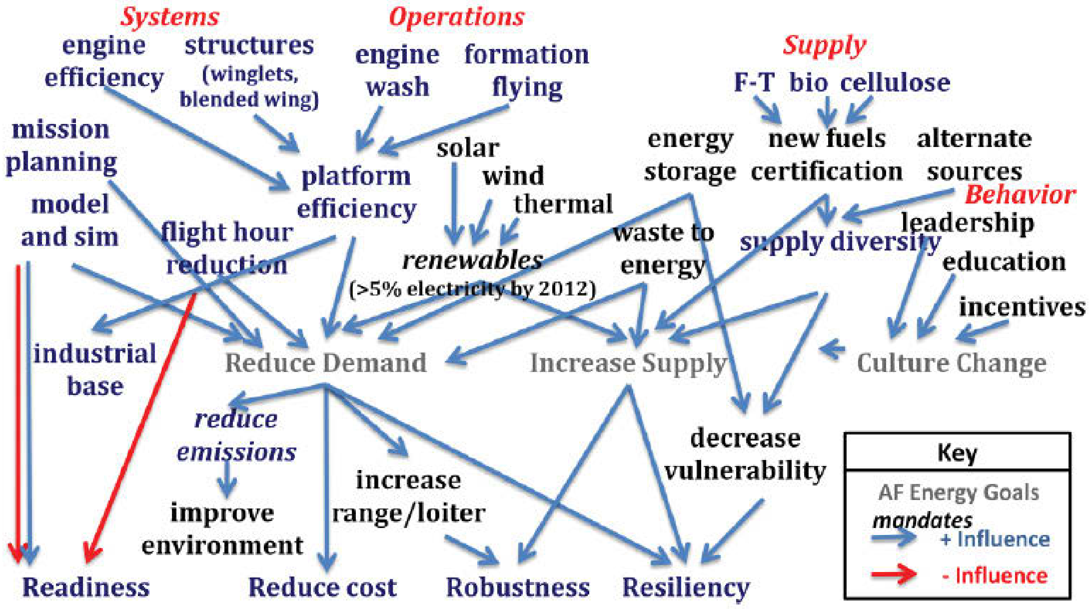

Figure J.1: *US Air Force operational outcome oriented approach.*[102]

If we assumed that reduce demand, increase supply, and change culture are the targeted RCAF energy goals, then the following examples reported for the US Air Force would apply. “Demand reduction can arise from improved platform efficiency through more efficient engines and structures (e.g., winglets, hybrid wings) as well as more efficient operations (e.g., engine washing, formation flying, optimized mission planning). Efficiencies vary widely. For example, whereas winglets or engine washing may inexpensively achieve 1% fuel savings, formation flying promises 7-10% fuel savings in early assessments with C-17s, and hybrid wings promise 15-20% fuel savings (although this requires capital investment in new airframes). Demand reduction also can arise from increased use of renewables (solar, wind, thermal, geothermal and biomass), waste-to-energy, and the use of modeling and simulation to substitute for some live training.” “In addition, more efficient air/space/cyber platforms or operations can increase loiter or range which in turn can diminish energy, basing, or refueling requirements, thus increasing robustness.” “Finally, a change in culture can drive behavior to reduce energy consumption and can be achieved through a range of activities including education and awareness, engaged leadership, and incentives. Importantly, each of these Energy Horizons outcomes generates not only environmental and economic benefits but can also lead to operational benefits such as increased readiness (e.g., increased simulator training), robustness or strength (e.g., more persistent operations from increased loiter), and resiliency (e.g., supply diversity) to mitigate vulnerabilities.”

For legacy and future platforms, advanced high-energy efficiency, smaller and lightweight electronics would reduce the platform weight while increasing the combat capabilities especially in combat aircraft and unmanned aerial vehicles (UAVs).

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[102] F-T (The Fischer–Tropsch process is a collection of chemical reactions that converts a mixture of carbon monoxide and hydrogen into liquid hydrocarbons.).

Other improvements to legacy platforms and new designs include adapted fairings which enhance airframe smoothness and reduce drag. These structures cover gaps and spaces between parts of an aircraft.

For legacy and future platforms, multi-functional materials offer advanced energy harvesting to reduce energy lost (heat and noise). For example, the energy dissipated as heat generated by IC engines can be tapped on by using thermoelectric or pyroelectrics to generate electricity. Pyroelectrics offer the advantage of high stability at high temperatures (1200°C). Using thermoelectric for cooling engines allows generating electricity which combined with super-capacitors and advanced batteries in a microgrid could allow to replace an aircraft auxiliary power unit (APU), thus saving fuel and eventually increase its combat capability (more range, cargo or agility).

A summary of the US Air Force report (AF/ST, 2012, p. 18) findings and recommendations can be captured under a few common air domain themes as follows:

- The use of remotely piloted aircraft (RPAs) as test platforms can greatly accelerate development and acquisition of new technologies across domain fleets. Developing and testing new technologies for fighter or large aircraft platforms can be time-consuming and costly. Particularly where the concept is scalable, it makes sense to test it on smaller, acquisition-agile platforms such as RPAs. One attractive area is in the development of novel antennas for sensors and communications.
- A single combat fuel makes sense in the near-term, but power systems in the future will gain resilience from consumption of a diversity of fuels. As scientists and engineers explore and embrace new thermodynamic cycles for engines, others are actively looking at new fuel feedstocks which could come with different properties and parameters. Future air systems will likely be omnivorous when it comes to fuels.
- Harvesting of energy and advanced engine cycles have the potential to be game-changers in the Air Domain. Flight, essentially, converts the chemical energy of fuel into heat, churned up air, thrust, and noise—there is a tremendous opportunity to capture some of this waste and reuse it. Many engine manufacturers are exploring potentially revolutionary engine cycles.

Annex K Short LENR review

Following the presentation by Dr Dennis Bushnell of NASA at NRCan[103], NRCan and DRDC asked AECL to prepare a literature review of the subject. In response, a comprehensive report on LENR publications was completed. Although not much was published in mainstream journals, the report included an impressive number of references, an executive summary and useful comments on this subject (Bromley and Roubtsov, 2013): "Compendium of Information on International Activities Pertaining to the Topic of Low Energy Nuclear Reactions (LENR)", February 2013, 150 pages.

Then after that AECL literature review, significant progress in patenting[104] methods and devices, as well as efforts in testing devices[105] and developing commercial products based on this technology were noted. For example, Andrea Rossi's energy catalyzer (E-cat) for a high temperature version of his technology, the E-cat HT, had this technology tested by a third party over several months. Then a third party testing[106] was completed and the E-cat HT trial report was published in June 2013 (Levi, *et al.*, 2013). Later, in a 24 January 2014 press release, Industrial Heat LLC announced that it has acquired Rossi's E-cat LENR technology rights for 11 million US$[107].

Examples of publications after the AECL's literature review include a few papers on LENR published in main stream journals and funding from DOE and industry were confirmed. Google Scholar (access date: 15 May 2014) reported 119 publications since 2013. Here are some of the LENR papers published in 2014 reported by Google Scholar on 15 May 2014 (Calleja, *et al.*, 2014, Evans, *et al.*, 2014, Hosseinimotlagh, *et al.*, 2014, Klimov, *et al.*, 2014, Kozima, 2014, Maiani, *et al.*, 2014, Mayer and Reitz, 2014, McDonald, *et al.*, 2014, Osouf, 2014, Ratis, 2014, Sapogin and Ryabov, 2014). Several theories have been published that try to explain LENR such as (Sarg, 2013) but there are no well accepted theory yet.

A review of the progress in LENR has been done by Swedish energy R&D institute (Engström and Bergman, 2013a, 2013b) which confirms that several of the related experiments succeeded in producing a net energy output with significant gravimetric and volumetric energy density.

During the E-CAT third party trial, IR camera images and data were compared against the thermocouple data. The experts saw that the temperatures achieved were real. It was as hot as stated, within a few degrees. However it was noted that at earlier demos the first E-CAT did not start, the second melted down and the third one worked well. One

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[103] Natural Resources Canada: Office of Energy Research and Development (OERD) Speaker Series, 19 December 2011, Dennis Bushnell, Chief Scientist at NASA Langley Research Centre; "Where is it ALL going?"

[104] http://www.st.com/web/en/home.html (Access date: 9 April 2013).

[105] http://www.e-catworld.com/companies-and-organizations-researching-in-lenr/ (Access date: 9 April 2013).

[106] http://arxiv.org/pdf/1305.3913v3 (Access date: 9 April 2013).

[107] http://coldfusion3.com/blog/it%E2%80%99s-official-us-startup-admits-to-purchasing-rossi%E2%80%99s-e-cat-lenr-technology (Access date: 9 April 2013).

can make the inference that not many of the units built worked to specification, but from the Elforsk-backed report[108] we can see that one at least started and ran well (Engström and Bergman, 2013a). So the E-CAT technology is not mature enough yet to consider it manufacturable (Lewan, 2014). Also it may take more time before a satisfying theory is verified.

Several other experiments from mW to kW range show that the excess of energy produced cannot be explained by known chemical processes. There is the MIT course on LENR which has been taught with demonstration since 2012 by Mitch Swartz and Peter Hagelstein. Based on such accumulated evidences it is unreasonable to deny that LENR is real and to say that it can't happen because there is no theory to explain it.

Other efforts were oriented toward what can be done if the LENR technology delivers as much energy as estimated. One of them is about the LENR car[109] and many other potential applications including LENR aircraft propulsion as reported by NASA. Doug Wells of NASA Langley Research Center has a project titled “Low Energy Nuclear Reaction Aircraft” with the purpose of investigating the potential vehicle performance impact of applying the LENR technology to aircraft propulsion systems[110]. It assumes that LENR has over 4,000 times the density of chemical energy with zero greenhouse gas or hydrocarbon emissions. The objectives of this project are to gather as many perspectives as possible on how and where to use a very high density energy source for aircraft including the benefits arising from its application, explore the performance impacts to aircraft, and evaluate potential propulsion system concepts.[111]

K.1 Perspective of some LENR trials

LENR is assumed to be a type of nuclear energy that is expected to be clean, safe, portable, scalable, and abundant. Some LENR devices were reported to generate heat in a catalyst process that combines nickel metal (Ni) with hydrogen gas (H). The initial testing and theory show that radiation and radioisotopes are extremely short lived and can be easily shielded.

An experimental investigation (Levi*, et al.*, 2013) of possible anomalous heat production in a special type of reactor tube named E-Cat HT was carried out. The reactor tube was charged with a small amount of hydrogen loaded nickel powder plus some additives. The reaction is primarily initiated by heat from resistor coils inside the reactor tube. Measurement of the produced heat was performed with high-resolution thermal imaging cameras, recording data every second from the hot reactor tube. The measurements of electrical power input were performed with a large bandwidth three-phase power

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[108] http://www.elforsk.se/Rapporter/?rid=13_90_ (Access date: 9 April 2014) Report: 15 November 2013.
[109] http://www.lenr-cars.com/ (Access date: 9 April 2013).
[110] http://nari.arc.nasa.gov/sites/default/files/attachments/17WELLS_ABSTRACT.pdf (Access date: 13 May 2014).
[111] http://newenergytreasure.com/2014/02/25/nasa-lenr-aircraft/ (Access date: 13 May 2014). NASA LENR Aircraft, Posted on February 25, 2014 by Amos Chinoz. NASA Aeronautics Research Institute is currently showcasing some of their innovative concepts developed by NASA researchers, primarily featuring work from the Seedling Phase 2 and Seedling Phase 1.

analyzer. Data were collected in two experimental runs lasting 96 and 116 hours, respectively. An anomalous heat production was indicated in both experiments.

The 116-hour experiment also included a calibration of the experimental set-up without the active charge present in the E-Cat HT. In this case, no extra heat was generated beyond the expected heat from the electric input.

Computed volumetric and gravimetric energy densities were found to be far above those of any known chemical source. Even by the most conservative assumptions as to the errors in the measurements, the result is still one order of magnitude greater than conventional energy sources.

Using the information from the E-cat HT test results (Levi*, et al.*, 2013), Defkalion's Hyperion prototype specifications[112] and data about known energy technologies a Ragone chart was produced and published on the web[113]. Figure K.1 is an adaptation of this Ragone chart for this report. It shows the tremendous advantage of LENR like devices (dark green: actual data points, light green: extrapolated values) over any other known energy technologies (orange: electrochemical storage, black: chemical sources, red: nuclear, blue: expected hot fusion, light blue: renewable when assuming a device life cycle). More details about the data and method used to generate this chart are available at the referenced web page.

As shown in Figure K.1, LENR stacks up against electrochemical devices, chemical reactions, nuclear fission plants, fusion and renewables.

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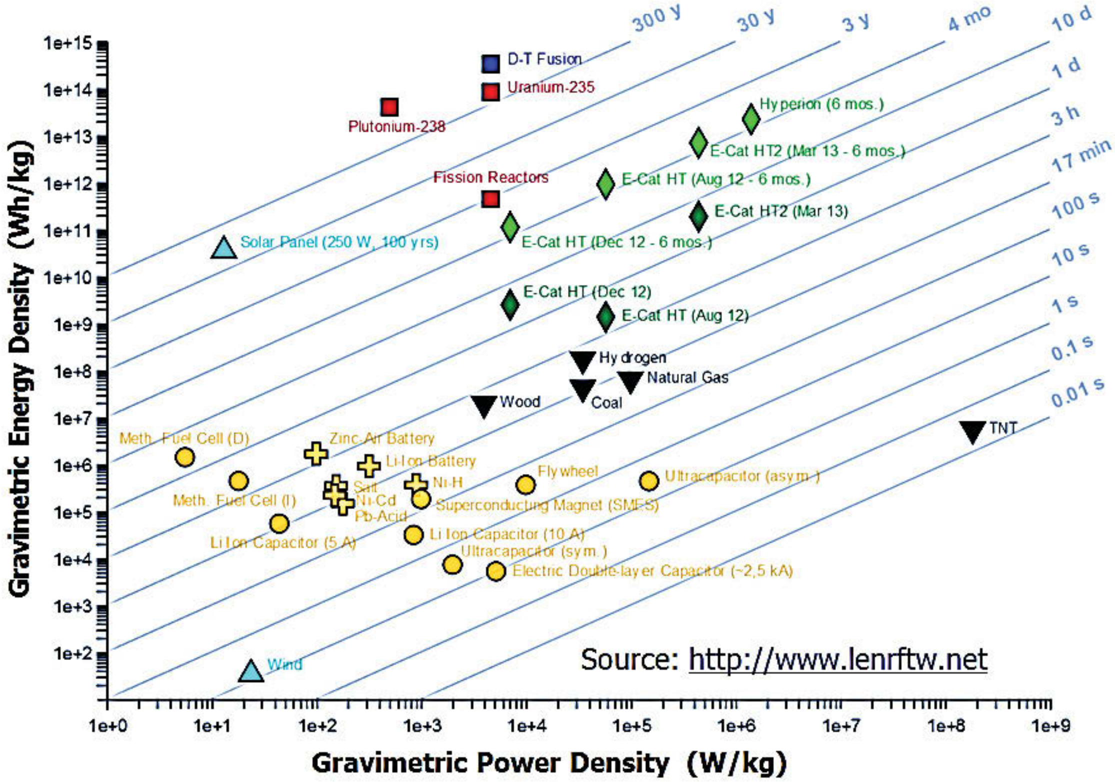
[112] http://fusion-fria.com/wp-content/uploads/2012/09/2012-08-13-ICCF-17__Paper_DGTG.pdf (Access date: 9 April 2014).
[113] http://www.lenrftw.net/comparing_energy_sources.html#chart-usage (Access date: 8 May 2014).



Source: http://www.lenrftw.net

Figure K.1: *Ragone chart to compare energy sources.*[114]

Most recent results from the third party independent E-Cat trials[115] showed exceptional energy densities. When including internal plus external components, the volumetric energy density observed was ($3.6\ 10^{4}$ ± 12%) MJ/L and the gravimetric energy density was ($1.3\ 10^{4}$ ± 10%) MJ/kg. The energy densities of gasoline are 32.4 MJ/L and 44.4 MJ/kg respectively. So the E-Cat is thousand times more volumetric energy dense and 29 times more gravimetric energy dense than gasoline.

The conservative E-Cat gravimetric power density was ($4.7\ 10^{3}$ ± 10%) W/kg. Jet engines of Boeing 747 and Airbus A300 offer a power density 5.67 kw/kg. So the E-Cat is almost as gravimetric power dense as these jet engines. Wärtsilä RTA96-C 14-cylinder two-stroke turbo diesel engines display 0.03 kW/kg. So the E-Cat is 100 times more gravimetric power dense than these ship engines.

The E-Cat fuel weight of the charge was 1 g. It delivered the following thermal energy density and power density: ($1.6\ 10^{9}$ ± 10%) Wh/kg or ($5.8\ 10^{6}$ ± 1 0%) MJ/kg, and ($2.1\ 10^{6}$ ± 10%) W/kg. These results place the E-Cat beyond any conventional source of energy. It is close to the energy densities of nuclear sources, such as U235, but it is lower than the latter by at least one order of magnitude.

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[114] More details about the data and methods used in developing this Ragone chart are available at: http://www.lenrftw.net/comparing_energy_sources.html (Access date: 8 May 2014).

[115] http://www.sifferkoll.se/sifferkoll/wp-content/uploads/2014/10/LuganoReportSubmit.pdf (Access date: 5 Oct. 2014).

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List of symbols/abbreviations/acronyms/initialisms

A/C	air conditioning and air cooling system
ADM (Fin CS)	Assistant Deputy Minister (Finance and Corporate Services)
ADM(IE)	Assistant Deputy Minister (Infrastructure and Environment)
ADM(Mat)	Assistant Deputy Minister (Materiel)
ADM(S&T)	Assistant Deputy Minister (Science and Technology)
ADP	assured delivery price
AES	all-electric ship
AFA	Alternative Fuels Act of 1995
AFB	Air Force Base (US designation)
AFDS	automated fuel data and management system
AFRL/RQ	US Air Force Research Laboratory, RQ for rocket
AFSP	auditable financial statement policy
AFUE	annual fuel utilization efficiency
AGW	anthropogenic global warming
Ah	ampere hour
APC	armoured personnel carrier
APOD	airport of disembarkation
APU	auxiliary power unit
ASAP	advanced soldier adaptive power
ATEG	automotive thermoelectric generator (converts waste heat to electricity)
ATF	alternative transportation fuels (as defined in the AFA)
AU	Australia
BCID	Battlefield Combat Identification
BEP	breakeven point
C4ISR	Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance
CA	Canadian Army
CADSI	Canadian Association of Defence and Security Industries
CAF	Canadian Armed Forces
CANR	chemically assisted nuclear reactions

CCD	comité des capacités de la Défense
CCGT	combined-cycle gas turbine
CERDEC	Communications-Electronics Research Development and Engineering Center
CFB	Canadian Forces Base
CFD	Canadian Forces Development
CFDS	Canada First Defence Strategy
CFR	compact fusion reactor by Lockheed Martin [NYSE: LMT] Skunk Works®
CFS	Canadian Forces Station
CMNS	condensed matter nuclear science
CO	carbon monoxide
CO_2	carbon dioxide
CONOPS	concept of operations
COP	coefficient of performance
COTS	commercial off-the-shelf
CPI	consumer price index
CPV	concentrated photovoltaics
CSA	Canadian Standards Association
D&S	defence and security
DC	direct current
DCB	Defence Capabilities Board
DEW	directed energy weapon
DF&L	Directorate of Fuels and Lubricants at ADM(Mat)
DMC	Defence Management Committee
DMFC	direct methanol fuel cell
DND	Department of National Defence
DOD	Department of Defense (US)
DOE	Department of Energy (US)
DOES	first ‘DND/CAF Operational Energy Strategy’ was introduced as the ‘Defence Operational Energy Strategy’ by the DOES working group.
DRDC	Defence Research and Development Canada
DRMIS	Defence Resource Management Information System
DSAB	Defence Science Advisory Board

DSTKIM	Director Science and Technology Knowledge and Information Management
E85	an alternative gasoline consisting of 85% denatured ethanol by volume
ECDIS-N	Electronic Chart Display and Information System – Navy
ECP	energy commodity price
ECS	environmental chief(s) of staff
EIA	Energy Information Administration (Official Energy Statistics from the US Government)
EJ	exajoule (1x10^{18} joules)
EPA	Environmental Protection Agency
ESA	European Space Agency
ETRD	emerging technologies raw material demand
EUI	energy use intensity
EV	electric vehicle (see PHEV)
F&E	fonctionnement et d'entretien
FAC	Forces armées canadiennes
FBCE	fully burdened cost of energy
FBI	Federal Building Initiative
FCU	fuel consumption unit
FMAS	Financial Management and Accounting System (progressively moving into DRMIS)
FOB	forward operating base
FSDS	Federal Sustainable Development Strategy
FY	fiscal year
GDP	gross domestic product
gensets	generator setups
GHG	greenhouse gas
GJ	gigajoule (1x10^{9} joules)
GL	general ledger
GoC	Government of Canada
GPS	Global Positioning System
GSHP	ground-source heat pump
GW	gigawatt (1x10^{9} watt)
GWh	gigawatt-hour

GWP	global warming potential
HEETE	Highly Efficient Embedded Turbine Engine
HEL	high energy laser
HPB	high-performance building
HPM	high power microwave
HVAC	heating, ventilation, and air conditioning
IC	internal combustion engine
ic	integrated circuit
IEA	International Energy Agency, http://www.iea.org/ (Access date: 9 April 2013)
IOSP	infrastructure operations and support price
IPCC	Intergovernmental Panel on Climate Change
ISSP	Integrated Soldier Systems Program
IT	information technology
JP-8, or JP8	jet propellant 8 is a jet fuel
kJ	kilojoule ($1x10^3$ joules)
KPP	key performance parameter
kt CO_2 eq.	kilo tonnes of carbon dioxide equivalent
kW	kilowatt
kWh	kilowatt hour
L1	level 1 manager
LANR	lattice assisted nuclear reactions
LED	light-emitting diode
LENR	low energy nuclear reactions
LFP	lithium iron phosphate
LFS	lithium/iron sulphide batteries (primary, i.e., disposable)
LIB	Li-ion battery, lithium-ion battery
$LiCoO_2$	lithium cobalt oxide
LMO	lithium manganese oxide
LPG	liquefied petroleum gas or liquid petroleum gas
LWP	Lightweight Water Purifier
MDN	Ministère de la Défense nationale

MEPS	Multimegawatt Electric Power System
METOC	Meteorology and Oceanography Command (US Navy)
MFC	microbial fuel cells
MHD	magnetohydrodynamic
MJ	megajoule ($1x10^6$ joules)
ML	million litres
MOD	Ministry of defence (UK)
Mt CO_2 eq.	million tonnes of carbon dioxide equivalent
Mtoe	million tonnes of oil equivalent
MW	megawatt
MWh	megawatt hour
N1	niveau un du MDN
NASA	National Aeronautics and Space Administration
NATO	North Atlantic Treaty Organization
NAVSEA	Naval Sea Systems Command
NCPV	National Center for Photovoltaics at NREL (US)
NDHQ	National Defence Headquarters
NEB	National Energy Board
NERC	Natural Environment Research Council (UK)
NiMH	nickel-metal-hydride batteries (rechargeable)
NMC	lithium nickel manganese cobalt oxide
NOx	nitrogen oxides
NRC	National Research Council Canada
NRC	United States Nuclear Regulatory Commission also listed as US NRC
NRCan	Natural Resources Canada
NREL	National Renewable Energy Laboratory (US)
NSS	National Safety and Security
NSWC	Naval Surface Warfare Center Carderock Division (US)
O&M	operations and maintenance
O&S	operations and support
OAG	Office of the Auditor General
OECD	Organisation for Economic Co-operation and Development
OEE	Office of Energy Efficiency

OEM	original equipment manufacturer
OERD	NRCan’s Office of Energy Research and Development
OGDs	other government departments
ONR	Office of Naval Research
OPEC	Organization of the Petroleum Exporting Countries
OPI	office of primary interest
OPS	operations
ORNL	Oak Ridge National Laboratory
OSH	Operational Support Hubs
OTAN	Organisation du traité de l’Atlantique Nord
OTEC	ocean thermal energy conversion technologies
PCM	phase-change material
PEM PEMFC	proton exchange membrane fuel cell
PGM	platinum group metals
PHEV	plug-in hybrid electric vehicle (see EV)
PJ	petajoule ($1x10^{15}$ joules)
PSC	Public Safety Canada
PWGSC	Public Works and Government Services Canada
R&D	research and development
RCAF	Royal Canadian Air Force
RCN	Royal Canadian Navy
RCN D Nav Strat	RCN Director Naval Strategy
RE	rare earth
RH	radio frequency
RFID	radio-frequency identification
ROI	return on investment
RPA	remotely piloted aircraft
RPB	relativistic particle beam
RTG or RITEG	radioisotope thermoelectric generator
S&T	science and technology
SC	strategic commitment (within the SDS)

SDCD	Stratégie de défense *Le Canada d'abord*
SDS	Sustainable Development Strategy
SEGS	Solar Electric Generating System
SENT	Smart Energy Team (NATO)
SEOD	Stratégie d’énergie opérationnelle de la Défense
SFC	specific fuel consumption
SMP	standard military pattern (vehicle)
SOA	standing offer agreement
SOFC	solid oxide fuel cell
SOR	statement of requirements
SP	security price
SPOD	seaport of disembarkation
SPV or SP	solar photovoltaic
SRG	Stirling radioisotope generator
SSTRM	Soldier Systems Technology Roadmap
STANAG	NATO standardization agreement
STG	solar thermal generation
STOA	state-of-the-art
SVP	Smart Voyage Planning
t CO_2 eq.	tonnes of carbon dioxide equivalent
T^3R&O	Technology Trends, Threats, Requirements, and Opportunities
TAC	Thermal Acoustic Converter designed by Etalim Inc.
TA-MHD	thermoacoustic-magnetohydrodynamic converter of heat to electricity (NASA)
TASHE	NASA’s thermoacoustic Stirling heat engines
TDP	Technology Demonstration Program
TDP	tactical delivery price of the FBCE framework
TDS	Technopôle Defence and Security
TEG	thermoelectric generator
TJ	terajoule (1x10^{12} joules)
TPES	total primary energy supply
TPV	thermophotovoltaic
TRIGA	Training, Research, Isotopes, General Atomics – a reactor design

TRL	technology readiness level
TSU	tactical small unit
TWh	terawatt-hour
UAV	unmanned aerial vehicles
UK	United Kingdom
US Armed Forces	United States Armed Forces
US Army	United States Army
US NRC	United States Nuclear Regulatory Commission
USA	United States of America
USAF	US Air Force
USN	United States Navy
VAATE	Versatile Affordable Advanced Turbine Engine

Glossary

Term	Definition
alternative energy	The energy derived from non-fossil fuel sources. Typically used interchangeably for renewable energy. Examples include: wind, solar, biomass, wave and tidal energy.
biofuel	Fuel produced from renewable biomass material, commonly used as an alternative, cleaner fuel source.
black swan	The 'black swan' theory is a metaphor that describes a high-profile, hard-to-predict, and unprecedented event that comes as a surprise and has a major effect.
capacity factor	The actual energy output over a period of time against generation potential. Typical capacity factors of nuclear power plant about 90%, hydroelectricity about 50%, solar and wind about 30% (in the northern hemisphere, solar is much lower during winter and larger during summer).
disruptive technology	Disruptive technologies are technological innovations that disrupt the status quo and improve a product or service in an unexpected manner. They may displace existing technology, or introduce an entirely novel concept to society that will transform the way we operate.
energy commodity price (ECP)	The FBCE first price element for consideration is the energy commodity itself. This is the rate that is charged to military customers by a vendor. The actual contracted delivery price should be used where available.
energy conversion efficiency	The ability to convert the maximum amount of source energy toward the desired work, function or amenity. For examples, fuel energy conversion to mechanical work of a gasoline engine is about 20% and diesel engine is about 30%.
energy intensity	A measure of the energy efficiency of a nation's economy. It is calculated as units of energy per unit of GDP. High energy intensities indicate a high price or cost of converting energy into GDP.

Term	**Definition**
energy security	In the defence context, the condition that exists whereby the CAF enjoys reliable access[116] to sufficient energy required to sustain operational readiness and where affordability[117] and integrity of supply lines are not limiting factors that affect mission[118] continuity.
energy use intensity (EUI)[119]	The energy consumption per unit area of building space per year calculated as follows: total energy consumed in one year (GJ) / total floor space of the building (m^2), usually expressed in $GJ/m^2/yr$.
full DND cost	It "is the sum of incremental cost plus the salaries of Regular Force personnel, equipment depreciation, command and support cost, as well as the operating cost of some major equipment, such as aircraft, that are within normal planned activity rates and, therefore, had not been included in incremental cost."[120]
fully burdened cost of energy (FBCE)	The commodity price for fuel plus the total cost of all personnel and assets required to move and, when necessary, protect the fuel from the point at which the fuel is received from the commercial supplier to the point of use.
gross domestic product (GDP)	The market value of all officially recognized final goods and services produced within a country in a given period of time. GDP per capita is often considered an indicator of a country's standard of living which equals to the gross domestic income (GDI) per capita.

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[116] Reliable access infers energy that is protected from, or invulnerable to, physical and cyber threats for an extended period regardless of the operating environment.

[117] Affordability implies the ability to buy energy, energy sources (fuel) and equipment that utilises energy without compromising either current or through-life budgetary limits.

[118] Mission refers to any of the CFDS missions, which are both domestic and expeditionary in nature.

[119] "Energy intensity – which measures the efficiency of energy use per unit of economic activity (gigajoules per gross domestic product [GJ/GDP]) – improved by 21% across the period. Energy use per capita, however, showed a 1% increase, reflecting lifestyle changes at home and in private transport." Ref.: http://oee.nrcan.gc.ca/publications/statistics/trends11/factsheet/factsheet.pdf (Access date: 8 May 2013) "Energy Efficiency Trends in Canada 1990 to 2009".

[120] http://www.vcds.forces.gc.ca/sites/internet-eng.aspx?page=14661 (Access date: 9 April 2014).

Term	**Definition**
incremental DND cost	It "is the additional costs for personnel and equipment that are directly attributable to the Canadian Forces operation. More specifically, incremental costs include the additional cost to deploy troops and equipment and to provide ongoing maintenance and support during the applicable operation, in addition to any specialized training required for the operation. DND does not include the full capital acquisition cost of major equipment in incremental cost, unless procured specifically for the mission with no life expectancy post operation, as this equipment will not be used in other CAF operations. However, the full cost includes depreciation of major equipment."[121]
infrastructure operations and support price (IOSP)	The third FBCE price element is infrastructure, which may include the price of O&S and recapitalization for the facilities (such as fuelling facilities and energy commodity storage sites and recharging stations) and related ground system equipment (such as pumps, fuel storage bladders, hose lines, and other refuelling equipment to include maintenance and parts for refuelling vehicles and other related ground refuelling equipment, as well as energy related material handling equipment, energy commodity storage facilities and energy recharging stations). The costs to deploy the delivery assets may also be included, if the assets need to be transported to the theatre of interest. This applies only to infrastructure that is operated by NATO and member countries in the theatres of interest.
operational energy	The energy utilised for accommodating, training, moving and sustaining military forces for operations, including the energy used to operate weapon, communications and ISR systems.
renewable energy	The energy derived from resources that are replaced rapidly by natural processes.

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[121] http://www.vcds.forces.gc.ca/sites/internet-eng.aspx?page=14661 (Access date: 9 April 2013).

Term	**Definition**
security price (SP)	The fourth FBCE price element includes the costs of escort protection of the energy supply chain in hostile environments. In the case of NATO force protection assets allocated to the energy commodity delivery forces, the operational and sustainment costs, direct commodity costs and the depreciation costs will also have to be estimated and included in the overall calculation. In essence, all of the costs considered in the second 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. In some high-risk scenarios, force protection costs may be the largest factor in the FBCE estimate.
tactical delivery price (TDP)	The second FBCE price element captures the burdens associated with the tactical delivery assets used by NATO countries to deliver the energy commodity from the point of acquisition (contract delivery point) to the system that will consume it. It includes: a) the Operating and Support (O&S) costs and b) the cost of depreciation of the actual delivery assets. Once NATO takes possession of the energy commodity at the point of sale, it must employ its own or contracted delivery assets. For the purposes of estimates, the ”energy commodity delivery assets” mean major items of energy delivery equipment, such as naval ships, aerial refueling aircraft for fixed-wing and rotary-wing aircraft, and tanker trucks and trailers for ground vehicles as well as transportation trucks for energy commodities other than liquid. It also includes planes that airdrop palletized energy commodities and rotary-wing aircraft carrying energy commodities for delivery.
wild card	A ‘wild card’ is an unpredictable or unforeseeable factor that occurs outside of normal rules and expectations.

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The intent of this document is to consolidate the information, evidences, facts and data that support and inform the first DND/CAF operational energy strategy (DOES) to address the need to improve our defence operational capabilities and their sustainability by decreasing the fully burdened cost of operational energy and reducing our supply chain vulnerabilities. It captures some of the knowledge that resulted from the DOES working group discussions and workshops with selected experts and organisations. Given the complexity of the domain and potential misinterpretation of raw data available in the various records of transactions, their interpretation for the purpose of developing the strategy was addressed collectively by selected representatives from concerned DND/CAF L1s' personnel.

Such a collective view is necessary to ensure that an appropriate understanding of the energy challenges ahead permeates our DND/CAF culture and becomes part of our decision making. Then, how to address them holistically through the sustainability looking glass will open new avenues to improving our defence operational capabilities for operations here and abroad.

Analyses of historical data and simulation results were used to develop the DOES energy baseline. That energy baseline was used to develop credible DOES targets. The baseline will be used later to assess the level of success of initiatives to achieve DOES targets. An inflation methodology was used to assess the potential savings of applying the DOES targets. Moreover, using simulation techniques with scenarios informed by previous operations, the impacts of DOES targets on expeditionary operations were estimated.

In addition, the report explores the DND/CAF domain of energy, sorts it in four dimensions and proposed principles to support the selection of effective initiatives in fulfilling DOES. Selected energy technologies required to power a large variety of DND/CAF capabilities are reviewed. Then more specific examples addressing DOES targets for each environment are provided. Fuelled by DND/CAF level of ambition, DOES targets will be used in developing potential action plans and in measuring progress resulting from remediation initiatives in achieving the strategy objectives.

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energy, power, operational, fuel, density, cost, CAF, RCAF, Royal Canadian Air Force, CA, army, RCN, Royal Canadian Navy, DND, defence, demand, engine, batteries, storage, audit, electricity, analysis, impact, strategy, capability, capacity